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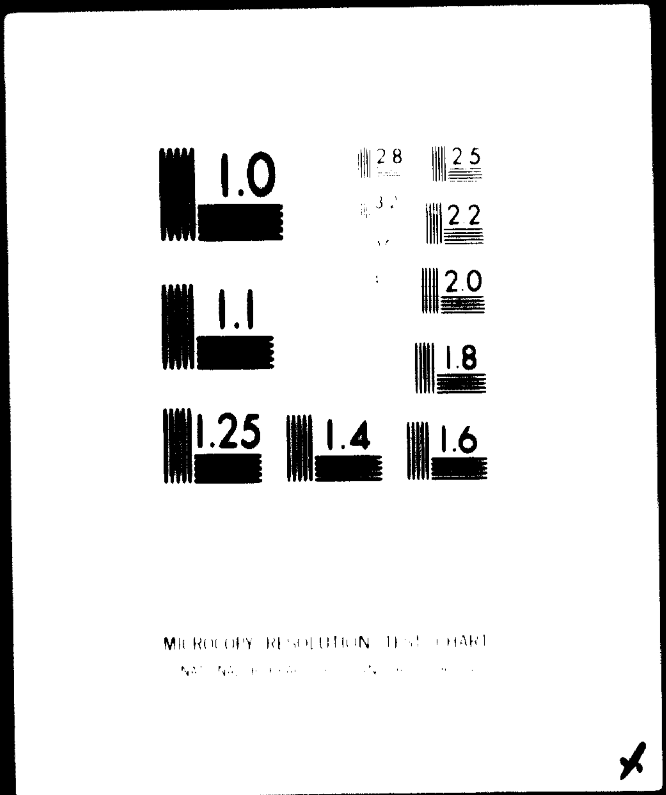
1 OF 9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which will actually be included in the initial Arab petrochemical projects, since the preliminary screening (later confirmed by our detailed work) shows most of these to offer a good combination of market potential and favourable production economics in the Arab locations.

The overall aim of the market analyses is to establish whether it will be realistically possible for export-oriented Arab projects to penetrate international markets for the product in question during the 1980's, and to recommend marketing policies to maximise this penetration.

2. Product Analyses

The international (i.e., non- Arab) market research has been carried out during mid-1975, involving extensive travel by Chem Systems' personnel to all market regions. Discussions were held with contacts in industry, government agencies and other relevant areas. The market forecasts made in this study have been developed by Chem Systems by analysis of past trends together with a careful assessment of the effects of the last three years upon future trends in consumption: the effects of oil price rises, energy supply limitations and industrial recession are thus incorporated in all projections.

The present study did not call for any field work by Chem Systems in the Arab States. The Arab demand projections are based upon published information, data supplied by IDCAS and our own in-house information. We have presented our results only for the Arab nations as a group, since we believe that detailed country analyses are not realistic without the benefit of extensive up-to-date local fieldwork. We believe, however, that these total Arab demand figures are realistic, and that this approach in quite adequate for a generalised export-oriented study such as this.

Our conclusions from a market standpoint on each of the considered products are briefly summarised below:

a) Ethylene Glycol

Ethylene glycol does not appear to be one of the more attractive prospects for inclusion in the early Arab petrochemical projects. Large overcapacity is predicted in all major developed market regions during the early 1980's, and the regional deficits likely to occur in the less developed markets are quite small. If ethylene shortages should develop in the developed regions, then glycol is likely to be one of the first products to suffer, however, and in such circumstances spot shipments could probably be sold.

Opportunities for exporting glycol from the Arab States will occur, but these are likely to be widely spread, short term and of small volume. A very flexible marketing and distribution organisation would be required to operate in this type of market, and we basically feel that glycol should only be included in an Arab project if a prospective partner is prepared to guarantee long-term offtake contracts at acceptable prices. Some glycol production for local polyester fibre manufacture will be required during the 1980's, but this demand will not support a large glycol capacity during this period.

b) High Density Polyethylene (HDPE)

Considerable new investment will be required in HDPE to meet the strongly growing market demands of the developed regions during the 1980's and a portion of this investment could be made in the Arab States. The USA and Western Europe appear to be the main target markets. The developing regions in Africa and Asia will also require imports during this period.

The HDPE market is very fragmented, with a large number of end-uses. The major problem in penetrating this market will be establishing adequate marketing facilities to meet customers' requirements in terms of product range, technical service and adequate distribution to a large number of small consumers. These requirements will probably be met, at least in the medium term, by establishing a Joint Venture or marketing agreement with an established HDPE producer.

Local Arab HDPE demand is growing strongly, and a significant portion of production could probably be sold locally by the mid-1980's.

c) Polypropylene (PP)

Although new investment will be required to supply the USA and Western European markets by the mid-1980's, we do not feel that these areas represent major export opportunities. Although PP is rapidly developing its markets, many applications are of a specialised technical nature. Suppliers have established their position on the basis of product performance and technical service, and are usually able to obtain a good profit level on this basis. There is therefore an incentive for them to invest in new local capacity to meet the growing demand.

The developing countries and the Arab States themselves are importing increasing quantities of PP from the developed areas. Again, technical support and the wide range of grades required suggest that the established producers in the developed regions will be in a strong position to hold these markets.

d) Ortho-xylene

A tight o-xylene supply situation is predicted during the 1980's due to the expanding demand for phthalic anhydride and plasticisers, and there appears to be potential for export of Arab material to the USA and particularly to Western Europe.

The o-xylene market is very fragmented, with a large number of small consumers. Thus, although it is a commodity product sold on specification, it is necessary to have good contact with the market and a good distribution set-up. It could be that the best initial approach to this market would be to arrange contracts with established aromatics distributors and merchants.

Local Arab demand for o-xylene will ultimately develop for production of plasticisers for flexible PVC manufacture.

e) Styrene

Styrene appears to be an extremely attractive prospect for Arab production. All developed markets will need major new investment during the 1980's to meet rapidly growing demand. The developing markets of Latin America and S.E. Asia will also present substantial opportunities for export of Arab material.

In addition to the capacity shortages likely in the developed regions, lack of ethylene and benzene feedstock could also become a major problem, adding to the attractions of importing Arab material.

In view of the large proportion of styrene that is used captively, particularly in Western Europe, the best approach to marketing this material is likely to be through long term arrangements with current manufacturers.

Local availability of styrene will facilitate the subsequent development of polymer and rubber industries in the Arab countries.

f) Vinyl Chloride Monomer (VCM)

Very major investment in VCM facilities will be required during the 1980's to meet rapidly growing demands for PVC in all regions. A significant portion of this growing demand could be supplied by imports from the Arab countries.

Large volume VCM sales into Western Europe and Japan will only be on the basis of arrangements with integrated consumers and producers, due to the high degree of market integration between VCM and PVC. In the USA this approach will also be appropriate, but merchant business could be obtained if adequate marketing and distribution can be established.

This study has considered the potential for VCM production in the Arab projects rather than further processing to PVC. This is in line with our general philosophy that this study should consider the first stages of Arab petrochemical development only. Arab PVC facilities will undoubtedly be established on the basis of the availability of local VCM, either as a coordinated development or as a subsequent phase of industrialisation.

Development of VCM production implies co-production of large quantities of caustic soda by-product, the disposal of which on the export market will itself prove difficult, if a large number of Arab projects are competing for the available market. Coordinated marketing will be particularly important for this material.

g) Polystyrene

New investment will be required in polystyrene facilities in both the USA and Japan to meet growing 1980's demand. Investment plans have been deferred due to uncertainties concerning styrene feedstock availability, particularly in Japan.

We do not consider, however, that polystyrene should have any high priority as an export product. This is due to the great importance of technical service and distribution arrangements in this highly fragmented industry. A wide range of grades are required, including many blended and rubber-modified grades. Since the export prospects for styrene monomer appear excellent, there seems little incentive to process further to polystyrene, at least in the initial phases of Arab petrochemical development.

Since polystyrene facilities are relatively inexpensive, some such capacity could be added later to supply growing local Arab demands.

h) Para-xylene

Almost all paraxylene is consumed in polyester fibre production, and despite worldwide overcapacity predicted up to 1980, new investment in p-xylene facilities will be required to meet growing demands in this market during the eighties.

Increasing demands upon all aromatics from the refinery gasoline pool, as permissible lead levels in gasoline are reduced in the developed countries, will cause increasing pressure upon xylene feedstocks. This will increase the potential for exports of Arab p-xylene to these markets. We believe that Western Europe and Japan represent reasonable prospective markets, providing world price levels can be matched or undercut.

j) DMT/TPA

Dimethyl terephthalate and terephthalic acid are the basis of the polyester fibre industry. Due to the recent dramatic downturn in the textile industry, large overcapacity in DMT/TPA is now likely during the early 1980's as a result of new capacity authorised during the previous boom period. In addition, the merchant markets of the US and Europe are dominated by a few well-entrenched companies, and would be very difficult to penetrate.

We do not therefore believe that production of DMT or TPA for export is an attractive option for the Arab States. Development of DMT/TPA production will depend upon local polyester fibre production, analysis of which is outside the scope of this present study.

k) Low Density Polyethylene (LDPE)

LDPE is the largest volume consumer of ethylene, and is still showing good growth in all regions. Massive new investment will be required to meet the growing demands of USA and Western Europe. A large proportion of this investment could be made in the Arab States, and we believe that this will in fact occur.

Although LDPE is processed by a very large number of companies, there are probably more large-volume users than for other plastics, due to the importance of film which is a high volume, capital intensive activity. This means that less technical service is required for LDPE than for most other polymers.

Because of the large volume purchasers, the smaller range of grades (particularly for film extrusion) and the lower level of technical service required, LDPE is probably the most attractive polymer for potential Arab exports.

In addition, substantial local demand already exists and could be rapidly developed when local production starts.

1) Benzene

Benzene production is closely linked with the oil refinery industry and is very much affected by the state of that industry. Worldwide benzene shortages were caused in 1973 by feedstock shortages, brought about by strong gasoline demand in the US and reduced refinery throughout in Europe. Increasing pressure from the gasoline pool is expected in the future, and although adequate capacity may exist, shortages may again develop due to lack of feedstocks.

Benzene is a widely traded commodity, and in view of the potential future feedstock pressures we believe that it offers good prospects for export from Arab facilities during the 1980's. Western Europe and Japan appear likely target markets. Arrangements with trading companies and merchants could prove an acceptable way of marketing this material.

Local Arab production of benzene is also desirable as a cornerstone of the future development of an integrated petrochemical and fibres industry.

m) Liquid Ethylene

Substantial new investment in ethylene facilities in all developed regions will be required throughout the 1980's to meet growing demands. It is possible that part of this demand could be met directly by import of liquid ethylene from the Arab States.

Due to the role of ethylene as the fundamental building block of the petrochemical industry, security of supply is of prime importance in consideration of potential new sources of supply. It seems unlikely that an ethylene consumer in the developed countries would be prepared to rely entirely for his feedstock upon material imported from an Arab project, though this situation could change in time with increasing volume of maritime transportation and demonstrated reliability. In the meantime it appears that the most promising method of marketing would be to several customers, all of whom have flexibility in their sources of supply. This effectively means selling through one of the pipeline systems.

There are two principal systems in Europe. One traverses central France, running northwards from near Marseilles; the other connects Belgium, Holland and Germany. A major system exists in the US Gulf Coast area, and there are minor systems in Japan and the UK. Due to the very high costs of ethylene shipping, only those systems closest to the Arab plants would seem to offer realistic prospects of viability. Exports from North Africa to Southern Europe or even Northern Europe look attractive prospects. From the Arabian Gulf area, even the nearest market of Southern Europe (via Suez) is so remote that the economics of such a scheme are very marginal.

Thus although market prospects for liquid ethylene exports look reasonable, economic consideration will dominate in this product.

3. Regional Analyses

a) USA

The USA is considered to be the least attractive of the three major industrially developed markets of USA, Western Europe and Japan, as an export market for the Arab States. There is a large domestic market which enables good economies of scale to be enjoyed, feedstocks are expected to continue to be available and shipping costs will add considerably to the production costs. However the US market tends to be less well integrated than Western Europe and therefore represents a bigger merchant market. Hence there could be opportunities in the longer term, if the economics are competitive and adequate marketing and distribution facilities are organised.

b) Western Europe

Western Europe would appear to be the most attractive potential export market for petrochemicals produced in the Arab States. Economies of scale cannot be practised to quite the same extent as they are in the USA, there is the prospect of some tightness in the supply of feedstocks, there are increasing difficulties in financing new investment, environmental controls are making it difficult to find sites

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FEASIBILITY STUDIES FOR THE DEVELOPMENT OF OLEFIN AND AROMATICS INDUSTRIES FOR INTERNATIONAL AND NATIONAL MARKETS IN ARAB STATES

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(1 of 2)

FINAL REPORT

Volume 1

Prepared for

THE INDUSTRIAL DEVELOPMENT CENTRE FOR
ARAB STATES (IDCAS)

through

THE UNITED NATIONS INDUSTRIAL DEVELOPMENT
ORGANISATION (UNIDO)

January, 1976

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for major new petrochemical development and Western Europe is the nearest of the major petrochemical consumers to the Arab States. However, for many petrochemical products the market is well integrated and the establishment of major export business will be largely dependent upon co-operation with established producers.

c) Japan

During the past several years, Japanese industry has been very closely involved in promoting overseas petrochemical projects in cooperation with local interests, including the Arab States. The rapid development of these overseas projects was based upon a number of factors which included:

- Yen revaluation, which reduced the competitiveness of Japanese exports.
- High foreign currency levels and a drive to invest money out of Japan.
- Reaction to pollution problems made it difficult to locate new sites for expansion in Japan.
- The high cost and questionable security of supply of energy has supported the implementation of petrochemical projects in oil producing countries.

Since the oil crises and resulting decrease in liquidity, a re-evaluation of the commitment to overseas projects has occurred, but the problems facing the Japanese petrochemical producers in the future, as indicated above, are still prompting serious interest in ventures with the Arab States. Japan must therefore be given serious consideration as a market for Arab States petrochemical exports.

d) Rest of the Non-Arab World

Certain developing regions in the rest of the non-Arab world also present reasonable prospects as target markets for Arab petrochemicals.

Latin America is generally seeking self-sufficiency in petrochemicals, but undoubtedly timing of local production will not always be right and the need for balancing imports will arise in many products.

East and South Africa represent moderately large markets for certain products, and the favoured location of Arabian Gulf facilities make these good target markets.

In the Asia/Pacific region, Southeast Asia is a region undergoing a significant change in petrochemical development. Most of this area has traditionally been an importer of raw materials for fabrication and re-export, and a major programme of back-integration is now under way. Although regional self-sufficiency is the general aim, significant opportunities for Arab exports to the region will occur on a balancing basis.

Australia adopts a protectionist policy towards its industry, and we believe that in general this will preclude significant imports of Arab products. One major exception is in caustic soda, of which massive imports will be required for the large alumina industry.

Countries such as India and Pakistan will not be able to support large imports due to acute shortages of foreign exchange and limited individual purchasing power.

In general, the Communist countries will achieve long-term self sufficiency, as a group, in all products, though again short term deficits will give opportunities for sale of some Arab material.

4. Marketing Approach

There are basically two fundamental approaches which the Arab States can adopt towards marketing their petrochemical production.

Firstly, conventional Joint Ventures could be established with major international chemical companies, encompassing all aspects of the development and operation of the petrochemical project. The foreign company would supply technical know-how in design and operation, and would be responsible for arranging product marketing, distribution and technical support. The attractions of this approach are considerable to an Arab State which has little existing expertise in this area and which also has a shortage of the skilled manpower required to administer such projects. Prospects of profitability of the venture could be improved by an undertaking from the foreign partner to lift a guaranteed proportion of production at guaranteed or market-indexed prices: the initial responsbilities of the Arab interests could initially be limited to the provision of feedstocks and capital, and the application of agreed terms of joint company taxation etc. The main appeal of this approach, provided that a suitable partner can be found and motivated, is that the very considerable organisational and management resources of an experienced major company will then be committed to the rapid and economic implementation of the project. The disadvantages, from the Arab point of view, are a reduction in control over the project, reduced opportunities for rapid development of Arab personnel, and the assignment of a significant proportion of total profits on the project.

The alternative approach which could be adopted to project implementation is for the Arab State, through the medium of a National Petrochemical Company, to undertake full responsibility for project implementation and product marketing, buying the expert services of contracting, operating, consulting and marketing organisations where appropriate. If this approach is adopted, maximum theoretical advantages in terms of retained profits, Arab involvement and control will be realised, but it must be noted that certain risks are involved. One major risk is the possibility of inadequate performance by the foreign companies due to lack of incentive and commitment. Thus if the project were to experience severe setbacks in terms of construction or operating problems, or if export markets were to become depressed and restricted, there is a danger that without equity involvement in the project the foreign company might opt to withdraw from the project and concentrate its resources upon its own plants in its home area. Contracts must therefore be arranged in such a way as to provide real incentives to all parties to optimise the profitability of the venture. A simple fixed fee is clearly inadequate for this purpose, and we believe that a share in the profits would have to be offered, even if there were no foreign equity participation in the project.

Reliability and security of supply are fundamental considerations to any company considering prospective long-term purchase contracts for basic petrochemicals. Since a new Arab project clearly cannot demonstrate any historical reliability of operation, any measures which the Arab project can undertake to reduce doubts about security of its production will be of great help in arranging marketing contracts. Suitable government assurances to the operating company concerning feedstock availability and price will be required, as will long-term commitments on taxation and other concessions to be applied to the project. Co-operative marketing and supply agreements between various Arab projects (when several such projects are established) would also improve customer confidence in supply reliability. In particular, if several olefin projects are established around the Arabian Gulf, we believe that consideration should be given to an ethylene pipeline linking adjacent plants to improve ethylene supply reliability. This would be particularly beneficial if direct export of liquid ethylene is being planned.

Cooperation and coordination between the various Arab projects, particularly in product selection, will be essential to avoid excessive conflict and competition in world markets. If it does not prove possible to reconcile individual national preferences to the extent of agreement on who makes which product, then at least a joint marketing organisation could minimise the adverse impact upon world market prices by coordinating sales efforts and making joint arrangements with established products traders and merchants.

C. TECHNOLOGY AND ECONOMICS

1. Introduction

This study includes sections giving detailed technical descriptions and discussions on the technology of olefins and aromatics production. Brief descriptions of the technology of all derivatives units under consideration are also presented. Costs and availability of suitable feedstocks are analysed and the economics of production of all considered end-products are calculated by comparison with price levels assumed to be set by production in the developed countries, together with shipping cost and tariff considerations.

2. Basic Assumptions

This study relates to the implementation of the first round of Arab petrochemical projects, producing basic commodity-type products largely for the export market. All cost of production calculations and profitability analyses are based upon plant start-up in 1980, which assumes effectively immediate (1976) project implementation. To estimate 1980 and future costs, general inflation in the industrialised countries is assumed to average 7½ percent per year from 1976 onwards, and energy costs (including FOB crude oil price) are assumed to increase at this rate to protect the purchasing power of the producers. Plant capital cost and labour costs are assumed to increase at 10 percent per year.

Capital and operating cost data is first developed on a Western European type basis. It is assumed throughout this study that production costs are effectively identical in Western Europe, USA and Japan. From this cost data Western European (and thus

US and Japanese) product prices are calculated on the basis of "production cost plus fair return on investment", and deviations from this are viewed in the light of current indications for the future market situation.

Two Arab coastal production locations are assumed: one in central North Africa, the other in the Arabian Gulf. Capital costs in the North African location are estimated to be 15 percent above European levels, and for the Gulf a 25 percent increase is assumed. Variations in this "location ratio" are considered in the economic evaluations.

3. Feedstocks

The feedstocks available in the Arab oil and gas producing countries may be broadly classified for present purposes as "gas" and "liquid" feeds. The gas feeds comprise ethane, propane, butane and various mixtures of these, such as can be recovered from the associated and unassociated gas available in the Arab States. These are all good olefin plant feedstocks. The liquid feeds considered are full range naphtha and atmospheric gasoil, both available from the large new coastal export refineries being planned for several Arab States. Both are common olefin plant feeds, and the catalytic reforming of naphtha is the primary route to aromatics. Other liquid feeds such as light naphtha and aromatics raffinate can also be used as olefin plant feedstock, but the economics of these are similar to the full range naphtha case.

It is not attempted in this study to accurately quantify the amount of Arab feedstocks available, since by any standards it may be safely assumed that supplies are more than adequate for the establishment of a large petrochemical industry. On conservative estimates over thirty world-scale ethylene plants (450 000 tonnes per year) could be fed by the liquids recoverable from the Arab associated gas alone.

The values placed upon Arab feedstocks are assumed to be set basically by alternate value considerations. Thus propane, butane, pentanes and naphtha costs are set by the FOB price at which they could be sold for direct export to developed markets. The value of natural gas itself (for fuel) and of ethane are assumed to be related to developed country fuel values by the economics of exporting the gas as LNG.

The 1980 valuation of the key feedstocks is thus estimated as follows:

	Units	North Africa	Arabian Gulf
Natural gas	$/million Kcals	4.9	2.0
Ethane	$/tonne	110	70
Propane/butane	$/tonne	110	90
Pentane +	$/tonne	147	137
Naphtha	$/tonne	165	155
Gasoil	$/tonne	130	120

The actual costs of production of the "gas" feeds are lower than these "alternate value" prices (e.g. $35/tonne for ethane), and these lower values are also considered in sensitivity analyses in the economic evaluations.

4. Ethylene

Costs of production of ethylene, propylene and other olefin plant co-products are calculated for both Arab locations and for Western Europe, using a variety of available feedstocks.

The transfer price of ethylene in the developed regions in 1980 is estimated at around $450 per tonne, with propylene at $315 per tonne, set basically by the economics of naphtha and gas oil cracking.

In North Africa simple ethane cracking to produce effectively only ethylene is shown to be the most attractive option. Ethylene can thus be produced at a transfer price of $400 per tonne, applying the same finance terms to the project as were used on the European plant. This is from a 450 000 tonne/year plant. If plant size is reduced to 300 000 or 200 000 tonne/year, ethylene price would increase to $440 and $487 per tonne respectively. The considerable incentive to use the maximum practical-sized plant is thus clearly demonstrated.

If propylene is also required, it could be made available at the N. African location by using a mixed ethane/propane feedstock at the reasonable transfer price of around $265/tonne. Thus if there are particular reasons for wishing to produce propylene derivatives, this should be economically realistic at the N. African plants.

Cracking of heavier feedstocks at the N. African location, such as naphtha or gasoil, does not look attractive. Naphtha cracking for example results in an ethylene price of $575 per tonne, or perhaps $535 per tonne if a premium price could be obtained for the butadiene coproduct (though export of this butadiene would be extremely difficult in the predicted worldwide oversupply situation). Thus it must be recognised that for an Arab state to develop a synthetic rubber industry based upon coproduct butadiene which implies cracking naphtha rather than ethane, then considerable economic penalties will be incurred by the olefin complex as a whole. If a synthetic rubber industry is considered desirable from a wider viewpoint than simple project economics (e.g. reduced import dependence, downstream industrial diversification and development, etc.) then the dangers of making the basic olefin complex uneconomic (due to higher ethylene prices) must be recognised.

In the Arabian Gulf location, simple ethane cracking is shown to be relatively even more attractive, due to the lower energy and ethane values in the Gulf. An ethylene transfer price of $365 per tonne is thus calculated: cracking any other feedstock gives far higher ethylene prices.

All the Arab ethylene prices indicated above are based upon the same finance terms and return on investment as applied to the European plants. In many cases lower capital charges will be appropriate to the Arab projects (as discussed below in Section C.8), resulting in lower ethylene prices.

5. Aromatics

The three primary aromatics, benzene, toluene and xylenes, are produced via catalytic reforming of naphtha. Market conditions dictate that only benzene, para-xylene and ortho-xylene are suitable for inclusion in an Arab aromatics complex. Technical descriptions and cost of production calculations are therefore presented in this study for the production of these products, taking naphtha feedstock from an adjacent large coastal export refinery.

Benzene production via an integrated complex involving reforming, extraction and toluene hydrodealkylation is assumed. Two cases are considered for xylenes production: one in which all xylenes are isomerised to para-xylene as the only product, and one in which ortho- and para-xylenes are produced jointly. In all cases, if the same finance terms and return on investment are applied to the Arab projects as to the corresponding European plants,

CONTENTS

Arab aromatics transfer prices are slightly above European price levels. Only minor concessions on capital charges are required, however, to enable European price levels to be matched.

6. Derivatives

Technical descriptions and production economics are presented for all considered derivatives. Transfer prices are calculated first assuming the basic feedstock prices and applying the same finance terms as used for the corresponding European plants. Variations in feed prices and capital charges are then considered to find what concessions must be given to each product to enable it to compete at world price levels.

Net-back prices which may be realised by an Arab project will basically be set by the economics of competing plants in the developed countries, together with tariff and shipping cost considerations.

When exporting to the developed countries, Arab net-back prices achievable will be developed country transfer price, less import duties, less freight costs.

Into developing regions, the Arab net-back price available is assumed to generally equal the developed country transfer price, on the argument that Arab material will not be at any disadvantage relative to products from the developed countries either in terms of freight costs or tariffs.

If it is anticipated that some product could be sold locally in the Arab markets, then prices are taken to be developed country price <u>plus</u> freight costs, since these are the minimum prices that would prevail if no local production existed.

For each product an estimate is made of the target market distribution between developed, developing and local Arab markets. This is not a prediction of the actual market penetration which could be achieved by a particular Arab project; rather it is a judgement on the relative target market sizes which would have to be developed to move the total proposed Arab production.

From these market and price estimates, an average net-back price to the Arab plants is calculated for each product, and compared to costs of production at the Arab locations. The relative attractions of one product as opposed to another for the Arab projects is thus clearly demonstrated.

In general, the most energy intensive products such as styrene, VCM, basic aromatics and ethylene itself, require little or no concessions to match developed-market price levels. The highly capital-intensive products, such as polyethylene and the other thermoplastics, suffer more due to the higher capital costs incurred in the Arab regions, and require more extensive "subsidies" on feedstock price or terms of finance.

7. Potential Arab Petrochemical Complexes

The individual product analyses demonstrate that most of the products under consideration are viable possibilities for inclusion in an Arab petrochemical project. Several credible complexes were therefore evaluated, including various combinations of the more likely products which met both market and production economics requirements. The products included were:

- liquid ethylene
- benzene
- para- and ortho-xylenes
- ethylene glycol
- styrene
- LDPE
- HDPE
- VCM

A discounted cash flow approach was used to evaluate the economics of nine different complexes combining these products. Sensitivity analyses showing the effects of higher capital costs and lower feedstock costs were also included. The "internal rates of return" were all found to be in the range of 21 to 30 percent p.a., before tax, on an inflation accounting basis, the most likely cases around 25 percent p.a.

In general, the likely profitability of a petrochemical complex in North Africa is shown to be very similar to the profitability of a similar project in the Arabian Gulf, despite the variations in costs and revenues between the two regions. In both regions, integrated olefin and aromatics complexes offer the best economics, though any of the complexes could be considered acceptable.

By comparing the returns on one complex with another, the following general comments on the potential profitability and desirability of each product can be made.

In both locations, styrene is shown to be the most attractive major option, with ortho-xylene also very favourable, though long-term uncertainties on o-xylene price mechanisms cloud this judgement somewhat. VCM, para-xylene and benzene also offer good economics in both regions. LDPE economics are not particularly attractive at either Arab location, but export and local market considerations suggest that this should be included in any complex as a reliable base-load product. HDPE economics are in fact marginally more attractive than LDPE, due to the higher energy and utility consumption of the process, but marketing prospects are less favourable and the economics are still less attractive than any other ethylene derivative considered. Inclusion of HDPE in the initial Arab complexes, therefore, seems less clearly beneficial. Ethylene glycol economics are quite favourable, but again marketing prospects are relatively poor.

Direct export of liquid ethylene from the North African location is quite an attractive prospect in terms of straight economics. Detailed sales discussions on a basis of firm project plans will be particularly necessary in the case of liquid ethylene sales, however, to identify specific sales opportunities and confirm the acceptability of large-volume imports to the European consumers and pipeline companies. The economics of liquid ethylene export from an Arabian Gulf location look distinctly unattractive, due to the high costs of shipping over the long distances involved, when compared to the alternative approach of using the ethylene locally and exporting derivatives.

The effects of higher capital costs are roughly equally damaging, in terms of returns on investment, to all complexes, though obviously the effect is marginally greater upon the highly capital intensive resin products (HDPE, LDPE) than upon the more energy intensive styrene, VCM, etc.

Cheap feedstock, i.e. charging in ethane at production cost rather than the higher "alternate value" price, has a major effect upon returns of the N. African complexes. This is particularly true of those complexes involving liquid ethylene export, in which cases the benefits of cheap ethane can more than outweigh the potential penalties of higher capital costs. For the Arabian Gulf complexes, the benefits of lowering ethane price to a production cost level are less marked, since the "alternate value" price in the Gulf is already quite low, due to the high costs of shipping gas or light gas liquids to market.

8. Economic Viability of Arab Petrochemical Projects

The general conclusion that can be drawn from these evaluations is that any of these Arab petrochemical complexes can be viable from the viewpoint of a state-owned Arab petrochemical company.

That is to say that all projects can yield net cash flows adequate to repay loans and interest charges, while leaving a reasonable surplus for profit and return on equity. If the project is based entirely upon loan finance, and a ten-year depreciation period is assumed, then a rate of return around 15 percent p.a. on total project costs is adequate to cover all debt service charges over the project's life at current commercial interest rates. The minimum rate acceptable to an Arab National Petrochemical company is thus probably in the range of 15 to 20 percent, allowing a margin over loan costs to cover overheads and profit, and to provide some safety factor against failing to reach operating or sales revenue targets.

The returns required by an international chemical or oil company will generally be significantly greater than those acceptable to the Arab organisation itself. This is because the State-owned Arab company will be basically motivated by a national political directive to develop the petrochemical industry: the considerations involved in formulating this directive are largely long-term economic and social factors, as discussed in Section X-D on "Indirect Benefits". They include such factors as employment and training benefits, generation of increased foreign exchange revenue by processing basic feedstocks ("value added"), and the intangible long-term national benefits of infrastructure development. While these indirect benefits are of prime importance in formulating Arab national policies, they are of little relevance to a foreign chemical company evaluating an investment decision in the Arab country. The company will view the proposed project as a separate entity, and apply only commercial criteria in evaluating it. (This is also true in the developed countries, where governments offer financial inducements to companies to invest in regions and industries which the government regards as desirable, for social reasons, but which are less attractive to the company than some other alternative.)

The main commercial criteria which the foreign company will apply are

- alternative uses for its available money, manpower and expertise.
- assessment of the commercial, political and other risks involved in the project, as compared to other projects in which it could invest.

The alternative use for the financial resources of an international company is basically investment in similar facilities in the developed countries. As is demonstrated in Section VIII, there are very few petrochemical products which can be manufactured in the Arab states to yield gross returns on capital equal to those achieved in the developed countries, assuming comparable taxation levels. Certainly a large multi-product Arab facility will not be able to achieve the same gross returns as a comparable integrated facility in a developed country. On inflation and other assumptions comparable to those used in evaluating the Arab projects, we calculate that the <u>after-tax</u> DCF returns on most W. European petrochemical projects will be around 20-22 percent p.a. if prices are set by the simple 25 percent ROI approach of Section VIII. This 20-22 percent after tax corresponds to 27-30 percent before tax. (It should be noted that the historical value of 15 percent DCF return after tax, which many companies have long used as a minimum acceptable return in project planning, was not based upon inflation accounting principles, i.e., it did not take full credit for future increases in product prices after plant start-up, and calculated the returns on the price levels predicted for the time of start-up. This 15 percent rate is roughly equivalent to 22-23 percent on the inflation-accounting basis used throughout this report and we believe that most major companies are presently looking for returns of this order in evaluating new projects.)

The rates of return on the better complexes therefore appear to be in line with the requirements of the foreign chemical companies. A complete absence of corporate income tax should therefore ensure adequate incentives to a potential foreign equity partner. Some of the more attractive complexes could bear some tax and still remain marginally viable.

The assessment of risk which a potential foreign equity partner will make of an Arab project depends upon many factors, most of them specific to the project and the company.

Firstly, the lack of experience with comparable projects in the Arab States increases the uncertainties regarding the actual time required to build a plant and the final costs

Secondly, the history of nationalisation of foreign assets and concessions by the oil-producing states over the past few years has made many major oil and chemical companies acutely aware of the political risks involved in investing outside their domestic regions.

Thirdly, project development costs and corporate overheads will be higher for a company developing and supporting a project outside its traditional areas of operation, and somewhat higher returns will be required to cover these costs.

Fourthly, there is one major factor which will tend to counteract the disincentives previously discussed. This is the attraction of guaranteed <u>availability</u> of feedstocks.

The oil embargo and shortages of 1974 made many integrated international companies acutely aware of the importance of security of supply for feedstocks and energy, and participation in a project in the Arab oil-producing states is one way in which a company could secure access to reliable feedstocks supplies. This incentive could lead the company to regard investment in an Arab petrochemical project as acceptable at a rather low return on investment than it would otherwise accept. An associated factor is the desire of the major oil companies to be seen to be "good citizens" in the countries in which they have established oil production operations: participation in a petrochemical venture (even of limited profitability) might be considered acceptable in the interests of good relations with the host government, thus preserving access to valuable crude oil supplies.

On a balance of the factors discussed above, a foreign major chemical company will generally require a higher rate of return on its investment in the project than will the State-owned Arab Petrochemical Company. If it is desired to attract foreign equity participation in the project, it will therefore generally be necessary to offer the project (or the foreign investor) more generous concessions on taxation, etc. than would be necessary from the viewpoint of the state participation. On this consideration, it may be regarded as undesirable to have any foreign equity participation in the project at all: in this case, some other form of joint venture would have to be entered into, possibly combining a technical service and management contract together with a product marketing contract.

We believe it to be very important, however, that an experienced major international company should be deeply involved in all phases of the implementation of the Arab petrochemical development, since the expertise of such companies can have a dominant impact upon the efficiency and profitability of the project. The most certain way to ensure total long-term commitment is for the foreign company to have an equity stake in the Joint Venture company; this ensures their interest in maximising project profitability, and also makes it inconceivable that they would abandon the project in the event of future difficulties of operation or marketing. If the Arab country does not wish to obtain foreign equity partners, due either to political inclination or to economic considerations, such as the required return on capital as discussed above, then the foreign expertise will have to be bought in some other way, and the risks of such alternate approaches must be considered.

A major international chemical company will not be prepared to involve itself in an Arab project, thereby associating its technical and commercial reputation with that project, and committing management services to it, without adequate incentive. Thus a simple technical service and management contract to execute and operate the project for a fee will not generally be desirable, since it offers little incentive to the foreign company to maximise project profitability. A contract based upon a fixed or reimbursable fee <u>plus</u> a percentage of profits would seem to be necessary to ensure adequate commitment of the foreign company. Even this arrangement is in some ways less certain than having foreign equity participation, since it is still conceivable that under certain adverse circumstances of operating problems coupled with badly depressed markets, a foreign company without equity involvement might abandon the project and concentrate upon the plants in its home area.

Risks and factors such as this must be weighed by the planners of each Arab project when deciding whether to invite foreign equity participation in the venture. We believe that in most cases this firm equity-based Joint Venture approach will offer the safest method of "buying" the necessary committed expertise from foreign companies.

CONTENTS

VOLUME I

VOLUME 2

Detailed Tables of Contents of each section are included at the front of the individual sections.

SECTION II : INTRODUCTION

Contents | Page No

II INTRODUCTION

A. BACKGROUND

Chem Systems were informed by telex on 28 February 1975 that their Proposal dated 10 January 1975 for the execution of UNIDO project DP/REM/71/208 on Olefins are Aromatics Industries in Arab Countries had been accepted. UNIDO Contract Number 75/6 was assigned to this project. The study was to be prepared for IDCAS, through UNIDO, as part of the main IDCAS planning programme.

Following Chem System's acceptance of this contract award, Chem Systems' personnel attended a briefing session during late March 1975 at UNIDO headquarters in Vienna. During this briefing session final contract details were agreed, and the contract was signed by both parties during early April. The effective date of contract award was specified as 1 April 1975, and work started during early April.

An Interim Report was presented to UNIDO on 1 September 1975. This summarised the work done to that date, and set out the scope and format of the remaining work programme. This Interim Report was accepted in principle by UNIDO during early September.

A Draft Final Report, covering essentially all Chem Systems' work on this study was submitted to UNIDO at end-November 1975. This Draft Report was reviewed in detail with IDCAS personnel, in Chem Systems' London offices, during December. In addition Chem Systems' personnel attended debriefing meetings at UNIDO headquarters in Vienna during late December. Numerous comments, questions and requests for further analysis work were made in these meetings by IDCAS and UNIDO: these additions are incorporated into these present volumes, which constitute the Final Report on this study.

B. OBJECTIVES

The primary objective of this feasibility study is to define the potential for the establishment of olefin and aromatics industries in the Arab States. The emphasis of the study is to assist the various decision-makers in the Arab States to implement oil and gas utilisation programmes which will give the maximum overall long-term benefits to the Arab economies. The studies are therefore of a general nature to permit their use for any North African or Arabian Gulf coastal location.

It is not realistic for a generalised study such as this to conclude that one specific petrochemical complex is preferable to all others for all Arab projects. In fact, it is clear that if several major Arab petrochemical projects are realised it will be essential that there is coordination between the planning of these to avoid excessive conflict and competition in world markets. Therefore a range of different products and complexes must be and will be implemented by the Arab States. A basic objective of this study is therefore to consider a wide range of potential products, and select from these the more attractive prospects on technical, market and economic grounds. Various credible combinations of these products are then analysed further as possible Arab petrochemical complexes, including ofefins, aromatics and combinations of these. The objective is not to give the best potential project, but to demonstrate the type of projects which will be viable and to analyse the many factors involved in the development and implementation of such projects.

SECTION II

SECTION III : EVALUATION DATA

SECTION III : EVALUATION DATA

III. EVALUATION DATA

This section presents the basic data and assumptions on capital and operating costs, site location and economic trends, and describes the methodology used throughout this study.

A. METHODOLOGY

The primary objective of this study is to define the potential for the establishment of olefin and aromatics industries in the Arab states. It is a fundamental assumption throughout the study that decisions on the implementation of petrochemical projects will be made on a sound economic basis. Information is therefore assembled on the two topics which are of dominant importance in defining this potential for a viable project, i.e. product markets and production economics.

1. Markets

To enable the products from an Arab petrochemical project to compete with production from the industrialised countries, large-capacity plants are essential to gain the very considerable economies of scale available. Since the Arab markets are not in general able at this time to absorb the resulting large quantities of petrochemical intermediates and end-products, the emphasis of these projects will be strongly export-oriented.

Section IV therefore presents in-depth worldwide market analysis of a range of twelve olefins, aromatics and derivatives. (These twelve products were selected from a comprehensive potential range in a preliminary screening analysis presented as Appendix I.)

The objective of this worldwide market analysis is to identify products and regions which in the medium-term future (1980, 1985 and 1990) will present opportunities for the sale of Arab material, and to estimate the potential volume of such sales.

The industrialised regions of the United States, Western Europe and Japan are considered in detail since these dominate total present world markets, and also represent the major growth areas in absolute terms throughout the time-frame of this study. The rest of the non-Arab world is considered as a single grouping, and in less detail. The International (i.e. non-Arab) market research has been carried out during mid-1976, involving extensive travel by Chem Systems personnel to all market regions.

The likely future size and structure of the local Arab markets is also predicted, based partly upon information supplied by IDCAS and supplemented by Chem Systems own data from recent fieldwork in several Arab states.

Having identified potential markets, recommendations are made on how Arab material could penetrate these various markets and achieve the market shares necessary to support the proposed projects.

2. Production Economics

The general approach to the economic evaluations in this study is to compare the proposed Arab project with the industrialised- country plants with which it must compete.

Thus it is assumed that the selling prices for Arab material will be basically set by the economics of production in the

SECTION I

industrialised countries. This means that when selling Arab material into Europe, say, the Arab product suffers a freight penalty which means that achievable ex-plant transfer price is less than for the competing European plants. When selling in local Arab markets, however, the freight advantage is reversed, and in third-country markets a balance of freight costs etc. must be considered.

Production costs from a new plant in a developed area (W. Europe, etc) are calculated, and used to estimate the ex-plant prices available to the Arab projects. Production costs for the Arab projects are then calculated on the basis of a series of projections and assumptions as set out below in Section B.

Each individual product (of the twelve considered) is analysed for potential profitability on the basis of achievable selling prices, markets and production costs.

A selection of the most favourable products is then made, and various possible Arab petrochemical complexes are then suggested and evaluated.

The various cost factors are defined and discussed below in Section B.

B. COST OF PRODUCTION BASIS

Capital and operating cost data is first developed on a Western European-type basis. From this cost data European (or U.S. or Japanese) product prices are calculated on the basis of "production cost plus fair return on investment", and deviations from this are viewed in the light of current indications for the future market situation.

It is assumed throughout these calculations that production costs are effectively identical in Western Europe, the U.S.A. and Japan. It has been generally accepted in the past that small differences in capital costs exist between these three regions, and also labour rates and productivity vary somewhat. These differences are all relatively small, however, and are certainly less than the potential fluctuations which could arise by 1980 (the base year used for these calculations) as a result of differential inflation and currency movements. Similarly, with regard to energy prices: it may be argued that Japan has a freight cost advantage on the marker crude, Arabian light, relative to the U.S. and Europe. Japan does not, however, have the indiginous supplies of lower cost coal, gas and oil which will help to hold down European and U.S. average energy costs. Again, therefore, any differences in the average energy cost situation between these three regions are assumed to be negligible for the purposes of these evaluations.

The "developed-country" cost calculations are therefore carried out on a Western European basis on the premise that the results will be applicable also to the U.S. and Japan.

The detailed cost of production and selling price calculations presented in this report follow the breakdown shown overleaf as Table III.B.1. The various cost factors used in this calculation are defined and discussed below:

TABLE III.B-1
PRODUCTION COST ESTIMATE

Capital Cost	$MM
Battery Limits Capital Cost	
Offsites Capital Cost	
Total Fixed	
Working	

Basis: Location-
Capacity-
Rate -

RAW MATERIALS	QUANTITY	UNIT	PRICE	ANNUAL COST	UNIT COST

TOTAL RAW MATERIALS:

UTILITIES:

TOTAL UTILITIES COST:

OPERATING COSTS:

Labour
Supervision
Maintenance Material and Labour @ 4% BLCC

TOTAL OPERATING COSTS:

OVERHEAD EXPENSES:

Direct Overhead - 30% (Labour & Supervision)
General Plant Overhead - 65% Operating Costs
Insurance, Property Taxes - 1.5% Total Fixed Capital
Depreciation - (Basis: 10% BLCC + 5% Offsites)
Interest - 10% on Working Capital

TOTAL OVERHEAD EXPENSES:

BYPRODUCT CREDIT:

TOTAL BYPRODUCT CREDIT:

TOTAL COST OF PRODUCTION:

RETURN 25% ON TOTAL FIXED INVESTMENT:

TRANSFER PRICE*

* $/unit

1. Units

Metric units are used throughout the report. Cost data is given in U.S. dollars.

2. Time Scale and Inflation

All cost of production calculations and profitability analyses are based upon plant start-up in 1980, which assumes effectively immediate (1975/76) project implementation.

To estimate 1980 costs, the following assumptions have been made:

a) General inflation as measured by most of the possible criteria varies widely throughout the industrialised countries at the present time. OECD data based upon local consumer prices shows a range for 1974 of 6.5 percent in W. Germany up to 18 percent in the U.K., and current mid-1975 rates are both higher and of wider variation.

However, since all costs, including crude oil, are quoted throughout this study in U.S. dollars, there is a compensating movement in relative currency parities which tends to off set these wide differences in inflation rates. Thus the fall in the value of the Pound Sterling against the Deutschmark during 1974 closely matched the difference in inflation as measured by the consumer price indices. While this mechanism is far from perfect in explaining currency movements it appears to be the most satisfactory approach for the purpose of rationalising assumptions on future costs for this present study. It allows a single consistent view to be taken on future capital cost and general inflation as expressed on a U.S. dollar basis.

Estimation of the level of future inflation can only be regarded as extremely hazardous and uncertain at the present time, and no great confidence can be placed in the results of such estimation. On the assumption that inflationary cost increases will affect projects in the Arab states no worse than they will affect comparable projects in the industrialised countries, overall profitability analyses in this study will not be affected by inflation. An estimate of cost inflation is included, however, to ensure that estimates of the actual as-built capital costs of the Arab projects will be as realistic as possible.

We accept the general forecast that after 1975 inflation will be reduced to below current levels, and will settle at a plateau higher than the historic 2 - 5 percent which most developed countries have experienced in the last twenty years. We take an average of 7.5 percent per year for the period 1975 - 1980, and where necessary we assume the same annual rate beyond 1980.

b) Plant Cost Inflation

Chemical plant construction costs have in the past borne a changing relationship to general inflation rates. During the early 1960's, gains from technological improvements and increased scale outweighed cost increases, and plant costs fell in real terms. Recently, these factors have been in balance. If one now postulates that plant capacities are levelling off and innovation is slowing down then actual plant costs will rise in line with equipment costs. The high labour component in equipment costs leads to a rate of plant cost inflation higher than the rate of general inflation.

We suggest that this latter assumption is valid, and use a 2.5 percent gap between plant cost inflation and the general inflation index.

Thus an inflation rate for both plant costs and also for labour is assumed to be 10 percent p.a. from 1976 onwards.

This rate is assumed to apply to all industrialised regions and also to the Arab projects under evaluation.

c) Energy Cost Inflation

We assume that the FOB cost of crude oil will rise in line with general inflation (i.e. a cost of living index) in the developed countries, to offset the decline in the producers purchasing power which would otherwise result. Thus starting from a base of $75 per tonne in 1975 for Arabian light FOB Ras Tanura, an FOB cost of $107.7 per tonne in 1980 is calculated. This is used as the base reference for energy costs in the cost of production calculations.

The costs to be assigned to energy and feedstocks for the Arab projects are discussed in detail in Section V.

d) Currency Exchange Rates

Currency parities existing at end-June 1975 have been used to estimate the 1975 capital costs, from which the 1980 data is calculated. Table III.B.2 summaries these parities.

TABLE III.D.2

U.S. DOLLAR PARITY VALUES AS AT JUNE 30TH 1975

Country	Local Unit	Value of U.S. Dollar
Belgium	Franc	35.4
France	Franc	4.04
Italy	Lira	630.5
Japan	Yen	296.6
Netherlands	Guilder	2.44
Norway	Krone	4.94
Spain	Peseta	56.1
Sweden	Krona	3.93
Switzerland	Franc	2.50
United Kingdom	Pound	0.436
W. Germany	Mark	2.36

3. Capital Cost

Capital cost includes the following elements:

a) Battery Limits Capital Cost
This is the total erected cost of the production unit including all material, labour and engineering costs. Included where appropriate is any initial catalyst loading and solvent inventory. Interest during construction is capitalised at 10 percent p.a.

b) Offsites
This is the total erected cost (including interest during construction) of ancillary equipment and buildings required to support the production unit, and includes such items as feed and product storage boilers, effluent disposal etc.

Offsites requirements will vary considerably depending upon whether the installation is part of an existing facility, integrated with a refinery or chemical complex, or a grassroots plant (new development on a new site). Another major consideration is the amount of storage to be provided, which depends upon the nature of the feedstock and the type of contracts for both feed and products. Thus, offsites as a percentage of battery limits costs can range from 40 percent for a plant integrated with many existing facilities, to over 100 percent for a self-sufficient grassroots installation with extensive storage capacity and dock facilities.

Table III.B.3 lists typical offsites required for a grassroots olefin plant (new development) in a developed country.

The Western European cost of production estimates base offsites upon a percentage of BLCC, generally 50 percent but varying somewhat depending upon plant complexity and level of offsite services required. In all cases, the percentage chosen is intended to represent costs applicable to a major new petrochemical development in a highly developed industrialised area.

Offsite costs for the Arab complexes considered were estimated on the basis of preliminary plant layouts and calculated utility, storage and other requirements as set out in later sections. The one exception to this approach is the Aromatics Unit, for which offsite costs are small and will be totally integrated with the refinery from which the naphtha feed is supplied. In this case the "percentage of BLCC" approach is again adopted.

TABLE III.B.3

TYPICAL OFFSITES REQUIRED FOR A GRASSROOTS ETHYLENE PLANT

OFFSITE ITEM PROVIDED	COMMENTS
Storage	1 month of capacity for each feed and product except where noted otherwise. All tankage fully instrumented, diked, and fire protected.
Feedstock	Salt domes for ethane and propane, floating-roof tankage for others.
Ethylene	Salt dome.
Propylene	Salt dome, short term refrigerated liquid at plant site. Not required for ethane plant.
C_4 Stream	Spheres. Not required for ethane plant.
Pyrolysis Gasoline	Floating-roof tankage.
Light Fuel Oil	Floating-roof tankage, not required for ethane plant.
Heavy Fuel Oil (Gas oil cracking only)	5 days maximum capacity due to high carbon content. Cone-roof tankage.
Utilities Systems	
Fuel	Knockout drum and connecting lines.
Steam	Supplementary boiler for start-up and standby.
Cooling Water	Induced-draft towers.
Power	Substation transformers, switchgear, and connecting cables.
Air	Compressors and lines for instruments and plant (decoking).

TABLE III.B.3
(Cont.)

OFFSITE ITEM PROVIDED	COMMENTS
Utilities Systems	
Water Supply	Wells, make-up to cooling tower and process area.
Boiler Feed Water Treating	Complete treating facilities for make-up water to boilers
Fire Water	Storage, piping loops, hydrants.
Inert Gas	Generator system
Supporting Facilities	
Flare Stacks	One ground level, one elevated.
Oil-Water Separator	API separator to treat all liquid effluents.
Railroad	Spur, car pullers, loading dock and rack.
Tanktruck Loading Station	Loading rack, scale, pit, weigh house.
Buildings	
Laboratory	Normally-equipped facility.
Administration	Fully furnished for approximately 50 people
Maintenance	Equipped to handle nominal maintenance jobs.
Civil	Site preparation, piling, foundations, dikes, yard fencing, roads, parking lot, storm and sanitary sewer systems.

SECTION I : EXECUTIVE SUMMARY

TABLE III.A.2
(cont.)

OFFSITE ITEMS PROVIDED	COMMENTS
OTHER	
Piping	Tie-ins to process, storage, and utility areas.
Communications	Network throughout plant.
Painting and Insulation	As needed.
Lighting	All yard facilities.
Fees	Contractor field and home office expense and profit.
Contingency	An arbitrary decision- assumed to be 8%.

c) Working Capital

This is the capital which an operating company must have available to finance materials and services for which it has to pay before the resulting product is sold. It covers items such as stocks, accounts receivable, in-plant materials etc. Ideally a formula based upon these components should be used, of the general form

Working capital = Stocks + Work in progress + Accounts receivable - Accounts payable

These factors vary widely between companies and chemicals, depending upon company sales pattern and accountancy practice. For example, if an ethylene producer sells his product to a storage/shipping company at an adjacent site and receives prompt payment, the producer may have to finance only two weeks production. In another commercial situation, particularly involving product exports, three months may elapse before payment. This one difference (two weeks versus three months production) can dwarf all other working capital requirements.

Past experience has shown that a reasonable average working capital for bulk petrochemicals in a typical commercial situation is given by using a percentage of BLCC. To give a uniform basis throughout this study we adopt this BLCC - related approach, using 10 percent to 50 percent depending upon plant type.

d) Start-up Costs

A producer will most certainly incur additional expenses prior to plant start-up and then during start-up. These include home office costs related to the planning, engineering, and management of the project and the cost of actually operating the new plant in start-up phase. During start-up little or no sales revenue is realised while attempting to reach design operating rate and product specifications.

The financial treatment of start-up expenses can vary quite dramatically. In some instances, all costs incurred prior to meeting operating guarantees are expensed in the year of occurrence. In other cases the costs are accumulated and capitalised in the year of start-up and amortised over the economic life of the project. Further, these expenses are sometimes combined with similar costs from other projects in a separate home office cost centre. The method of handling such expenses is obviously highly dependent on a company's particular tax position, corporate financial policy, etc.

The effect of delayed production and revenue due to start-up delays is allowed for in the overall economic evaluations in Section X. The effect of other "start-up" costs, such as project planning costs etc., is ignored in these evaluations, since their overall effect on project economics is small and they will be broadly comparable for Arab projects and for the competing developed-country projects.

4. Raw Materials

a) Industrialised Countries

The costs of the major hydrocarbon feedstocks (naphtha, gas oil etc.) include an energy-related cost and a capital- related cost element. The capital element is related to the cost of equipment necessary to separate the product from crude, or to otherwise refine or produce it. The energy-related element is proportional to crude oil cost and is a measure of the amount of energy consumed in separating or producing the product. This cost breakdown into capital and energy elements may be expressed as a simple equation. For gas oil in W. Europe in 1975, for example, a stable market price is given by the equation

$$\text{Gas oil price} = \$(11 + 1.05C) \text{ per tonne,}$$

where C is the cost per tonne of crude oil. Market forces obviously cause actual prices to vary around this predicted figure, but to finance the expenditure needed to supply a growing market it is necessary for prices to be at an average level which gives an adequate return on capital investment.

1980 feedstock prices are therefore based upon cost equations of this type, applying the energy and capital cost inflation estimates described in Section III.B.2.

b) Arab States

The costs to be assigned to energy and feedstocks for the Arab projects are discussed in detail in Section IV.

5. Utilities

The utility costs used in the cost of production calculations are tabulated in Table II.B.4, below. These costs are derived in a similar manner to the hydrocarbon feedstock costs as discussed above, i.e. as a combination of energy and capital-related elements.

Thus a cost of steam to a plant in W. Europe in 1976 is given by

$$\text{Steam cost} = \$(0.52 + .073C) \text{ per tonne,}$$

where C is the cost per tonne of crude oil.

1980 W. European costs are calculated using the energy and capital cost inflation estimates of Section III.B.2.

Utility costs for the proposed Arab petrochemical projects are calculated from similar equations, allowing for the differences in plant and equipment costs and using the energy values which will be derived later in Section V.

TABLE III.B.4

1980 UTILITIES COSTS

Item	Unit	Cost, $/unit		
		W. Europe	Arabian Gulf	W. Africa
Electric Power	1000 kWh	43.5	22.4	27.0
Steam	Tonne	9.6	2.7	4.3
Fuel	10^6 k.cal	11.6	2.0	4.9
Cooling Water	1000 m^3	16	12 (1)	12 (1)
Boiler Feed Water	1000 m^3	400	800 (2)	600

(1) Sea water

(2) Distilled and treated

6. Labour, Maintenance and Overheads

Rates for labour and supervision are based upon current average Western European values escalated to 1980 in accordance with the inflation estimates of Section III.B.2, i.e. at 10 percent per year. The same rates are also used for the Arab plant locations, on the assumption that labour shortages and training costs, together with a percentage of high-cost expatriate assistance in early years, will lift average costs to European levels.

Thus the values used for 1980 are

Labour	$19,000 per man year
Supervision	$27,000 per man year

Staffing levels are based upon European and U.S. practice. The same levels are used for W. Europe and the Arab locations.

For maintenance and overheads, Chem Systems standard formulae are applied. As these are all percentages on other items, no escalation is needed. The same values are used for European and Arab locations:

Maintenance	4% of BLCC
Direct Overhead	30% of Labour plus Supervision
General Overhead	65% of Operating Cost, i.e. Labour, Supervision plus Maintenance
Insurance and Property Taxes	1.5% of Total Fixed Investment
Depreciation	10% on BLCC plus 5% on Offsites
Interest	10% on Working Capital

7. Return on Investment (ROI)

This is a pre-tax return on total fixed investment. For petrochemical plant of the type under study the industry generally uses 25 percent ROI assessing projects by this simplified method.

The ROI approach is used in this study to choose between various products and select various combinations of petrochemical complex. These complexes are then evaluated in Section X using more sophisticated discounted cash flow and other methods.

8. Selling Costs

Selling costs are ignored in these evaluations since for commodity petrochemicals of the type under study selling costs typically represent only 2 - 3 percent of sales price. This is expected to be broadly similar for the Arab projects and for the developed- country projects. Although market development for the new project is obviously expensive, the Arab venture will probably concentrate upon a few large-volume contracts whereas the (say) European competitors will also service a large number of smaller outlets with higher percentage selling costs.

Selling costs and marketing approach are discussed in Section X on overall economic evaluation.

9. Plant Operating Rate

For the purposes of the cost of production calculations, all plants in Europe and in Arab locations are assumed to be operating at 90 percent of nameplate capacity. The effect of variations in this, and of a realistic pattern of build-up of plant output, are analysed in Section X.

C. LOCATION FACTORS

The capital cost of a plant erected in the Arabian Gulf area or on the North African coast, will be significantly higher than that of the same plant in Western Europe. This cost differential results from a number of factors:

- Shipping costs for equipment and materials
- Different design parameters, e.g. cooling water temperature, ambient air temperature, dust proofing requirements, etc.
- Travel and maintenance costs for expatriate personnel
- Higher field construction costs, due to lack of industrial infrastructure and local workforce
- Longer project schedules, which inflate overhead and interest charges.

These are generalisations which do not apply equally to all Arab states, but most of these factors will apply to most Arab projects. Each point is elaborated below.

1. Shipping Costs

No consideration is given here to freight costs for products: that subject is covered in Section IX.

This present section discusses the cost penalty due to shipping equipment and materials of plant construction to, say, the Arabian Gulf as opposed to a site in North West Europe.

The main cost penalty is not in general associated with shipping major equipment such as compressors, turbines or large pressure vessels. These items are procured on an international basis and for a plant in the U.K., say, it would be common for the compressors to be Swiss, the turbines German, pressure vessels Japanese, etc. etc. Such equipment therefore generally has to be packed for export, loaded and shipped, even if only for a relatively short distance. Due to the high cost per ton of such equipment, freight is a small percentage of total cost. The marginal penalty (on average) of delivering all major equipment to an Arabian Gulf location compared with a European location is unlikely to exceed around 2 percent of their total cost.

The main cost penalty to an Arab project will lie in the large quantities of bulk materials such as piping, structural steelwork, cement, welding materials etc. which would generally be available to a European site from local sources, but will often have to be imported to a typical Arabian Gulf location. Freight costs as a percentage of total value of such materials can frequently exceed 20 percent.

2. Design Parameters

Higher ambient temperatures, more stringent dust proofing requirements, and other differences in basic design parameters between Europe and a typical Arab state can have very major effects upon plant capital and operating costs. For example, a gas turbine rated at 10,000 horsepower output for a European location (20°C design temperature) might be de-rated to 8,700 horsepower at an Arabian Gulf site with design ambient temperature of 35°C. This represents a 15 percent increase in cost per horsepower.

Similarly a major cascade refrigeration system, which represents 10 - 15 percent of the battery limits cost of a European ethylene plant, could be increased in size and cost by

I EXECUTIVE SUMMARY

A. GENERAL

Chem Systems was awarded a Contract through UNIDO, effective April 1st, 1975 for the preparation, as assistance to IDCAS, of "Feasibility Studies for the Development of Olefins and Aromatics Industries for International and National Markets in Arab States". These volumes are the Final Report required under the terms of the Contract and present all Chem Systems' work and conclusions on this study. This Final Report incorporates further information and analysis work requested by both UNIDO and IDCAS during review meetings with Chem Systems in December 1975.

The objective of this Study is to define the potential for the establishment of olefin and aromatics industries in the Arab States. The emphasis is to assist the various decision-makers in the Arab States to implement oil and gas utilisation programmes which will give the maximum overall long-term benefits to the Arab economies. Due to the vast quantities of feedstocks available, the available economies of scale, and the very limited current size of local Arab markets, these initial projects will be largely export oriented.

A fundamental assumption throughout the study is that decisions on the implementation of petrochemical projects will be made on a sound economic basis. Information is therefore assembled on the two topics which are of dominant importance in defining this potential for a viable project, i.e. product markets and production economics. If it is considered desirable to implement a particular project or programme for reasons other than direct project economics (e.g. reduced import dependence, downstream industrial diversification and development, foreign exchange improvement through "added value" processing, etc.) then the treatment adopted in this study aims to demonstrate and quantify the direct financial penalties incurred by such a course of action. Discussion is also presented on the "indirect benefits" of petrochemical

25 - 40 percent by increasing the design air or cooling water temperature from 20° to 35°C. Dust proofing and air inlet filters for machinery in a coastal desert environment might add another 10 percent to European cost levels.

These are major cost increases, and contribute significantly to the differential between total European and Arabian Gulf/North African plant costs.

Offsetting these factors in some cases are the increasing costs which are being incurred in Europe, the U.S. and Japan in meeting restrictive environmental and pollution limits. Restrictions which apply to highly industrialised, densely populated European/Japanese sites will not in general be applicable to Arab locations, resulting in some cases in cost savings for the Arab projects.

Another factor tending to reduce capital costs in Arab oil/gas producing regions is the low cost of energy. Optimum design of equipment will tend to swing towards higher energy consumption and lower capital costs, for example by accepting smaller pipe sizes with higher pressure drop etc.

The balance between these conflicting cost factors (higher ambient temperatures, lower environmental and energy costs, etc.) will vary from site to site and for different types of plant.

J. Expatriate Personnel

If the remote nature of the plant site requires the construction of extensive housing and facilities to accommodate and maintain large numbers of expatriate construction and operating personnel, several million dollars can be expended on a major project. High salaries to induce personnel to work away from home, together with extensive travel costs, can result in average manpower costs for an Arab location higher than for a comparable European site.

4. Field Construction Costs

The lack of industrial infrastructure and local workforce at many Arab locations can result in considerable increases in construction costs and time schedules. Construction of access roads and docks will normally be required. Utilities such as electric power and fresh water will not generally be available from public supply. Local pipe fabrication facilities, etc., will not exist and must be set-up on site. All field equipment (earth-moving, lifting, welding etc.) must often be imported.

Offsetting these factors, the complete absence of a local erection workforce sometimes makes it possible for a construction contractor to import a large established team of experienced itinerant workers. Such teams exist around the Arabian Gulf, and where they can be used they tend to lower field construction costs.

5. Longer Project Schedules

The combination of the time taken to ship equipment to site, together with the lack of local industrial infrastructure, generally combine together to extend the time taken to build a plant in the Arabian Gulf area, as compared to a European or U.S. location. This extension should in theory be of the order of three months, to cover shipping and infrastructure development, but the experience of many contractors has shown that six months or longer is more typical. These longer project schedules inflate overhead and interest charges, and can add 5 - 10 percent to the total cost of a project. The delay in revenue due to deferred start-up can be an even more serious blow to project profitability.

6. Summary

The increased battery limits cost of an erected unit in an Arabian Gulf location is dependant upon numerous factors, the balance of which for a typical case is largely a matter of informed judgement.

The range of views presented in Table III.C.1, below, are the result of discussions with numerous companies and organisations knowledgeable of recent major plant construction in the Gulf. Comparison is made with a base Western European mid-1975 breakdown believed to be typical of plant such as the proposed ethylene and derivetive units.

TABLE III.C.1

COMPARISON OF PLANT CAPITAL COSTS : W. EUROPE VS. ARABIAN GULF

Item	W. Europe (%)	Arabian Gulf (%) Low	Arabian Gulf (%) High	Arabian Gulf (%) "Best Estimate"
Equipment	50.0	55.0	60.0	58.0
Civil work	5.0	5.0	6.0	6.0
Erection	30.0	30.0	40.0	36.0
Engineering & procurement	10.0	11.0	13.0	12.0
Engineering services	5.0	6.0	8.0	7.0
Total	100.0	107.0	127.0	119.0
Incremental construction period (months)	-	3	12	6
Incremental cost due to interest over longer construction period (% of total)	-	2.5	10	5
Overall Cost Ratio	1.00	1.10	1.40	1.25

This wide spread reflects the differences between one Gulf State and another (some having far better developed infrastructure than others), and also between one type of plant and another.

In cost estimates and evaluations in this study we use the "best estimate" that average Arabian Gulf costs are 25 percent above those in Western Europe.

Similar estimates for a typical North African location suggest a "best estimate" of costs 15 percent above Western Europe. This is a less severe differential than for the Gulf due to shorter shipping distances, less severe ambient temperatures, and generally better infrastructure development. This 15 percent figure is used in cost estimates and evaluations in this study for a North African location.

Sensitivity analyses in Section X investigate the effect of variations in these relative costs of plant construction. These analyses may be used to evaluate a specific site for which more precise cost data is available.

SECTION IV : MARKET ANALYSES

Contents Page No.

industrialisation, and any decisions based upon considerations other than project economics must be made by the individual Arab States based upon their specific situation and requirements.

It is not realistic for a generalised study of this type to conclude that one specific petrochemical complex is preferable to all others for all Arab States. It is in fact clear that if several major Arab petrochemical projects are realised it will be essential that there is some coordination between the planning of these to avoid excessive conflict and competition in world markets. The objective of this study is not therefore to find the best possible project, but to demonstrate the type of projects which will be viable, and to analyse the many factors involved in the development and implementation of such ventures.

We regard this study as covering only the initial phase of Arab petrochemical development. The object is therefore to evaluate schemes involving basic commodity-type petrochemical products, which can be established as viable large-scale, largely export-oriented industries. These will form the first and most important stage of Arab petrochemical industrialisation. It is certain that many other products will subsequently be produced in the Arab states, using these locally available materials, in following stages of petrochemical and industrial development.

Page No.

SECTION IV : MARKET ANALYSES

B. MARKETS

1. Introduction

Product markets are analysed worldwide, with the analysis for each product broken down into the following geographical regions:

- United States
- Western Europe
- Japan
- Rest of non-Arab World
- Arab States

Detailed market analyses are included for twelve products, which were themselves selected from a comprehensive potential range in a preliminary screening exercise presented as Appendix 1. The products selected are:

- ethylene glycol
- high density polyethylene
- polypropylene
- orthoxylene
- styrene
- vinyl chloride monomer
- polystyrene
- paraxylene
- dimethyl terephthalate/terephthalic acid
- low density polyethylene
- benzene
- liquid ethylene

This product range was agreed with IDCAS during an early stage of the study. We believe that it includes most of the products

Figures

IV MARKET ANALYSES

A. BASIS FOR MARKET ANALYSES

The petrochemical industry world-wide has passed through a very turbulent period during the last three years. In 1973 there was an economic boom throughout the developed world. It has frequently occurred that a boom in one area has taken place during a slump in another so that world-wide demand has evened out. However, in 1973 there was a very rapid increase in industrial activity simultaneously in the USA, Western Europe and Japan. The petrochemical industry shared in this activity and enjoyed record sales, and profits.

There is little doubt that as the year progressed, and prices continued to rise, there was a considerable amount of stockpiling taking place in industry. This, in fact, aggravated the rapid increase in demand and brought about further increases in prices. Towards the end of 1973 came the dramatic increase in oil prices resulting shortly after in very much higher prices for petrochemical feedstocks. Early in 1974 demand started to turn down, and buyers began a rapid destocking process. This took place during the second half of 1974 and first half of 1975 and together with reduced consumption world-wide resulted in a drastic downturn in the demand for petrochemical raw materials, intermediates and finished products.

At the end of 1975 it appears that the bottom of the recession has been reached. However, the problem remains in determining the time at which growth will start again, and at what rate the growth will be.

There has been a major discontinuity in the trend line for petrochemical consumption in the developed and developing nations. Forecasts made prior to the downturn of 1974/75 are, in practically all cases, considered to be too optimistic and have had to be revised downwards. This has been brought about not only by the reduction which has taken place in the last two years, but also because future growth in consumption is generally regarded as likely to be at a lower level than previously.

The forecasts made in this study have been developed by an analysis of past trends with a careful assessment of the effects of the last three years on future trends in consumption. This has taken into account the competitive position of synthetic materials versus natural products and the reduced level of GNP growth indicated for the developed nations. For a number of products it has also been necessary to take into account the planned production of these materials in developing countries and subsequent loss of export opportunities for established manufacturers in the developed regions.

These factors have combined to bring about considerably lower forecasts for the 1980-1985 period than were previously being considered. It has also meant, for a number of products, that plans for new investment made in the optimistic climate of mid-1973 are likely to result in an overcapacity situation in the 1977/78 period. However, an opposite situation is now occurring in that the difficult period through which the petrochemical industry is now passing is causing a careful re-assessment of investment plans and some delay in the progress of new projects. This is resulting in a sizeable deficit figure occurring for a number of products in 1980.

The comments made above mainly refer to the US, West European and Japanese markets. The developing countries have also suffered from the rapid inflation of the developed world and here too it has been necessary to revise some of the earlier forecasts.

The present study did not call for any field work by Chem Systems in the Arab States. The demand forecasts for these countries were to be based on published information and the results of previous studies carried out on behalf of UNIDO and IDCAS.

These studies have been examined by Chem Systems and, in the absence of other data, have been used in the section on supply/demand in the Arab States. However, in our opinion these figures must be treated with some caution. Firstly the different reports have given widely divergent results which it is very difficult to reconcile. Secondly much of the work is based upon mathematical and economic forecasts which are valid in a developed economy but do not seem appropriate to the Arab States. There are a number of reasons why this approach does not seem to work.

Firstly it is very difficult to generalise about the Arab States as they vary considerably in population, infrastructure, raw material resources, economic development and future potential. Secondly in practically all cases petrochemical development is at a very early stage and is not established on a well defined trend line. Thus there can be very large changes in demand for a product brought about by the establishment of one new consuming plant. Thus demand for DMT and ethylene glycol can move from zero to several tens of thousands of tons within a short period as new polyester fibre facilities are brought on stream. The use of mathematical forecasts and economic relationships such as relative per capita GNP and plastics or fibre consumption will not take this into account. Neither will such methods indicate the very rapid rise in consumption which is normally associated with the availability of locally produced materials. Once the economies of the Arab States have become established then such methods of forecasting will become appropriate. However, this still lies some way into the future and meantime there seems little alternative to a country by country study in order to build up a satisfactory view of likely trends in demand during the period 1975 to 1985 and even to 1990.

Nevertheless it is considered that the level of demand stated for the Arab States as a group is realistic, and provides a reasonable indication of the supply/demand situation that is developing in the area.

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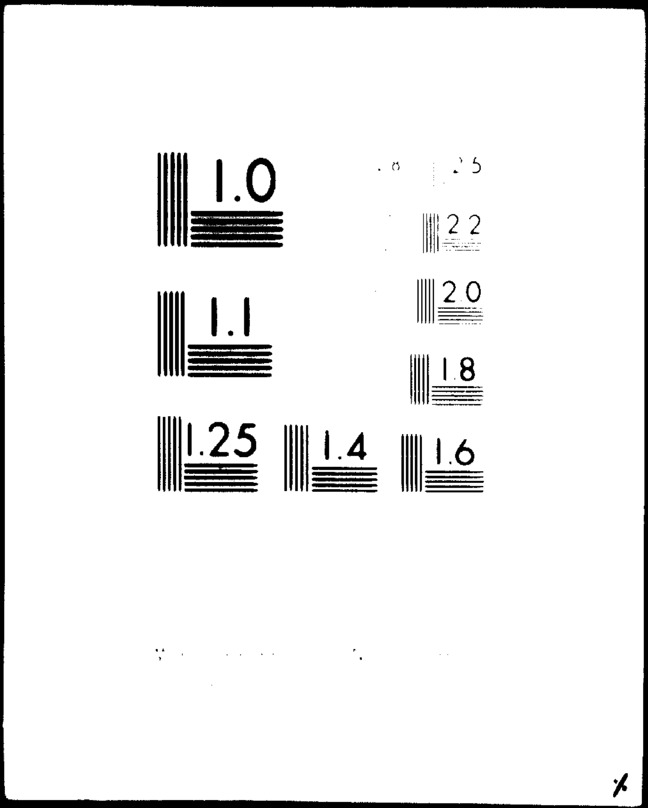

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of ethylene feedstock during the next decade.

Petrochemical growth is therefore linked directly to a growing demand for naphtha, with only a small proportion likely to be based on other feedstocks. In the past the availability of naphtha from basic refinery operations has either met or exceeded the demand for petrochemicals. As chemical demand has grown at a higher rate than the fuel uses of crude oil products the naphtha supply has gradually become tighter, and in the recent past has sometimes led to seasonal or temporary shortages and high prices. Despite the current recession this tightening process is expected to continue and by about 1979-81 will lead to a continuing need to increase naphtha supply. This can readily be achieved by adding refinery units such as hydrocrackers or catalytic crackers, and would not lead to any great increase in naphtha cost. However, the total refinery capacity in Europe is well in excess of actual throughput and there is an understandable reluctance by refiners to install new units. Once the initiative to add conversion capacity has been taken however the added flexibility to refineries should make naphtha supply more assured and its price less volatile.

In summary, therefore there is a possibility that at the end of this decade the feedstock situation could pass through a period of unsettled supply and price, but by the mid 1980's a steadier feedstock market should exist.

Western Europe would appear to be the most attractive potential export market for petrochemicals produced in the Arab States. Economies of scale cannot be practiced to quite the same extent as they are in the USA, there is the prospect of some tightness in the supply of feedstocks, there are increasing difficulties in financing new investment, environmental controls are making it difficult to find sites for major new petrochemical development and Western Europe is the nearest of the major petrochemical consumers to the Arab States.

However for many petrochemical products the market is well integrated and the establishment of major export business will be largely dependent on co-operation with established producers.

3. Japan

With a population density of 742 persons/square mile, Japan is one of the more densely populated countries. This factor is beginning to affect the overall industrial growth of the country. The annual population growth is about 1.2 percent. The capital and chief commercial centre, Tokyo, has a population of 8.7 million. The other principal cities are Osaka (2.8 million), Yokohama (2.5 million) and Nagoya (2.1 million). With a labour force a year ago of 51.4 million, unemployment levels were only 1.4 percent. This has increased during the past year, due to the reduced level of overall business activity. However, the levels of the United States and Western Europe should not be reached.

The Gross National Product, which had increased at a compound annual rate of 10.5 percent in real terms during the 10 year period of 1964-73, has declined in 1974 and by comparison to 1973 levels was down about 3-3.3 percent. This period constitutes the most severe business slump since 1945 in Japan. The difficulties of the economy have been two-fold: inflation coupled with recession. The inflationary pressure of the 1973 GNP growth of 23.3 percent, in real terms, pushed prices to the highest level recorded.

The Research Institute for National Economy sees the real economic growth in the year 1975 (ending March 31, 1976) to be 5.2 percent. The increase in the GNP is slightly higher than the 4.3 percent rate indicated by the government.

The Japanese economy appears to be shifting to a growth phase. Many industrialists and economists recognise that the growth of the past will not occur as the Japanese manufacturer will be less competitive in the international markets. The equilibrium level for future GNP growth can only be postulated and economists indicate levels of 6-7 percent. This will yield a serious re-evaluation of Japanese plans for future industrial expansion.

The chemical industry in Japan was affected in a similar manner as total industry due to the economic slowdown. Within this sector, the synthetic fibre and petrochemical industries have been the hardest hit. Fabric manufacturers are faced not only with the loss of competitiveness of their exports but an increased penetration of their domestic market by imports from Southeast Asia. In the latter region, labour rates are significantly beneath those prevalent in Japan. Synthetic fibre inventories reached their highest point during August of 1974.

Petrochemical producers began 1974 in a sellers market due to a combination of factors including rising demand and reduced product availability. The latter situation was caused by a series of plant problems which limited the production of ethylene and the prime ethylene derivatives. With the sharp downturn in the construction and consumer related industries, as well as the export market, by July/August 1974, inventories rose and there were severe price cuts in the plastics industry. These cuts were to stimulate demand and maintain market share in the export market. The ethylene production level which is a barometer of petrochemical activity has declined since last November when about 300,000 metric tons were produced. This output constituted 70 percent of rated ethylene capacity.

While there are environmental problems with broad expansion at existing petrochemical sites, much of the expansion at these locations will be of the "scrap and build" approach. In addition, approval has been granted for the developing of new petrochemical complex sites on Hokkaido and the northern part of Honshu. This should alleviate, to a degree, the environmental concerns. Full development of these northern sites in the near future is however questionable and during most of the study period, petrochemical development will occur at or near existing plant locations.

While the Japanese petrochemical industry should expand at a rate which is lower than traditional, there has been a re-evaluation of the Japanese producers role in overseas petrochemical projects. The rapid development of the overseas projects was based on a number of factors which included:

- Yen revaluation which reduced the competitiveness of Japanese exports.
- High foreign currency levels and a drive to invest money out of Japan.
- Reaction to pollution problem made it difficult to locate new sites for expansion in Japan.
- The high cost and questionable supply of energy has supported the implementation of petrochemical projects in oil producing countries.

Since the oil crises and resulting decrease in liquidity a re-evaluation of the commitment to overseas projects has occurred.

There are a number of problems facing the Japanese petrochemical producers in the future, as indicated above, and these are prompting serious interest in ventures with the Arab States. Japan must therefore be given serious consideration as a market for Arab States petrochemical exports.

4. Rest of the non-Arab World

The supply/demand situation for the selected chemicals has been considered in detail for the three main regions, USA, Western Europe and Japan. The other regions, which have been reviewed, but not examined in detail, are as follows:-

Canada
Latin America
Eastern Europe
Africa
Asia/Pacific

These regions are now discussed briefly in terms of their petrochemical development and potential as export markets for petrochemicals from the Arab States.

a) Canada

The Canadian petrochemical industry developed primarily to serve the domestic market and has not been heavily orientated to exports. This will tend to change as world scale facilities are being built based on utilisation of domestic petroleum and natural gas reserves.

For the reason given above and the proximity and competitiveness of the US producers Canada is not regarded as providing a major export potential for petrochemicals produced in the Arab States.

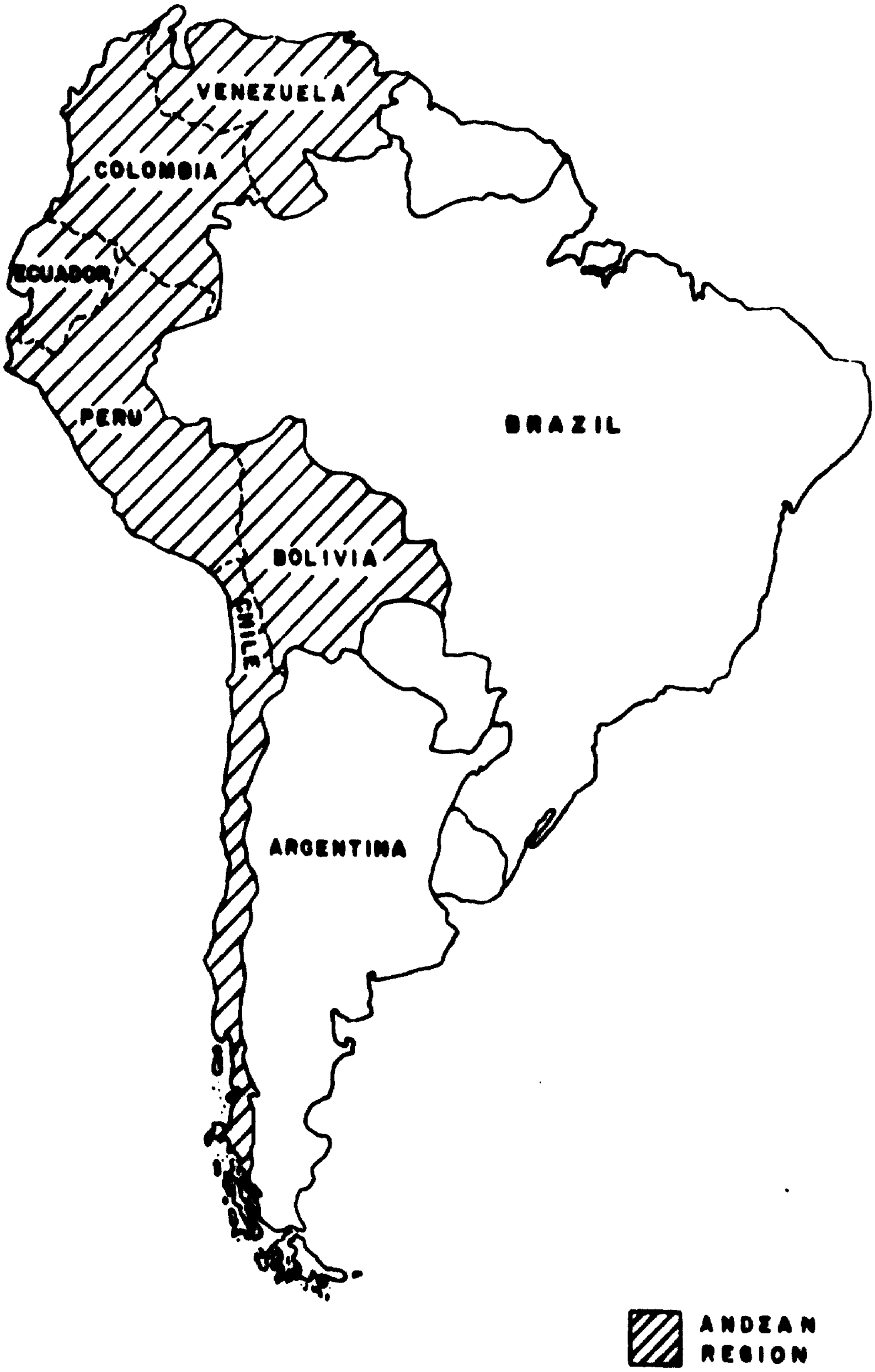
b) Latin America

The Latin American market can be conveniently divided as follows:-

Argentina
Brazil
Mexico

FIGURE IV.8.1

LATIN AMERICAN MARKET REGION
(less Mexico)



Andean Region
- Venezuela
- Columbia
- Ecuador
- Peru
- Bolivia
- Chile

The petrochemical development within other countries is at a very low level of development and will have minimal impact on the supply/demand situation within the Latin American area during the study period.

Argentina is active in developing its petrochemical industry but will not be able to become self sufficient for some years. It will therefore continue to be dependent upon imports from the major manufacturing centres in the USA, Western Europe and Japan, and from new projects in the nearby developing countries of Brazil and Venezuela. In the longer term Argentina will seek to be self sufficient but will no doubt require balancing imports to supplement domestic production.

Brazil is the largest and most economically dynamic country in Latin America. There is one petrochemical complex in operation in Sao Paulo and another under construction near Bolivia in the northeast of Brazil. However, it is estimated that these will not be sufficient to meet estimated 1980 demand. A study is now in hand to examine possible expansions of existing plants or the establishment of a new "grass roots" facility. If the timing of new investment is right then Brazil expects to be self sufficient in basic petrochemicals, if not there will be a period during the early eighties when imports will be required to satisfy domestic demand

Since the nationalization of the Mexican oil industry in 1938, this industry has been controlled and utilized by the government for socio economic programs. The government has divided the products petrochemical industry into four basic groups and indicated which are to be produced by the government agencies and which can be produced by the private sector. Products falling into Group 1 and Group 11 are made from refinery oil products and by-products. The manufacture of these are reserved for Petroleos Mexicanas (PEMEX), the government's oil agency. The third group is formed by those products which require a presidential permit for production but which can be produced by the government and private enterprise or by government alone. Companies which manufacture products in the group must have 60 percent Mexican capital, the fourth group is open to all and manufacture does not require a permit. The grouping of products relevant to this study are indicated in Table IV.B.5. It is evident that PEMEX will play an important role in meeting the local requirements for most of the products of interest.

TABLE IV.B.5

GROUP DEFINITION FOR RELEVANT PRODUCTS

Group	Product
I	Ethylene
	Propylene
II	Butadiene
	Vinyl Chloride
	Cumene
	Styrene
	Ortho-Xylene
	Para-Xylene
	Ethylene Oxide
	Polypropylene
	High Density Polyethylene
III	Acetone
	Phenol
	Styrene and Butadiene Copolymers
	Ethylene Copolymers
	Ethylene Glycols
	Phthalic Anhydride
	Dimethyl Terephthalate

PEMEX has ambitious plans for a wide range of products due to come on stream during 1977/78. There will obviously be export opportunities arising but once again these are only likely to be required to supply temporary deficits in local production.

Andean Region

This group was formed to foster economic development among the member states. Within the petrochemical sector, the future manufacture of individual products has been divided amongst the various countries. Venezuela, with indigeneous oil, is seeking to be the leader of the region and is establishing a major integrated facility for the production of ethylene and propylene derivatives. It is planned to sell many of the products on the international market.

Colombia, Ecuador and Peru also have plans for production of various products but these are unlikely to be realised before the early eighties. Imports will therefore be required for some time in order to meet local demand. However, this is likely to remain at a relatively low level.

Forecast demand for the Latin American region indicates that there could be a growing potential demand for imports. However, in general the area will seek to invest in new capacity to enable a self sufficient position to be established. Undoubtedly the timing will not always be right and the need for balancing imports will almost certainly arise.

c) Eastern Europe

It is virtually impossible to establish the situation of the East European petrochemical industry owing to the lack of available information, particularly on consumption.

Some attempt has been made to quantify the situation, but the reliability of the actual supply/demand figures is not as high as for the major developed areas of W. Europe, US and Japan. It does seem clear, however, that this area cannot be regarded as providing a stable, large volume export market. Domestic production is supplemented by imports of certain products but these are carefully controlled so as to preserve hard currency.

There is a great deal of new investment being made in the petrochemical industry and a high level of co-operation is maintained between the various countries. Thus raw materials are piped from the major source, the USSR, and ethylene pipelines are also being established between various production centres.

Apart from the opportunities for "spot" exports which will occur it may be possible to establish a special deal, with an individual East European country, for long term supplies of a particular product. This is a situation which will require negotiation at a governmental level.

d) Africa

The African continent can be conveniently divided into North, West, East and South. North Africa is made up of Arab States and is not part of this section. West Africa currently relies upon imported materials, mainly from Western Europe. However, Nigeria is planning development of its indigenous raw material sources and will seek to establish a petrochemical industry supplying not only its own needs, but also those of neighbouring countries.

East Africa has no domestic resources for petrochemicals and, in most cases does not have a local market which would

B. PETROCHEMICAL OVERVIEW BY MARKET AREA

1. USA

The United States has a population of 211 million which has been growing by about 1 percent/yr until recently. Current GNP is approximately $1.4 trillion (1974 dollars) or $6600/capita. Maximum potential GNP growth of the economy is about 3.5-4.0 percent/yr on a constant dollar basis, but the economy is not expected to reach this growth level in future years. Projections for GNP and population growth are shown below.

TABLE IV.B.1

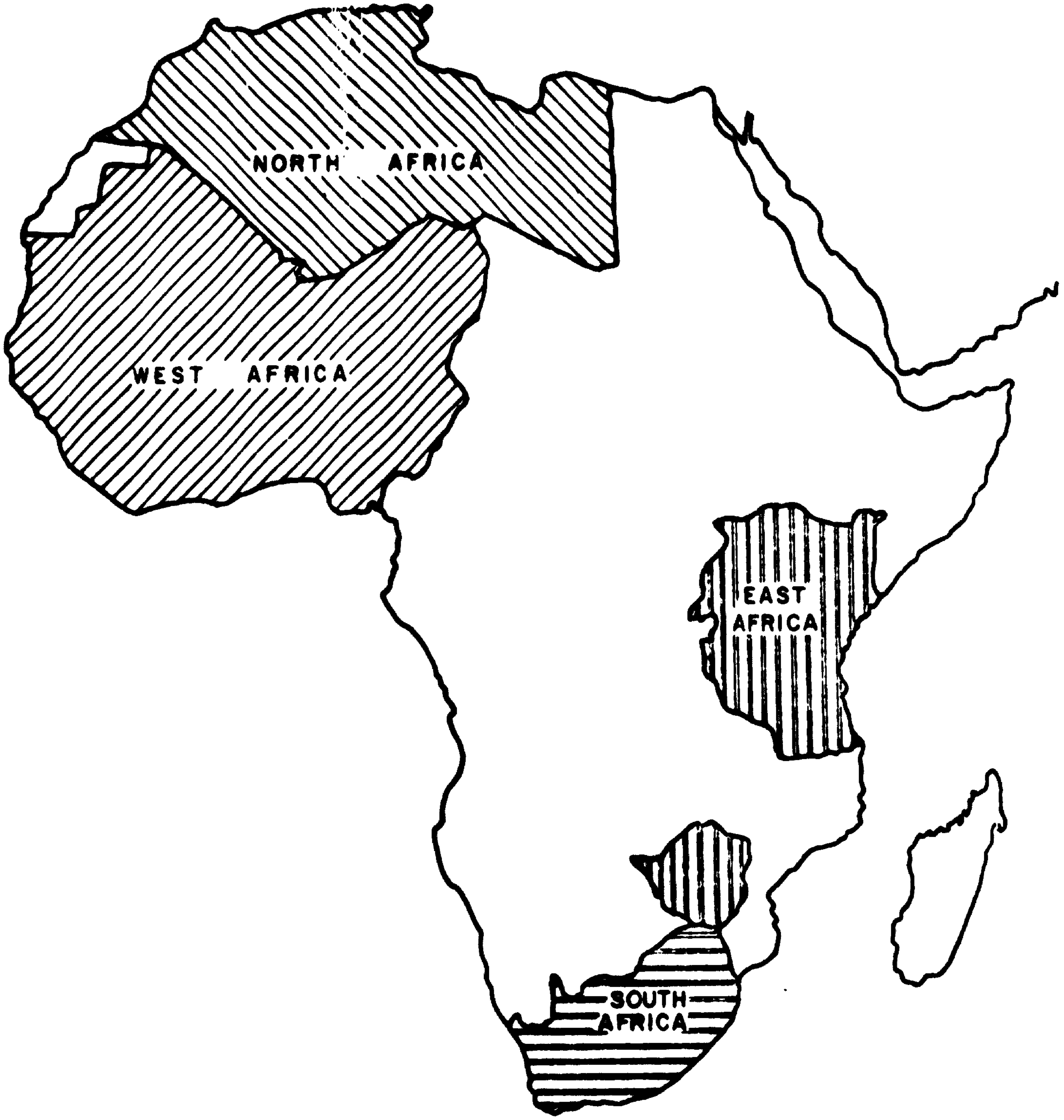
US GNP AND POPULATION PROJECTIONS

Year	GNP (1973 dollars)	Population
1973	1 289 billion	209.9 million
1974	1 260	211.4
1975	1 221	213.3
1980	1 447	223.1
1985	1 693	232.7
1990	1 972	242.5

The United States has the most highly developed petrochemical industry in the world with current revenues of about $40 billion. The industry had its start in the US based initially on various refinery streams. However, it has flourished due to the availability of cheap natural gas liquids in the Southwest and the large demand for motor gasoline which aided the production of aromatics. The US petrochemical industry has been in the forefront of technology and the large domestic market has enabled plant sizes to be greater than elsewhere in the world. Historically the US has been a major exporter of petrochemicals and currently enjoys a petrochemical trade balance estimated at $3 billion for 1974.

FIGURE IV.B.2

AFRICAN REGIONS



justify production untis of an economic size. It is considered that this area will continue to depend upon imported finished goods, and intermediates, to satisfy its petrochemical needs.

South Africa has an established petrochemical industry based upon large reserves of coal. However, not all its requirements are produced locally and import requirements are expected to continue.

e) Asia/Pacific

This is an area composed of very different economic conditions and petrochemical resources. On the one hand countries such as India and Pakistan have very low per capita consumption of petrochemical products and potentially, a large demand. It is most unlikely however that this potential will develop in the near future due to the lack of money amongst the major part of the population. Without a massive level of economic assistance, therefore, such countries will not be able to afford any substantial level of petrochemical imports.

Southeast Asia is a region which is undergoing a significant change in petrochemical development. Most of this area has traditionally been an importer of raw materials for fabrication and re-export. The governments of many countries in this region intend to utilize this fabricating base to support back integration programmes and this represents a rationale to justify many new regional projects. The countries that are included in this region are: the ASEAN countries (Singapore, Malaysia, Indonesia, Thailand and the Phillipines), Australia and New Zealand, India, Burma, Republic of China (Taiwan), Hong Kong, and Korea. These are indicated in the map. The ASEAN states have been highlighted on this map.

Certain downstream units are being planned on a scale that will exceed regional requirements. However, the participation of multi-national companies in the basic projects and downstream units should provide the necessary assistance in developing export markets through their world-wide supply and distribution systems for excess products. These new projects will certainly displace a large part of the imports which come into the ASEAN region at this time.

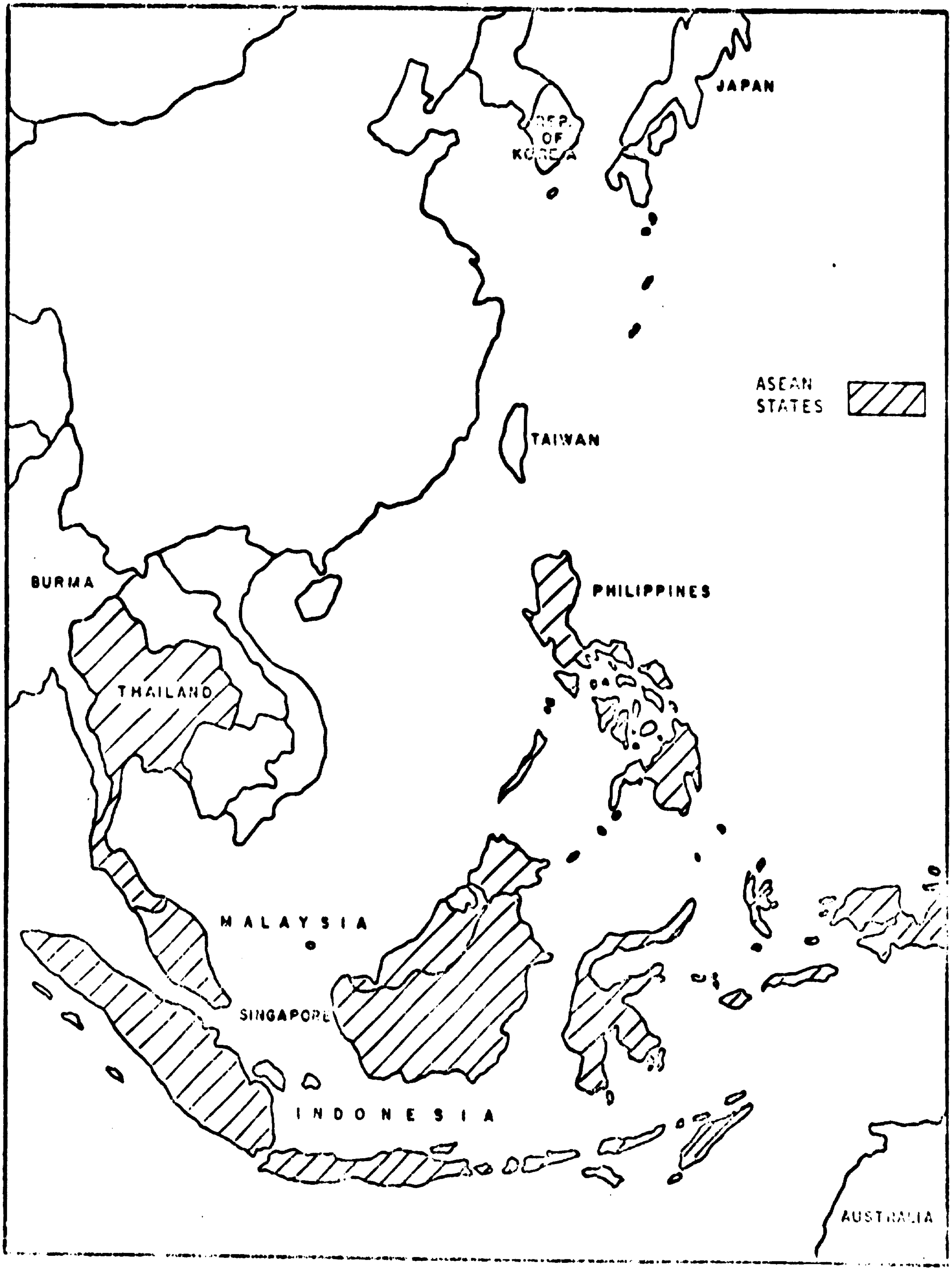
As the 1980's approach it appears that Southeast Asia should be relatively self sufficient in most basic petrochemically derived products and surpluses should contribute to the regional balance of payments. Further development of the industry beyond 1980 will depend largely on further discovery and development of desirable hydrocarbon feedstocks. Current exploration effort supports the existance of sufficient reserves to support extensive energy related industrial development.

A very wide range of petrochemical and plastic products are currently produced in Australia. This production is, however, largely from relatively small (by world scale standards) plants. Australia's geographical distance from potential suppliers or customers for petrochemical products combined with relatively small indigenous markets undoubtedly explains the small plant sizes. With the country's protectionist policy, local industry has been under no pressure to increase scale size. Accordingly, the prices paid by Australian consumers of petrochemicals and petrochemical products rank high on any scale.

In general, we feel that this protectionist policy will continue to inhibit importation of large amounts of petrochemicals or products into Australia. This protectionist

FIGURE IV.B.3

ASIA/PACIFIC REGIONS



policy will continue to affect the chemical business as local producers can expand their production capabilities fast enough to meet the growing demand of local consumers.

The major exception to this general forecast is in the case of caustic soda. Due to the large amount of alumina production in the country, caustic demand will continue to far exceed local production capability and local chlorine demand.

C. PRODUCT ANALYSIS : ETHYLENE GLYCOL

1. Overview

Assuming the availability of ethylene, there will be adequate ethylene glycol capacity to meet market requirements in the developed countries up to the early 1980's. Projected supply/demand balance for world markets are summarised in Table IV.C.1.

TABLE IV.C.1.

SUPPLY/DEMAND SUMMARY AS SURPLUS OR (DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	441	303	(327)
W. EUROPE	623	969	729
JAPAN	(18)	85	115
CANADA	(14)	1	54
LATIN AMERICA	(41)	(20)	(88)
E. EUROPE	(150)	(130)	(290)
AFRICA	(4)	(6)	(10)
ASIA/PACIFIC	(91)	(35)	(39)
ARAB WORLD	(1.5)	20	120

The regional deficits likely to occur by 1985 in the lesser developed markets are very small in comparison to the large overcapacity that will exist particularly in Western Europe. The apparent shortage developing in the USA is simply a reflection of the fact that ethylene oxide expansions announced to date will not be adequate to supply 1985 glycol demand. Adequate oxide/glycol conversion capacity already exists, and we consider it probable that the necessary investment in oxide capacity will be made in the US in time to avoid any shortage. If tempory deficits do develop in the US, W. Europe is in the best position to supply them, but a small ethylene feedstock price differential between the two areas would make this difficult.

The main restriction on production is the availability of ethylene feedstock, with the rather anachronistic situation that in the oil producing states ethylene glycol is often considered in a complex's product slate merely to use up the excess ethylene, whereas in the developed market areas ethylene which may be destined for ethylene glycol production may be diverted into the manufacture of more profitable products, such as styrene and HDPE, in times of shortage.

The major end uses for ethylene glycol are antifreeze and polyester fibres. The antifreeze market is in general very slow growing and seasonal. Growth in the polyester fibre sector has resulted in major capacity expansions in glycol over recent years, but the synthetic fibre industry is undergoing a harsh recession and a decline in growth here will also lead to a world wide overcapacity in ethylene glycol. This is certainly the case in the developed markets, but in some of the smaller markets of South East Asia, they will be projecting annual growth rates of around 25 percent for polyester fibre demand (cf 9 - 10 percent in U.S.A., W. Europe and Japan). Hence a continuing dependance on imports is expected.

World wide movements of ethylene glycol are quite extensive, but actual levels of shipments fluctuate widely as local surpluses and deficits occur. Western Europe is a net exporter (largely to the East Bloc). USA has a considerable export potential but is undergoing a lot of operating difficulties at present. Japan is in a potentially strong position in South East Asia, since in the event of any shortages in the domestic market there are several back up plants under the control of Japanese companies, situated in other Pacific countries.

Ethylene glycol is a largely merchant market with very few producers actually being integrated in antifreeze or polyester fibre. Close contact with the different markets is essential particularly for antifreeze which is a seasonal business and operates through very many different retail outlets, although the number of companies in the world handling the packaging and distribution is small. Antifreeze also tends to be the last resort for dumping any surplus glycol. The polyester fibre industry is different in that there are fewer manufacturers involved and they purchase on the basis of quality, reliability of supplies and price.

Estimates of the future supply/demand situation in the U.S.A., Western Europe and Japan suggest that there will be adequate ethylene glycol available to meet requirements through to the mid eighties. If ethylene shortages should develop in these regions, then glycol is likely to be one of the first products to suffer. In such circumstances spot shipments could probably be sold.

Eastern Europe is seeking to build up polyester fibre production and it appears that glycol facilities are not keeping pace with demand. This area will probably continue as an importer for some years. However the long term trend will be to establish self sufficiency. Also as imports are used as a balancing operation which can be affected by imposed restrictions on supply and demand it is impossible to be certain about regular import opportunities which have to be approached on a spot basis.

Many developing countries in Latin America and Asia are establishing polyester fibre plants which will have to depend upon imported raw materials for some years. Quantities will remain relatively small and be spread over a number of consumers.

Opportunities for exporting ethylene glycol from the Arab States will occur but these are likely to be widely spread, on a geographical basis, require fairly small shipments and be of a short term nature. This situation implies the need for a very flexible marketing and distribution organisation of a kind provided by established chemical traders, or ethylene glycol producers with a strong position in the merchant market.

There will be a growing demand for ethylene glycol in the Arab States as polyester fibre plants are brought on-stream. However whilst these may justify glycol facilities the level of demand will not be great enough to support more than one or possible two ethylene oxide plants during the period to 1995.

2. U.S.A.

a) Supply

The current US ethylene glycol capacity is estimated to be 2 260 thousand tonnes/year, and there are announced

TABLE IV.C.2

UNITED STATES ETHYLENE OXIDE/GLYCOL PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	ETHYLENE OXIDE			ETHYLENE GLYCOL		
		CAPACITY	EXPANSIONS,	YEAR	CAPACITY	EXPANSIONS,	YEAR
BASF-Wyandotte	Geismar, La.	104	18	1975	91		
Calcasieu	Lake Charles, La.	75			84		
Celanese	Clear Lake, Texas	136			136		
Dow	Freeport, Texas	91			109		
	Plaquemine, La.	182			214		
ICI America	Atlas Point, Del.				5		
Jefferson (Texaco)	Port Neches, Texas	227			164		
Northern Petrochemical	Joliet, Ill.	109			127		
Olin	Brandenburg, Ky.	38			45		
Oxirane	Channelview, Texas					364	(1978)
PPG	Beaumont, Texas	39			45		
	Guayanilla Bay, P.R.	182			136		
Shell	Geismar, La.	136			102		
Sun Olin	N. Claymont, Del.	47					
Texas Eastman	Longview, Texas	24			34		
Union Carbide	Seadrift, Texas	399			395		
	Taft, La	205	135	(1975)	241	136*	(1975)
	Ponce, P.R.	273			332		
	Seadrift or Texas City, Texas		230	(1977)		227*	(1977)
		2261	383		2260	727	

* Estimated

The petrochemical industry is entirely in the private sector but the nature of the industry is being shaped to a sizeable degree by national, state and local policies regarding price and availability of feedstocks, environmental problems and zoning for heavy industry. There are no strong governmental incentives for locating plants in the US to serve local markets in preference to imports with the exception of tariffs on certain classes of petrochemicals which tend to preclude importation. There really has been no need to supply incentives since abundant reasonably priced raw materials, a large market, and a good transportation system overwhelmingly favoured domestic production. The incentives for plant location have been primarily at the state or local level. These have involved such mechanisms as raising capital for plant construction through tax-free industrial or pollution control bonds, training programmes for workers, and assurances that feedstocks will be available from intrastate sources.

In 1974, petrochemical demand for feedstocks and associated energy uses represented 7-8 percent of total refinery and LPG hydrocarbons, with olefins and aromatics production requiring slightly more than half of the total (less some recycling of fuel products to the energy sector). In that year, US ethylene production was 23.6 billion pounds per year and BTX aromatics production (for petrochemicals) was about 190 000 barrels per day. With a continuation of traditional growth in demand for these materials, namely 8.5 percent for ethylene and 7.5 percent aromatics, and a further assumption that all new ethylene and BTX aromatics will be produced from naphtha or other liquid feedstocks, the following quantities of light and heavy feedstocks would be required for the years indicated:

expansions which will increase capacity by an estimated 727 thousand tonnes before the end of the decade. In addition to these announced new facilities there are firms such as Dow who are committed to the ethylene oxide/glycol business and will undoubtedly install new facilities in the future. A list of US ethylene oxide and glycol manufacturers is shown in Table IV.C.2, together with present capacity and expansions announced to date.

b) Demand

The 1974 US ethylene glycol breakdown, by end use is given in Table IV.C.3.

TABLE IV.C.3

1974 US ETHYLENE GLYCOL CONSUMPTION BY END-USE
(thousand tonnes)

Antifreeze	790	56%
Polyester fibre	510	36%
Polyester film	32	2%
Industrial fluids	86	6%
Total demand	1418	100%

At present the largest use for ethylene glycol in the USA is for antifreeze. Due to trends towards smaller cars, with smaller cooling systems, and the probability of longer periods between antifreeze changes, demand is expected to increase by only 1 percent/yr in the next decade. Polyester fibre is the second largest use and is expected to be the major market for ethylene glycol by

1980. During the remainder of the 1970's polyester fibre production is expected to have an average growth of only 9 - 10 percent/yr. This growth is substantially lower than the rates that have prevailed in the past. Synthetic fibres now represent two-thirds of total fibre use in an industry where growth in consumption has only averaged 4 percent/yr during the last decade. Polyester film used for industrial photographic film, audio and computer tapes, packaging and in slit film textile applications will continue good growth, while the mature industrial fluids market is expected to average 3 - 4 percent growth during the next few years.

Total ethylene glycol consumption is expected to grow from 1418 thousand tonnes in 1974 to 1870 and 2500 thousand tonnes in 1980 and 1985, respectively with the growth rate for the period being about 4 percent/yr.

c) Supply/Demand Analysis

Ethylene glycol supply cannot be accurately indicated simply in terms of the capacity of the glycol production units. Facilities tend to be oversized relative to the ethylene oxide available, and incorporate some flexibility in order to vary the amounts of di- and triethylene glycol according to the individual producer's needs. On average about 60 percent of the ethylene oxide is processed into ethylene glycol. The supply forecast is based on a continuation of this situation. This is a reasonable assumption since the projected growth rates for both ethylene oxide and glycol are similar. On this basis the ethylene glycol supply/demand in the United States is summarised in Table IV.C.4.

TABLE IV.C.4.

US ETHYLENE GLYCOL SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1859	1970	2173	2173
Projected Demand	1418	1500	1870	2500
Surplus/(Defitic)	441	470	303	(327)

* calculated as using 60% ethylene oxide capacity

\+ estimated actual

In 1974 ethylene glycol exports totalled 74 thousand tonnes, while imports were 60 thousand tonnes. This relatively high level of imports was caused by feedstock and operating problems, which severely curtailed production for a few months.

Basically, with the announced and projected ethylene oxide/glycol expansions in the USA, there will be sufficient supply within the region to meet demand until the early 1980's. We consider it probable that adequate new oxide capacity will be installed in the US in time to avoid the potential deficit indicated for 1985 in Table IV.C.4. Conversion capacity (oxide to glycol) already exists to meet predicted 1985 demand.

3. Western Europe

a) Supply

Ethylene glycol capacity in 1974, was 1 169 thousand tonnes. The manufacturers are listed in Table IV.C.5,

TABLE IV.C.5

WEST EUROPEAN ETHYLENE OXIDE/GLYCOL PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	ETHYLENE OXIDE			ETHYLENE GLYCOL		
		CAPACITY	EXPANSIONS, YEAR		CAPACITY	EXPANSIONS, YEAR	
BELGIUM							
BASANT	Antwerp	110			90	+ 10	(1979)
UCC	Antwerp	120			80	+ 20	(1979)
Petrochim	Antwerp	20	(shut down '75?)				
Total Belgium		250			170		
FRANCE							
Naphthachimie	Lavera	170	+ 10	(1975)	165	+ 35	(1976)
Ethylox	Choques	90			60		
Total France		260			225		
WEST GERMANY							
Erdol	Koln	60			60	+ 60	(1979)
Hoechst	Gendorf	110			75		
	Kelsterback	40			45		
Huels	Marl	90	+ 40	(1976)	40		
BASF	Ludwigshafen	45					
Dow	Stade	-	120	(1976)			
Total West Germany		345			220		
HOLLAND							
Shell	Pernis	65			50	shut down	(1975)
	Moerdijk	70			85	+ 165	(1976)
Dow	Terneuzen	120			110		
Total Holland		255			245		
ITALY							
ANIC	Gela	25	+ 15	(1975)	25	+ 22	(1976)
SIR	Porto Torres	-	30	(1975)			
Montedison	Ferrara	20	+ 60	(1975)	15		
	Brindisi	20			20		
	Priolo	30	+ 120	(1977)?	30	shut down	(1977)
Liquichimica	Augusta	-	200	(1977)	-	130	(1978)
Total Italy		95			90		
SPAIN							
IQA	Tarragona	10	+ 30	(1976)	9	+ 31	(1979)
Alcudia	Puertollano	10	+ 10	(1976)	9	+ 6	(1976)
Total Spain		20			18		
SWEDEN							
Berol	Stenungsund	40			20		
UNITED KINGDOM							
ICI	Wilton	140	+ 30	(1975)	110	+ 20	(1975)
UCC	Hythe	25			16		
Shell	Carrington	100			55	+ 55	(1977)
Total United Kingdom		265			181		
TOTAL WESTERN EUROPE		1530	+ 645		1169	+ 474	

together with existing capacities and announced expansions.

b) Demand

The relative importance in Western Europe of the various uses during 1974 is shown in Table IV.C.6.

TABLE IV.C.6.

1974 WEST EUROPEAN ETHYLENE GLYCOL CONSUMPTION BY END-USE

(thousand tonnes)

Polyester fibres	317.5	50%
Antifreeze	203	32%
Polyester film	25.5	4%
Other uses	89	14%
Total demand	635	100%

It can be seen that demand by polyester fibre producers largely determines the demand trends of ethylene glycol in Western Europe. The present downturn in the textile cycle, coupled with reduced growth rates for polyester fibre, will tend to keep the growth in demand for ethylene glycol at a lower level for the future than in the recent past.

It is estimated that consumption of ethylene glycol in 1974 was 6.3 percent below 1973, reaching a level of 635 000 tonnes. This constitutes a drop of 4.1 percent.

From 1976 growth rates are forecast at 6 percent/year through to 1980, with a gradual reduction to 5 percent/year in the mid-to-late 1980's.

c) Supply/Demand Analysis

The supply/demand situation for ethylene glycol in Western Europe from present day through to 1985 is summarised in Table IV.C.7.

TABLE IV.C.7.

WEST EUROPEAN ETHYLENE GLYCOL SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1258	1353	1789	1789
Projected Demand	635	609	820	1060
Surplus/(Deficit)	623	744	969	729

* calculated as using 60% ethylene oxide capacity

\+ estimated actual

It can be seen that ethylene glycol manufacturers in Western Europe will have sufficient capacity to take care of demand until well through the eighties. This is further supported by in-place and projected ethylene oxide capabilities.

Ethylene glycol is moved extensively within Western Europe as the glycol itself and as antifreeze. Only small quantities are imported from outside, and these are mainly from the U.S. (10 - 20 000 tonnes). Approximately 80-90 000 tonnes were exported from Western Europe, with Eastern Europe being the principal market.

In the face of the continuing surplus forecast through the 1980's, it would seem that this situation will continue, with Western Europe attempting to increase exports.

4. Japan

a) Supply

There are currently four ethylene oxide/glycol producers having a total glycol capacity of 386 000 tonnes per annum.

The current and proposed plant capacities are listed in Table IV.C.8.

b) Demand

The Japanese requirement for ethylene glycol is anticipated to decline by 17-18 percent during 1975 from the 1974 consumption levels of 382 000 tonnes/year (268 000 tonnes/year on an EO equivalent basis). This drop is the result of the decline in domestic demand for polyester fibre, which constitutes 66 percent of the ethylene glycol consumption. Other outlets are small, relative to total ethylene glycol consumption, and sharp changes in demand will not appreciably affect total EG requirements. The ethylene glycol consumption pattern is indicated in Table IV.C.9.

TABLE IV.C.8.

JAPANESE ETHYLENE OXIDE/GLYCOL PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	ETHYLENE OXIDE		ETHYLENE GLYCOL		
	CAPACITY	EXPANSIONS, YEAR	CAPACITY	EXPANSIONS, YEAR	
Mitsubishi Petrochemical	84		86	120	1988 (old plant to be partially scrapped)
Nippon Shokubai Kagaku	146		150		
Mitsui Petrochemical	90		90	90	(40 to be scrapped)
Nisso Petrochemical	60		60	50	late 1975
Sumitomo Chemical	-		-	25	1978/79
Mitsubishi Chemical	-		-	25	1978/79
Total	380	+ 210	386	+ 270	

TABLE IV.C.9.

1974 JAPANESE ETHYLENE GLYCOL CONSUMPTION BY END-USE

(thousand tonnes)

Polyester fibres	254	(66%)
Antifreeze	44	
Unsaturated polyester resins	19	
Cellophane	12	
Alkyds and polyurethanes	10	
Capacitors	3	
Solvents	9	
Intermediates	15	
Explosives	1	
Miscellaneous	15	
Total demand	382	

The future polyester fibre demand is anticipated to expand at a compound annual rate of 6.5-7 percent during 1976-1985 and slightly lower for the subsequent period. The demand for antifreeze is forecast to increase at 3.5 and 2.5 percent/year during this time. On this basis the growth in demand for ethylene glycol should increase to 480 000 tonnes by 1980 and 750 000 tonnes by the end of the 1980's.

c) Supply/Demand Analysis

The projected ethylene glycol supply/demand balance is shown in Table IV.C.10.

TABLE IV.C.10.

JAPANESE ETHYLENE GLYCOL SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	364	364	565	565
Projected Demand	382	314	480	450
Surplus/(Deficit)	(18)	50	85	115

* calculated as using 70% ethylene oxide capacity

\+ estimated actual

It would appear that Japan will have sufficient capacity to meet local requirements through most of the 1980's. The involvement of Japanese producers in overseas projects, which are in traditional Japanese export markets, will enable these manufacturers to maintain their strong raw material supply position in these regions. Any deficit beyond 1985 in Japan would probably be met by imports from a Japanese controlled project in the Pacific basin.

5. Rest of Non-Arab World

a) Supply

A list of ethylene glycol producers in the rest of the world is given in Table IV.C.11, together with present capacity and any expansion plans announced to date.

TABLE IV.B.2

POSSIBLE FEEDSTOCK REQUIREMENTS FOR OLEFINS AND AROMATICS PRODUCTION

Year	Feedstock Demand (BPD)
1975	980 000
1980	1 480 000
1985	2 170 000

Total petroleum products demand in 1985 was, up to recently, estimated to rise to the level of about 23 MM barrels per day. The supply of this demand is not yet established, but the most optimistic estimate for domestic production being about 15 MM BPD, with most estimates substantially lower. On this basis petrochemical feedstock demand for ethylene (and most other olefins) and BTX aromatics would then represent about 10 percent of total consumption, with total petrochemical feedstock/fuel demand substantially in excess of that amount. More significantly, olefins-aromatics feedstock demand would also represent 20/25 percent of domestic oil and NGL production.

The frequently-heard statement that "petrochemical producers should be able to bid feedstocks away from the energy market" on the basis of greatly upgraded value for final petrochemical products, should tend to be true for the most extent through the 1970's without unduly imposing on the US energy market, or creating very high cost penalties on final chemical products consumers. By the 1980's however, it is doubtful that this statement would hold. One current reservation is the unpredictable effects of current and future government actions, such as permanent price ceilings and minimum production requirements on petroleum products (primarily gasoline) which tends to interfere with

TABLE IV.C.11

REST OF NON-ARAB WORLD ETHYLENE GLYCOL ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COUNTRY	CAPACITY	EXPANSIONS, YEAR
CANADA	95	(possible 60 as part of a Japanese J-V)
LATIN AMERICA		
Argentina	-	20 (Bahia Blanca)
Brazil	35	100
Andean Group	-	60 (1980), 120 (1985)
Mexico	25	80 (1977)
Total Latin America	60	+260
E EUROPE		
USSR	110	-
GDR	-	100 (by 1980)
Rumania	40	+ 28 (1975) + 10 (1980)
Czechoslovakia	20	+ 75 (1975)
Bulgaria	10	
Poland	70	plans
Total E Europe	250	+213+
ASIA/PACIFIC AREA		
ASEAN Countries	-	+200 (1979/80)
Australia	20	-
India	10	+ 20 (1977)
Taiwan	-	50 (1975) 100 (1977)
		+125 (1977)
Korea	-	56 (1982)
Turkey	-	25 (1982)
Pakistan, Iran	-	plans
Total Asia/Pacific	30	+525
TOTAL REST OF NON-ARAB WORLD	435	

b) Demand

- Canada

  The 1974 demand is estimated at 89 000 tonnes and this is anticipated to grow at about 6.5 percent through to 1980 to give a level of 133 000 tonnes and then to 194 000 tonnes by 1985. Antifreeze represents nearly two thirds of the Canadian requirement, but is quite a slow growing sector.

- Latin America

  The total 1974 demand for this region is estimated at 98 000 tonnes, with Brazil and Mexico being the major consumers. The most significant end use is polyester fibres and the individual countries involved anticipate growth rates of around 10-12 percent for the period up to 1985.

- E. Europe

  The 1974 demand for the COMECON countries probably amounted to about 350 000 tonnes (based on estimated production plus imports.) The rapidly expanding fibre industry will boost demand particularly in Hungary, Poland and E. Germany, and by 1980 almost 450 000 tonnes will be used.

- Africa

  The only country with any ethylene glycol requirement at present is the Republic of S. Africa, which consumed 4 000 tonnes in 1974. This will increase very slowly reaching 10 000 tonnes by 1985.

- Asia/Pacific

  The total requirement for this region in 1974 was about 115 000 tonnes, about 75 percent of which demand is concentrated on the ASEAN Community, Taiwan and S. Korea.

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World ethylene glycol are given below in Table IV.C.12.

TABLE IV.C.12

REST OF NON-ARAB WORLD ETHYLENE GLYCOL SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	75	131	244
Forecast Demand	89	130	190
Surplus/(Deficit)	(14)	1	54
LATIN AMERICA			
Potential Supply	57	220	342
Forecast Demand	98	240	430
Surplus/(Deficit)	(41)	(20)	(88)
EAST EUROPE			
Potential Supply	200	360	500*
Forecast Demand	350	490	790
Surplus/(Deficit)	(150)	(130)	(290)
AFRICA			
Potential Supply	-	-	-
Forecast Demand	4	6	10
Surplus/(Deficit)	(4)	(6)	(10)
ASIA/PACIFIC AREA			
Potential Supply	24	205	421
Forecast Demand	115	240	460
Surplus/(Deficit)	(91)	(35)	(39)

\+ estimated actual * estimate

- **Canada**
  It can be seen that there ought to be sufficient supply within Canada through to the end of the 1980's, and USA will make up the small deficit over the next few years.

- **Latin America**
  This area will continue to be dependent on imports to support their polyester fibre industry, but the installation of new facilities in Brazil will alleviate the shortage around 1980. Either Venezuela or Ecuador have production slated for the late 1980's.

- **E. Europe**
  Ethylene glycol would seem to be one of the chemicals in which the Eastern Bloc may develop a shortage over the foreseeable future. Russia, Poland, Yugoslavia and East Germany are already importing substantial quantities to meet the requirements of local fibre industries. They will require installation of new capacity to reduce this dependence in the 1980's.

- **Africa**
  The only country figuring in the ethylene glycol business is the Republic of South Africa. If local production does not occur and the import demand continues to rise steadily the market will continue to be under the control of Dow and Shell, who both have established local markets and multinational supply networks.

- Asia/Pacific
  There is a considerable deficit in this region at present and the major consuming countries, Taiwan, Korea and the ASEAN community rely on imports from Japan. With substantial capacity installation planned for Indonesia, Taiwan and S. Korea towards 1980 the deficit in the next decade will be greatly reduced.

6. The Arab World

a) Supply

At present there is no installed ethylene glycol capacity operating in the Arab States, but several planned complexes for the area do include glycol in their product slate. These plans are listed in Table IV.C.13.

TABLE IV.C.13.

ARAB ETHYLENE GLYCOL PRODUCTION PLANS
(thousand tons)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria (Skikda)	50	1982
Morocco, Tunisia, Libya	-	-
Egypt	50	1980
Kuwait	120	1982
Iraq, Qatar, Saudi Arabia, United Arab Emirates	-	-
Total	220	

b) Demand

Current glycol demand in the Arab states is negligible. Polyester fibre projects planned for Algeria, Egypt and elsewhere in the early 1980's would provide significant local demand, but no other major outlets are envisaged. The Polyester fibre plans are very tentative at this stage, but a 25 000 tonne unit could consume 10 000 tonnes of glycol : the supply/demand analysis below assumes the phased start-up of three such plants through 1985.

c) Supply/Demand Analysis

The supply/demand situation is summarised in Table IV.C.14.

TABLE IV.C.14.

ARAB SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974	1980	1985
Potential Supply (60% cap)	-	30	150
Projected Demand	1.5	10	30
Surplus/(Deficit)	(1.5)	20	120

The Arab countries are likely to have substantial export potential by the mid 1980's, since polyester fibre demand seems unlikely to rise as fast even as announced glycol capacity.

D. PRODUCT ANALYSIS : HIGH DENSITY POLYETHYLENE (HDPE)

1. Overview

Considerable new investment will be required for HDPE to avoid the shortages which are otherwise forecast to occur in both developed and developing country markets during the 1980's.

Projected HDPE supply/demand balances for world markets are summarised in Table IV.D.1.

TABLE IV.D.1.

SUPPLY/DEMAND SUMMARY AS SURPLUS OR (DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	194	(105)	(1105)
W. EUROPE	505	385	(280)
JAPAN	353	410	270
CANADA	(19)	(86)	(116)
LATIN AMERICA	(77)	30	(25)
E. EUROPE	(30)	10	(250)
AFRICA	(26)	(45)	(70)
ASIA/PACIFIC	(50)	(84)	(119)
ARAB WORLD	(33)	(110)	(50)

These figures are based on existing and announced plants and represent the need for additional capacity in the years shown. Thus the USA will need new investment, within the next few years, to meet the anticipated shortfall which is forecast for

1980. In Western Europe capacity appears to be adequate into the early 1980's and, in the case of Japan, through to the second half of the decade.

Demand in the industrialised areas in 1974 is estimated at approximately 2.5 million tonnes, with the major uses being blow moulding and injection moulding. As it is a product which has reached maturity in terms of application and very few new end uses are foreseen the growth rate in USA, W. Europe and Japan will decline from levels of around 15 percent to steady off at around the 8 percent mark in the 1980's. The competition between HDPE and polypropylene is also an important factor in keeping the growth rates down.

In the developing markets HDPE capacity amounted to 13.5 percent of total world capacity (excluding the Arab states) in 1974, whilst demand was considerably higher. There are several planned projects for the next 10-15 years, particularly in Latin America, Eastern Europe and parts of S.E. Asia. If they are realised they could support a growth rate of 18 percent/year. This would seem quite feasible for such new markets and consequently a balanced supply/demand situation should develop overall with the possibility of some local excess or deficit occuring. It is expected that Japan will be able to maintain a substantial level of exports and will provide a large part of the deficit forecast to exist in the Asian and Pacific region.

There is a large volume of international trade in HDPE, but in view of the feedstock limitations which could be affecting all three of the major producing areas, the level of exports could be reduced in the next few years. However, when the supply situation gets tight and domestic price controls are operating, it is often more profitable to export material even although this gives an exaggerated domestic shortage and artificially high import requirements.

The HDPE market is very fragmented with a large number of end-uses. There is a number of different grades offered for each end use and large manufacturers may produce anything up to twenty different grades.

Companies processing plastics are of two main types. There are those firms whose main activity is the manufacture of cars, domestic appliances, electrical equipment etc., who have a plastics fabrication shop, or subsidiary company, moulding components. These are subsequently incorporated into their own products, and hence represent captive production. Such companies will be moulding specific items for limited end uses. The second group is the custom moulders. These firms purchase plastics and mould components for sale and incorporation in other manufacturers finished products. They have no captive market.

The USA and Western Europe will require substantial new investment to meet forecast demand for the 1980's and therefore appear to offer substantial opportunities for exports from the Arab States. The major problem in this case will be establishing adequate marketing facilities to meet customers requirements in terms of product range, technical service and adequate distribution to a large number of small consumers. These requirements will probably best be met, at least in the medium term, by establishing a market agreement with an established HDPE producer. However there are a number of independent chemical traders who have some specialisation in plastics who might be able to provide an adequate service.

normal supply and demand forces for naphtha and related hydrocarbons, that have alternate uses in the energy and feedstock markets. However, there is a reason to believe that the upgraded value of chemical feedstocks will generally give chemical producers preference over straight energy consumers. On balance, it is unrealistic to assume that the petrochemical use of feedstocks will reach the levels anticipated based on historical market expansion and that more realistic growth rates are about 7 percent for ethylene and 5-6 percent for BTX aromatics. This lower demand growth will develop as a result of decreased demand for derivatives oriented toward the energy sector (e.g., smaller cars use less glycol), loss of exports to OPEC petrochemical plants, and a general slowdown in the US standard of living.

It is generally expected that (1) for the next ten years or so, petrochemical growth rates will continue at somewhat less than current rates, traditional feedstocks will be available with increasing difficulty from the existing hydrocarbon pool and certainly at substantially higher prices than those applicable to straight energy uses, (2) chemical firms will take various steps to improve their position with respect to hydrocarbon supplies in addition to those bid away from the refinery, and (3) while a number of interesting projects will likely be consummated with oil-rich nations, the total effect of these projects on feedstock/primary petrochemicals demand will be relatively small for the industry as a whole during the period up to 1985.

The USA is considered to be the least attractive of the three major industrially developed markets of USA, Western Europe and Japan, as an export market for the Arab States. There is a large domestic market which enables good economies of scale to be enjoyed, feedstocks are expected to continue to be available and

Opportunities for spot sales to Eastern Europe will occur but the plans are aimed to bring about self-sufficiency and this area cannot be regarded as a regular large scale export market.

Africa and Asia will probably require imports to supplement local production for a number of years. These markets are currently supplied by producers in the developed countries and could be covered by joint marketing agreements set up with established suppliers as indicated above.

There is a growing demand for HDPE in the Arab States and, on the basis of present plans, it will continue to be necessary to import HDPE into the area.

2. U.S.A.

a) Supply

The current US HDPE nameplate capacity is 1 473 thousand tonnes per annum. There have been 7 expansions announced to date, which will increase nameplate capacity by 633 thousand tonnes by 1980. Besides these Hoechst, and USS Chemicals are known to be considering entry into the HDPE business. A list of US producers is shown in Table IV.D.2.

TABLE IV.D.2.

US HDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
Allied Chemicals	Baton Rouge, La.	155	
	Orange, Texas	14	
	Tonawanda, N.Y.	14	
Amoco	Alvin, Texas	45	+136 (1976)
Arco Polymers	Port Arthur, Texas	64	
Chemplex	Clinton, Ia.	95	+ 68 (1978/9)
Dow	Freeport, Texas Plaquemine, La.	159	+136 (1976/7)
Du Pont	Orange, Texas	102	+102 (1976)
Gulf	Orange, Texas	86	+ 91 (1977)
Monsanto*	Alvin, Texas	82	
National Petrochem	LaPorte, Texas	159	+ 23 (1977/8)
Phillips	Pasadena, Texas	214	
Solvay	Pasadena, Texas	193	
Union Carbide	Seadrift, Texas	91	+ 77 (1975)
	Totals	1473	+633

* operating at half capacity and could close down altogether

b) Demand

The 1974 end use breakdown for HDPE in the US is shown in Table IV.D.3.

TABLE IV.D.3.

1974 US HDPE CONSUMPTION BY END-USE

(thousand tonnes)

Blow moulding	435	38.4%
Injection moulding	322	28.4%
Pipe & conduit	150	13.3%
Film	43	3.8%
Wire & cable	40	3.5%
Sheet & other extruded products	72	6.4%
Others	70	6.2%
Total demand	1132	100.0%

In the past few years growth of high density polyethylene in the US has been dramatic, with production increasing at an average 16 percent/year for the last 5 years. Growth was retarded by the severe shortages at the beginning of 1974 which slowed development of major new end uses. This slowdown, the current recession, and the anticipated improved competitive position of polypropylene have tended to decrease the long-term growth outlook. By 1980 demand should increase about 75 percent from the 1974 level of 1132 thousand tonnes and should grow by an additional 50 percent during the 1980-85 period. Blow moulded bottles and injection moulded articles will continue to be the major uses throughout the 1980's.

c) Supply/Demand Analysis

The potential supply/demand situation for HDPE in the US is summarised in Table IV.D.4. This is based on supply from existing and announced plants only.

TABLE IV.D.4.

US HDPE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1326	1395	1895	1895
Projected Demand	1132	1075	2000	3000
Surplus/(Deficit)	194	320	(105)	(1105)

* 90% nameplate
\+ estimated actual

It would seem that without new plants there will be a deficit by 1980. However, this seems unlikely and it is expected that capacity will be increased and that US will remain a net exporter of the material through the mid-1980's. A low level of imports from low-cost facilities are possible since a large percentage of the exports are anticipated to be in the more specialised grades. The US tariff on polyethylene imports is $28.7/tonne + 10 percent.

3. Western Europe

a) Supply

The nameplate capacity for HDPE in W. Europe during 1974 is estimated to have been 1575 thousand tonnes.

The producing companies, with existing capacity and announced expansions, are listed in Table IV.D.5.

At the present time no other announcements have been made for capacity expansions beyond 1980, but several companies have indicated their intention to invest further in HDPE.

A number of the HDPE plants in W. Europe are dual purpose HDPE/PP units and expansions or reductions in output for the future may well be made by varying the production ratio of the two products.

TABLE IV.D.5.

WEST EUROPEAN HDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974
(Thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
AUSTRIA			
OMV	Schwechat	60	
BELGIUM			
NV Polyolefines	Zwijndrecht, Antwerp	60	+ 40 (1975)
Dow	Tessenderloo	-	30 (1976)
Total Belgium		60	
FRANCE			
Manolene (R-P)	Gonfreville	40	+ 10 (1975)
Naphthachemie	Lavera	60	+ 10 (1975)
Soc. Industrielle de. Polyolefins SA	Gonfreville	35	+ 25 (1975-1977)
Solvay	Sarralbe	110	
Total France		245	
WEST GERMANY			
Hoechst	Hoechst	250	
	Knapsack	60	shut down (1976)
	Munchmunster	75	
ROW	Wesseling	130	+ 60 (1976)
Ruhrchemie	Oberhausen	110	
Vestolen	Gelsenkirchen	140	+ 40 (1977)
Wacker Chemie	Koln	25	+ 25 (1976)
Total West Germany		790	
ITALY			
Montedison	Brindisi	130	+ 20 (1976)
Solvay	Rosignano	60	
Rumianca	Cagliari	30	
ANIC	Gela	20	+ 10 (1975) + 10 (1976)
Total Italy		240	
NETHERLANDS			
DSM	Beek	60	
NORWAY			
Saga	Rafnes	-	40 (1977)
SPAIN			
Calatrava	Puertollano	40	+ 25 (1975)
Dow	Tarragona	-	50 (1975)
TAQSA	Tarragona	-	50 (1977)
Total Spain		40	
SWEDEN			
Unifos Kemi AB	Stenungsund	30	+ 5 (1975)
UNITED KINGDOM			
BP	Grangemouth	50	+ 40 (1976)
WEST EUROPEAN TOTALS		1575	+430

b) Demand

Table IV.D.6 gives an end use split for HDPE in Western Europe, for 1974.

TABLE IV.D.6.

1974 WEST EUROPEAN HDPE CONSUMPTION BY END-USE

(thousand tonnes)

Blow moulding	384.5
Injection moulding	384.5
Pipe and conduit	55
Film and sheeting	27
Monofilaments	37
Wire and cables	9
Miscellaneous	18
Total demand	915

It is clear that blow moulding and injection moulding account for the major part of HDPE consumption (85 percent) and indeed over half of the HDPE usage is in the packaging industry.

When considering the future demand for HDPE in Western Europe, it should be recognised that this is a product which has reached maturity in terms of application and that very few new uses are forseen. In the past the development of new applications, and growth in demand for each end use, led to a growth rate of 15-16 percent/year. The future will not be able to sustain such a rate on existing applications alone.

It is widely believed that the West German HDPE market has reached saturation, and that growth in demand in the future will have to come by closing the gap that exists between per capita consumption in West Germany and the remainder of Western Europe.

The competition between HDPE and polypropylene (PP) for a number of applications can lead to a potential 30 percent overlap. In Italy and more especially the U.K., PP has gained a strong position, leaving low per capita consumption figures for HDPE. It is unlikely that PP will be replaced where it already has an application and therefore the potential growth in the Western European HDPE market is probably further reduced.

Based on this appraisal of the market, a forecast of 11 percent/year is made for Western Europe HDPE demand growth from 1976 to 1980. A decline of 8.0 percent is expected for 1975 itself. After 1980 the constraining factors described above will reduce this growth rate progressively to around 8 percent/year in the mid-1980's.

c) Supply/Demand Analysis

The supply/demand balance for HDPE in W. Europe is shown in Table IV.D.7.

Supply is taken at 90 percent of nameplate capacity, which in turn comprises existing plants and announced expansion in W. Europe to date. No allowance is made for likely investment beyond 1980 in new HDPE capacity.

TABLE IV.D.7.

WEST EUROPEAN HDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1420	1600	1800	1800
Projected Demand	915	840	1415	2080
Surplus/(Deficit)	505	760	385	(280)

* 90% nameplate

\+ estimated actual

It can be seen that production in W. Europe, based on existing plant and announced expansion is sufficient to meet demand until the early 1980's.

There is a very active intra-European trade in HDPE, with West Germany exporting their surplus production to all parts of Western Europe. Apart from this internal trade there is a small amount of HDPE being exported to other countries in the world. The first quarter 1975 contract price for blow and injection moulding grades of HDPE in Western Europe stands at about $760/tonne, having fallen from a mid-1974 level of around $800/tonnes. Price development depends almost entirely on ethylene availability and pricing. Supply is likely to be tighter from 1977 for a period, and this tightness will lead to higher price increase than would normally result from inflation and feedstock cost increases through 1980.

4. Japan

a) Supply

The current capacity for HDPE production is 730,000 tonnes. A list of producers, together with present capacity and expansion plans, is given in Table IV.D.8. By 1980, additional olefin and associated HDPE capacity will be commercialised in Japan. This should increase the capability of the domestic industry to 1 020 thousand tonnes. In the subsequent period further expansion will be tied to the ability of the petrochemical industry to expand on the Japanese islands.

shipping costs will add considerably to the production costs. However the US market tends to be less well integrated than Western Europe and therefore represents a bigger merchant market. Hence there could be opportunities in the longer term, if the economics are competitive and adequate marketing and distribution facilities are organised.

2. Western Europe

Western Europe is defined as 18 countries having a total population of 338 million. The area can be further broken down into 2 main trading associations of 9 and 7 countries, namely the EEC (European Economic Community) and EFTA (European Free Trade Area), respectively, Greece and Spain are the "other" countries. The individual countries and their respective trading associations are indicated in Table IV.B.3.

TABLE IV.B.3

WESTERN EUROPEAN COUNTRIES AND ASSOCIATIONS

	EEC	EFTA	Other
	Denmark	Sweden	Greece
	Belgium/Luxembourg	Norway	Spain
	Holland	Finland	
	West Germany	Austria	
	France	Switzerland	
	Italy	Portugal	
	UK	Iceland	
	Irish Republic		
Total Population, Million	255	40	43
% of Western European Population	75.4	11.8	12.9

TABLE IV.D.8

JAPANESE HDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	CAPACITY	EXPANSIONS, YEAR
Mitsui Petrochemical	200	+ 60
Showa Denko	140	+ 50
Mitsubishi Chemical	90	-
Asahi Chemical	90	-
Nisseki	80	+ 60
Chuka Chemical	45	-
Nissan	35	-
Chisso	30	-
Mitsubishi Petrochemical	20	+ 60
Idemitsu	-	60
	730	+ 290 (by 1980)

b) Demand

The demand for HDPE in Japan during 1974 is estimated to have been 307 000 tonnes. It should reach 470 000 and 700 000 tonnes in 1980 and 1985, respectively. The projected compound annual growth rate for the 1980-85 period is 8 percent. An end use split for HDPE consumption in Japan is given in Table IV.D.9.

TABLE IV.D.9.

1974 JAPANESE HDPE CONSUMPTION BY END-USE

(thousand tonnes)

Injection moulding	123	40%
Blow moulding	60	20%
Flexible tape	44	14%
Fibre	27	9%
Film	17	6%
Pipe	7	2%
Others	29	9%
Total demand	307	100%

c) Supply/Demand Analysis

The supply/demand balance for HDPE in Japan is shown in Table IV.D.10.

TABLE IV.D.10.

JAPANESE HDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	660	660	880	970
Projected Demand	307	300	470	700
Surplus/(Deficit)	353	360	410	270

+ estimated actual

As a significant proportion of the Japanese resin production has traditionally been exported, a sizeable overcapacity situation exists and is forecast to continue to exist through the mid-1980's.

5. Rest of Non-Arab World

a) Supply

A list of HDPE producers is given in Table IV.D.11, together with existing nameplate capacities and expansion plans announced to date.

TABLE IV.D.11

REST OF NON-ARAB WORLD HDPE ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COUNTRY	CAPACITY	EXPANSIONS, YEAR
CANADA	90	+ 25 (1977)
LATIN AMERICA		
Argentina	-	15 (1978/9) + 15 (?)
Brazil	27.5	+ 87.5 (1980)
Andean Zone	-	80 (1978) + plans
Mexico	-	100 (1977)
Total Latin America	27.5	+300 minimum
E EUROPE		
USSR	158	+440 (1977-8)
E GERMANY	90	+ 30 (1975) + plans
Rumania	-	+130 (1980)
Czechoslovakia	60	+ 30 (1980) + 80 (1985)
Bulgaria	10	+ 15 (1978) + 25 (1985)
Poland	-	+ 30 (1977) + 60 (1980's)
Hungary	-	plans
Yugoslavia	-	50 (1975) +100 (1980
Total E Europe	318	+990 minimum
AFRICA		
S Africa	50-60	-
Total Africa	50-60	-
ASIA/PACIFIC		
ASEAN Countries	-	40 (delayed) + 50 (after 1980)
Australia	90	+ 30 (1982)
India	24	+ 6 (1976)
Taiwan	25	+ 95 (1980)
Korea	-	40 (1978) + plans
Turkey	-	40
Iran	-	100 (1977 delayed) + plans
Total Asia/Pacific	139	+401 minimum
TOTAL REST OF NON-ARAB WORLD	630	

b) <u>Demand</u>

- **Canada**

  The 1974 demand is estimated at 100 000 tonnes, and this is projected to grow at 10 percent or over for the next several years and reach 190 000 tonnes and 310 000 tonnes by 1980 and 1985, respectively.

- **Latin America**

  The total demand for this region is 102 000 metric tons. This will more than double by 1980. Mexico probably has the highest growth rate of the region at 15 percent.

- **E. Europe**

  The area consumption of HDPE in 1974 was estimated at approximately 330 thousand tonnes. Growth in demand is going to be very high compared with that for LDPE and by 1985 a level of 1 550 thousand tonnes could be reached.

- **Africa**

  Demand in Africa is about 65 000 tonnes, 50 000 of which is attributed to S. Africa, but here the future growth rate is very uncertain and could lie anywhere between 2 and 10 percent per year through 1980.

- **Asia/Pacific**

  Consumption in 1974 was estimated at 173 000 tonnes. Australia and New Zealand use up almost a quarter of this total and the Asean Community are also significant users. The Republic of South Korea would seem to be expecting the fastest growth rate for the area and are predicting a domestic consumption of over 200 000 tonnes by the end of the 1980's.

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World's HDPE is given below in Table IV.D.12.

TABLE IV.D.12.

REST OF NON-ARAB WORLD HDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	81	104	194
Forecast Demand	100	190	310
Surplus/(Deficit)	(19)	(86)	(116)
LATIN AMERICA			
Potential Supply	25	260	415
Forecast Demand	102	230	440
Surplus/(Deficit)	(77)	30	(25)
E. EUROPE			
Potential Supply	300	990	1 300
Forecast Demand	330	980	1 550
Surplus/(Deficit)	(30)	10	(250)
AFRICA			
Potential Supply	40	45	50
Forecast Demand	66	90	120
Surplus/(Deficit)	(26)	(45)	(70)
ASIA/PACIFIC AREA			
Potential Supply	129	286	601
Forecast Demand	179	370	720
Surplus/(Deficit)	(50)	(84)	(119)

+ estimated actual

- Canada
  There will be a deficit developing in this area and the country must continue to be a net importer for the foreseeable future. Most of the imports come from the US at present, but the duty exacted is quite high, at 10 percent.

- Latin America
  This region is highly dependent on imports at present, but with the commercialisation of many schemes in the area around the late seventies self sufficiency ought to be achieved by 1980. Thereafter supplies will again get tight unless further proposed capacity expansions come onstream at the scheduled date.

- E. Europe
  On the whole this region is in balance and will remain so well into the 1980's. The projected deficit for 1985 is false, since additional capacity is planned.

  Russia the main force in this area has set a consumption level of 140 000 tonnes for 1975, but this is believed to be highly optimistic, since both production and consumption targets are considerably behind planned levels. Yugoslavia reckon on requiring 50 000 tonnes of imported material in 1975. Czechoslovakia and E. Germany both have adequate capacity to export to the other countries in the region and in general the Eastern European countries have as one of their priorities the balancing of each member country's commodities.

- Africa

  The HDPE production in the major country, South Africa, is restricted by ethylene shortages and imports are necessary. A new cracker is due onstream in the early eighties and this should somewhat alleviate the situation by enabling expansion of the existing HDPE capacity or making use of a dual purpose HDPE/polypropylene plant owned by Safripol.

  The increasing deficit forecast for the area is due to the slowly developing demand for HDPE in East and West Africa.

- Asia/Pacific

  This area is a net importer and will continue to be through to the mid-1980's. Japan is probably the major supplier to the S.E. Asian countries. Several plants have been planned for this area in the 1980's but it is questionable whether the local markets could support any large scale production without first developing potential export markets. Provided ethylene feedstocks are available by then there is no reason why the import requirement of this area could not be vastly reduced.

6. The Arab World

a) Supply

The plans for HDPE production in the Arab States are shown in Table IV.D.13.

TABLE IV.D.13.

ARAB HDPE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	100	1982
Tunisia	(50)?	1980
Morocco, Libya	-	-
Egypt	100	1985
Kuwait	100	1981/2
Iraq	30	1981/2
Abu Dhabi	190	1982
Qatar, Saudi Arabia Bahrein Syria, Jordan Lebanon	-	
Total	570	

b) **Demand**

Current Arab HDPE demand is modest and highly fragmented : analysis of precise consumption by country is complicated by re-exports. The total consumption for the whole Arab block is estimated at around 33 000 tonnes for 1974, with a large percentage of this in Algeria.

c) Supply/Demand Analysis

The supply/demand situation for HDPE in the Arab World is summarised in Table IV.D.14.

TABLE IV.D.14.

ARAB HDPE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1986
Potential Supply	-	-	120
Projected Demand	33	110	170
Surplus/(Deficit)	(33)	(110)	(50)

Overall the region is dependent on imports and will be throughout the study period although the level should decrease when local production starts in the 1980's.

North Africa will exist on imported HDPE supplies until the plant at Skikda comes onstream in 1982 when there will be a change to exporting material for a short time before demand catches up with production again in the late 1980's.

Egypt has a very small HDPE requirement and anticipates this to continue for the next 5-10 years. The 100 000 tonne plant planned for 1985 will supply other market areas.

These countries represent a highly developed economic and industrial environment, with a very well established petrochemical industry. As a petrochemical market, it must be considered as one area, based on the high degree of inter-country trade and cross-frontier investment by the major European and other multinational chemical companies.

In most cases the product demand forecasts provided in this report show a significant reduction from the historical trends reported over the last few years. This reflects the situation brought about by the general downturn in economic activity in Europe in 1974 and 1975 and the slowed growth expected in future years. This is illustrated below in the table showing historical and forecast growth in real GNP for the various European countries.

The Gulf States have no local production and will not have until 1981/2 when units at Kuwait, Iraq and Abu Dhabi may start-up. Production levels by 1986 are still being estimated at lower than demand levels despite the projected capacity plans for the area.

E. PRODUCT ANALYSIS : POLYPROPYLENE (PP)

1. Overview

A good deal of new investment in polypropylene capacity will be required by the mid 1980's in the USA and, to a lesser extent, in Europe. Projected polypropylene supply/demand balances for world markets are summarised in Table IV.E.1.

TABLE IV.E.1

SUPPLY/DEMAND SUMMARY AS SURPLUS OR (DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	196	(180)	(1140)
W. EUROPE	230	460	(720)
JAPAN	397	465	235
CANADA	(65)	-	(20)
LATIN AMERICA	(88)	(93)	(171)
E. EUROPE	(5)	5	15
AFRICA	8	(24)	(27)
ASIA/PACIFIC	113	(286)	(370)
ARAB WORLD	(9)	(70)	-

The US analysis suggests a deficit situation by 1978, W. Europe by 1982 and Japan by the late 1980's. Up until 1980 Western Europe and Japan are in the strongest position to supply developing markets where there is a growing demand.

Polypropylene has the best growth prospect of the large volume thermoplastics, due to the development of new applications and to the price differential between ethylene and propylene, allowing polypropylene to penetrate established HDPE markets. Western Europe lags behind the USA and Japan in utilising polypropylene to its full potential. Because it is a younger, less developed market then HDPE the projected growth rates are higher than for the other polyolefins.

The market situation is similar to that for HDPE with a large number of customers many of whom require technical assistance. Technical service is, if anything, rather more important for PP compared with HDPE due to the many applications which are being developed for engineering mouldings and fibre applications. Consequently for export markets, a sophisticated marketing service organisation will be required.

Whilst a deficit situation will develop in the USA and West Europe by the mid eighties and in Japan by end of the decade it is not felt that these areas represent major export opportunities. Although polypropylene is rapidly developing as a major "high volume" thermoplastic many applications are of a technical nature. Suppliers therefore have established their position on the basis of product performance and technical service. They are usually able to obtain a good profit level on this basis and consequently there will be an incentive to invest in new capacity to meet the growing demand. The forecast deficit is therefore likely to be made up by added capacity put in by established producers.

The developing countries are taking increasing quantities of polypropylene from the developed areas and it will be some time before local production is able to meet demand.

Numerous applications are also developing in the Arab States and these will undoubtedly be stimulated by local production. In view of the likely preference for ethane feedstocks, and consequent limited availability of propylene in the Arab States it is unlikely that any substantial volume of polypropylene will become available for export during the study period.

2. U.S.A.

a) Supply

The current US polypropylene nameplate capacity is approximately 1.2 million tonnes/yr. Entry into the market by Gulf and announced and planned expansions will increase capacity by an additional 425 thousand tonnes/yr by 1980. In addition other expansions by existing producers and possible entry into the US market by Solvay are expected to contribute to additional polypropylene supply in the study period. A list of US polypropylene producers and estimated nameplate capacities is shown in Table IV.E.2.

TABLE IV.E.2.

US POLYPROPYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR	
Amoco	New Castle, Del.	114		
	Alvin, Tex.	114		
Dart	Odessa, Tex	59		
	Baytown, Tex		68	1976
Diamond Shamrock	Deer Park, Tex.	50	23	1975/6
Eastman	Longview, Tex	41	16	1976
Exxon	Baytown, Tex.	159		
Gulf	Cedar Bayou or Orange, Tex.		91	1978/9
Hercules	Lake Charles, La.	341		
	Baytown, Tex.	91	91	1976
			136	1978/9
Novamont	Neal, W. Va.	73		
Phillips	Pasadena, Tex.	39		
Shell	Woodbury, N.J.	127		
	Totals	1208	425	

b) Demand

Polypropylene has the best growth prospects of the large volume thermoplastics due to the development of new applications and an increasingly favourable cost structure due to process improvements and the anticipated spread in prices between ethylene and propylene. Domestic US demand for polypropylene was about 891 000 tonnes in 1974. Demand is expected to double by 1980 and be nearly three times as large by 1985. Injection moulded articles which constitute nearly 40 percent of current demand are expected to grow at a rate slightly above that for the product as a whole. In addition, blow moulded articles, a relatively modest market at present, are expected to show high growth due to development of new resin grades and increasing attractiveness in comparison to high density polyethylene and other resins. On the other hand, polypropylene fibres and filament, the other large current use for the product will have below average growth due to the growth limitations of the overall fibres market. 1974 US demand by major applications area is shown in Table IV.E.3.

TABLE IV.E.3

1974 US POLYPROPYLENE CONSUMPTION BY END-USE

(thousand tonnes)

Injection moulding	346	38.8%
Film	64	7.1%
Fibres and filament	303	34.1%
Blow moulding	16	1.7%
Extruded products	70	7.8%
Miscellaneous	93	10.5%
Total demand	891	100.0%

c) Supply/Demand Analysis

The potential supply/demand for polypropylene in the United States is summarised in Table IV.E.4, based on the supply from existing and announced plants.

TABLE IV.E.4

US POLYPROPYLENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1087	1087	1470	1470
Projected Demand	891	870	1650	2610
Surplus/(Deficit)	196	217	(180)	(1140)

* calculated as 90% capacity
\+ estimated actual

In 1974, the US exported approximately 15 percent of production. Nearly half of the exports were to Canada which will be virtually selfsufficient in the product due to completion of a facility in 1975. In future years it is anticipated that exports will be a smaller percentage of production and they will be limited to special product grades and to meet local supply/demand imbalances. The current US polypropylene imports are minimal and in future years are expected to be small relative to consumption.

The above figures suggest a substantial polypropylene deficit in the region by 1980. However, it is anticipated that most of this deficit will be covered by new US polypropylene projects utilising propylene from the new heavy liquids crackers, but there is likely to be polypropylene imports throughout the 1980's. The US tariff on polypropylene is 28.6 $/tonne + 10 percent.

3. Western Europe

a) Supply

The present W. European nameplate capacity is 920 000 tonnes.

West European polypropylene manufacturers are listed in Table IV.E.5. together with plant capacities. These are based on existing plants and an appraisal by Chem Systems of the likely pattern of expansions based on announcements.

These capacities assume the shelving and scrapping of some expansion plans, and it is not hard to imagine the cancellation or delay of one or two of the smaller plants listed as due to come onstream during the 1970's. In addition, ROW in Germany are thought to be experiencing plant problems, and a shutdown is possible.

Despite the forecast of some cancellations of PP expansions in Western Europe up to 1980, a number of manufacturers and potential manufacturers are known to be actively interested in expansion plans beyond 1980, as and when necessary.

TABLE IV.E.5.

WEST EUROPEAN POLYPROPYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
AUSTRIA			
Danubia	Schwechat	35	30 (1975)
BELGIUM			
Amoco	Geel	-	55 (1978)
Hercules	Paal	-	50 (1976) 100 (1977)
FRANCE			
Naphthachimie	Lavera	30	+ 40 (1977)
SNPP	Lillebonne	55	+ 20 (1975)
ATO	Gonfreville	-	50 (1978)
Solvay	Sarralbe	-	50 (1978)
Total France		85	
WEST GERMANY			
Hoechst	Kelsterback	100	+ 100 (by 1980)
ROW	Wesseling	25	+ 25 (1976)
Vestolen	Gelsenkirchen	40	+ 45 (by 1980)
Total West Germany		165	
ITALY			
Montedison	Ferrara Brindisi Terni	225	+ 50 (1976)
ANIC	Gela	40	+ 10 (1975)
Total Italy		265	
NETHERLANDS			
DSM	Beek	-	50 (1977) 100 (1980)
Polyolefin	Pernis	75	
Total Netherlands		75	
NORWAY			
SAGA	Rafnes	-	50 (1978)
SWEDEN			
Unifos	Stenungsund	-	50 (1979)
SPAIN			
Calvo Sotelo	Tarragona	-	50 (1978)
Paular	Puertollano	35	+ 25 (1977)
Total Spain		35	
UNITED KINGDOM			
ICI	Wilton	140	+ 50 (1977)
Shell	Carrington	120	
Total United Kingdom		260	
WEST EUROPEAN TOTALS		920	+ 900

b) Demand

In the past, polypropylene demand has grown at over 20 percent/year in Western Europe with 1973 levels 29 percent over the previous year. It is estimated that the feedstock supply problems, and the reduced demand in the latter half of 1974, combined to give a growth of only 4 percent after the boom year of 1973.

The consumption of polypropylene in Western Europe during 1974 is estimated to have been 600 000 tonnes. An end use analysis is given in Table IV.E.6.

TABLE IV.E.6

1974 WEST EUROPEAN POLYPROPYLENE CONSUMPTION BY END-USE

(thousand tonnes)

Moulding & extruding	336	56%
Split/slit fibres (flat yarns)	132	22%
Monofilament fibre	72	12%
Fibre	60	10%
Total demand	600	100%

In Western Europe, polypropylene would seem to have a brighter future in terms of growth in demand then HDPE. A number of applications have still not been exploited to the extent that they have in the US and Japan, especially fibre applications.

However, some doubts exist in Europe on the acceptability of polypropylene fibre and there is a great deal of

TABLE IV.B.4

GROWTH IN REAL GNP

EEC	Average 1959-60 to 1971 - 1972	From Previous Year		
		1973	1974	1975
Belgium	4.9	6.1	4-1/2	3
Denmark	4.8	3.5	1-1/2	1
France	5.8	6.0	4-3/4	3
Ireland	4.0	6.8	2-1/2	1-1/2
Italy	5.5	6.0	4-3/4	-1/4
Netherlands	5.2	4.2	2-1/2	2-1/2
United Kingdom	3.1	5.3	-1/2	1-3/4
West Germany	4.9	5.3	1	2-1/2
EFTA				
Austria	5.1	5.5	5	3
Finland	5.4	6.0	3-1/4	3
Iceland	na	na	na	na
Norway	5.0	3.7	4	5-1/2
Portugal	na	na	na	na
Sweden	4.2	1.5	3	2-1/2
Switzerland	4.7	3.5	1-1/2	1
Other				
Greece	na	na	na	na
Spain	7.3	7.9	5-1/2	4-1/4

Source: OECD Economic Outlook, December 1974 uncertainty over the future growth of the car industry in Western Europe, a major outlet for PP. Based on these feelings and on opinions expressed in the marketplace, a forecast of 15 percent/year growth rate for PP demand in Western Europe from 1975 to 1985 is made. This reflects confidence in the long term future of the product. However in 1975, the market is expected to decline by 2.0 percent, with the automotive industry and the consumer durables industry, both of which are important outlets for PP, being particularly slack. Polypropylene demand should increase to about 4 million tonnes by 1990.

c) Supply/Demand Analysis

The supply/demand balance for polypropylene in Western Europe is shown in Table IV.E.7.

Supply figures are taken at 90 percent of nameplate capacity.

TABLE IV.E.7

WEST EUROPEAN POLYPROPYLENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	830	960	1630	1630
Projected Demand	600	550	1170	2350
Surplus/(Deficit)	230	410	460	(720)

* calculated as 90% nameplate

\+ estimated actual

It can be seen that production in Western Europe based on existing and expansions announced (where these are considered valid) is sufficient to cope with expected demand until the early 1980's.

Trade within West European boundaries accounts for approximately 130 000 tonnes annually, but trade to and from Western Europe is normally of the order of 20 to 30 000 tonnes. In the future, Western European producers are looking to markets outside the area to dispose of the developing surplus. Small quantities of PP are imported from the US and even smaller amounts from Japan. Many of the US exports have probably fallen into the categories of 'specialist' material or market development efforts in the past. Much of this should be replaced by home produced material before the 1980's.

The Montedison patents for PP production and use have placed Italy in the major exporting role in Western Europe in the past, but the gradual expiry of these should change this situation. It is notable that Italy is already exporting small quantities to Mediterranean/ Middle Eastern countries. Polypropylene pricing is, of course, dependent on propylene availability, and the major PP producers contacted had no fears for propylene supplies over the next five years based on realistic appraisals of investment intentions. In the 1980's propylene availability will depend on cracker investment, and this is expected to materialise to provide ample supplies for Western Europe propylene users.

4. Japan

a) Supply

The current capacity for polypropylene production is 991 000 tonnes. The producers and their respective capacities are summarised in Table IV.E.8. While only one major new market entry is anticipated by 1980, that of Idemitsu, new polypropylene capacity will parallel new ethylene plant construction, and by 1982/83, nameplate capacity levels should exceed 1 350 000 tonnes/year.

TABLE IV.E.8.

JAPANESE POLYPROPYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	CAPACITY	EXPANSIONS, YEAR
Mitsubishi Petrochemical	190	+ 60
Mitsui Toatsu Chemicals	136	+ 20
Sumitomo Chemical	126	+ 60
Chisso Petrochemical	146	+ 20
Mitsui Petrochemical Industries	120	+ 60
Showa Yuka	75	+ 60
Ube Industries	90	
Tokuyama Soda	70	
Tonen Sekiyukagaku	40	+ 20
Idemitsu	-	60
Total	901	+ 360 (by 1982)

b) Demand

The demand for polypropylene resin in Japan should decline during 1975 by about 9 percent from a 1974 level of 493 000 tonnes to 450 000 tonnes. This is the result of the overall depressed condition of the economy and perhaps more importantly the automobile, small appliance and fibre industries which are major outlets for polypropylene. The product consumption pattern is indicated in Table IV.E.9.

TABLE IV.E.9

1974 JAPANESE POLYPROPYLENE CONSUMPTION BY END-USE
(thousand tonnes)

Injection moulding	230
Film	100
Flat yarn	65
Extrusions	52
Fibre	35
Blow moulding	11
Total demand	493

With an economic recovery anticipated in the other major market regions by late 1975 or early 1976, Japanese production should reach 1974 levels next year. The growth of GNP in the future will be less that the historical 11-15 percent and this will depress the compounded annual growth rate for products like polypropylene.

The demand for PP should expand at an annual rate of 8.4 percent until about 1983 and 7.4 percent for the remainder of the decade. This reflects a reduced rate of exports containing polypropylene components, due to the reduced rate of total consumer spending in other major market areas.

c) Supply/Demand Analysis

The supply/demand projection for polypropylene in Japan is given in Table IV.E.10.

TABLE IV.E.10

JAPANESE POLYPROPYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974◆	1975	1980	1985
Potential Supply*	890	890	1135	1225
Projected Demand	493	450	670	990
Surplus/(Deficit)	397	440	465	235

* calculated as 90% nameplate

◆ estimated actual

Adequate polypropylene capacity exists in Japan to meet local requirements through to the mid '80's and Japan will continue to be in a position to export PP resin. Unless the olefin industry expands more rapidly than anticipated, resin exports will continue to become a less important component of the end-use pattern. Japan will continue to supply resin to countries on the Western rim of the Pacific Ocean, and will begin competing with material from other parts of the world in the ASEAN countries.

5. Rest of Non-Arab World

a) Supply

A list of polypropylene producers is given in Table IV.E.11. together with existing nameplate capacities and expansion plans announced to date.

b) Demand

- **Canada**

  In 1974, Canadian demand for polypropylene was approximately 65 000 tonnes, with a similar end-use split to the USA. Demand is projected to more than double by 1980 and exhibit good growth through the 1980's.

- **Latin America**

  Current demand in this area is 88 000 tonnes with Brazil and the Andean group accounting for about 65 percent of this figure. Growth rates of 13-15 percent are expected up to 1980 and increase steadily thereafter. Mexican and Brazilian demand will show the most rapid increases.

- **E. Europe**

  The 1974 demand for the area is estimated as 190 thousand tonnes, projected to approximately double by 1980 (395 thousand.)

- **Africa**

  The 1974 demand in Non-Arab Africa was approximately 28 000 tonnes, dominated by a South African consumption of 20 000 tonnes. This is expected to

TABLE IV.E.11.

REST OF NON-ARAB WORLD POLYPROPYLENE ESTIMATED
NAMEPLATE CAPACITY, 1974
(THOUSAND TONNES)

COUNTRY	CAPACITY	EXPANSION PLANS, YEAR
CANADA	-	68 (1975) + 75 (1980) + further unit?
LATIN AMERICA		
Argentina	-	30 (1977/78)
Brazil	-	80 (1979) + 70 (1982) + 70 (1985)
Andean Group	-	110 (1982)
Mexico	-	60 (1979) + 60 (1982)
E EUROPE		
USSR	60	+ 15 (1975) + 30 (1977) + 100 (1980's)
GDR	30(HDPE/PP)	+ 30 (1977/8)
Rumania	-	10 (1975)
Czechoslovakia	110	+ 30 (1980)
Bulgaria	-	+ 50 (1980) + 50 (1988)
Poland	30	+ 30 (1976) + 30 (1980's)
Hungary	2.5	+ 80 (by 1980)
Yugoslavia	-	10 - 20 (1975)
Total E Europe	232.5	+ [illegible]
AFRICA		
South	40(HDPE/PP)	+ 30 (when req) + 50 (1980's)
West	-	Plans in Nigeria (1985)
Total Africa	40	+ [illegible] minimum
ASIA/PACIFIC		
ASEAN Countries	20	+ 100 (1982) +105 (mid-80's)
Australia/New Zealand	68	+ 30 (1978/9)
India/Burma	-	30 (1976/7)
Taiwan	-	50 (1975) +220 (1978/9)
Korea	30	+ 30 (1982/3) plans later
Turkey	-	60 (1982)
Pakistan	-	plans (?)
Iran	-	50 (1977 delayed) plus
Total Asia/Pacific	118	+ 675 minimum
TOTAL REST OF NON-ARAB WORLD	390	

grow at 10-15 percent through to 1985, with some of the acceleration due to the substitution of HDPE. The already small consumption levels in other countries will increase only very marginally due to government restrictions on any material which might compete with natural fibre and the need for UV stabilisation in tropical countries (this being an expensive process).

- Asia/Pacific
  Total demand in 1974 was estimated as 231 000 tonnes. The major consumers are the Asean group as a whole and Korea. Growth rates have been very high in this area in recent years but are expected to level off at between 10 and 15 percent around 1980, once the novelty of HDPE substitution has subsided.

c) Supply/Demand Analysis

The supply demand balances for the Rest of the Non-Arab World is given below in Table IV.F.12.

TABLE IV.E.12

REST OF NON-ARAB WORLD POLYPROPYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974*	1980	1985
CANADA			
Potential Supply	-	130	200
Forecast Demand	65	130	220
Surplus/(Deficit)	(65)	-	(20)
LATIN AMERICA			
Potential Supply	-	157	329
Forecast Demand	88	250	500
Surplus/(Deficit)	(88)	(93)	(171)
E. EUROPE			
Potential Supply	185	400	545
Forecast Demand	190	395	530
Surplus/(Deficit)	(5)	5	15
AFRICA			
Potential Supply	36	36	63
Forecast Demand	28	60	90
Surplus/(Deficit)	8	(24)	(27)
ASIA/PACIFIC AREA			
Potential Supply	118	255	690
Forecast Demand	231	540	1060
Surplus/(Deficit)	(113)	(285)	(370)

* estimated actual

Earlier forecasts for 1975 have been revised downward and the OECD are hesitant in giving forecasts beyond 1975. In earlier publications where this has been done, the estimates for the year 1976/1990 were, in almost all cases, below the average growth for the period 1960/71.

For many chemicals, 1973 was a "boom" year and very large growth rates were recorded. Stockpiling undoubtedly affected this movement and the subsequent destocking which took place in the second half of 1974 and continuing into 1975 has exaggerated the movements of the consumer market. However, it is generally accepted that for many products it will be some years before there is a return to historic growth rates and the five and ten years forecasts made in 1972 and 1973 may be delayed by about three or four years before they are realised. In a number of cases this is bringing about an overcapacity situation as expansion plans were made on the basis of growth continuing at established levels.

There is, however, an important factor to be considered with respect to new chemical plant investment and that is the environmental controls which are now in effect. These are causing considerable delays in planning and for a large plant, such as a cracker, it may take up to two years for planning permission. There is also increasing difficulty in finding acceptable sites for new grass-roots facilities, particularly in Northern Europe. This means that European chemical manufacturers will face increased costs for pollution control and lengthy delays in site planning for investment in the coming decade.

Petrochemical feedstocks in Europe are almost entirely based on crude oil, the major exception being natural gas for methanol and ammonia. The condensates from natural gas are as yet unimportant, but are expected to provide a useful marginal source

- **Canada**

  Canada will probably remain a net importer at least through the early 1980's, but due to the entrenched position of a number of US polypropylene firms in the Canadian market, imports are already well-defined. These will be lessened by 1980 due to new capacity installation.

- **Latin America**

  This area is a net importer of polypropylene and will continue to be so through to the mid 1980's, even although by this time Argentina and the Andean Zone will be nearing self sufficiency, based on local production.

- **E. Europe**

  Like HDPE, the region as a whole is probably in balance for polypropylene, as there is considerable intra East European trading of the polymer.

  Russia is the major consumer at present, and will continue to import supplies from other East-Bloc countries.

  Czechoslovakia will be in a position to supply the requirements of E. Germany, whilst Yugoslavia is the only other country projected to have an import demand in the 1980's.

- **Africa**

  South Africa is the dominating country in this area and is expected to remain self-sufficient in polypropylene throughout the eighties, provided supply is assured at 90 percent of capacity, the existing plant is expanded, and a plant scheduled for 1982 comes onstream in time.

East and West African countries will have to continue importing the small tonnages that they need through the eighties.

- Asia/Pacific

  This area as a whole relies fairly heavily on imports, largely from Japan and there is need for installed capacity, even although the countries concerned have low plastics utilisation levels.

  The countries most likely to install new units beyond those definitely announced are Taiwan and Australia, although the latter envisages running into feedstock difficulties since here the ethylene producers are going over to light hydrocarbons which means a low propylene ratio. Iran has also plans to install new capacity.

  There is quite a high potential market for polypropylene as a jute or other natural fibres replacement in the underdeveloped Asian markets.

6. The Arab World

a) Supply

The plans for polypropylene production in the Arab States are shown in Table IV.E.13.

TABLE IV.E.13.

ARAB POLYPROPYLENE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	50	1982
Morocco, Tunisia, Libya	-	-
Egypt	100	1982
Kuwait, Iraq, Qatar, Saudi Arabia, United Arab Emirates and Lebanon, Syria, Bahrein	-	-
Total	150	

Potential supply in Algeria and Egypt is based upon usage of propylene derived from the naphtha crackers planned for these countries. Iraq is also planning for propylene and polypropylene in its second complex, which will use a naphtha feedstock.

b) **Demand**

Current North African demand is very small, but could expand rapidly towards 1980 to a total of around 50 000 tonnes.

Demand in the Gulf States could develop quite rapidly based upon requirements for fertilizer packaging.

c) Supply/Demand Analysis

The supply/demand situation for polypropylene is summarised in Table IV.E.14.

TABLE IV.E.14.

ARAB POLYPROPYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974	1980	1985
Potential Supply	-	-	150
Projected Demand	9	70	150
Surplus/(Deficit)	(9)	(70)	-

F. PRODUCT ANALYSIS : O-XYLENE

1. Overview

There is a tight overall supply/demand situation developing for ortho-xylene by 1980, due to the expanding demand for phthalic anhydride. The projected global situation is summarised in Table IV.F.1.

TABLE IV.F.1

SUPPLY/DEMAND SUMMARY AS SURPLUS OR (DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	211	1	(209)
W. EUROPE	33	(95)	(415)
JAPAN	107	150	40
CANADA	(11)	(25)	(55)
LATIN AMERICA	(11)	32	32
E. EUROPE	(206)	(280)	(460)
AFRICA	(5)	(6)	(19)
ASIA/PACIFIC	(38)	(35)	(2)
ARAB WORLD	-	-	-

There is potential for much increased capacity levels for o-xylene throughout the world, but until recently when the synthetic fibre demand was growing at a high level the para-isomer was preferentially produced to satisfy DMT/TPA requirements throughout the world. As the textile cycle has undergone a recession this year the p-xylene requirements will no longer be advancing so rapidly and o-xylene production may be stepped up from different aromatic facilities throughout the world.

Japan has traditionally had sufficient o-xylene to supply the needs of the Pacific area and even as the phthalic anhydride requirements are increased there should be enough o-xylene for this purpose through to 1985. Thereafter as PVC resin markets expand the phthalate plasticiser production will necessitate increased o-xylene feedstock.

The only alternative to o-xylene feedstock to meet this area of demand is naphthalene, which competes with o-xylene as a basis for phthalic anhydride manufacture. However this is not very likely to make any great inroads in the o-xylene market.

The o-xylene market is very fragmented, with a large number of small consumers. Thus, while it is a commodity product sold on specification, it is necessary to have adequate contact with the market and a distribution set-up, which will enable rapid supplies to be made available to a number of customers, who will probably lack large scale storage facilities. It could be that the optimum approach to dealing with this market, prior to any new producers plans to set up his own distribution facilities, would be for contracts to be arranged with established aromatics distributers and merchants.

Opportunities could arise for exports to a number of markets with Western Europe representing the priority target.

2. U.S.A.

a) Supply

The current US o-xylene nameplate capacity is 684 thousand tonnes/yr. Since o-xylene is recovered by fractionation of mixed xylenes stream, this capacity is flexible, and a number of facilities go in and out of operation depending on the current market situation. At present there are no announced expansions in o-xylene capacity.

A list of US o-xylene producers is shown in Table IV.F.2.

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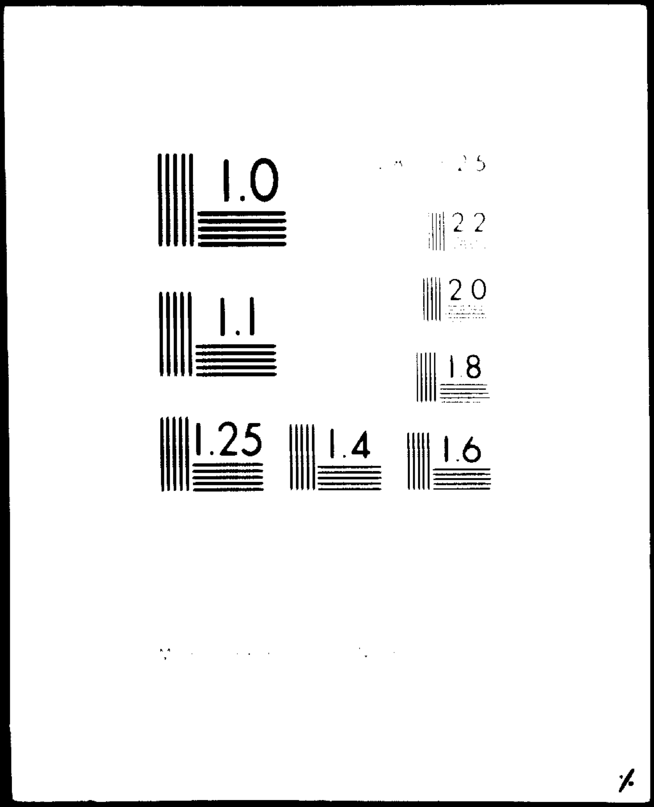

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c) Supply/Demand Analysis

The supply/demand situation for o-xylene in Japan is summarised in Table IV.F.8.

TABLE IV.F.8.

JAPANESE O-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	290	290	290	290
Projected Demand	123	86	140	250
Surplus/(Deficit)	167	204	150	40

* calculated as 90% capacity

\+ estimated actual

Adequate capacity exists to meet the requirements of the Japanese industry through to the mid-1980's. Future xylene plants will not necessarily have provision for o-xylene recovery but still a balanced situation is expected.

5. Rest of Non-Arab World

a) Supply

A list of o-xylene producers in the Rest of the Non-Arab world is given in Table IV.F.9, together with 1974 capacities and expansion plans if known.

TABLE IV.F.9.

REST OF NON-ARAB WORLD O-XYLENE ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COUNTRY	CAPACITY	EXPANSION, YEAR
CANADA	25	-
LATIN AMERICA		
Argentina	-	12.5
Brazil	-	10 +13(1977) + 50
Andean Region	25	+ 28 (1980's)
Mexico	25	+ 25 (1983)
Total Latin America	50	+ 140
E. EUROPE		
USSR	60	+ 60 (1976)
E. Germany	45 (+95 mixed)	
Rumania	70 (+426 BTX)	
Czechoslavakia	15 (+260 mixed)	+ 15 (1980)
Bulgaria	20	
Poland	- (235 mixed)	+ 150 mixed (1988)
Hungary	-	12 (1976)
Total E Europe	210 minimum	+ 87 minimum
ASIA/PACIFIC		
ASEAN Countries	-	40 (1978) + plans
Taiwan	-	60 (1979)
Turkey	-	30 (1982/3) + 80(plans)
Iran	-	20 (1977 delayed) + plans
Total Asia/Pacific	-	+ 230
TOTAL REST OF NON-ARAB WORLD	285	

b) <u>Demand</u>

- Canada
  The o-xylene required to meet the Canadian phthalic anhydride demand is forecast to increase from 36 000 tonnes in 1974 to 53 000 in 1980 and thereafter grow at 7-8 percent until the mid eighties, decreasing to around 5 percent p.a. by the end of the decade.

- Latin America
  The regional demand is estimated at 61 000 tonnes. The growth rate parallels PVC and polyester resin growth.

- E. Europe
  The o-xylene requirement for the COMECON countries in 1974 amounted to 375 000 tonnes. This is projected to almost double by 1985.

- Africa
  The only country with any interest in o-xylene is S. Africa, which had a 1974 import demand of about 5 000 tonnes and is not forecast to grow very rapidly, since being a coal producing country she is much more likely to develop naphthalene based phthalic anhydride.

- Asia/Pacific
  Total demand in this region at present is estimated at 38 000 tonnes located almost entirely in Australia and Korea, with most of the member countries having no demand whatsoever and very little import requirement.

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World's o-xylene are given below in Table IV.F.10.

TABLE IV.F.10.

REST OF NON-ARAB WORLD O-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply*	25	25	25
Forecast Demand	36	50	80
Surplus/(Deficit)	(11)	(25)	(55)
LATIN AMERICA			
Potential Supply	50	142	192
Forecast Demand	61	110	160
Surplus/(Deficit)	(11)	32	32
E. EUROPE			
Potential Supply	170	230	260
Forecast Demand	375	510	720
Surplus/(Deficit)	(205)	(280)	(460)
AFRICA			
Potential Supply	-	-	-
Forecast Demand	5	6	19
Surplus/(Deficit)	(5)	(6)	(19)
ASIA/PACIFIC AREA			
Potential Supply	-	65	168
Forecast Demand	38	100	170
Surplus/(Deficit)	(38)	(35)	(2)

* calculated as 90% capacity + estimated actual

- Canada

  There is no particular incentive to promote additional o-xylene production in Canada and hence there is projected an increasing dependance on imports, which happen to be duty free.

- Latin America

  The region is a net importer at present, but as several capacity installations are underway the region will be an exporter by the 1980's, with the Andean region having the largest surplus.

- E. Europe

  There is substantial xylene capacity in many of the countries e.g. Rumania, Czechoslovakia, Poland and Yugoslavia but to date separation and recovery systems are inadequate, and hence the deficit situation portrayed is highly exaggerated. However an overall shortage of o-xylene might occur in the Eastern Bloc if there were any cut-back in material over the next 10-15 years, but otherwise announced capacity should be adequate, taking into account the mixed xylene capacity.

  The most important countries in this group, Russia and E. Germany both rely on imports and will continue to do so well into the 1980's. Rumania and Czechoslavakia have material for export, whilst the remaining countries are in balance.

  An exchange deal operating between Yugoslavia and Rumania involves the shipment of ethylene from Pancevo to Rumania for the return of phthalic anhydride, thus reducing Yugoslavia's o-xylene supply requirements.

- **Africa**
  O-xylene is imported to meet the phthalic anhydride requirement in South Africa, but due to the S. African policy of self sufficiency this will be a very slow growing market as it competes directly with naphthalene, a coal based feedstock.

- **Asia/Pacific**
  The area will show a diminishing deficit through to the 1980's, as capacity is installed and consumption requirements are not growing very rapidly. There are some imports from USA and Japan at present but countries like Taiwan and Indonesia will be in a position to reverse this trend in the next decade as the domestic plasticiser markets are highly underdeveloped.

6. The Arab World

a) Supply

The plans for o-xylene production in the Arab World are shown in Table IV.F.11.

TABLE IV.F.11.

ARAB O-XYLENE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria, Morocco Tunisia, Libya	-	-
Egypt	48	1982
Kuwait, Saudi Arabia, Iraq, Qatar, United Arab Emirates Bahrein, Labanon, Syria	-	-
Total	48	

b) Demand

In North Africa there is no demand at present and none will develop until the early 1980's when phthalic anhydride plants are scheduled for Egypt and elsewhere.

In the Gulf Arab States any o-xylene demand is of insignificant proportions and liable to remain so over the next decade.

c) Supply/Demand Analysis

The supply/demand situation for o-xylene in the Arab world is summarised in Table IV.E.12.

TABLE IV.F.12.

ARAB O-XYLENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1985
Potential Supply	-	-	50+
Projected Demand	-	-	60
Surplus/(Deficit)	-	-	(-)

O-xylene is not going to figure to any extent in the Arab States petrochemical industry for the next 10 years.

The only countries with any projected interest in it are Algeria, where there is no production of the ortho isomer planned but there should be adequate supply from a mixed BTX facility scheduled for the early eighties, and Egypt where planned supply will be greater than projected demand and hence no import requirement is foreseen.

G. PRODUCT ANALYSIS : STYRENE

1. Overview

The obvious feature of the styrene business is the necessity for new capacity in the 1980's to meet forecast world requirements. The projected styrene supply/demand balances for world markets are summarised in Table IV.G.1.

TABLE IV.G.1.

SUPPLY/DEMAND SUMMARY AS SURPLUS OR (DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	614	507	(543)
W. EUROPE	360	640	(800)
JAPAN	(9)	(90)	(710)
CANADA	20	122	(28)
LATIN AMERICA	(67)	(192)	(357)
E. EUROPE	(60)	(5)	(355)
AFRICA	(10)	30	10
ASIA/PACIFIC	(62)	38	(190)
ARAB WORLD	(30)	(60)	450

All three developed markets are going to need new investment in the 1980's. Although not indicated in the above table, it is almost certain that the companies already operating in the styrene business will initiate expansion in USA and Western Europe to avoid the large deficits forecast for the 1980's.

The situation in Japan is less certain. Shortages are projected here much earlier and no announced plans of capacity expansions or new plant have been made. They feel that the domestic market could only support a small scale plant which is not a very feasible proposition given current economies of scale. The lack of ethylene and benzene feedstock could become a major problem in all market areas.

The market for styrene is a largely captive one in Western Europe, whilst it is only one third captive in USA and Japan, with polystyrene and copolymers providing by far the largest requirement. 75 percent of styrene produced is polymer grade.

Thus the USA is really the only major styrene exporter, although Japan certainly exported small quantities up until very recently. There is very little export trade out of Western Europe, but a good deal of intra European activity still exists. It is interesting to note that although adequate styrene capacity exists, W. Europe still imports substantial quantities from the US, because it proves economical to do so. (The end-1974 price of styrene in W. Europe was $506/tonne). As long as a US surplus accompanied by an attractive price differential exists W. Europe may continue as a net importer, perhaps even with some domestic plants closed down.

There is increasing potential for any styrene which may come on the export market to go to the Latin American, or S.E. Asian countries, which are without production. In some instances, the lesser developed markets import polystyrene direct as their economies could not support polymerisation facilities.

TABLE IV.F.2.

US O-XYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
Arco	Houston, Tex.	95
Champlin	Corpus Christi, Tex.	3
Chevron	Richmond, Calif.	59
Coastal States	Corpus Christi, Tex.	19
Commonwealth	Penuelas, P.R.	68
Cosden	Big Spring, Tex.	9
Crown Central	Houston, Tex.	34
Exxon	Baytown, Tex.	45
Monsanto	Alvin, Tex.	14
Phillips	Guayama, P.R.	59
Shell	Houston, Tex.	91
Southwestern	Corpus Christi, Tex.	45
Sun	Corpus Christi, Tex.	73
Tenneco	Chalmette, La.	70
		684

In view of the large proportion of styrene that is used captively, particularly in W. Europe, the best approach to marketing this material is likely to be through long term arrangements with a current manufacturer. This would enable this manufacturer to secure sources of raw materials without necessarily having to make major investments in that area. It is unlikely that any such manufacturer would put a major proportion of his business to an outside source, but nevertheless it should be possible by arrangements with a number of the captive users to sell quite substantial tonnages during the eighties when, as indicated above, substantial shortages are likely to develop.

Whilst some business certainly exists it is likely to be difficult to establish long term trends based purely on the merchant markets.

Local demand for styrene will develop in the Arab States with the installation of polymerisation facilities to serve the domestic market. However these will not take up the very substantial volume of styrene planned for the area and careful attention will have to be given to the export situation.

2. U.S.A.

a) Supply

The existing US nameplate capacity for styrene is 3265 thousand tonnes/year. Announced expansions will increase the supply by 754 thousand tonnes before 1980. In addition to announced expansion plans, it is known that Arco and other firms are considering new facilities.

A list of the US producers are given in Table IV.G.2.

TABLE IV.G.2.

US STYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR	
Amoco Chemicals	Texas City, Tex.	364		
Arco/Polymers	Houston, Tex.	55		
	Kobuta, Pa.	200		
Cosden	Big Spring, Tex.	55		
Cos-Mar (Borg-Warner/ Cosden)	Carville, La.	273	318	(1976)
Dow	Midland, Michigan	182		
	Freeport, Tex.	750		
El Paso	Odessa, Tex.	55		
Foster Grant	Baton Rouge, La.	341		
Gulf	Donaldsonville, La.	227		
Monsanto	Alvin/Tex. City, Texas	591		
Oxirane	Channelview, Tex.		436	(1977/8)
Sun	Corpus Christi, Texas	36		
Union Carbide	Seadrift, Tex.	136	—	
	Totals	3265	754	

b) Demand

The major use for styrene is in the production of a wide variety of plastic resins including polystyrene, ABS, SAN, and unsaturated polyesters. Demand for the various resins should exhibit moderate to good growth. About 12 percent of U.S. demand is in SBR elastomer which are only forecasted to grow by 2 percent/year due to increasing radial tyre production, the trend towards smaller cars, and a slowdown in the growth in miles driven. SBR latices which find a wide variety of uses in the coatings, textile, carpet and other industries will continue to exhibit moderate growth. US demand for styrene in the US is projected to increase from 2 325 000 tonnes in 1974 to 3 110 000 and 4 160 000 tonnes in 1980 and 1985, respectively. A demand forecast for styrene by major end-use is shown in Table IV.G.3.

TABLE IV.G.3.

1974 US STYRENE CONSUMPTION BY END-USE

(thousand tonnes)

Polystyrene Resins	1450	62.4%
ABS and SAN resins	230	9.9%
SBR elastomer	285	12.2%
SBR resins and latices	210	9.0%
Unsaturated polyester resins	100	4.4%
Miscellaneous	50	2.1
Total demand	2325	100.0%

c) Supply/Demand Analysis

The potential supply/demand for styrene in the US is summarised in Table IV.G.4, based on the supply from existing and announced plants.

TABLE IV.G.4.

US STYRENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply-Existing & Announced Plants*	2939	2939	3617	3617
Projected Demand	2325	2100	3110	4160
Surplus/(Deficit)	614	839	507	(543)

* calculated as 90% capacity
\+ estimated actual

Basically, there is sufficient existing and announced capacity in the US to meet projected demand until the early 80's. Since it is anticipated that firms with major positions in the regional styrene business will add capacity around that time, there is no need for imported material until the mid-1980's at the earliest.

3. W. Europe

a) Supply

The styrene capacity in 1974 was 2 870 000 tonnes.

W. European producers are listed in Table IV.G.5, together with existing capacities and announced expansions to date. No expansions beyond 1980 have been noted, but indications within industry suggest that these are in hand.

TABLE IV.G.5.

WEST EUROPEAN STYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSION, YEAR	
BELGIUM				
Belgochim		-	250	(1976)
FRANCE				
Cd. F Chimie	Carling	100	+ 100	(1975)
ATO (Elf/SNPA)	Gonfreville	200		
SNPA	Lacq	45		
Total France		345		
WEST GERMANY				
BASF	Ludwigshafen	470		
ROW (Shell/BASF)	Wesseling	360		
Huels	Marl	220		
Total West Germany		1050		
ITALY				
ANIC	Ravenna	25	+ 25	(1976)
SIR	Porto Toraes	70		
Rumianca	Assemini	-	100	(1976)
			+ 100	(1977)
			+ 100	(1980)
Montedison	Montova	340		
Total Italy		435		
NETHERLANDS				
Dow	Terneuzen	260	+ 100	(1977)
			+ 140	(1978)
Gulf	Rotterdam	220		
Shell	Pernis	30	+ 220	(1978)
Total Netherlands		510		
SPAIN				
Dow	Huelva	-	200	(1980)
Montoro	Puertollano	80		
Total Spain		80		
UNITED KINGDOM				
Forth Chemicals	Baglan Bay	300	- 50	(1977)
	Grangemouth	70	+ 180	(1977)
Shell	Carrington	70	close down	(1976)
ISR	Hythe	60		
Total United Kingdom		500		
WEST EUROPEAN TOTALS		2920	+ 1390	

b) Demand

In 1974 styrene consumption was estimated as 2 080 000 tonnes (a fall of 5.5 percent from the 1973 level). This resulted from benzene shortages in the first 6 months of the year, followed by falling demand for polystyrene, ABS and SBR in the last half of the year. This decline reflected the worsening situation in Western Europe. The styrene demand in 1975 is forecast to fall by a further 3.2 percent to 2 015 000 tonnes.

The end use analysis is given in Table IV.G.6.

TABLE IV.G.6.

1974 WEST EUROPEAN STYRENE CONSUMPTION BY END-USE
(thousand tonnes)

Polystyrene	1500	72%
Styrene copolymers (ABS and SAN)	120	6%
SBR	280	13%
Polyester resin	120	6%
Miscellaneous	60	3%
Total demand	2080	100%

c) Supply/Demand Analysis

The styrene supply/demand situation for W. Europe is summarised in Table IV.G.7.

Supply is taken as 85 percent capacity, which is viewed as realistic, and no expansions are included for the period beyond 1980.

TABLE IV.G.7.

WEST EUROPEAN STYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	2440	2550	3670	3670
Forecast Demand	2080	2015	3030	4470
Surplus/(Deficit)	360	535	640	(800)

* calculated as 85% capacity

\+ estimated actual

There has been a large net styrene import situation into Western Europe, with the US accounting for a major portion of this. Volume reached a peak in 1972 at 300 000 tonnes and fell to half this in 1973. Much of this fluctuation has been due to imports by Dow, which reached a peak in 1972, but which still continue today although at a reduced level.

There is a high volume of intra-West European trade, but only small quantities of exports to other parts of the world.

In the future, the US - Western Europe price differential may keep a net import situation, although there should be enough material available in the region to enable demand to be met comfortably until the early eighties.

4. Japan

a) Supply

The current styrene capacity in Japan is 1 152 000 tonnes/year. The producers and their respective capacities are summarised in Table IV.G.8. The only major expansion is that of Nihron Oxirane which is due for commercialisation. This is a joint venture project involving Sumitomo, Showa Denko, Arco Chemicals and Halcon International. The project is a coproduct plant in which propylene oxide is to be produced in addition to styrene. The nominal styrene capacity is 300 000 tonnes/year. Although the plant is to be completed soon, Sumitomo indicate that operation will be limited to testing overall performance. Market conditions and excess capacity for both products do not justify project startup.

TABLE IV.G.8.

JAPANESE STYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
Asahi Dow	Kawasaki	60
	Mizushima	300
Chukei Chem	Yokkaichi	80
Denki Chem	Goi	90
Mitsubishi Petrochemical	Kashima	80
	Yokkaichi	205
Nippon Steel Chemical	Tobata	18
	Oita	56
Osaka Gas	Torishima	18
Asaka Styrene	Sakai	80
Sumitomo Chiba	Sodegaura	100
Tokuyama Styrene	Tokuyamo	65
		1152

b) Demand

O-xylene is used for the manufacture of phthalic anhydride which can also be made from naphthalene. The major markets for phthalic anhydride are in plasticisers where the product's growth is dependent upon the growth of flexible PVC, alkyd resins, a mature product, and unsaturated polyester resins which are projected to have good growth prospects for the next few years. Table IV.F.3 shows the US o-xylene demand in terms of phthalic anhydride.

TABLE IV.F.3.

1974 US O-XYLENE CONSUMPTION BY END-USE

(thousand tonnes)

Phthalic Anhydride Consumption		
Plasticisers	215	48%
Alkyd Resins	105	23%
Unsaturated Polyester Resins	100	22%
Other	28	7%
Total Demand	448	100%
Phthalic anhydride from Naphthalene	140	
Phthalic anhydride from o-xylene	308	

Therefore o-xylene demand 370

b) Demand

The demand for styrene is expected to continue declining in 1975 due to the lower demand for hard goods. These products are the principal outlets for styrene resins. Demand for polystyrene, ABS and SBR, the principal styrene derivatives is influenced strongly by the demand for appliances and automobiles. The styrene consumption pattern for 1974 is indicated in Table IV.G.9. The demand for 1975 should drop to about 925 000 tonnes.

TABLE IV.G.9.

1974 JAPANESE STYRENE CONSUMPTION BY END-USE
(thousand tonnes)

Polystyrene	665	63.7%
SBR	142	13.6%
ABS resins	128	12.3%
Unsaturated polyester resins	81	7.8%
Others	28	2.6%
Total demand	1044	100.0%

With a return to an expansionary economy in Japan by the 3rd or 4th quarter of 1976, demand levels for styrene should exceed those for 1974 by the end of that year. The styrene consumption should expand at an annual rate of slightly under 8 percent through 1983 and average 7-7.2 percent/year for the subsequent five year period. These would yield a styrene demand level of 2 040 000 tonnes for 1985.

c) Supply/Demand Analysis

The potential supply/demand for styrene in Japan is summarised in Table IV.G.10, based on the supply from existing and announced plants.

TABLE IV.G.10.

JAPANESE STYRENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1035	1035	1330	1330
Projected Demand	1044	925	1420	2040
Surplus/(Deficit)	(9)	110	(90)	(710)

* calculated as 90% capacity

\+ estimated actual

With the projected supply/demand balance summarised in Table IV.G.10, Japan will continue to be in relative styrene balance through to 1980. In the subsequent period there will be an increased reliance on imports unless the local producers expand their capabilities at a rate consistent with styrene growth.

5. Rest of Non-Arab World

a) Supply

A list of styrene producers is given in Table IV.G.11, together with existing nameplate capacities and expansion plans announced to date.

b) Demand

- Canada
  The Canadian demand pattern for styrene is similar to that of the USA. It was estimated at 156 000 tonnes in 1974 and is projected to increase to about 300 000 by 1980.

- Latin America
  The total 1974 demand for this region was estimated at 223 000 tonnes with Brazil requiring more than one third of this total. Polystyrene is by far the major end-use and growth rates vary but average out at about 12 percent for the zone.

- E. Europe
  The 1974 consumption of styrene in Eastern Europe was 550 000 tonnes, 65 percent of which went into polystyrene and the remaining 35 percent for styrene rubbers. By 1980 total demand will have approximately doubled.

- Africa
  South Africa is the only country in non-Arab Africa which registers any consumption - 25 000 tonnes in 1974. This is projected to rise to 47 000 by 1980. 64 percent of the demand goes for polymer manufacture.

- Asia/Pacific
  The total requirement for this region in 1974 was 135 000 tonnes with Australia/New Zealand consuming over one third. Several of the Asean group countries have no demand at present, but countries like Iran will develop demands, with the installation of polystyrene and rubber units.

TABLE IV.G.11.

REST OF NON-ARAB WORLD STYRENE ESTIMATED NAMEPLATE CAPACITY, 1974
(thousand tonnes)

COUNTRY	CAPACITY	EXPANSION, YEAR	
CANADA	196	+ 273	(1978/9)
LATIN AMERICA			
Argentina	50	+ 50-75	(1981) plans
Brazil	76	+ 100	(1980)
Mexico	30	+ 90	(1977)
Total Latin America	156	+ 240 minimum	
E. EUROPE			
USSR	350	+ 300	(1975)
		+ 300	(1978-80)
GDR	50	+ 100 (?)	
Rumania	15	+ 50	(1977)
Czechoslovakia	150		
Bulgaria	20		
Poland	6	+ 72	(1975)
Yugoslavia	20		
Total E Europe	611	+ 822	
AFRICA			
South	20	+ 70	(1978/9)
Total Africa	20	+ 70	
ASIA/PACIFIC			
ASEAN Group	-	100	(by 1990) + plans
Australia/New Zealand	20	+ 100	(1977) + plans
India/Burma	33	+ 30	(1977)
Taiwan	-	50	(1976)
		+ 50	(1977)
S. Korea	-	40	(+ expansions)
Turkey	25	+ 45	(1982)
Iran	-	93	(1977 delayed) + plans
Total Asia/Pacific	78	+ 508 minimum	
TOTAL REST OF NON-ARAB WORLD	661		

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World's styrene are given below in Table IV.G.12.

TABLE IV.G.12.

REST OF NON-ARAB WORLD STYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	176	422	422
Forecast Demand	156	300	450
Surplus/(Deficit)	20	122	(28)
LATIN AMERICA			
Potential Supply	156	268	443
Forecast Demand	223	460	800
Surplus/(Deficit)	(67)	(192)	(357)
E. EUROPE			
Potential Supply	490	1 145	1 145
Forecast Demand	550	1 150	1 500
Surplus/(Deficit)	(60)	(5)	(355)
AFRICA			
Potential Supply	15	80	80
Forecast Demand	25	50	70
Surplus/(Deficit)	(10)	30	10
ASIA/PACIFIC AREA			
Potential Supply	73	388	500
Forecast Demand	135	350	690
Surplus/(Deficit)	(62)	38	(190)

+ estimated actual

- **Canada**

  There is sufficient existing and announced capacity to meet projected demand until 1984, and since it is anticipated that firms with major positions in the regional styrene business will add capacity in the early 1980's, there is no need for imported material until the mid-1980's, at the earliest.

- Latin America

  This area will show an increasing deficit of styrene through the 1980's. The Andean countries produce no styrene monomer and have no plans to install capacity. Brazil will soon be needing to import half of its requirements to meet a fast expanding economy. Mexico is the only country within this group with adequate domestic supplies.

- E. Europe

  There is a current deficit of styrene. By 1980 the area will be in balance, but thereafter a shortage will develop as synthetic rubber production grows quite rapidly and styrene production falls behind.

  Specifically, Russia is relying on the timely coming-onstream of the Turkestan facility to supply her needs. East Germany needs to import styrene but her polystyrene industry is fairly static. Hungary, Yugoslavia and Poland are short in styrene and survive on imports from Czechoslavakia and Bulgaria. This requirement will be increased in the early 1980's with the installation of styrene rubber plants in several East European countries.

- Africa

  South Africa will be self sufficient until the mid-1980's once the Sasol capacity is increased. At present 10 000 tonnes have to be imported to supplement local production.

  East and West Africa do not figure in styrene markets.

- Asia/Pacific

  This region is a net importer of styrene, will become almost self sufficient by 1980 and then thereafter rely on imports again.

  Several of the lesser developed economies import polystyrene direct as their small plastic utilisation level does not warrant any monomer production. Australia is the major styrene consumer but plans to expand her own capacity to achieve self sufficiency, provided that the benzene feedstock continues to be available.

6. The Arab World

a) Supply

The plans for styrene production in the Arab World are shown in Table IV.G.13.

TABLE IV.G.13.

ARAB STYRENE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	200	1982
Morocco, Tunisia, Libya	-	-
Egypt	90 + 100	1979 + 1985
Kuwait	150 (+100)	1981/2
Saudi Arabia	125 + 125	1982 + 1985
Qatar, Iraq, United Arab Emirates Syria, Bahrein, Lebanon	-	-
Total	890	

b) Demand

The Arab States of North Africa consume 10 000 tonnes of styrene at present, predominantly in Algeria. This is projected to double by around 1980, when a 25 000 tonne polystyrene plant starts producing, and grow steadily thereafter.

In Egypt there is little demand at present and there will not be until the early 1980's when polystyrene and SBR plants could create a demand for the styrene monomer in the region of 90 000 tonnes.

The total consumption of the remaining Arab nations is 20 000 tonnes at present. This will double by 1980 and treble by 1985 as Kuwaiti and Saudi Arabian polystyrene plants come into operation.

c) Supply/Demand Analysis

The supply/demand situation for styrene in the Arab World is summarised in Table IV.E.14.

TABLE IV.E.14.

ARAB STYRENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1985
Potential Supply	-	-	670
Projected Demand	30	60	220
Surplus/(Deficit)	(30)	(60)	450

There will be considerable overcapacity by 1985 and substantial quantities available for export as in most of the major producing countries, Algeria, Kuwait and Saudi Arabia the phasing in of polystyrene and SBR plant will be delayed. Only Egypt expects a balanced situation in the early 1980's.

H. PRODUCT ANALYSIS : VINYL CHLORIDE MONOMER (VCM)

1. Overview

While there will be an overall world surplus up until 1980, significant investment will be required during the eighties to cope with increased global requirements during the next decade. Projected VCM supply/demand balances for world markets are summarised in Table IV.H.1.

TABLE IV.H.1.

SUPPLY/DEMAND SUMMARY AS SURPLUS/(DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	542	(470)	(1540)
W. EUROPE	780	930	(650)
JAPAN	154	400	(330)
CANADA	14	(110)	(40)
LATIN AMERICA	2	(33)	(123)
E. EUROPE	(220)	250	140
AFRICA	(88)	(122)	(270)
ASIA/PACIFIC	(34)	85	(247)
ARAB WORLD	(75)	(157)	560

The situation of recent years in which USA was the largest exporter has been reversed and America now finds herself in the position of fast becoming a net importer from Western Europe who has gone ahead and developed capacity in keeping with forecast demand, whereas the US has responded more rapidly to environmental decisions and cut back on expansion plans.

US o-xylene requirements are forecast to grow from 370 000 tonnes in 1974 to 580 000 in 1980 and 790 000 tonnes in 1985 and then grow at about 6 percent per annum.

c) Supply/Demand

The potential supply/demand for o-xylene to meet US phthalic anhydride requirements, under the assumption that there is sufficient phthalic anhydride capacity, is shown in Table IV.F.4, based on the supply from existing and announced plants.

TABLE IV.F.4.

US O-XYLENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	581	581	581	581
Project Demand	370	400	580	790
Surplus/(Deficit)	211	181	1	(209)

* calculated as 85% capacity

\+ estimated actual

The US will be short in o-xylene from 1980 onwards, with the deficit increasing to just over 200 000 tonnes in 1985. It is expected that due to the need for xylenes in gasoline and for p-xylene, that significant o-xylene capacity will only come onstream when the next round of

Almost all VCM produced in the world is of polymer grade as there is no other significant end use. The growing reluctance to accept PVC has meant greatly reducing the growth projections for the industrialised markets.

The developing nations do not show any substantial deficits of the monomer, because to date most of PVC plants have been built with corresponding VCM capacity alongside. Alternatively, countries imported the finished polymer. Now with the planned installation of additional polymerisation facilities, there will be a shift towards these countries being supplied by VCM imports rather than PVC.

The United States is the least structured of the developed markets, having only about 50 percent of its vinyl chloride producers vertically integrated and a large number of polymer producers with no captive VCM. Hence there is a considerable volume of merchant business. Western Europe is well integrated with only a small merchant market. Although Japan has several PVC producers with no captive VCM it can pull on the output of some subsidiary joint ventures in the Pacific Basin. Thus large volume VCM sales into Europe and Japan will only be on the basis of arrangements with integrated producers and consumers. In the USA this will also be appropriate, but there is opportunity to enter the merchant business if adequate marketing and distribution can be established.

In the developing areas efforts will be made to balance VCM and PVC capacity although times will certainly occur when this is not possible. It is likely that supplies will continue to be taken in the form of polymer rather monomer in a number of countries.

Forecast demand in the Arab States will not be sufficient to take up all planned production and careful consideration will have to be given to establishing an export market.

2. U.S.A.

a) Supply

The current US nameplate capacity for vinyl chloride monomer is approximately 3 million tonnes. There are no new plants under construction at present primarily due to the unsettled state of the industry, caused by the health problems of plant personnel exposed to VCM. Once new workable guidelines for VCM are adopted it is expected that there will be new facilities since firms such as Goodrich, Diamond Shamrock, PPG, and Dow are known to be considering new plants. A list of US VCM producers is shown in Table IV.H.2.

b) Demand

Virtually all VCM is used in the production of PVC resins and copolymers with small quantities also used for the production of trichlorethylene and vinylidene chloride and in modacrylic fibres. The PVC industry is in a state of uncertainty over vinyl chloride emission in polymerisation plants and problems of residual monomer content. Since PVC resins are important to many segments of the economy and since there are no readily available substitutes for PVC in a large number of applications it is not felt that the growth of the product will be seriously affected by the current problems. Table IV.H.3. shows the end use demand for VCM, mainly via PVC applications. Building and construction is the fastest growing segment and is expected to triple before the end of the eighties.

TABLE IV.H.2

US VCM PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
Allied	Geismar, La.	136
American Chemical	Watson, Calif.	78
Conoco	Lake Charles, La.	318
Dow	Freeport, Tex.	91
	Oyster Creek, Tex.	318
	Plaquemine, La.	155
Ethyl	Baton Rouge, La.	123
	Houston, Tex.	68
Goodrich	Calvert City, Ky.	454
Monochem (Borden/Uniroyal)*	Geismar, La.	150
PPG	Guayanilla, P.R.	227
	Lake Charles, La.	182
Shell	Keer Park, Tex.	382
	Norco, La.	318
		3 000

* Acetylene Based

TABLE IV.H.3

1974 US VCM CONSUMPTION BY END-USE
(thousand tonnes)

VCM Demand

PVC	2 006	93.3%
Trichlorethylene	81	
Vinylidene Chloride	51	
Other	20	
Total demand	2 158	

PVC Demand

Building and Construction	840
Wire and Cable	160
Packaging	145
Consumer Goods	235
Household Uses	240
Transportation	115
Other Applications	271
Total PVC demand	2 006

If VCM demand grows at 6 percent per year in the early 1980's, the US requirement for 1985 would be 4 240 000 tonnes.

c) Supply/Demand Analysis

The potential supply/demand for VCM in the United States, based on supply from existing and announced plants, is summarised in Table IV.H.4.

TABLE IV.H.4

US VCM SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	2700	2700	2700	2700
Projected Demand	2158	2000	3170	4240
Surplus/(Deficit)	542	700	(470)	(1540)

* calculated as 90% nameplate capacity

\+ estimated actual

i.e. there is a projected deficit of VCM starting in the near future. This will not be as severe as indicated above because it is forecast that some additional VCM capacity will be built. The situation still remains that the US will become a significant importer of the material in contrast to its traditional role of being a major exporter.

3. Western Europe

a) Supply

The Western European manufacturers of VCM are detailed in Table IV.H.5. The existing capacities and announced capacity expansions have been indicated for the individual manufacturers.

The current West European capacity is 4.57 million tonnes. It is recognised that plans exist for increasing

TABLE IV.H.5

WEST EUROPEAN VCM PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSION, YEAR
BELGIUM			
BASF	Antwerp	110	
LVM	Tessenderloo	200	+ 200 (1979)
Solvic	Jemreppe	225	
Total Belgium		535	
FINLAND			
Pekema Oy	Porvoo	50	+ 35 (1976)
FRANCE			
Daufac	Jarrie	200	+ 100 (1979)
DSM/EMC	Ottmarsheim	-	100 (1976)
Rhone Progil	St. Auban	120	
	Lavera	150	+ 50 (1976)
Solvic	Tavaux	225	
Total France		695	
WEST GERMANY			
BASF	Ludwigshafen	80	
Dynamit Nobel	Lulsdorf	60	
Hoechst	Gendorf	175	
	Knapsack	100	+ 80 (1976)
Huels	Marl	350	
Solvay	Rheinberg	200	
Wacker	Burghausen	250	
Total West Germany		1 215	
ITALY			
ANIC	Ravenna	140	+ 20 (1978)
Montedison	Brindisi	180	
	Porto Marghera	180	
Liquichimica	Ferrandina	55	
Rumianca	Cagliari	50	+ 60 (1976)
SIR	Porto Torres	120	
Solvic	Rosignano	55	
Total Italy		780	

TABLE IV.H.5
(cont.)

COMPANY	LOCATION	CAPACITY	EXPANSION, YEAR
NETHERLANDS			
AKZO	Botlek	300	+ 50 (1975)
DSM	Delfziji	-	300 (1977)
	Beek	-	200 (1977)
Shell NV	Pernis	75	
Total Netherlands		375	
NORWAY			
Norsk Hydro	Bamble	-	300 (1977)
PORTUGAL			
CNP	Sines	10	
SPAIN			
Aragonesa	Sabinanigo (Huesea)	5	
Viniclor SA	Martorell	120	+ 80 (1977)
Monsanto Iberica	Vilaseca	40	+ 60 (1975)
Total Spain		165	
SWEDEN			
Kema Nord	Stenungsund	105	
SWITZERLAND			
Lonza	Visp	20	
UNITED KINGDOM			
BP	Baglan Bay	260	+ 40 (1975)
ICI	Millhouse	180	+ 30 (1976)
	Runcorn	180	+ 30 (1976)
Total United Kingdom		620	
TOTAL WEST EUROPE		4 570	+1 735

capacity in the future, but these and the future capacity expansions listed above must be in some doubt in face of the overcapacity situation which is developing. The new capacity announcements preceded the recognition of the employee and environmental concerns associated with VCM.

b) Demand

Approximately 95 percent of VCM consumed is used for PVC production. There have been a number of problems surrounding VCM use in Western Europe over recent years. These have included plant operating problems, labour troubles, feedstock shortages in 1973/early 1974, and the economic downturn in 1974. They have been augmented by the current controversy over liver cancer.

It is estimated that Western European VCM consumption fell by 8 percent in 1974 to a level of 3 310 000 tonnes, and a further decline in demand of 3 percent is forecast for 1975.

In the future, PVC is expected to face problems of consumer acceptance in many fields based on fears associated with the VCM residual. In addition, the extra investment that will be required to keep monomer levels acceptable during manufacture and processing will raise costs. High density polyethylene, polypropylene and even styrene and styrene copolymers may compete strongly for a number of outlets in the future. When this is combined with the reduced growth expectations of the automobile industry in Western Europe, a fairly low growth rate trend for PVC, and hence VCM, can be expected - probably levelling out at 7.5 percent in the 1980's.

c) Supply/Demand Analysis

The supply/demand situation for VCM in Western Europe is summarised in Table IV.H.6. Supply is taken as 90 percent of capacity and no additional capacity is assumed beyond announced expansion intentions.

TABLE IV.H.6

WEST EUROPEAN VCM SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	4090	4185	5650	5650
Projected Demand	3310	3210	4720	6300
Surplus/(Deficit)	780	975	930	(650)

\+ estimated actual

It can be seen that Western European capacity will be sufficient to cover regional demand through to the early 1980's.

There is a considerable amount of VCM traded internally in Western Europe with large quantities going to West Germany in particular. This is moving mostly from the Netherlands and Belgium.

Western Europe has been a net importer of VCM in the past, with the US being the prime supplier. This position has now changed, with substantial quantities of VCM exported to Eastern Europe during 1974. Basic reasons for the change are increased ethylene availability for VCM manufacture in W. Europe, and changes in demand patterns in the USA.

In the future, given reasonable ethylene availability, Western Europe will probably continue to try exporting the potentially large surplus of VCM. Current VCM prices in Western Europe are of the order of $270-285/ tonnes.

4. Japan

a) Supply

The current installed capacity is 2 024 thousand tonnes. The VCM producers and their respective capacity levels are detailed in Table IV.H.7. Additions planned for Mitsui Sempoku and Central Chemical have been delayed. Capacity expansion will parallel investment in new ethylene facilities and by 1983 Japanese VCM capacity should reach 2 800 thousand tonnes.

b) Demand

The demand for vinyl chloride is expected to decline in 1975 from 1974 levels due to the continued slump in construction and industry expansion. As the bulk of PVC resin is employed in rigid applications such as sheet, piping and profiles, the dependence on the construction industry is evident. Demand in 1975 should drop to 1 600 thousand tonnes. The outlook is being affected by the environmental and FDA regulatory trends in the United States. Japanese manufacturers are evaluating the impact of these trends on the US VCM and PVC producers, since they recognise that environmental controls are becoming increasingly stringent in Japan. Some Japanese PVC producers saw the tightening controls in the US regarding VCM levels in fabricated products as an opportunity for para-isomer plants are undertaken and this will be too late to obviate o-xylene shortages.

3. Western Europe

a) Supply

The manufacturers of o-xylene in Western Europe are listed in Table IV.F.5, together with their estimated installed capacity. Although plans are know to exist for expansions in capacity, no firm announcements have yet been made.

b) Demand

The only significant use of o-xylene in Western Europe is in the production of phthalic anhydride which is itself used for phthalic plasticisers, alkyd resins and polyester resins. It is estimated that the consumption of o-xylene in Western Europe fell by 9 percent in 1974 to reach a level of 652 000 tonnes. A forecast of a further drop of 5 percent in demand in 1975 is made to bring the total for Western Europe in this year to 620 000 tonnes. Based on an examination of the growth trends in the end-use of phthalic anhydride, a demand growth trend of 7 percent/year is forecast for o-xylene from 1976 to 1980. This rate should continue through to the early 1980's and thereafter drop to around 6 percent for the rest of the decade.

TABLE IV.H.7

JAPANESE VCM PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	CAPACITY
Toyo Soda Yokkaichi	127
Nanyo	150
Kashima	220
Kanegafuchi	168
Chiba Vinyl Chloride Monomer	160
Kasei Mizushima	150
Kureha	140
Japanese Geon	130
Sanyo (Nippon Zeon/Asahi/Chisso)	120
Sun Arrow	110
Central Chemical	75
Mitsubishi Monsanto	63
Mitsui Toatsui	60
Mitsui Sempoku	60
Sumitomo	56
Chisso Petrochemical	51
Asahi Penn	50
Nisson Chemical	50
Tekekosoho Toayosu	48
Denki	36
	2 024

the Japanese resin producer. With no comparable controls in Japan, it would have been feasible to produce PVC fabricated parts in Japan for subsequent export to the US. The recent success of the US PVC producers in meeting the initial environmental control levels has introduced a degree of realism into the planning activities of the Japanese PVC and VCM industry.

Following a return to an expansion economy by late 1976 the PVC and hence VCM demand will grow at 7.2 percent until the early 1980's then at 6.4 percent, giving a Japanese consumption of 2 770 thousand tonnes in 1985.

c) Supply/Demand Analysis

The supply/demand situation for VCM in Japan is summarised in Table IV.H.8. Supply is taken as 90 percent nameplate capacity.

TABLE IV.H.8

JAPANESE VCM SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	1840	1840	2380	2440
Forecast Demand	1686	1600	1980	2770
Surplus/(Deficit)	154	240	400	(330)

+ estimated actual

i.e. there should be sufficient VCM to meet product requirements through to the early 1980's. A significant expansion programme will be needed in the subsequent period, or alternatively some of the projected deficit could be met by resin or fabricated imports from Japanese subsidiaries in other South East Asian countries.

5. Rest of Non-Arab World

a) Supply

A list of VCM producers is given in Table IV.H.9, together with existing nameplate capacities and expansion plans announced to date.

b) Demand

- Canada

  The 1974 Canadian demand for VCM was 116 000 tonnes. The usage pattern is very similar to that of USA. Demand is expected to almost double by 1980, due to growth in PVC demand and some reduction in PVC imports, which are currently about 45 000 tonnes.

- Latin America

  The total regional consumption in 1974 was 306 000 tonnes. Demand in the individual markets will almost double by 1980 and therefore increase at a rate between 10-13 percent.

- E. Europe

  Demand at present is 1 300 thousand tonnes, projected to increase to 1 750 thousand by 1980.

TABLE IV.H.9

REST OF NON-ARAB WORLD VCM PRODUCERS AND ESTIMATED NAMEPLATE CAPACITIES, 1974
(thousand tonnes)

COUNTRY	CAPACITY	EXPANSION, YEAR	
CANADA	145	expansion planned	
LATIN AMERICA			
Argentina	36	+ 100	(1978/9)
Brazil	100	+ 250	
Andean Region	40	+ 400	(1979-1986)
Mexico	100	+ 140	
Total Latin America	276	+ 890	
E. EUROPE			
USSR	525	+ 120	(1977)
		+ 270	(1978)
GDR	200	110	(1978)
Rumania	240		
Czechoslovakia	85	+ 120	(1975)
		+ 50	(1980)
Bulgaria	50	+ 150	(1978/9)
Poland	150	205	(1978/9)
Hungary	50	+ 160	(1977)
Yugoslavia	50	+ 100	(1975)
		+ 200	(1978/9)
Total E Europe	1 350	+1485	
AFRICA			
South	40	+ 80	(1979/80)
		+ 80	(1983)
West	-	+ 300	(1982/3)
Total Africa	40	+ 460	
ASIA/PACIFIC			
ASEAN Group	10	+ 178	(1980's)
Australia/New Zealand	99	expansion	
India/Burma	48	+ 96	(late 1970's)
Taiwan	63	+ 240	(by 1980)
Korea	60	150	(1976)
		+ 100	(1980's)
Turkey	60	+ 100	(1982)
Pakistan	5	+ 15	(1978)
		+ 15	(1980)
Iran	36	+ 150	(1977 delayed + plans)
Total Asia/Pacific	381	+ 894	
TOTAL REST OF NON-ARAB WORLD	1 390	+3859 minimum	

- **Africa**
  South Africa is the major non-Arab consumer, and used 80 000 tonnes VCM in 1974, half of which had to be imported. PVC is expected to stagnate through to 1976, and then grow at 15 percent at most through to 1980, with a corresponding VCM requirement. East and West Africa used 48 000 tonnes as PVC in 1974.

- **Asia/Pacific**
  The total demand for this region in 1974 was estimated at 382 000 tonnes, with Australia, Taiwan and S. Korea requiring the largest quantities.

c) <u>Supply/Demand Analysis</u>

The supply demand balances for the Rest of the Non-Arab World's VCM is given below in Table IV.H.10.

- **Canada**
  Based on existing and awarded capacity as a source of supply there is a projected deficit of vinyl chloride starting in the near future. The country will therefore have to remain an importer of VCM until 1982, when a world scale facility is built in Alberta. However, growth in demand will again make Canada an importer in the latter part of the 1980's.

- **Latin America**
  This region is quite well balanced - Brazil being completely integrated with respect to VCM/PVC whilst Argentina and the Andean Zone both plan new installations during the 1980's to meet growing demand. Mexico is going to be the only country that should be relying on imports by the 1980's.

TABLE IV.H.10

REST OF NON-ARAB WORLD VCM SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974	1980	1985
CANADA			
Potential Supply	130	130	310
Forecast Demand	116	240	350
Surplus/(Deficit)	14	(110)	(40)
LATIN AMERICA			
Potential Supply	308	617	1017
Forecast Demand	306	650	1140
Surplus/(Deficit)	2	(33)	(123)
E. EUROPE			
Potential Supply	1080	2000	2600
Forecast Demand	1300	1750	2460
Surplus/(Deficit)	(220)	250	140
AFRICA			
Potential Supply	40	108	180
Forecast Demand	128	230	450
Surplus/(Deficit)	(88)	(122)	(270)
ASIA/PACIFIC AREA			
Potential Supply	348	985	1533
Forecast Demand	382	900	1800
Surplus/(Deficit)	(34)	85	(247)

- E. Europe

  In the Eastern Bloc, the tendency is for PVC installations never to be built without the corresponding monomer supply unit, so unless the ethylene feedstocks are in short supply, demand for VCM should never greatly exceed production. The deficit in 1974 is due to early operational difficulties with VCM units. The PVC levels of consumption are often overestimated with the result that VCM supply is usually adequate. This situation will ensue in the 1980's.

  Russia set her 1975 VCM requirement at 436 000 tonnes and East Germany at 150 000 tonnes (50 000 of which comes from Czechoslovakia in exchange for ethylene). The other member countries have relatively smaller needs and domestic requirements are met at present and probably will be through the eighties.

- Africa

  During the period of 1980 to 1985, VCM import demand in South Africa will fluctuate from a high of 80-90 000 tonnes to around 30 000 tonnes in 1980 and 1983. These variations are due to the phasing in of new capacity. The South Africans will probably build new capacity by 1985-86 to cut back on the import level.

  East and West Africa do not deal in VCM but rely on PVC imports.

- Asia/Pacific

  This area as a whole does not have a very large deficit but will experience a shortfall in the future. There should be adequate supplies of VCM to meet the regions polymerising capacity to 1980 and thereafter several countries have calculated that the increasing demand could support additional capacity-namely in Singapore, the Philippines, Taiwan and Korea. Iran will have to install additional capacity to cope with their fast growing PVC industry.

6. The Arab World

a) Supply

The plans for VCM production in the Arab World are listed in Table IV.H.11.

TABLE IV.H.11.

ARAB VCM PRODUCTION PLANS
(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	40 : 160	1976 : 1982
Morocco, Tunisia		
Libya	-	-
Egypt	107 : 150	1979 : 1985
Kuwait	200	1982
Saudi Arabia	125 + 125	1982 + 1985
Iraq	63	1982
Abu Dhabi	200	1983/4
Qatar, Bahrein		
Lebanon, Syria	-	
Total	1 070	

b) Demand

In North Africa there is no VCM demand as such since the PVC market is being supplied by resin imports. On this basis, demand in 1974 is estimated as 33 000 tonnes (as PVC requirement) - a large percentage for Algeria.

In Egypt there is no VCM demand at the present time and PVC demand is met by imports. As imports are severely restricted there will be an artifcially low growth in consumption until such time as domestic VCM/PVC is convented. When this occurs consumption is forecast to rise rapidly.

The Gulf States, likewise, have no VCM demand but consume 30 000 tonnes as PVC. This requirement will treble by 1980.

c) Supply/Demand Analysis

The supply/demand situation for VCM in the Arab World is summarised in Table IV.H.11.

TABLE IV.H.11.

ARAB VCM SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1985
Potential Supply	-	120	965
Projected Demand (as PVC)	75	277	405
Surplus/(Deficit)	(75)	(157)	560

Demand for the region will have to be met by small local production and increasing imports until 1980. Thereafter domestic production will start up at a fairly steady rate and self-sufficiency will be achieved by 1985.

At present PVC used in the Arab World is largely for consumer uses, not industrial and construction applications as in the most developed markets.

TABLE IV.F.5.

WEST EUROPEAN O-XYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1978
(thousand tonnes)

COMPANY	LOCATION	CAPACITY
FRANCE		
Antar	Donges	23
Esso Chimie	Port Jerome	35
CFR (Total)	Gonfreville	75
Total France		133
WEST GERMANY		
Deutsche - BP	Dinslaken	25
Deutsche - Shell	Godorf	100
Gelsenberg	Gelsenkirchen	35
URBK	Wesseling	30
Veba-Chemie	Gelsenkirchen	30
Deutsche - Texaco	Heide	10
Total West Germany		230
ITALY		
Mobil Chimica	Naples	60
Montedison	Priolo	50
Saras Chimica	Sarroche	70
SIR	Porto Torres	50
Total Italy		230
NETHERLANDS		
Esso Chemie	Botlek	55
SPAIN		
Cepsa	Algeciras	25
UNITED KINGDOM		
BP - Chevron	Isle of Grain	25
	Grangemouth	130
Total United Kingdom		155
TOTAL WESTERN EUROPE		828

J. PRODUCT ANALYSIS : POLYSTYRENE

1. Overview

The world supply/demand situation for polystyrene is summarised in Table IV.J.1. These figures assume an adequate supply of styrene monomer to maintain plants at full operational capacity.

TABLE IV.J.1.

WORLD POLYSTYRENE SUPPLY/DEMAND SITUATION
AS SURPLUS/(DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	360	310	(500)
W. Europe	685	660	200
Japan	110	(200)	(800)
Canada	(27)	(50)	(50)
Latin America	20	120	50
E. Europe	(100)	40	(130)
Africa	(10)	(20)	20
Asia/Pacific	(55)	40	(140)
Arab World	(27)	(20)	210 (actual excess is in form of monomer)

(The summary table has included supplies of standard grade and expanded polystyrene but does not account for styrene copolymers)

The polystyrene business worldwide has been subject to considerable problems during the last few years. During late 1973 and 1974 there were severe shortages and extraordinary price rises brought about by shortages of monomer. This situation had been largely caused by the lack of benzene feedstock. During 1975 there has been a dramatic turnaround with benzene price falling and a severely reduced demand for polystyrene in major outlets such as packaging and consumer goods. Forecasts for future demand have had to be reduced and consequently a sizeable overcapacity now appears to be inevitable for Western Europe and, to a lesser extent, the USA. In Japan the feedstock situation has been so uncertain that investment plans have been cut back and delayed. It is apparent that new capacity is urgently required in this area.

The major outlets for polystyrene are in packaging, technical mouldings for electrical appliances, cars etc and household goods. Injection moulding is the most important technique for processing polystyrene.

There is a large volume of trade between various West European countries. In total there is a net export of polystyrene out of West Europe. The USA and Japan also export polymer. Total volume of exports from these three areas is estimated to run at about 150-200 000 tonnes.

There are a large number of companies involved in processing polystyrene. Hence a large sales and distribution organisation is required to handle the market. The situation is further complicated by the importance of "custom moulders". These are processors who convert plastics on behalf of other end users. This means that the purchasing decision may be split between the ultimate user of the polystyrene moulding and the company which actually carries out the moulding operation.

Polystyrene is supplied in three basic forms: standard, high impact or rubber modified and expanded. Within the first two categories there are a wide variety of different grades. Technical service is an important aspect of the marketing of polystyrene due to the large number of relatively small companies involved in processing, the variety of end uses and the range of polymer types available.

Projected demand for the Arab States indicates that some styrene polymerisation facilities could be supported by the domestic market. Such plants can be sized to meet local demand and will not have to go for export markets in order to be economic.

Because of the likely problems in export marketing, and the possibility of having economic capacity purely for domestic markets it is recommended that polystyrene should not have any high priority as an export product.

2. USA

a) Supply

The 1974 US polystyrene capacity is estimated to be 2 020 thousand tonnes/year. This includes about 250 000 tonnes of expanded polystyrene, produced mainly by Arco and BASF. A list of manufacturers is shown in Table IV.J.2, together with present capacity, and expansions announced to date.

TABLE IV.J.2.

US POLYSTYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
A & E Plastic Pak, Inc	City of Industry Cal.	15	
American Petrofina,	Big Spring, Texas	120	
Inc. (Cosden subsid)	Calumet City, Ill	70	
Amoco Chemicals	Jolliet, Ill	90	
(Std. Oil-Ind.)	Willow Sp, Ill	20	
	Medina, Ohio	20	
	Torrance, Calif	15	
Arco Polymers Inc.	Kobuta, Pennsylvania	200	
BASF-Wyandotte	Jamesburg, NJ	50	
Dart Industries	Mass, Ill, Calif.	65	
Dow Chemicals	Torrance, Calif	85	
	Gale's Ferry, Conn	75	+ 80 (1975)
	Girontan, Ohio	90	
	Joliet, Ill	-	55 (1975)
	Midland, Mich	125	
Foster Grant	Leominster, Mass	55	
	Chesapeake, Va	70	
	Peru, Ill	110	
Gordon Chem Co	Oxford, Worcester, Mass.	40	
Monsanto	Addystan, Ohio		
	Springfield, Mass		
	Long Beach, Cal	365	
	Decatur, Ala		
Polysar Group	Leominster, Mass	55	
	Forest City, NC	15	
Richardson Co	West Haven, Conn	40	
Shell Chems	Marietta, Ohio	70	
Union Carbide Corp	Bound Brook, NJ Marietta, Ohio	160	
US Industries	Copley, Ohio	-	25 (1975)
US Steel Corp	Haverhill, Ohio	-	+ 90 (1975)
	US TOTAL	2 020	+260

Note: In addition to the companies detailed there may be small polystyrene units attached to various other polymer producing industries in the United States.

Another 300 000 tonnes is expected to be operated by 1980 although details of location are not known.

b) Demand

The 1974 US polystyrene consumption was estimated at 1460 thousand tonnes (620 unmodified resin, plus 840 rubber modified or impact polystyrene). This is a reduction of 5 percent compared to the 1973 demand. A breakdown by end use or process is given in Table IV.J.3.

TABLE IV.J.3.

1974 US POLYSTYRENE CONSUMPTION, BY END-USE

(thousand tonnes)

Injection Moulding	788	54%
Solid Extrusions	380	26%
Foamed Extrusion	146	10%
Expanded Bead Moulding	146	10%
	1 460	100%

c) Supply/Demand Analysis

The supply/demand balance for polystyrene in USA is shown in Table IV.J.4.

Supply is taken as 90 percent of nameplate capacity and projections include anticipated expansions in capacity through to 1980.

TABLE IV.J.4.

USA POLYSTYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	1 820	2 120	2 390	2 390
Projected Demand	1 460	1 165	2 080	2 890
Surplus/(Deficit)	360	955	310	(500)

\+ estimated actual

Present and planned polystyrene capacity appears to be adequate to meet projected demand to 1980. Thereafter new investment will be required.

3. W. Europe

a) Supply

Polystyrene manufacturers are listed in Table IV.J.5, together with present capacity and expansion plans announced to date. Some caution must be exercised in any forecast of future capacity for polystyrene since two manufacturers, Dow and BASF, who currently account for over 40 percent of total West European capacity, do not reveal very much information on their plants, and there is therefore considerable variation in the capacity attributed to them. The 1974 standard polystyrene capacity is however estimated at 1.8 million tonnes expanding to around 2.1 million by the end of 1976, and probably no further expansions in this decade.

In addition there exists over 0.5 million tonnes of expanded polystyrene producing facility. (Table IV.J.6.)

TABLE IV.J.5.

W. EUROPEAN STANDARD POLYSTYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
BELGIUM			
BASF	Antwerp	150	
Belgochim	Feluy	60	+ 15 (1976)
	Total:	210	
FINLAND			
Stymer Oy	Porvoo	20	
FRANCE			
ATO	Mont Gonfreville	120	
CdF Chimie	Deuize	60	+ 20 (1976)
Monsanto	Wingles	70	
Plastichimie (R. Progil)	Ribecourt	60	
	Total:	310	
W. GERMANY			
BASF	Ludwigshafen	350	
C W Huls	Marl	110	+ 30 (1975)
	Total:	460	
GREECE			
Dow Chemicals	Lavrion	10	
ITALY			
Dow Chemicals	Livorno	30	+ 60 (1975)
Montedison	Ferrara Mantova	160	+ 80 (1976)
SIR	Porto Torres	50	
	Total:	240	

TABLE IV.J.5.
(contd)

NETHERLANDS			
Dow Chemicals	Terneuzen	100	+ 20 (1975)
Polystyrene Breda	Breda	100	+ 30 (1976)
(Hoechst)	Total:	200	
NORWAY			
Bruderer Sinde		5	
SPAIN			
Arrahona	Barcelona	15	+ 30 (1976)
Dow Unquinesa	Vizcaya	40	
Monsanto Iberica	Monzon	40	
	Total:	95	
SWEDEN			
Svenska Polystyrene	Kavlinge	20	
UK			
BP Chemicals	Stroud	40	
Dow Chemicals	Barry/Kings Lynn	40	
Monsanto	Newport	25	
Shell	Carrington	70	
Sterling Moulding	Stalybridge	60	+ 20 (1975)
	Total:	235	
W. EUROPEAN TOTAL		1 805	+305

TABLE IV.J.6.

W. EUROPEAN EXPANDED POLYSTYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
FINLAND		
Finska Polystyrene (Huls)	?	15
FRANCE		
Soc. Disp. Plastiques	Villiers St Paul	50
GERMANY		
BASF	Ludwigshafen	300
ITALY		
Mazzuchelli	Castigliari Golvia	15
Montedison	Ferrara	20
		35
NETHERLANDS		
Hoechst	Breda	30
UK		
Monsanto	Newport	25
Shell	Carrington	50
		75
	W. EUROPEAN TOTAL	505

c) Supply/Demand Analysis

The supply/demand balance for o-xylene in Western Europe is detailed in Table IV.F.6. Supply is taken as 90 percent of available capacity.

TABLE IV.F.6

WEST EUROPEAN O-XYLENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	745	745	745	745
Forecast Demand	652	620	840	1160
Surplus/(Deficit)	83	125	(95)	(415)

* calculated as 90% capacity
\+ estimated actual

It can be seen that a capacity deficit is due to develop in Western Europe by the end of the 1970's. However, there are capacity expansion plans in Western Europe for p-xylene/o-xylene separation facilities. The possible availability of low cost U.S. surplus of o-xylene is a factor complicating expansion plans.

4. Japan

a) Supply

The current o-xylene capacity is 329 000 tonnes. Due to the flexibility of the xylene units, however, operation

b) Demand

The 1974 consumption of standard grade polystyrene in W. Europe is estimated at approximately 1.0 million tonnes. Although the end-use pattern varies slightly from country to country, the total West European market may be split as shown in Table IV.J.7.

TABLE IV.J.7.

1974 W. EUROPEAN POLYSTYRENE CONSUMPTION, BY END USE

(thousand tonnes)

Packaging	478	43%
Refrigeration	55	5
Appliances	55	5
Household goods	100	9
Furniture	44	4
Building	111	10
Toys	55	5
Automotive	22	2
Miscellaneous	190	17
	1 110	100%

West European consumption of expanded polystyrene was estimated at 270 000 tonnes (60 percent for building and 35 percent for packaging purposes).

The 1974 demand was 5-10 percent lower than 1973 and 1975 will probably end up as 20 percent down on 1974. After this decline the market is expected to pick up and, following growth rates of 10 percent and 20 percent for 1976 and 1977 respectively, there will be a levelling off at around 7 percent p.a. through to 1980 and subsequently, 5 percent. This pattern is the same for standard grade and expanded resin.

c) Supply/Demand Analysis

The supply/demand situation for standard and expanded polystyrene in W. Europe is given in Tables IV.J.8. and IV.J.9. respectively.

TABLE IV.J.8.

WEST EUROPEAN STANDARD POLYSTYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1 625	1 900	1 900	1 900
Projected Demand	1 110	890	1 320	1 680
Surplus/(Deficit)	515	1 010	580	220

TABLE IV.J.9.

WEST EUROPEAN EXPANDED POLYSTYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	440	440	440	440
Projected Demand	270	215	360	460
Surplus/(Deficit)	170	225	80	(20)

(* 90 percent nameplate capacity
\+ estimated actual)

Capacity is sufficient to cover projected demand for both types of polystyrene for the next decade. However there could be some difficulty in operating plants at full capacity due to possible shortages in ethylene and benzene feedstocks.

4. Japan

a) Supply

The 1974 nameplate capacity for polystyrene in Japan is about 681 thousand tonnes/year standard plus 96 thousand tonnes of expanded polymer. Table IV.J.10. lists the producers and estimated nameplate capacity for 1974. There will probably be an additional 200 000 tonnes by 1985 but details are not known.

TABLE IV.J.10.

JAPANESE POLYSTYRENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
Asahi-Dow	Chiba	102*	
	Kanagawa	84	
	Okayama	110	
Nihon Polystyrene	Kanagawa	67	
Mitsubishi Monsanto	Yokkaichi	91	expansions (1975)
Denki Chemicals	Chiba	70	expansions (1975)
Idemitsu Petrochem	Mie, Yamaguchi	30	
Toyo Polystyrene	Kanagawa	35	
Sekisui Plasticks	Torishima, Osaka	38	
Kanegefuchi	Takasago Ibaraka	66*	
Ube Industries		-	30 (1977)
Hitachi	Mie	9*	
Daicel Ltd	Mie	30	
Yuka Badische	Mie	45*	
		777	

(* includes some expandable)

b) Demand

The 1974 demand for polystyrene in Japan is estimated at 530 000 tonnes (400 000 standard grade and 130 000 tonnes expanded grade)

The Japanese demand for standard grade polystyrene is broken down as follows (Table IV.J.11)

TABLE IV.J.11.

1974 JAPANESE POLYSTYRENE CONSUMPTION, BY END USE

(thousand tonnes)

Electrical and Industrial Machinery	133	33 %
Containers	135	34
House Utensils	70	17.5
Toys	34	8.5
Stationery & Office supplies	14	3.5
General Industrial Use	14	3.5
	400	100 %

c) Supply/Demand Analysis

The supply/demand situation for polystyrene in Japan is summarised in Table IV.J.12.

TABLE IV.J.12.

JAPANESE POLYSTYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	640	700	750	900
Projected Demand	530	500	950	1 700
Surplus/(Deficit)	110	200	(200)	(800)

(*83 percent for 1974, thereafter 90 percent nameplate)

\+ estimated actual

Japan exports around 17 percent of its total production at present, but unless further capacity is installed substantial imports will be needed in the future. Expansion plans have been delayed due to uncertainties over the future availability of feedstocks.

5. The Rest of the Non-Arab World

a) Supply

The existing capacity for polystyrene in the Non-Arab World is summarised in Table IV.J.13. Planned expansions are listed, where known. (NB. Bracketed figures denote the tonnage of expanded polystyrene included in the total).

TABLE IV.J.13.

REST OF NON-ARAB WORLD POLYSTYRENE ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COUNTRY		CAPACITY	EXPANSIONS, YEAR
CANADA		91 (10)	+ 85
LATIN AMERICA			
Argentina		30 (7)	+ 9
Brazil		86 (13)	+ 88 (1976)
Andean Region		35	+ 43
Mexico		28 (4)	+ 52 (1977)
	Total:	179	+ 192
E. EUROPE			
USSR		100	+ 320
E. Germany		40	+ 35
Rumania		40	+ 10
Czechoslovakia		50	+ 50
Poland		30	+ 50
Bulgaria		20	+ 40
Hungary		20	+ 30
Yugoslavia		50	+ 40
	Total:	350	+ 575
AFRICA			
South		17	expansions
East, West		-	-
	Total:	17	
ASIA/PACIFIC			
ASEAN Countries		19	-
Australia/New Zealand		29 (5)	-
India/Burma		22 (2)	+ 21
Taiwan/Hong Kong		39 (8)	+ 68 (1976)
Korea		42 (10)	-
Turkey		-	15
Pakistan		-	-
Iran		-	145 (1977 delayed)
		151	+ 249
TOTAL REST OF NON-ARAB WORLD		582	

b) Demand

- o Canada

  The 1974 consumption for standard and expanded grade polystyrene is estimated at 107 000 tonnes.

- o Latin America

  Demand for 1974 is calculated as 140 000 tonnes, with Brazil having the largest requirement 60 000 tonnes, followed by Argentina at 45 000 tonnes and Mexico at 30 000 tonnes. Demand is expected to grow to almost 275 000 tonnes by 1980.

- o E. Europe

  The 1974 demand for standard and expanded grade polystyrene in the East Bloc is 380 000 tonnes. This is anticipated to more than double over the next 10 years or so.

- o Africa

  Demand in Africa for polystyrene is around 25 000 tonnes, mainly for the Republic of South Africa.

- o Asia/Pacific

  1974 demand for standard and expanded polystyrene in this region is estimated at 190 000 tonnes, with Hong Kong having by far the largest requirement at 80 000 tonnes, followed by Australia's 28 000 tonnes, Taiwan's 18 000 tonnes and S. Korea's 12 000 tonnes. The remaining countries in this region all consumed less than 10 000 tonnes.

c) Supply/Demand Analysis

The supply/demand situation for polystyrene in the Rest of the Non-Arab World is summarised in Table IV.J.14.

TABLE IV.J.14.

REST OF THE NON-ARAB WORLD POLYSTYRENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	80	160	250
Forecast Demand	107	210	300
Surplus/(Deficit)	(27)	(50)	(50)
LATIN AMERICA			
Potential Supply	160	330	330
Forecast Demand	140	210	280
Surplus/(Deficit)	20	120	50
E. EUROPE			
Potential Supply	280	700	740
Forecast Demand	380	660	870
Surplus/(Deficit)	(100)	40	(130)
AFRICA			
Potential Supply	15	20	90
Forecast Demand	25	40	70
Surplus/(Deficit)	(10)	(20)	20
ASIA/PACIFIC AREA			
Potential Supply	135	360	360
Forecast Demand	190	320	500
Surplus/(Deficit)	(55)	40	(140)

\+ estimated actual

- **Canada**

  Canada has to import small quantities of polystyrene at present. This requirement will probably double by 1980 and then level off as there are expansions in the country's polystyrene capacity.

- **Latin America**

  There is adequate polystyrene capacity to meet projected demand throughout the study period.

- **E. Europe**

  This area is a net importing region and without vast capacity expansions will continue to be so for the next 5-10 years. The only country with sizeable plans for additional capacity is Russia, but even including these production will be short of future demand for the foreseeable future.

- **Africa**

  The African supply/demand balance does not make much impression on the world situation. At present there is a small deficit, but in the early 1980's the coming onstream of Shell's polystyrene plant in S. Africa will turn this into a comparable surplus.

- **Asia/Pacific**

  Like E. Europe, S. E. Asia is dependent on imported polystyrene. If the large units planned for Iran and India came onstream before 1980 domestic supply will be sufficient to cope with demand but thereafter in the absence of expansion plans a deficit situation will occur again.

below this level could support increased production through a different isomerisation ratio. No expansions in capacity have been announced. The producers are listed in Table IV.F.7.

b) Demand

The demand for ortho-xylene in 1975 is anticipated to drop sharply from the 1974 level of 123 000 tonnes. This decline is being caused by the sharp decrease in demand for the products requiring phthalic anhydride such as plasticisers, unsaturated polyester resins, pigments and coatings. Phthalic anhydride production is the only major outlet for o-xylene.

There is an additional problem affecting ortho-xylene demand, in that phthalic anhydride producers who employ a naphthalene feed have captive raw material supplies and would tend to preferentially reduce their o-xylene purchases.

Almost 30 percent of phthalic anhydride production in Japan is based on naphthalene at present, but most of the future capacity will be based almost entirely on o-xylene. On this basis the demand should increase at around 9 percent until the early 1980's and thereafter fall to just over 6 percent, as the flexible PVC market matures.

6. The Arab World

a) Supply

At the present time only Algeria and Egypt have announced firm plans for polystyrene production although Iraq will almost certainly be an additional PS producer by 1985. It should be noted that polymerisation of styrene can be undertaken on a relatively small scale and is likely to develop quite rapidly once styrene monomer becomes available in the area. Known plans are summarised in Table IV.J.15.

TABLE IV.J.15.

ARAB POLYSTYRENE PRODUCTION PLANS
(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	25	1982
Egypt	75	1979
Kuwait*	250	1982
Saudi Arabia*	125 (+125)	1982
Total	600	

* Present plans are only for styrene monomer. Obviously both countries will be able to support substantial polymer production in the 1980's.

b) Demand

The 1974 demand for polystyrene in the Arab countries of North Africa including Egypt, is estimated as approximately 12 000 tonnes. This is met entirely by imports.

Total demand in other Arab countries for 1974 amounted to approximately 15 000 tonnes. By 1980 this is expected to have trebled to over 45 000 tonnes.

c) Supply/Demand Analysis

The supply/demand situation for polystyrene in the Arab World is summarised in Table IV.J.16.

TABLE IV.J.16.

ARAB POLYSTYRENE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1985
Potential Supply	-	60	400
Projected Demand	27	80	190
Surplus/(Deficit)	(27)	(20)	210

Currently the area depends on imported material, as no local production will be intiated before 1979. By the mid 1980's there will be substantial overcapacity in monomer and the Arab market will have a substantial volume of styrene available for export. It is anticipated that polymer capacity is likely to keep in step with requirements.

K. PRODUCT ANALYSIS : P-XYLENE

1. Overview

The world supply/demand situation for p-xylene is summarised in Table IV.K.1.

TABLE IV.K.1.

P-XYLENE SUPPLY/DEMAND SITUATION
AS SURPLUS/(DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	7	530	(300)
W. Europe	320	380	120
Japan	41	40	(230)
Canada	(36)	(70)	(120)
Latin America	(30)	(70)	(80)
E. Europe	(155)	(40)	20
Africa	-	(3)	(5)
Asia/Pacific	-	220	(470)
Arab World	-	90	30

Until recently p-xylene has been a commodity which has only figured in the trade of developed markets, but this will change substantially over the next decade as developing countries establish DMT/TPA facilities to feed the rapid growth of the polyester fibre industry.

The sector which looks in the strongest position to supply p-xylene at present must be Western Europe. This area has a large surplus because of a drastic cut back in the polyester fibre production in 1975 resulting from decreasing stocks and reduced export. This has lead to a corresponding decline in p-xylene demand, with a slow recovery forecast through the next decade.

The future situation is complicated by potential low price US exports entering the W. European market for the next few years. However these are expected to tail off quite soon as US DMT/TPA facilities will consume the domestic excesses of p-xylene to an increasing extent, and reduce the export level quite substantially.

The other major developed market, Japanese is suffering a severe recession in the synthetic fibre industry, since the recent energy crisis. The level of polyester fibre production is currently very low, and hence activity in the intermediate DMT/TPA markets and in p-xylene have been very much reduced over the last few years. There is a tendency for back-integration of S.E. Asian fibre producers to reduce the Japanese market export potential e.g. Teijin in Indonesia.

There is a very significant surplus of p-xylene building up in S. E. Asia where although the fibre industry is being built up rapidly, particularly in places like Taiwan and Indonesia, the intermediate facilities are not keeping pace and there is overcapacity of p-xylene and hence considerable quantities are available for export. Several countries attempting to build up a fibre industry deal primarily in DMT/TPA as their consumption requirements do not warrant domestic production of p-xylene.

Almost all p-xylene is consumed in the manufacture of DMT and TPA and, in turn, over 90 percent of these intermediates provide the basis of the polyester fibre industry, with the remainder used for the production of film and engineering plastics. It can therefore be seen that the demand for p-xylene is almost entirely dependent on the textile business and on the penetration of polyester fibres into the total synthetic fibre industry.

The earlier comments imply a substantial volume of trade in p-xylene, which is indeed the case. However there are wide fluctuations in the directions in which the p-xylene moves. Thus in the early seventies material moved in fairly substantial quantities from Europe to the USA but during 1975 has been flowing in the opposite direction. At the present time however the textile industry in the USA in beginning to pick up and opportunities are developing to export p-xylene to the USA. In the eighties it is expected that both Europe and Japan may provide export opportunities.

The p-xylene market is concentrated in the hands of relatively few companies. Four companies in W. Europe and five in the USA make up the major part of the business, which is very largely merchant.

Development of the p-xylene market in the Arab States is dependant upon establishment of DMT facilities which feature in the plans of a number of countries. However there could well be an excess available for export and, as indicated above, Western Europe and Japan could provide possible markets.

2. USA

a) Supply

The U.S. nameplate capacity for p-xylene in 1974 was 1 320 thousand tonnes. This capacity will nearly double within the next 3 years, due to the completion of a number of expansions and new facilities. A list of producers is shown in Table IV.K.2.

TABLE IV.K.2.

UNITED STATES P-XYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY
(thousand tonnes)

Producer	Location	Capacity	Expansions, Year
Amoco	Decatur, Ala.	136	391 (1977)
	Texas City, Tex.	136	205 (1975)
Arco	Houston, Tex.	182	
Charter Oil	Houston, Tex.	7	
Chevron	El Segundo, Calif	41	
	Pascagoula, Miss.	136	
	Richmond, Calif	50	
Cities Service	Lake Charles, La.	16	
Cosden	Big Spring, Tex.	3	
Exxon Chemical	Baytown, Tex.	114	91 (1975)
Hercor	Guayanilla Bay, P.R.	239	89 (1975/6)
Hercules/Hess	St. Croix, V.I.	-	225 (1976)
Phillips	Guayama, P.R.	34	214 (1977)
Shell Chemical	Houston, Tex.	45	
Sun Oil	Corpus Christi, Tex.	136	
Tenneco	Chalmette, La.	45	
	Totals	1 320	+1 245

b) Demand

p-xylene is used for the production of DMT and TPA, which are primarily used in the production of polyester fibre and film. An end-use pattern based on DMT/TPA is given in Table IV.K.3. (NB even the minor end uses are basic in these chemicals).

TABLE IV.K.3.

1974 U.S. P-XYLENE CONSUMPTION, BY END USE
(thousand tonnes)

Polyester fibre	1 020	84.5%
Polyester film	64	5.3%
Polybutylene terephthalate	5	0.4%
Others (inc. DMT/TPA export)	118	9.8%
Total demand	1 207	100%

Demand is expected to grow at 7-8 percent through to 1980, giving a consumption level of 1 830 thousand tonnes by the end of the decade.

c) Supply/Demand Analysis

The potential supply/demand situation for p-xylene is summarised in Table IV.K.4, based on the supply from existing and announced plants.

TABLE IV.K.4.

U.S. P-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1 214	1 490	2 360	2 360
Forecast Demand	1 207	1 180	1 830	2 660
Surplus/(Deficit)	7	310	530	(300)

(* 92 percent of nameplate
+ estimated actual)

It should be noted that the effective existing and announced U.S. p-xylene supply is sufficient to meet the U.S. demand through to the early eighties.

3. W. Europe

a) Supply

p-xylene capacity in Western Europe is divided among the six producing countries as indicated in Table IV.K.5.

At present only Deutsche Shell and Saras have capacity expansions pending, although several other plants could be expanded when required.

b) Demand

The West European consumption of p-xylene in 1974 was 620 000 tonnes. All of that went to the production of DMT/TPA. Because of a drastic cut-back in polyester fibre production, of 16 percent, in 1975, due to decreasing stocks and reduced exports, the p-xylene demand will show a corresponding dramatic decline of 17 percent, and recover only very slowly through the next decade, to give a 1985 level of almost 900 000 tonnes.

c) Supply/Demand Analysis

The W. European supply/demand balance is shown in Table IV.K.6. No assumptions of future capacity expansions, beyond those already announced, have been made in this analysis.

TABLE IV.F.7.

JAPANESE O-XYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
Idemitsu Petrochemical	Tokuyama	40
Mitsubishi Gas Chemical	Mizushima	32
Maruzen Oil	Matsuyama	12
Teijin Petrochemical	Tokuyama	30
	Matsuyama	30
Toho Gas		45
Tonen Petrochemical	Orita	40
Toray Petrochemical	Kawasaki	100
		329

TABLE IV.K.5.

W. EUROPEAN P-XYLENE PRODUCERS, AND ESTIMATED NAMEPLACE CAPACITIES, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
FRANCE			
Antar	Donges	15	
Esso-Chemie	Port Jerome	30	
Rhone-Poulenc	Gonfreville	70	
Total France		115	
WEST GERMANY			
Deutsche - BP	Dinslaken	20	
	Vohburg	25	
Deutsche - Shell	Godorf	75	+ 25 (1977)
Gelsenberg	Gelsenkirchen	19	
URBK	Wesseling	78	
Veba-Chemie	Gelsenkirchen	50	
Total West Germany		267	
ITALY			
Mobil Chemica	Naples	55	
Montedison	Priolo	75	
Saras Chemica	Sarroch	60	+ 20 (1976/7)
SIR	Porto Torres	21	
Total Italy		211	
NETHERLANDS			
Esso Chemie	Botlek	106	
SPAIN			
Cepsa	Algeciras	21	
UNITED KINGDOM			
BP - Chevron	Isle of Grain	20	
	Grangemouth	100	
ICI	Wilton	60	
	Wilton	140	
Total United Kingdom		320	
TOTAL WESTERN EUROPE		1 040	+ 45

TABLE IV.K.6.

W. EUROPEAN P-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	940	940	1 020	1 020
Projected Demand	620	515	640	900
Surplus/(Deficit)	320	425	380	120

* 90 percent capacity

\+ estimated actual

Based on this fairly conservative view of the recovery of p-xylene demand after 1975, the area should be self sufficient through to the mid eighties.

4. Japan

a) Supply

The current producers of p-xylene and their respective capacities are detailed in Table IV.K.7. The intitial major expansion is slated for 1977/78, but the investment programmes for many of the major companies have been indefinitely delayed.

TABLE IV.K.7.

JAPANESE P-XYLENE PRODUCERS, AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

Company	Capacity
Toray	200
Teijin Yuka	135
Mitsubishi Gas Chemical	80
Matsuyama	70
Tonen Chemical	50
Asia Oil	25
Kururay Yuka	23
	583

b) **Demand**

The demand for para-xylene in 1975 is anticipated to decline to 361 000 tonnes from a 1974 level of 484 000 tonnes. This is based on the current low level of polyester fibre production. Not only has the Japanese demand level been substantially reduced but also the demand for Japanese fibre intermediates and fibre in the international market has declined. It is doubtful that Japan will be as important a factor in the international fibre business in the future as the Japanese manufacturers were prior to the energy crisis. The backward integration of fibre producers in South East Asia will reduce the market potential for Japanese fibre and fibre intermediate exporters to this important traditional export region.

c) Supply/Demand Analysis

The supply/demand situation for p-xylene is shown in Table IV.K.8.

TABLE IV.K.8.

JAPANESE P-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	525	525	640	600
Projected Demand	484	361	600	830
Surplus/(Deficit)	41	164	40	(230)

* 90 percent capacity

\+ estimated actual

Domestic supply will be able to meet demand to the early eighties, whereupon imports DMT/TPA from a Japanese overseas venture will be required, or new investment in p-xylene facilities.

5. Rest of Non-Arab World

a) Supply

A list of p-xylene producers in the Rest of the Non-Arab world is given in Table IV.K.9, together with 1974 capacities, and expansion plans which have been announced.

TABLE IV.K.9.

REST OF NON-ARAB WORLD ESTIMATED NAMEPLATE CAPACITIES, 1974

(thousand tonnes)

COUNTRY	CAPACITY	EXPANSIONS, YEAR
CANADA	-	-
LATIN AMERICA		
Argentina	-	40 (1977)
Brazil	-	60 (78) + 50 (81) +60 (1985/6)
Andean Region	-	50 (1981) +50 (1987)
Mexico	20	+60 (1977) +75 (1983)
Total Latin America	20	+445
E. EUROPE		
USSR	94	+726 (by 1980's)
E. Germany	-	30 (1980)
Rumania	36	expansions planned
Czechoslovakia	40	expansions (1976-80)
Bulgaria	12	
Poland	48	+12 (by 1980)
Hungary	-	-
Yugoslavia	(46) mixed xylenes	
	276	+768
AFRICA		
South, East, West	-	-
ASIA/PACIFIC		
ASEAN Countries	-	+300 (1979) +300 (1980)
Australia/New Zealand	-	
India/Burma	-	
Taiwan/Hong Kong	-	+100 (1977-8) +100 (1982)
Korea	-	200 (1981)
Turkey	-	30 (1982)
Pakistan	-	
Iran	-	100 (1977 - delayed)
Total Asia/Pacific	-	+1 130
TOTAL: Rest of Non Arab World	296	

b) Demand

- Canada
  At present there is no demand for p-xylene in Canada, since there are no DMT/TPA facilities within the country. Production of these chemicals is not foreseen within the next several years since the consumers of DMT/TPA in Canada have their own facilities in other countries and also access to the product from large scale U.S. plants. A p-xylene demand figure calculated in terms of DMT/TPA requirement would be 36 000 tonnes for 1974.

- Latin America
  To date, the only country in the region with a p-xylene demand is Mexico at 50 000 tonnes. However as the polyester fibre industry develops within this area, p-xylene will be consumed in all contributing countries and by 1980 Latin America will require 240 000 tonnes.

- Eastern Europe
  The p-xylene demand for the East European countries in 1974 was 375 000 tonnes. With a rapidly expanding fibre industry, this will increase to approximately 820 000 tonnes by 1985.

- Africa
  There is currently no demand for p-xylene in Africa and the only country where any is likely to develop is South Africa, where a polyester fibre plant is slated for 1980, and if the DMT is to be produced locally 3 000 to 4 000 tonnes of p-xylene will be required.

- Asia/Pacific

  There is no demand for p-xylene at present as these countries favour importing the intermediate materials for their polyester fibre industry. Taiwan will have the earliest consumption of 80 000 tonnes by 1980, and along with Korea will have substantial demand levels by the mid eighties.

c) <u>Supply/Demand Analysis</u>

The supply demand balances for the Rest of the Non-Arab World's p-xylene is given below in Table IV.K.10.

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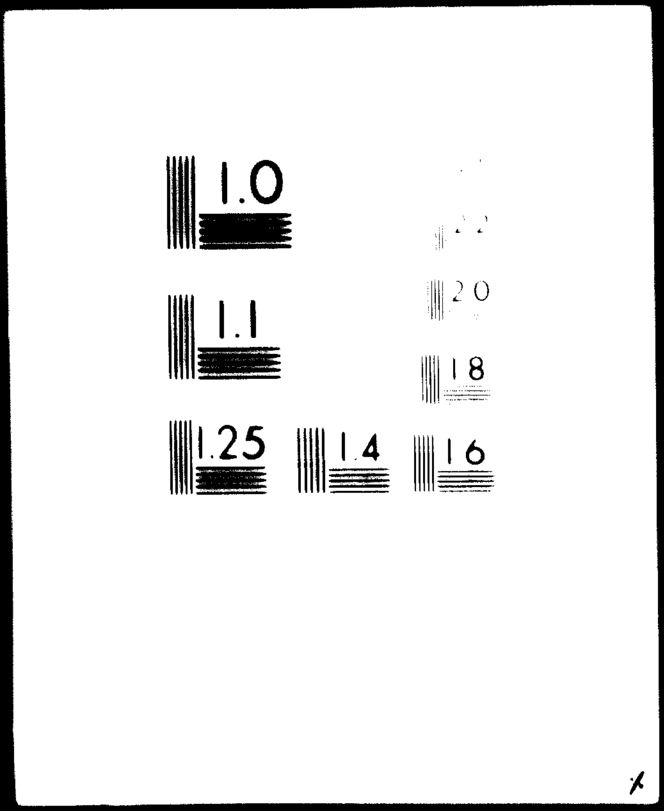

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in Table IV.L.1. at the beginning of this section. It is anticipated that there will be increasing investment in DMT/TPA facilities in these areas which will reduce their dependence on imports, so that the import potential suggested will probably not in fact develop.

In the USA approximately two-thirds of the business is merchant whilst the converse applies in Western Europe where two-thirds is captive. Japan follows the US pattern with about 70 percent merchant business. In the US and Europe, the merchant business is dominated by Hercules, Amoco and others, and would be difficult to penetrate.

There are 17 producers of polyester fibre in the USA, 26 in Western Europe and 8 in Japan.

Development of DMT/TPA in the Arab States will probably be linked with growth in local polyester fibre production. The beginning of fibre production will probably be based on imported intermediates but domestic production should be adequate in the mid eighties.

2. USA

a) Supply

The 1974 U.S. nameplate capacity for DMT/TPA is 2 127 thousand tonnes. The manufacturers and their capacities are shown in Table IV.L.2. The producers are currently re-evaluating expansion programmes in the light of the current drop in demand for polyester fibres and lower long term growth projections for DMT/TPA.

TABLE IV.L.2

USA DMT/TPA PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY DMT	CAPACITY TPA	EXPANSION, YEAR
Amoco	Decatur, Ala	90	545	227 TPA (1975)
	Joliet, Ill	68	32**	123 DMT (1978)
	Southeast			454 TPA (1978)
DuPont	Old Hickory, Tenn	115*		+ 182 DMT (1977-8)
	Wilmington, NC	364		
	Charleston, SC			+ 182 DMT (1977)
Hercules	Burlington, NJ	68*		
	Wilmington, NC	545		
	Eastover, SC			+ 363** DMT (1977)
Eastman	Kingsport, Tenn	228		
	Columbia, SC		+	+ 90 DMT (1976) + TPA plans
Hoechst	Spartanburg, Va	72		
		1 550	577	
TOTAL USA CAPACITY		2 127		+ 1 621

Footnote

* suspended producer

** convertible DMT/TPA capacity

b) Demand

The 1974 U.S. demand for DMT/TPA was estimated at 1 692 thousand tonnes. This is almost equivalent to the 1973 level because of a drastic decrease in the fourth quarter of 1974. This reduced level is expected to continue through 1975 resulting in a 1975 consumption of 1 142 thousand tonnes which is expected to recover quite rapidly thereafter and growth rates of 11-13 percent per annum are forecast through to 1985, giving consumptions of 2 800 thousand tonnes and 4500 thousand tonnes in 1980 and 1985, respectively.

(NB Demand data has been quoted in DMT equivalents, where
1.12 pounds DMT 1 pound polyester fibre and
1.11 pounds DMT 1 pound polyester film)

c) Supply/Demand Analysis

The supply/demand balance for DMT/TPA in the U.S.A. is shown in Table IV.L.3.

Supply is taken as 90 percent of nameplate capacity for DMT plus TPA since the actual level of production may vary from year to year and demand is based on DMT equivalents.

TABLE IV.L.3.

US DMT/TPA SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1 914	1 914	3 370	3 370
Projected Demand	1 692	1 142	2 800	4 500
Surplus/(Deficit)	222	772	570	(1 130)

* 90 percent nameplate + estimated actual

i.e. Supply will be adequate to meet demand through until the early 1980's.

3. W. Europe

a) Supply

In 1974, there were 12 manufacturers of DMT/TPA in Western Europe, with a total nameplate capacity of 1 433 thousand tonnes. This was split 1 013 thousand tonnes of DMT capacity and 420 thousand tonnes of TPA.

Table IV.L.4. lists the manufacturers of DMT and TPA in Western Europe, together with their known expansion intentions.

This list shows the introduction of the Spanish company, Interquison as a manufacturer of DMT and TPA in 1976. Interquison is an Amoco/Cepsa joint venture, and their proposed entry into the market is a firm intention. No new capacity plans are shown for Portugal, where Ammonia co Portuguesa have indicated their intention to start producing DMT in 1976/77. Industry opinion is that this project may never materialise, and certainly the forecast overcapacity situation in Western Europe would seem to support this view. Therefore it would seem that there could be 13 manufacturers of DMT/TPA in Western Europe by 1980. One reservation on this number concerns Huls whose small DMT plant has been reported to be having operating problems. With such a small plant in West Germany, and with Dynamit, the largest DMT merchant supplier in Western Europe, so close, the economics of even captive production might be questioned, operating problems or not.

Western European DMT plants are based on either Dynamit's Witten technology, modifications of it, or an Amoco technology. TPA plants all use Amoco technology.

Since exports of DMT/TPA in 1974 were around 100 000 tonnes, import volume low, and home consumption 815 000 tonnes, it can be seen that a DMT/TPA production of around 900 000 tonnes represented only 63 percent utilisation of available capacity. In 1975, reduced demand both at home and in export markets is forecast to cut production to around 750 000 in Western Europe. Although this represents only 53 percent capacity utilisation overall, it is known that some plants have closed down completely for varying periods of time in 1975. Forecasts of production of DMT/TPA will be made in Section c), and in each case capacity utilisation is forecast to remain low to 1985.

TABLE IV-1-4

WESTERN EUROPEAN DMT/TPA PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY DMT	CAPACITY TPA	PROCESS	EXPANSIONS, YEAR
Belgium					
Amoco	Geel	65	90	Amoco for TPA and DMT	-
France					
Rhone Poulenc	St. Fons	70	-	Own-Witten type	-
	Chalampe	50	50	Amoco for DMT and TPA	
	Total France	120	50		
West Germany					
Dynamit Nobel	Witten	60	-	Witten	-
	Lulsdorf(1)	60	-	Witten	-
	Lulsdorf(2)	170	-	Witten	-
	Liebenau/ Steyerberg	-	-	Witten - improved process	140 DMT plant (end 1977)
	Gerstoffen	96	-	Witten) improved by Hoechst	
	Offenbach	96	-	Witten)	Potential to expand to 210 by debottlenecking
	Hoechst	10	-	Recyling plant	-
Huels	Marl	21	-	Own Witten type	thought to be having operating problems - could withdraw by -977
	Total West Germany	513	-		
Italy					
Montedison	Ferrara	33	-	Witten	Closedown in 1979
	Porto Marghera	26	40	Amoco	Closedown of DMT plant in 1979
	Naples	-	-	Witten	140 DMT (1979)
Chimica del Tirso (Montedison/ANIC	Ottania	-	70	Amoco	+ 10 (1976)
SIR	Porto Torres	15	-	Own	+ 5 (1976)
		74	110		
Netherlands					
Hercules	Middelburg(1)	60	-	Witten-Hercules -	
	" (2)	-	-	" "	70 (1976)
Hoechst	Vlissingen	86	-	Witten - improved by Hoechst	could reach 100 by debottlenecking
AKZO	Delfzijl	50	-	Amoco	+2 (1976)
	Total Netherlands	200	-		
Spain					
Interquisa	Algerciras (Amoco/Cepsa)	-	-	Amoco	65 DMT (1976) 25 TPA (1976) + 15 TPA (by 1977)
U.K.					
I.C.I.	Wilton	40	170	Own DMT Amoco (ICI improved) TPA	+ TPA (by 1977) decreasing DMT to 20 by 1977
	Total DMT and TPA	1013	420		
	Total Western Europe	1433			

b) Demand

The use of DMT/TPA for polyester fibre and film production constitutes virtually 100 percent of the Western European consumption of these materials.

In 1974, the consumption of DMT/TPA by polyester fibre and film producers is estimated to have been 815 000 tonnes, a fall of 6.3 percent from the previous year. (93.4 percent of total demand was attributed to fibre production)

W. Germany constitutes by far the largest share of the market for DMT/TPA in Western Europe, over 40 percent of the total figure.

The demand for DMT/TPA in polyester fibre and film production is forecast to fall by 16 percent in 1975 to 685 000 tonnes in Western Europe. This does not represent a fall in demand of 16 percent for polyester fibre and film themselves, but largely a fall in the required production level of polyester fibre.

1973 was something of a boom year for the Western European polyester fibre industry, with exports at a high level, particularly to the U.S., and home demand very strong. 1974 saw the downturn of the textile cycle not only in Western Europe but also in the world textile business. As a result, home and export demand fell, and only channeling production into stocks kept polyester fibre production levels at just over 70 percent of installed capacity.

1975 is forecast to show only a small drop of 0.7 percent in home demand for polyester fibre, but a continuing drop in exports and a net decrease in stock levels. Production is therefore forecast to drop by 17 percent in 1975, producing a correspondingly large drop in DMT/TPA demand.

The forecast demand for DMT/TPA - in Western European polyester fibre production is 630 000 tonnes in 1975, 17 percent down on the 1974 level. This should represent 92 percent of total demand for DMT/TPA in Western Europe in 1975.

It should be noted that the polyester fibre demand does not totally control the production level of polyester fibre and hence the demand for DMT/TPA. Stock changes and net exports are important variables to be considered with home demand as such. Taking all these factors into account the overall growth rate for DMT/TPA has been estimated at 5.8 percent for the period 1975-1985. It should be noted that the cyclical nature of the textile business in Western Europe may alter the year-by-year forecasts, but the underlying growth trend is valid.

c) Supply/Demand Analysis

Table IV.L.5. shows the Western European Supply/Demand situation for DMT/TPA.

TABLE IV.L.5.

W. EUROPEAN DMT/TPA SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1 433	1 433	1 860	1 860
Projected Demand	815	685	930	1 290
Surplus/(Deficit)	618	748	930	570

\+ estimated actual

*Supply is given as nameplate capacity for DMT/TPA, since the actual level of production will vary from year to year. Production in 1974/5, a bad time for domestic demand and for exports was estimated at only 53 percent of total nameplate capacity, and with the forecast for continuing overcapacity made here, the utilisation rate is likely to remain low.

It can be seen from this table that a vast overcapacity situation exists in Western Europe and is forecast to continue throughout the 1975-1985 period, based only on capacity expansion intentions announced to-date. The likelihood of some of these expansion intentions coming to fruition must be questioned in face of these figures.

Some of the excess capacity can be taken up by exports of DMT/TPA, certainly for the 1975-1979 period, but the construction of DMT/TPA plants in the Far East, Turkey and the U.S. is forecast to have the combined effect of reducing traditional and other world export markets for Western European DMT/TPA manufacturers.

4. Japan

a) Supply

The 1974 Japanese nameplate capacity for DMT/TPA is 1432 thousand tonnes. The manufacturers, and their capacities are shown in Table IV.L.6. The Amoco process is basically used by all TPA manufacturers, with the exception of Toray, who uses its own process.

TABLE IV.K.10.

REST OF THE NON-ARAB WORLD P-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	-	-	-
Forecast Demand	36	70	120
Surplus/(Deficit)	(36)	(70)	(120)
LATIN AMERICA			
Potential Supply	20	170	350
Forecast Demand	50	240	430
Surplus/(Deficit)	(30)	(70)	(80)
E. EUROPE			
Potential Supply	220	600	840
Forecast Demand	375	640	820
Surplus/(Deficit)	(155)	(40)	20
AFRICA			
Potential Supply	-	-	-
Forecast Demand	-	3	5
Surplus/(Deficit)	-	(3)	(5)
ASIA/PACIFIC AREA			
Potential Supply	-	300	1 120
Forecast Demand	-	80	650
Surplus/(Deficit)	-	220	470

(+ estimated actual)

TABLE IV.L.6

JAPANESE DMT/TPA PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY		EXPANSIONS, YEAR
		DMT	TPA	
Matsuyama Petrochemical Co	Matsuyama	90	100	+ 50 (1976)
Mitsui Petrochemical Co	Iwakuni	100	200	+ 180 (1976)
Mitsubishi Chem Ind Co	Kurosaki	113	222	
Toray Co	Tokai Mishima	120	150	+ 50 (1976)
Kuraray Petrochemical Co	Yokkaichi	96	78	? (1977)
Teijin Hercules Co	Matsuyama Two other plants	240	-	-
Mizushima Aroma Co	Mizushima	-	99	+ 87 (1976) + 130 (1977)
		759	849	+ > 497
TOTAL JAPAN		1 608		

b) Demand

The Japanese demand situation is somewhat confused. It is virtually impossible to get a consensus forecast for the polyester fibre intermediates, as the price structure of the market at present seems so uncertain.

In 1974 the demand in terms of DMT (including crude TPA which has been converted) is estimated at 680 thousand tonnes and this is expected to increase at 7-8 percent through to 1980, and perhaps 9.0 percent for the subsequent 5 year period.

c) Supply/Demand Analysis

The supply/demand situation for DMT/TPA in Japan is summarised in Table IV.L.7.

TABLE IV.L.7.

JAPAN DMT/TPA SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	1 276	1 276	1 800	2 000
Projected Demand	680	720	1 160	1 760
Surplus/(Deficit)	596	556	640	240

+ estimated actual

There should be sufficient DMT/TPA in Japan for the next decade, even although no increases in DMT production are forecast. Any deficit in this area will be overcome by increased supply of fibre grade TPA, as this is a growing general trend of most synthetic fibre manufacturers in Japan.

5. Rest of Non-Arab World

a) Supply

A list of DMT/TPA producers in the Rest of the Non-Arab is given in Table IV.L.8, together with 1974 capacities and expansion plans, if known.

TABLE IV.L.[illegible]

REST OF NON-ARAB WORLD DMT/PTA ESTIMATED NAMEPLATE CAPACITIES, 1974

(thousand tonnes)

COUNTRY	CAPACITY		EXPANSIONS, YEAR	
	DMT	TPA	DMT	TPA
CANADA	-	-	-	-
LATIN AMERICA				
Argentina	16		50 (1977)	
Brazil	-		60 (1977)	50 (1975)
Andean Zone	-		25 (?)	
Mexico	-		← 137 (1975) →	
TOTAL LATIN AMERICA	16	-	135 + 137 +	50
E EUROPE				
USSR	81		+ 40 ('76) + 90 ('78)	
E Germany	-		-	
Rumania	64	45	-	
Czechoslvakia	-		-	
Bulgaria	14		-	
Poland	84		22 (?)	
Hungary	-		-	
Yugoslavia	-		-	
TOTAL E EUROPE	243	45	+ 152 + plans	-
AFRICA				
South, East, West	-	-	-	-
ASIA/PACIFIC				
ASEAN Countries	-	-	220 (1978)	120 (1977)
Australia, NZ	-	-	-	-
India, Burma	24	-	+ 30 (1975)	-
Taiwan, Hong Kong	26	-	+ 26 (1975)	250 (1976)
Korea	-	-	100 (1975)	100 (1977)
Turkey	-	-	60 (1976)	70 (?)
Pakistan	-	-	-	-
Iran	-	-	-	-
TOTAL ASIA/PACIFIC	50	-	436 +	540
REST OF NON-ARAB WORLD TOTAL	309	45		

b) Demand

- Canada and Latin America

  The 1974 consumption of DMT/TPA in America, excluding the USA was estimated at 245 000 tonnes for the polyester fibre industry which constitutes almost the total consumption of these materials in this geographical zone.

- Eastern Europe

  The 1974 demand for the polyester fibre industry was estimated at 292 000 tonnes and based on planned growth within the industry is likely to increase to 630 000 by 1980 and 920 000 by 1985.

- Africa

  There is no planned entry into the polyester fibre business hence no interest in DMT/TPA for the next decade at least.

- Asia/Pacific

  Current demand is rated at 225 thousand tonnes rising to 1 088 thousand by 1980 and approximating 1600 by the middle of the eighties.

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World's is given below in Table IV.L.9.

TABLE IV.L.9.

REST OF THE NON-ARAB WORLD DMT/TPA SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA/LATIN AMERICA			
Potential Supply	15	310	310
Forecast Demand	245	710	1 040
Surplus/(Deficit)	(230)	(400)	(730)
E. EUROPE			
Potential Supply	260	400	400+
Forecast Demand	292	630	920
Surplus/(Deficit)	(32)	(230)	(<520)
ASIA/PACIFIC			
Potential Supply	45	880	880
Forecast Demand	225	1 090	1 600
Surplus/(Deficit)	(180)	(210)	(720)

+ estimated actual

o Canada and Latin America

These areas are almost entirely dependent on US exports of the fibre monomers to keep their polyester fibre industry running and in fact Canada and Mexico account for over half of the total exports. Canada doesn't seem to be making any provision to alter this situation, but there are several plans for DMT and/or TPA plants to be installed in Mexico and South America, although the scale of operation is not really sufficient to meet a fast growing demand.

- Eastern Europe

  This area is virtually in balance at the moment, but as the fibre industry is developed and polyester plants were incorporated into almost all member country's 5 year plans a deficit will develop by 1980 unless the p-xylene expansions slated for the East Bloc are accompanied by the installations of DMT/TPA units.

- Asia/Pacific

  In S. E. Asia the polyester fibre business is really escalating and demand for DMT/TPA is likely to outweigh supply for many years. Large DMT and TPA units are being installed over the next 5 years especially in Indonesia, Taiwan and Turkey but they will be insufficient to prevent the deficit situation continuing.

6. Arab World

a) Supply

The plans for production of DMT/TPA in the Arab market are summarised in Table IV.L.10.

TABLE IV.L.10.

ARAB DMT/TPA PRODUCTION PLANS
(thousand tonnes)

COUNTRY	PLANNED CAPACITY	START-UP YEAR
Algeria	25 (DMT : TPA)	1981
Egypt	50 (DMT)	1981
Iraq	50 (DMT)	1982
	125	

b) Demand

There is no demand for DMT/TPA production at present, as the polyester fibre industry has not yet been developed.

There are plans for polyester fibre production in Algeria, Egypt and Iraq. It is expected that the supply/demand situation will probably be brought into balance by 1985.

c) Supply/Demand Analysis

The supply/demand situation for DMT/TPA in the Arab World is summarised in Table IV.L.11.

TABLE IV.L.11.

ARAB DMT/TPA SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974	1980	1985
Potential Supply*	-	-	110
Projected Demand	-	40	110
Surplus/(Deficit)	-	(40)	-

* 90% nameplate

There will be a deficit in 1980 but domestic demand will build up by the middle of the decade to use up local production.

M. PRODUCT ANALYSIS : LDPE

1. Overview

The world supply/demand situation for LDPE is summarised in Table IV.M.1.

TABLE IV.M.1.

LDPE SUPPLY/DEMAND SITUATION AS SURPLUS/(DEFICIT)

(thousand tonnes)

	1974	1980	1985
USA	26	(500)	(2 180)
W. Europe	617	30	(2 170)
Japan	223	510	60
Canada	(26)	70	(20)
Latin America	(90)	(50)	(220)
E. Europe	30	40	(30)
Africa	(110)	(220)	(270)
Asia/Pacific	53	60	(420)
Arab World	(60)	(70)	1 490

LDPE is the largest volume thermoplastic with an estimated worldwide consumption of some 7 million tonnes in 1975. Although a well established product here has been steady growth in consumption of about 13.5 percent per annum during the last ten years. However, in common with most other plastics, 1974 and 1975 have seen reduced demand in most markets. Not only this but future growth forecasts have had to be reduced to take account of higher prices for LDPE and lower growth in the economies of the developed world.

Nevertheless considerable new investment will be required in the USA and Western Europe to meet forecast demand in the 1980's. By 1985, for example, it is anticipated that over 2 million tonnes of new capacity will be needed in each of these markets.

Also by 1985 it is expected that something like 1.5 million tonnes of LDPE capacity will be available in the Arab States over and above the quantity required for the domestic market. Western Europe, the USA, and Japan would appear to offer the main export opportunities for LDPE produced in the Arab States, with some quantities also required in Africa and S.E. Asia.

Extruded film represents the major outlet for LDPE in all markets although its importance varies from a low figure of 58 percent in Japan to a high of 68 percent in Western Europe. Approximately half of this film is used in the packaging industry.

There is considerable trade in LDPE with West Germany and France, the two major producers in Western Europe, each exporting around 40 percent of their projection. Whilst a large proportion of this is inter-European trade Western European maintains a substantial net export of LDPE. Exports from the USA have been running at 7-8 percent of production.

- **Canada**

  Canada's requirements can quite adequately be supplied by the U.S.A. through to 1980, at least.

- **Latin America**

  This area is going to be increasingly short of p-xylene over the next decade, because although the policy is to develop capacity at the same rate as DMT/TPA production, this target is not quite being achieved. Argentina is the only country with any export capacity, but this is more than accounted for by the relatively substantial requirements of Brazil and Mexico. There will not be much domestic production before 1977.

- **Eastern Europe**

  As with o-xylene, the para isomer is one of the chemical intermediates, which could conceivably become short within the near future, if there were a cut back in raw materials, but planned expansions should cover regional demand through to 1985.

  Russia exports p-xylene even though her own situation is tight. By 1980 they estimate a consumption level of 500 000 tonnes which is optimistic but if necessary can be more than covered by the huge expansions scheduled. Czechoslovakia is in the same position, with a rapidly expanding fibre industry being satisfied by plans for new p-xylene facilities.

  East Germany and Hungary both rely on imports of p-xylene whilst Bulgaria is in a balanced situation.

It is estimated that in the early 1970's nearly 1 million tonnes of LDPE were exported out of Western Europe, USA and Japan each year.

LDPE is processed by many hundreds of companies although there are probably more large volume users than for other plastics due to the importance of film which is a capital intensive, high volume activity. The importance of film and the tendency for larger companies to be involved in this business, means that LDPE probably requires less technical service than most other polymers.

The film business operates in a very competitive situation and film grade LDPE can be subject to severe pressure on prices in times of oversupply. Large scale automated operation also necessitates supplies of consistent quality.

Because of the large volume purchasers which exist, the smaller range of grades, particularly for film extrusion and the lower level of technical service which is required, LDPE is probably the most attractive of the large volume polymers to be considered for exporting from the Arab States. In addition, with polymer producers in the developed countries needing to maximise their returns from investment and feedstocks, it is not going to be a priority product for new investment. Adequate distribution facilities will be a priority in establishing a position in the export business.

2. USA

a) Supply

The 1974 US LDPE capacity is estimated to have been 2 907 thousand tonnes/year and there are announced expansions, which will increase capacity by an estimated 651 thousand tonnes before the end of the decade.

A list of U.S. LDPE manufacturers, together with present capacity and expansion plans to date are shown in Table IV.M.2.

TABLE IV.M.2.

U.S. LDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, (YEAR)
Arco Polymers	Port Arthur, Tex.	170	+ 80 (1976)
Chemplex	Clinton, Iowa	141	
Cities Service	Lake Charles, La.	104	+ 23 (1975)
Dow	Freeport, Texas	204	+160 (1975)
	Plaquemine, La.	114	
DuPont	Orange, Texas	232	
	Victoria, Texas	102	
Eastman	Longview, Texas	123	
Exxon	Baton Rouge, La.	181	+114 (1977)
Gulf	Cedar Bayou, Tex.	127	+113 (1975)
	Orange, Texas	136	
Mobil	Beaumont, Texas	-	136 (date unknown)
Monsanto	Texas	45	to shutdown
(operated under lease to Arco Polymers)			
National Distillers	Deer Park, Texas	159	+ 80 (1977)
	Tuscola, Ill.	68	
Northern Petrochemical	Joliet, Ill	248	+ 41 (1976)
Rexene Polymers	Odessa, Texas	184	
(joint venture with El Paso Products)			
Union Carbide	Penuelas, P.R.	141	
	Seadrift, Texas	164	+182 (1975)
	Texas City, Texas	100	
	Torrane, Calif.	55	
	Whiting, Ind.	109	
TOTAL USA		2 907	+884

b) Demand

The 1974 US LDPE demand was 2 580 thousand tonnes. An end use breakdown is shown in Table IV.M.3.

TABLE IV.M.3.

1974 U.S. LDPE CONSUMPTION, BY END USE

(thousand tonnes)

Film	1 520	59%
Injection moulding	310	12%
Extrusion coating	260	10%
Wire and cable	230	9%
Other	260	10%
Total demand	2 580	100%

Although film is not quite so important in the U.S.A. as in Europe, it is clearly the dominant factor in the consumption pattern of LDPE. Almost 60 percent of film produced goes into packaging.

Assuming continued feedstock availability, but making some allowance for a slower growth than historical rates might suggest, demand will probably reach nearly 4 000 thousand tonnes by 1980 and 5 590 thousand tonnes by 1985.

c) Supply/Demand Analysis

The potential supply/demand situation for LDPE in the U.S. is summarised in Table IV.M.4. This is based on supply from existing and announced plants only.

TABLE IV.M.4.

US LDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	2 606	3 047	3 410	3 410
Projected Demand	2 580	2 410	3 990	5 590
Surplus/(Deficit)	26	637	(580)	(2 180)

* 90 percent nameplate

\+ estimated actual

It is clear that further new investment will be required to satisfy projected 1980 demand and it is anticipated that additional expansion plans will be announced for the end of the decade.

3. W. Europe

a) Supply

The nameplate capacity for LDPE in W. Europe during 1974 is estimated to have been 4 505 thousand tonnes.

The producing companies with existing capacity and announced expansions, are listed in Table IV.M.5.

TABLE IV.M.5.

W. EUROPEAN LDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
AUSTRIA			
Danubia Olefinwerke	Schwechat	80	+ 25 (1975) + 15 (1979)
BELGIUM			
Belgochim	Feluy	100	
BASF	Antwerp	35	+ 45 (1975)
Union Carbide	Antwerp	-	150 (reinstated in 1978)
USI	Antwerp	165	+ 80 (1976)
Essochem	Vorst or Meerhout	-	260 (1977)
Total Belgium		300	
DENMARK			
Danbritkem	Copenhagen	30	
FINLAND			
Pekema Oy	Borga	80	+ 90 (1975)
FRANCE			
ATO Plastique	Balam, Mont, Gonfreville	310	+ 40 (1975) + 100 (1976)
Cochime	Berre	180	
Ethylene Plastique (CdF Chimie)	Lillebonne and Mont	235	+ 100 (1976)
CdF Chimie	Carling, Dunkirk	120	+ 115 (1975) + 150 (later)
ICI	Fos	80	
Total France		925	
GERMANY, WEST			
BASF	Ludwigshafen	30	closing down
Erdolchemie	Koln	135	+ 65 (1975) + 200 (1980)
ROW	Wesseling	620	+ 120 (1975)
Ruhrchemie	Oberhausen	100	+ 75 (1976)
Vestolen	Gelsenkirchen	200	
Total Germany, West		1 085	

TABLE IV.M.5.
(contd)

ITALY			
Montedison	Brindisi, Ferrara Priolo	320	+ 50 (1976)
ANIC	Gela, Ragusa	200	planned expansions
SIR	Porto Torres	130	
SISAS	Milan	-	100 (1975)
Rumianca	Cagliari	70	
Total Italy		720	
NETHERLANDS			
Dow	Terneuzen	150	+ 50 (1976)
ICI	Rozenburg	150	
DSM	Beek, Eemshaven	200	+ 55 (1975) + 200 (1978) + 200 (1982)
Total Netherlands		500	
NORWAY			
Saga	Bamble	-	50 (1977) + 50 (1978)
PORTUGAL			
CNP	Sines	-	120 (1979)
SPAIN			
Alcudia	Puertollano	70	+ 50 (1975) + 100 (1976)
UERT	Huelva	-	+ 100 (1976) + 150 (1978)
Saera	Tarragona	-	100 (1976)
Dow Quimica Iberica	Tarragona	100	+ 45 (1976)
Total Spain		170	
SWEDEN			
Unifos	Stenungsund	145	+ 200 (1977)
UNITED KINGDOM			
BXL	Grangemouth	100	
ICI	Wilton	230	+ 15 (1976)
Monsanto	Fawley	50	
Shell	Carrington	90	
Total United Kingdom		470	
TOTAL WESTERN EUROPE		4 505	+>3 235

b) Demand

The 1974 LDPE end use pattern is shown in Table IV.M.6.

TABLE IV.M.6.

1974 W. EUROPEAN LDPE CONSUMPTION, BY END USE

(thousand tonnes)

Film and sheet	2 325	68%
Injection moulding	410	12%
Blow moulding	171	5%
Extrusion coating	171	5%
Other	342	10%
Total demand	3 419	100%

The consumption of LDPE is entirely dominated by its use in film and sheet form, which accounts for two-thirds of the total consumption. Approximately three-quarters of all LDPE is processed by extrusion.

Demand is forecast to reach 6 740 thousand tonnes by 1980.

c) Supply/Demand Analysis

The potential supply/demand situation for LDPE in W. Europe is summarised in Table IV.M.7. This is based on supply from existing and announced plants only.

TABLE IV.M.7.

W. EUROPEAN SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	4 036	4 621	6 770	6 950
Projected Demand	3 419	3 000	6 740	9 120
Surplus/(Deficit)	617	1 621	30	(2 170)

* 90 percent nameplate

\+ estimated actual

Announced plans for LDPE capacity in Europe would appear to be sufficient through to the end of the decade. However plant is likely to be under-utilised owing to the shortage of ethylene.

4. Japan

a) Supply

The current installed capacity is 1 303 thousand tonnes. The LDPE producers and their respective capacity levels are detailed in Table IV.M.8. No specific expansion plans are known but there is expected to be an additional 500 thousand tonnes by 1980.

TABLE IV.M.8.

JAPANESE LDPE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY
Sumitomo Chemical	Ohe	100
Sumitomo Chiba Chemical	Chiba	130
Mitsubishi Petrochemical	Yokkaichi	215
	Kashima	50
Mitsui Polychemical	Ohtake	60
	Chiba	90
Nippon Unicar	Kawasaki	159
Asahi Dow	Kawasaki	35
	Mizushima	80
Ube Kosan	Chiba	100
	Sakai	50
Toyo Soda	Nan-yo	64
	Yokkaichi	20
Nippon Sekiyu Kagaku	Kawasaki	60
Showa Yuka	Ohita	30
Mitsubishi Chemical	Mizushima	60
Total Japan		1 303

b) Demand

The 1974 demand for LDPE is estimated at 950 thousand tonnes and is projected to rise at just over 5 percent per annum for the next few years of restricted growth and

The remaining countries, Rumania, Poland and Yugoslavia are in the position that whilst they have adequate xylene capacity it is largely in the form of mixed isomers and requires the development of separation facilities to realise sufficient p-xylene supplies to meet the growth in the fibre industry through to 1985.

- Africa
  Any p-xylene demand which develops in S. Africa, will be met by imports, although they are much more likely to import the fibre acid monomers. Should a decision be made to alternatively produce p-xylene domestically, BTX recovery facilities will be incorporated in one of the refinery expansions.

- Asia/Pacific
  This area has no current market for p-xylene and countries like Australia, India and Hong Kong do not foresee any activity in this chemical before 1985.

  There will be over 200 000 tonnes surplus in 1980, mostly concentrated in Indonesia and unless further DMT/TPA plants are installed this will all be released onto the export market. Taiwan is building up a substantial fibre industry, but will achieve a balanced situation with parallel p-xylene capacity. Korea will also be in the same position by the mid eighties.

  Although some of the lesser countries in this region may have a slowly developing fibre industry they deal only in DMT/TPA as the scale of demand does not warrant the production of the starting material, p-xylene.

then recover to around 7 percent giving a 1980 consumption level of 1 120 thousand tonnes.

The end use split for Japan is shown in Table IV.M.9.

TABLE IV.M.9.

1974 JAPANESE LDPE CONSUMPTION, BY END USE
(thousand tonnes)

Film	551	58%
Extrusion coating	124	13%
Wire coating	76	8%
Injection moulding	66	7%
Others	133	14%
Total	950	100%

c) Supply/Demand Analysis

The supply/demand situation for LDPE in Japan is summarised in Table IV.M.10.

TABLE IV.M.10.

JAPANESE LDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	1 173	1 173	1 630	1 630
Projected Demand	950	870	1 120	1 570
Surplus/(Deficit)	223	303	510	60

* 90 percent capacity

+ estimated actual

5. Rest of Non-Arab World

a) Supply

A list of LDPE producers in the Rest of the Non-Arab world is given in Table IV.M.11, together will 1974 capacities and expansion plans if known.

TABLE IV.M.11.

REST OF NON-ARAB WORLD LDPE ESTIMATED NAMEPLATE CAPACITIES, 1974

(Thousand tonnes)

COUNTRY	CAPACITY	EXPANSION
CANADA	286	+100
LATIN AMERICA		
Argentina	33	+ 27
Brazil	170	+100 (1976)
Andean Region	64	+ 23 (1976) + plans
Mexico	33	
Total Latin America	300	+>150
E. EUROPE		
USSR	144	+120 (1975)
E. Germany	64	
Rumania	64	+ 60 (?)
Czechoslovakia	72	+ 18 (1980)
Bulgaria	90	plans
Poland	100	
Hungary	36	
Yugoslavia	20	+ 60 (1975)
Total E. Europe	[illegible]	+258
AFRICA	66	+ 50 (plans)
ASIA/PACIFIC		
ASEAN Countries	96	+200 (1976) +100 (1978)
Australia	83	+ 40 (1975)
India	110	
Taiwan	80	
Korea	100	
Iran	-	60 (1977, delayed)
Turkey	78	
Pakistan	-	16 (plans)
Total Asia/Pacific	547	+>416
Total Rest of Non-Arab World	1 704	

b) Demand

- Canada

  Canada currently consumes 233 thousand tonnes of LDPE. Assuming growth rates approximate US levels this will rise to 380 thousand tonnes by 1985.

- Latin America

  Argentinean demand in 1974 amounted to almost 70 000 tonnes, Brazil 120 000 tonnes, the Andean region uses about 50 000 tonnes, and Mexico required around 80 000 tonnes.

- E. Europe

  Demand for LDPE in 1974 was 470 000 tonnes. This will almost double by 1985, which is quite slow growth when compared with HDPE.

- Africa

  Demand for LDPE in this region is of the order of 150 000 tonnes.

- Asia/Pacific

  The total regional demand for 1974 was about 543 thousand tonne, 40 percent of which can be attributed to the ASEAN community, with Australia the next biggest consuming entity at 95 000 tonnes.

c) Supply/Demand Analysis

The supply/demand balances for the Rest of the Non-Arab World's LDPE is given below in Table IV.M.12.

TABLE IV.M.12.

REST OF THE NON-ARAB WORLD LDPE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	207	360	360
Forecast Demand	233	290	380
Surplus/(Deficit)	(26)	70	(20)
LATIN AMERICA			
Potential Supply	260	400	400
Forecast Demand	350	450	620
Surplus/(Deficit)	(90)	(50)	(220)
E. EUROPE			
Potential Supply	500	710	890
Forecast Demand	470	670	920
Surplus/(Deficit)	30	40	(30)
AFRICA			
Potential Supply	40	80	180
Forecast Demand	150	300	450
Surplus/(Deficit)	(110)	(220)	(270)
ASIA/PACIFIC AREA			
Potential Supply	490	900	900
Forecast Demand	543	840	1 320
Surplus/(Deficit)	(53)	60	(420)

+ estimated actual

- **Canada**
  Canada, traditionally an importer of this material, will soon be in reasonable balance due to the projected expansions.

- **Latin America**
  This region has quite a high consumption relative to its state of development and relies on imported material. Further capacity will have to be installed to prevent large deficits in the 1980's.

- **E. Europe**
  On the whole this region is in balance, and will remain so well until the early 1980's, when a slight deficit will develop.

  Russia the main partner in this community has set herself a consumption target of 523 000 tonnes for 1975, but it is felt that this exceeds domestic production plus the quantity which can be obtained on the open market, and hence this and future demand data have been revised downwards to give the resultant supply/demand situations shown in Table IV.M.12.

  Bulgaria, Czechoslovakia and Poland all have too high production levels for their own needs and can therefore subsidise the other East-Bloc countries.

- **Africa**
  There is a deficit situation at present and this is likely to continue despite the installation of 80 000 tonnes by S. Africa and probable further additions in capacity by Nigeria.

- **Asia/Pacific**

  This area is due to go from one of surplus at the end of the decade to one with a sizeable deficit in the early 1980's. As with HDPE there are several tentative plans to allay this situation e.g in Indonesia and Hong Kong where demand is growing at the highest rate, but as things look at present there will be an increasing dependance on imports for this region over the next 10 years or so.

6. The Arab World

a) Supply

There are a large number of LDPE projects being considered by the Arab States at the present time. These are at various stages of planning and it is impossible to be certain about the outcome of the plans. The following table represents the type of capacity situation which it is believed could develop during the next 10-15 years.

TABLE IV.M.13.

ARAB LDPE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PROPOSED CAPACITY	START-UP DATE
Algeria	48 + (60)?	1976
Morocco, Tunisia, Libya	300	1980's
Egypt	170 + 200	1980's
Iraq	60	1980-81
Kuwait	200 + 250	1981+later
Qatar	(150)	mid 1980's (?)
Saudi Arabia	200 + 200	1982 + 1985
United Arab Emirates	150	1982
Syria, Dubai	150 + 150	1980's
	2 288	

i.e. most of the Arab countries include large scale LDPE units in their petrochemical plans for the next decade. The first due onstream should be the 48 000 plant at Skikda, Algeria. As well as the plants detailed above several of the countries involved are known to have further plans e.g. Saudi Arabia, in addition to the Shell venture and a second complex at Jubayl, expects to build another two polymerisation units bringing the total capacity eventually to almost 1 million tonnes.

b) Demand

The 1974 demand for LDPE in Egypt is about 11 000 tonnes rising to 35 000 tonnes by 1980 and 70 000 tonnes by 1985.

In the North African Arab countries including Egypt present demand stands at around 40 000 tonnes (with a large percentage of this concentrated in Algeria). This is expected to reach around 120 000 tonnes by 1980 and 240 000 tonnes by 1985.

Total LDPE consumption levels in other Arab countries are as follows

1974	1980	1985
20 000	50 000	110 000

c) Supply/Demand Analysis

The supply/demand situation for LDPE in the Arab World is summarised in Table IV.M.14.

The main feature is that at present there is quite substantial consumption of LDPE products but as production will not start before 1976 at the earliest, the Arabs rely entirely on imports to supply their needs. By the 1980's however there are numerous facilities scheduled to provide this requirement and if all plans come to fruition there will be substantial export potential.

TABLE IV.M.14.

ARAB LDPE SUPPLY/DEMAND SITUATION
(thousand tonnes)

	1974	1980	1985
Potential Supply (90% nameplate)	-	100	1 800
Projected Demand	60	170	350
Surplus/(Deficit)	(60)	(70)	1 450

N. PRODUCT ANALYSIS : BENZENE

1. Overview

The world supply/demand situation for benzene is summarised in Table IV.N.1.

TABLE IV.N.1.

WORLD BENZENE SUPPLY/DEMAND SITUATION AS SURPLUS/(DEFICIT)

(thousand tonnes)

	1974	1980	1985
USA	165	(390)	(3 650)
W. Europe	100	1 440	90
Japan	283	(560)	(1 680)
Canada	41	(50)	10
Latin America	187	180	(30)
E. Europe	(66)	(280)	(970)
Africa	(5)	(10)	(40)
Asia/Pacific	492	1 030	920
Arab World	-	-	(220)

Benzene, like most other chemicals experienced a fairly drastic recession in 1975 but a recovery is expected by 1976 in most market areas, probably earliest in the US sector where

6. The Arab World

a) Supply

The proposed p-xylene capacities are listed in Table IV.K.11.

TABLE IV.K.11.

ARAB P-XYLENE PRODUCTION PLANS

(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	40 (+300 mixed xylenes)	1976
Morocco, Tunisia, Libya	-	-
Egypt	50 → 100	1981 - 1983
Iraq, Kuwait, Qatar, Saudi Arabia, UAR	-	-
	140	

NB This is thought to be a conservative total since probably at least another 100 000 tonnes of p-xylene will be incorpated in aromatic complexes.

derivative operations are already picking up considerably. By 1980 growth rates should be back to normal levels.

Production of benzene is closely linked with oil refining and is very much affected by the state of the oil industry and throughput of refineries. In 1973 there was a worldwide shortage of benzene largely brought about by a surge in demand for gasoline in the USA and a reduction in fuel oil demand in Europe causing a shortage of feedstocks for chemical aromatics. This situation has now eased due to the slackening in demand for benzene referred to above.

The benzene market is subject to considerable fluctuation and a simple examination of the supply/demand figures can be misleading. Thus in 1974 although Western Europe has an apparent overcapacity there were considerable imports. Again the 1980 figures indicate plenty of available capacity but there are some doubts about the availability of feedstocks to supply the likely demand.

By 1980 the USA and Japan will need substantial new investment in benzene capacity to meet forecast requirements. In the latter case there are likely to be some difficulties with feedstocks. For the USA the question of feedstock availability is somewhat dependant upon decisions on lead removal from gasoline. If legislation brings about further reduction in lead levels, or even bans lead altogether, this will bring about an increased demand for aromatics in gasoline. The chemical supply may then suffer again as it did in 1973.

The major outlet for benzene is in the production of ethyl benzene for styrene. This accounts for nearly a half of all benzene consumed in the US, Western Europe and Japan. Cumene/phenol and cyclohexane are the other two main applications.

There is considerable world trade in benzene with the direction of movements depending upon feedstock availability, feedstock price and market requirements within a particular area at a particular time. It is therefore difficult to establish any particular pattern to the trade. Western Europe has tended to be a net importer during recent years, both from Eastern Europe and the USA, but this practice is unlikely to continue.

The West European market is highly integrated with two-thirds of the benzene being consumed captively. Three companies account for two-thirds of the merchant business. In the USA 50 percent is merchant with four companies taking over 60 percent of the merchant volume. Substantial volumes of benzene are handled by trading companies who operate mainly in the spot market but are getting increasingly involved in contract business.

Demand for benzene will build up quite rapidly in the Arab States for the supply of the planned styrene facilities. A large proportion of the styrene is reckoned to be exported and so this will have some effect on benzene demand in the markets where the styrene is sold. Nevertheless it seems likely that there will be some problems with benzene supplies in the future particularly in Western Europe and Japan. These two markets might well prove interesting for exports of benzene from the Arab States if prices are competitive and reliability of supply can be demonstrated.

2. USA

a) Supply

Benzene capacity in the United States of America in 1974 was estimated to have been about 5 847 thousand tonnes. Expansions this year brought it up to 6 177 thousand tonnes and a further rise to 6 400 thousand is expected for 1976. Beyond that, capacity levels are uncertain, but 8 200 may be achieved by 1980. A list of US producers, nameplate capacities and 1975 expansion plans is given in Table IV.N.2.

In the United States 81 percent of benzene supply comes from reformate extraction i.e. including hydrodealkylation of crudes (30 percent). 12 percent pyrolysis gasoline (i.e. steam crackers) and 7 percent from coal conversion processes.

In 1974, the production level was 5 051 thousand tonnes.

TABLE IV.N.2.

US BENZENE PRODUCERS, AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
Allied Chem Corp	Winnie, Texas	15	
Amerada Hess Corp	St Croix, VI	65	
American Petrofina (Cosden)	Big Spring, Texas	99	
Ashland	Ashland, Kentucky	198	
	Tonawanda, NY	83	
Atlantic Richfield	Houston, Texas	138	
	Wilmington, Calif	52	
Arco/Union	Nederland, Texas	60	
Charter Int.	Houston, Texas	65	
Cities Services	Lake Charles, La	83	
Coastal States	Corpus Christi, Tex	247	
Commonwealth Oil	Penuelas, PR	627	+ 100 (1975)
Crown Central	Houston, Texas	72	
Dow Chemical	Bay City, Mich.	99	
	Freeport, Texas	165	
Exxon Chem	Baton Rouge, La	270	
	Baytown, Texas	165	
Gulf Oil	Alliance, Tex	230	
	Philadelphia, PA	99	
	Port Arthur, Tex	125	+ 115 (1975)
Marathon Oil	Detroit, Mich	20	
	Texas City, Tex	20	
Mobil Oil	Beaumont, Tex	230	
Monsanto	Alvin, Texas	230	
Pennzoil Utd	Shreveport, La	40	
Phillips Petroleum	Sweeney, Tex.	72	
	Guayama, PR	330	
Shell Oil Co	Deer Park, Tex	215	
	Odessa, Tex	43	
	Wood River, Ill	132	
	Norco, La	-	115 (1975)
Shell Oil	El Dorado, Kan	33	
Southwestern Oil	Corpus Christi, Tex	20	
Std Oil (Calif)	El Segundo, Calif	66	
Std Oil (Indiana)	Texas City	380	
Std Oil (Ohio) BP		50	
Sun Oil Co	Marcus Hook, Pa	50	
	Corpus Christi, Tex	92	
	Tulsa, Okla	83	
Tenneco	Chalmette, La	33	
Texaco Inc	Port Arthur, Tex	165	
	Westville, NJ	198	
Union Carbide	Taft La	165	
	Ponce PR	75	
Union Oil	Lemont, Ill	115	
Union Pacific Corp	Corpus Christi, Tex	33	
US TOTAL		5,847	+ 330

b) Demand

The 1974 consumption of benzene for petrochemical uses was probably of the order of 4.9 million tonnes. This fell drastically to 3.77 million tonnes in 1975. In the long term a recovery to 6.95 million by 1980 is expected to occur.

The break down of demand, by end use is shown in Table IV.N.3.

Ethyl benzene is by far the most important use, taking up almost half of total US benzene requirement.

TABLE IV.N.3.

US BENZENE DEMAND BY END USE, 1974

(thousand tonnes)

		Percent
Ethylbenzene	2 345	48
Cumene	928	19
Cyclohexane	733	15
Maleic Anhydride	195	4
Aniline	195	4
Chlorobenzenes	246	5
Alkylbenzenes	195	4
Others	49	1
Total	4 886	

c) <u>Supply/Demand Analysis</u>

The supply/demand situation for benzene in the United States is summarised in Table IV.B.4.

TABLE IV.B.4.

US BENZENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974*	1975	1980	1985
Potential Supply*	5 061	3 706	6 560	6 560
Projected Demand	4 896	3 770	6 860	10 210
Surplus/(Deficit)	165	(64)	(300	(3 650)

(*assumed at 80, except for 1975 which was only 60 percent, 1974 estimated actuals.)

The US benzene market is currently very depressed but is expected to pick up in 1976 when styrene and cyclohexane starts growing again. Additional capacity will have to be installed by 1980, or enhanced operating rates achieved, to meet this healthier petrochemical demand for benzene.

3. W. Europe

a) Supply

Benzene capacity in W. Europe in 1974 was estimated to have been about 5.9 million tonnes. A list of the producers together with existing capacities and planned expansions is given in Table IV.H.5.

Production of benzene has been well below nameplate capacity in Western Europe over recent years and, although low price and alternate sources were the primary reason, there also appear to be underlying technical limitations. During 1973 there were major engineering problems on a number of European plants at a time when they were running at the highest rate yet attained. A study of U.S. experience indicates that even at a time of acute benzene shortage plants failed to operate at above 90 percent of nameplate capacity. This leads us to believe that there will be operating limitations in Europe even if feedstock supplies can be assured.

TABLE IV.N.5.

W. EUROPEAN BENZENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
AUSTRIA			
ÖMV	Schwechat	85	
*Coal Based production		15	
Total Austria		100	
BELGIUM			
Petrochim	Antwerp	115	
*Coal Based production		35	
Total Belgium		150	
FRANCE			
ATO	Gonfreville	10	150 (1976)
Antar	Donges		
BP	Lavera		200 (1979)
CdF Chimie	Carling	200	
Elf Union	Feyzin	110	
Shell	Berre	30	
SNPA	Lacq	90	
CFR	Gonfreville	70	
*Coal Based Production		140	
Total France		650	+350
W. GERMANY			
Erdölchemie	Dormagen	150	
Gelsenberg	Essen	45	
Marathon	Burghausen	100	
Shell	Godorf	420	
Texaco	Heide	17	
Veba	Gelsenkirchen	270	
Wintershall	Lingen	58	
*Coal Based Production		350	
Total W. Germany		1 410	
ITALY			
ANIC	Gela	65	
Liquichimica	Sibari		(300 date unknown)
Mobil	Naples	110	
Shell	Rho	8	
Montedison	Brindisi	45	
Saras	Sarroch	175	
Sincat	Priolo	250	+450 (1976)
SIR	Porto Torres	100	+170 (1978)
Total	Trieste	8	
Rumianca	Galati		120 (1978)
Esso	Calati		40 (1975)
*Coal Based Production		25	
Total Italy		[illegible]	[illegible]

NETHERLANDS			
Dow	Terneuzen	450	
DSM	Geleen	115	
Esso	Botlek	300	
*Coal Based Production		-	
Total Netherlands		865	
SPAIN			
CEPSA	Algecira	95	
RT	Huelva	125	
Calvo Sotelo	Puertollano		75 (1976
*Coal Based Production		25	
Total Spain		245	+ 75
UNITED KINGDOM			
Conoco	Killingholm	100	
ESSO	Fawley	145	
Gulf	Milford-Haven	190	
ICI	Teesside	450	
Shell	Stanlow	450	+250 (1975) (?)
BP	Grangemouth		250 (1979)
Staveley	Chesterfield	70	
*Coal Based Production		150	
Total United Kingdom		1 555	+500
TOTAL CAPACITY - WEST EUROPE		5 841	+>1 735

b) Demand

Benzene consumption in W. Europe in 1974 was estimated to have been 4.0 million tonnes.

The relative importance of the various end-uses is shown in Table IV.N.6.

TABLE IV.N.6.

1974 W. EUROPEAN BENZENE CONSUMPTION, BY END USE

(thousand tonnes)

Ethylbenzene	1 770	44%
Cumene	710	18%
Cyclohexane	750	19%
Maleic Anhydride	120	3%
Miscellaneous	650	16%
	4 000	100%

Clearly ethylbenzene (for styrene production) dominates the demand pattern, with cumene (for phenol) and cyclohexane (for nylon) the only other important end-uses.

c) Supply/Demand Analysis

The potential supply/demand situation for benzene in Western Europe is summarised in Table IV.N.7.

This is based on supply from existing and announced plants only.

b) Demand

In 1974 Arab demand for p-xylene was almost negligible. It is anticipated that no significant demand will develop until the early eighties, when polyester fibre plants are scheduled to come onstream in Algeria, Egypt, Iraq and possibly elsewhere.

Integrated p-xylene, DMT, polyester fibre projects are likely.

c) Supply/Demand Analysis

The supply/demand situation for p-xylene summarised in Table IV.K.12.

TABLE IV.K.12.

ARAB P-XYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974	1980	1985
Potential Supply	-	90	130
Projected Demand	-	-	100
Surplus/(Deficit)	-	90	30

TABLE IV.N.7.

W. EUROPEAN SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	4 100	5 257	6 900	7 130
Demand	4 000	3 800	5 460	7 040
Surplus/(Deficit)	100	1 457	1 440	90

* 90 percent nameplate capacity

\+ estimated actual

It is evident that, feedstock permitting, there should be adequate supply of benzene in W. Europe well into the eighties.

4. Japan

a) Supply

The 1974 benzene capacity in Japan was estimated at 2 375 thousand tonnes. Table IV.N.9. lists the producers, together with existing nameplate capacity and any known expansion plans. Plans for 1980 will boost total capacity to 3 090 thousand tonnes but details of exact locations of such units are not known.

TABLE IV.N.9.

JAPANESE BENZENE PRODUCERS, AND ESTIMATED NAMEPLATE CAPACITIES, 1974

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSIONS, YEAR
Asia Oil	Yokohams	100	
	Mizushima	160	
General Sekeyu	Osaka	30	
Idemitsu Petrochemical	Tokuyama	170	+ 100 (1975)
Kawatitsu Chemicals	Mizushima	40	
Maruzen Oil	Matsuyama	8	
Maruzen Petrochemical	Chiba	159	
Mitsubishi Oil	Kawasaki	4	
	Mizushima	134	
Mitsubishi Petrochemicals	Yokkaichi, Kashima	356	+ 85 (1976)
Nippon Petrochemicals	Kawasaki, Ukishima	248	
Nippon Steel	Oila, Herohala	182	
Sanyo Petrochemicals	Mizushima	230	
Shin-Daikyowa Pet.	Yokkaichi	79	+ 100 (1975)
Toa Oil	Chiba	84	
Tonen Sekiyukagaku	Wakayama	40	
Toray Industries	Ukishima	83	
Ube Industries	Mizushima	-	100 (1977)
Yawata Chemicals	Oita	120	
	Total Japan	2 375	+ 385

b) Demand

The 1974 consumption level was estimated at 1 855 thousand tonnes, very slightly lower than the previous year. In 1975 it will decrease to 1 622 thousand tonnes (i.e. only 63 percent of capacity utilisation) but thereafter a recovery is anticipated and growth rates of around 8.8 percent are foreseen through to 1980.

The end use pattern for benzene consumption is detailed in Table IV.N.9.

TABLE IV.N.9.

JAPANESE BENZENE CONSUMPTION, BY END-USE, 1974

(thousand tonnes)

		Percent
Styrene	900	48
Cyclohexane	475	26
Cumene/Phenol	280	15
Maleic Anhydride	35	2
Alkyl Benzene	65	4
Others	100	5
Total	1 855	100%

c) Supply/Demand Analysis

The supply/demand situations is summarised in Table IV.N.10.

TABLE IV.N.10.

JAPANESE BENZENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	2 138	1 650	2 640	3 200
Projected Demand	1 855	1 622	3 200	4 880
Surplus/(Deficit)	283	28	(560)	(1 680)

+ estimated actual

(*85-90 percent nameplate, expect for 1975 when production is as low as 64 percent capacity)

5. Rest of Non-Arab World

a) Supply

A list of benzene producers in the Rest of the Non-Arab world is given in Table IV.N.11, together with 1974 capacities, and expansions plans, which have been announced.

TABLE IV.N.11.

REST OF NON-ARAB WORLD BENZENE ESTIMATED NAMEPLATE CAPACITIES, 1974

(thousand tonnes)

COUNTRY		CAPACITY	EXPANSIONS, YEAR
CANADA		389	+ 340 (by 1985)
LATIN AMERICA			
Argentina		70	+ 30
Brazil		180	+ 115 (1978)
Andean Zone		150	
Mexico		340	
	Total	710	+ 145
E. EUROPE			
USSR		1 600	+ 100 +
E. Germany		300	expansion plans
Rumania		120	
Czechoslavakia		180	
Bulgaria		40	
Poland		180	+ 220 (1971-8)
Hungary		90	
Yugoslavia		100	
	Total	2 610	+>320
AFRICA			
South		42	-
East, West		-	
	Total	42	
ASIA/PACIFIC			
ASEAN Countries		500	+ 505 (1976-8)
Australia/New Zealand		80	
India/Burma		162	+ 24 (1976)
Taiwan/Hong Kong		-	54
Korea		105	+ 51
Turkey		20	
Pakistan		-	
Iran		-	145 (1977 delayed)
TOTAL ASIA/PACIFIC		867	+ 750
TOTAL REST OF NON-ARAB WORLD		5 378	

Supply is definitely higher than this level as there are several general BTX facilities throughout this area which produce benzene streams, depending on demand at any given time.

b) Demand

- Canada
  The 1974 benzene consumption was estimated at 269 000 tonnes.

- Latin America
  The regional demand for Latin America, including Mexico in 1974 was stated at 383 000 tonnes. Mexico consumption constitutes about one third of this total.

- Eastern Europe
  Chemical demand in 1974 was set at 2 355 000 tonnes but only actually achieved 1 906 000 tonnes.

- Africa
  The 1974 consumption level for benzene in Africa is 40 000 tonnes.

- Asia/Pacific
  Demand levels in S. E. Asia for 1974 was estimated at 203 000 tonnes.

c) Supply/Demand Analysis

The supply/demand situation for benzene in the Rest of the Non-Arab World is summarised in Table IV.N.12.

TABLE IV.N.12.

REST OF THE NON-ARAB WORLD BENZENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1980	1985
CANADA			
Potential Supply	310	310	520
Forecast Demand	269	360	510
Surplus/(Deficit)	41	(50)	10
LATIN AMERICA			
Potential Supply	570	690	690
Forecast Demand	383	510	720
Surplus/(Deficit)	187	180	(30)
E. EUROPE			
Potential Supply	1 840	2 100	2 370
Forecast Demand	1 906	2 380	3 340
Surplus/(Deficit)	(66)	(280)	(970)
AFRICA			
Potential Supply	35	40	40
Forecast Demand	40	50	80
Surplus/(Deficit)	(5)	(10)	(40)
ASIA/PACIFIC AREA			
Potential Supply	695	1 300	1 300
Forecast Demand	203	270	380
Surplus/(Deficit)	492	1 030	920

+ estimated actual

- **Canada**

  In Canada there is adequate capacity at present and the installation of large plants by 1985 will alleviate the shortage which is forecast to develop beyond 1980.

- **Latin America**

  Here there is an overcapacity situation, and will continue to have until the 1980's when demand for styrene and ethylbenzene plants will cause a reversal of the situation.

- **Eastern Europe**

  There is a general policy towards self-containment. The benzene and derivative industry is large and the growth potential high, and unless large capacity additions are planned for the next 10 years vast deficits will occur. Russia is the largest producer and consumer and is traditionally an exporter of the material, but this situation is soon to end as a balance is achieved within the country.

  E. Germany has to import small quantities of benzene to supplement its domestic production as does Rumania and Bulgaria.

  Czechoslovakia and Polish derivative plants use up domestic production to the full, whereas Hungary and Yugoslavia tend to have low consumption levels and hence surplus available for export.

- **Africa**

  Demand at present slightly exceeds production and with no plans to add capacity over the next decade an increasing deficit situation will develop.

- Asia/Pacific
  S. E. Asia is an area of great overcapacity and is likely to become more so in the next decade as derivative capacity does not keep pace with benzene capacity being installed.

6. The Arab World

a) Supply

There is no benzene capacity at present in the Arab World but several aromatic complexes are planned. The most firmly defined of these are listed in Table IV.N.13.

TABLE IV.N.13.

ARAB BENZENE PRODUCTION PLANS
(thousand tonnes)

COUNTRY	PLANNED CAPACITY	START-UP DATE
Algeria	335	1980's
Egypt	155	1980's
Total	490	

Further major benzene capacity is expected within the Arab World by the mid 1980's (probably including Kuwait and Iraq).

b) <u>Demand</u>

In the absence of styrene production, demand for benzene in the Arab market is almost negligible at present and it will probably be into the 1980's before there are any sizeable demands for benzene as a feedstock

By 1985 Algeria will probably need around 700 000 tonnes, Egypt 90 000 tonnes and the OAPEC countries about 100 000 tonnes for styrene and ethylbenzene plants in Kuwait and Iraq.

c) <u>Supply/Demand Analysis</u>

The supply/demand situation for benzene in the Arab World is summarised in Table IV.B.14

It can be seen that there is going to be a deficit of benzene by 1985 unless other countries incorporate aromatics complexes in their refinery schemes. It is anticipated that this will in fact occur, and demand for benzene in derivative units will always be matched by additional local benzene capacity. Based upon the most firmly announced plans to date, however, the apparent situation is as shown.

<u>TABLE IV.B.14</u>

<u>ARAB BENZENE SUPPLY/DEMAND SITUATION</u>

(thousand tonnes)

	1978	1980	1985
Potential Supply	-	-	[illegible]
Projected Demand	-	-	[illegible]
Surplus/(Deficit)	-	-	(290)

There is no p-xylene interest at present, but capacity installed in the 1980's will include some for export as there is insufficient developing demand.

Algeria, Egypt and Iraq are the only countries which plan to incorporate DMT or TPA units in their petrochemical projects otherwise demand will not be created to take up the domestic production of p-xylene.

P. PRODUCT ANALYSIS : LIQUID ETHYLENE

1. Overview

The world supply/demand situation for ethylene is summarised in Table IV.P.1.

TABLE IV.P.1.

WORLD ETHYLENE SUPPLY/DEMAND SITUATION AS SURPLUS/(DEFICIT)

(thousand tonnes)

	1979	1984	1990
USA	-	(400)	(300)
W. Europe	1 100	(10)	(1 520)
Japan	200	130	(2 270)
Canada	(140)	190	200
Latin America	(115)	(10)	(700)
E. Europe	(120)	136	(20)
Africa	45	(20)	200
Asia/Pacific	(200)	210	750
Arab World	-	(30)	1 000

The ethylene business has been seriously affected by a number of factors including price and availability of feedstocks, and the worldwide economic recession which has reduced derivative consumption. However whilst it has been necessary to reduce the level of forecast demand, in practically all end uses, there is still a considerable level of growth expected for ethylene.

During the late sixties and early seventies demand for ethylene in the major markets of the USA, Western Europe and Japan was increasing at an average rate of 10-15 percent p.a. In 1975 demand was down by about 8 percent in the USA and W. Europe and 16 percent in Japan. Recovery is forecast to take place during 1976 but future growth rates have been put at 7-8 percent p.a. In spite of this forecast reduction in growth substantial new investment will be required, in all markets to supply estimated demand in the 1980's. Thus by 1985 it is forecast that the USA will require about 10 million tonnes per annum of new capacity, Western Europe about 7 million tonnes and Japan approximately 3 million tonnes.

The rapid increases in the demand for ethylene have been brought about by the development of the plastics industry, particularly thermoplastics. Ethylene is a component of four of the five major thermoplastics and these account for about 70 percent of ethylene requirements.

Ethylene movement is presently limited to very small quantities going by ship and intercompany movements within an ethylene pipeline. Such pipelines exist in the UK, Northern Europe linking Belgium, Netherlands and Germany, Southern France and the Gulf coast of the USA. In addition there are limited systems in Japan and a considerable network planned for linking the COMECON countries in Eastern Europe.

The limitations on ethylene movement indicated above mean that a high proportion of ethylene is consumed captively. The only merchant business takes place between producers and consumers linked to a pipeline. However even in this situation there is not the freedom of operation that is normally associated with a true merchant market.

The economics of moving liquid ethylene from the Arab States is discussed in Section IX. The following points are made with regard to the possible marketing strategy that could be considered.

A prime requirement for a company seeking to secure ethylene is reliability of supplies. A great deal of capital is tied up in downstream plants and therefore every effort is made to ensure that they are operating at the maximum level. It is therefore most unlikely that any company will be willing to make its plants wholly dependent upon ethylene shipped by sea from a distant location. Not only this but there is the added physical distribution problem of transporting seaborne ethylene to the final location where it will be used. In these circumstances it appears interesting for the Arab States to investigate the possibility of an ethylene terminal linked to an established pipeline system. This could offer a number of advantages to both producers and consumers. For the former it could mean:

shared cost in terminal and storage facilities
greater flexibility in adjusting output
co-operative marketing organisation

For the consumers there would be:

a greater security of supply
opportunity to use established physical distribution system

Of course this scheme presupposes that a satisfactory arrangement can be made with the pipeline operators and users. It does, however, appear to offer the only feasible means for direct ethylene sales.

As a complementary feature of such a scheme consideration might also be given to establishing an Arabian Gulf pipeline system. This could assist in levelling supply/demand fluctuations that may occur in the area due to the linking of derivative plants, and could provide an effective means of supplying a shipping terminal.

2. USA

a) Supply

The 1974 nameplate capacity for ethylene in the US is 11 248. During the early part of 1975 a reduced demand has limited production of petrochemicals but there will be a slight increase in ethylene production capacity during this year. The 454 000 tonne Amoco unit is the only new facility scheduled to come onstream. This was timed for mid-1975 and along with the Mobil and Eastman expansions would raise the installed ethylene capacity in the US to about 11.8 million tonnes/year. During the 1975-80 period general petrochemical production will grow, due to the construction of new refining and petrochemical facilities, and new olefin plants to be commercialised in the 1975-80 period will lift the US ethylene nameplate to 16.6 million tonnes/year (It is perhaps a bit optimistic to expect production to parallel this growth as feedstock uncertainties will persist, contractors will be strained and plant construction will probably continue to be delayed)

Almost all the ethylene in the US is obtained by steam cracking, with only very small quantities being recovered from refinery gas.

US ethylene producers and estimated nameplate capacities are given in Table IV.P.2.

TABLE I-[illegible]

UNITED STATES ETHYLENE [illegible]

NAMEPLATE CAPACITY, [illegible]

(thousand tons)

(**E = Ethane** P Propane N = Naphtha [illegible] Field Condensate G = Gas Oil)

Company	Location	Source, Ref[illegible]	Capacity	Expansion, Year
Allied/BASF/Marbon	Geismar, La	SC - E/[illegible]	318	
Amoco	Texas	SC [illegible]	-	454 (1975) + 454 (197[illegible])
ARCO	Wilmington, Calif	R/SC [illegible]	3[illegible]	+ 591 (197[illegible])
ARCO/Polymers	Houston, Texas	SC - E/[illegible]	22[illegible]	+ 591 (197[illegible])
Chemplex	Clinton, Iowa	SC [illegible] E/P	22[illegible]	
Cities Service	Lake Charles, La	R/SC [illegible]	42[illegible]	
Continental	West Lake, La	[illegible] - E	29[illegible]	
Corco/PPG	Pen[illegible], [illegible]	SC - N/G	4[illegible]4	
Dart/El Paso	Odessa, Texas	[illegible] E/P	2[illegible]	
Dow	Bay City, Michigan	SC [illegible] N	[illegible]	
	Freeport, Texas	SC [illegible]	1,04[illegible]	+ 454 (1978-9)
	Plaquemine, La	[illegible]	454	
DuPont	Orange, Texas	SC [illegible]	341	
Exxon	Baton Rouge, La	R/SC [illegible]	[illegible]	+ 91 (197[illegible])
	Baytown, Texas	R	4[illegible]	
Goodrich	Calvert City, Ky	SC [illegible]	159	
Gulf	Cedar Bayou, Texas	R/[illegible]	18[illegible]	+ 545 (1976)
	Port Arthur, Texas	R/SC [illegible]	52[illegible]	
Jefferson	Port Neches, Texas	SC [illegible]	2[illegible]	
Mobil	Beaumont, Texas	R [illegible] N	21[illegible]	+ 104 (197[illegible])
Monsanto	Alvin, Texas	[illegible]	[illegible]	
	Texas City, Texas	[illegible]	[illegible]	
Northern Petrochemical	Joliet, Illinois	[illegible]	[illegible]	
[illegible]lin	Brand[illegible]		[illegible]	
Phillips	[illegible]	[illegible]		
Shell	Deer Park, Texas	[illegible]	[illegible]	
	Deer Park, [illegible]	[illegible]	[illegible]	
	Nor[illegible]		[illegible]	+ [illegible]
Sun Olin	[illegible]	R/SC [illegible]	[illegible]	
Texaco	[illegible]	[illegible]	[illegible]	+ 454 (197[illegible])
Texas Eastman	[illegible]		[illegible]	+ [illegible]
Union Carbide	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	+ [illegible] (197[illegible])
	Texas [illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	
	[illegible]		[illegible]	
	[illegible]		[illegible]	+ [illegible]
[illegible] Industrial	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	+ [illegible]

b) Demand

Historically ethylene demand has grown at 11.5 percent/yr. In 1974, demand was limited by supply to 10 540 tonnes, a growth rate of only 3.3 percent over the 1973 level. Under conditions of unlimited supply ethylene demand would be expected to grow by 7.5-8 percent/yr during the remainder of the decade. However, as production in 1980 is only expected to be 14.99 million tonnes, demand is projected to increase to 15.91 million tonnes.

The 1974 consumption pattern for ethylene is shown in Table IV.P.3.

TABLE IV.P.3.

1974 US ETHYLENE CONSUMPTION, BY END-USE

(thousand tonnes)

		Percent
Low Density Polyethylene	2 890	27.4
High Density Polyethylene	1 414	13.4
Ethylene Oxide/Glycol	1 900	18.0
Vinyl Chloride	1 264	11.9
Ethylbenzene/Styrene	960	9.1
Ethyl Alcohol	450	4.3
Acetaldehyde	396	3.8
Linear Alcohols	256	2.4
Linear Alpha Olefins	177	1.7
Vinyl Acetate	210	1.9
Ethylchloride	136	1.3
Other	495	4.8
	10 540	100

c) Supply/Demand Analysis

The supply/demand situation for ethylene in the United States is summarised in Table IV.P.4. Supply is taken at 90-95 percent of the nameplate capacity.

TABLE IV.P.4.

US ETHYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply	10 540	11 111	15 460	(22 000)*
Projected Demand	10 540	9 800	15 910	22 320
Surplus/(Deficit)	-	2 311	(450)	(320)

(*estimate)

+ estimated actual

Ethylene will become increasingly tight, as long as demand for its end-products remains unrestricted.

3. W. Europe

a) Supply

The 1974 nameplate capacity is estimated to have been 12 365 thousand tonnes. Table IV.P.5. lists all European manufacturers together with capacities and expansion plans. The tabulation also gives information on feedstocks utilised and an indication of the cracking severity, where this information was available. Several older plants have been shut down (thus explaining the absence of plant No. 1 in some instances). In addition to the manufacturers shown several companies have announced their intentions of becoming ethylene producers e.g. SKAB, Sweden and Petrosul, Portugal but commissioning would be unlikely before 1980 in the present climate.

In addition to the capacity shown, several companies have announced their intentions of starting up new operations in the 1980's. These are as follows:

. CdF/Qatar, France	450 000	tonnes
. Shell/Napthachemie, France	450 000	
. Texaco, W. Germany	325 000	
. Veba, W. Germany	400 000	
. DSM, Netherlands	450 000	
. ERT, Spain	450 000	
. Shell/Esso, UK	500 000	
	3 025 000	

[illegible] CAPACITY, 1974

(thousand tonnes)

Company		Location	Feedstock	C_2/C_3 Product Wt. Ratio	Capacity	Expansions, Year
AUSTRIA						
ÖMV		Schwechat	Naphtha	.55	140	-
BELGIUM						
Petrochim		Antwerp	Naphtha Naphtha	.50 45	200 300	+ 30 (1975)
Total Belgium					500	
DENMARK						
Maersk		Copenhagen	Naphtha	.70	50	
FINLAND						
Neste Oy		Skoldvik	Naphtha	.50	125	+ 25 (1976)
FRANCE						
Association Vapocraqueur		Feyzin	Naphtha	.50	200	+ 200 (1978)
ATO		Lacq	Ethane	-	100	
	1	Gonfreville	Naphtha	.65	60	
	2			.50	320	
CdF Chimie	1	Carling	Naphtha	.50	200	+ 20 (1976)
	2			.50	-	200 (1975)
Esso		Port Jerome	Nap/G.O	-	250	
Naphthachimie						
	1	Lavera	Naphtha	.75	130	close down (1976)
	4	Lavera	Naphtha	.70	[illegible]	
	5	Lavera	Naphtha	.60	-	[illegible] (1976)
Shell		Berre	Naphtha	.60	115	
Total France					[illegible]	
GERMANY						
BASF		Ludwigshafen	Crude Naphtha	 .55	35 170	
Caltex		Raunheim	Naphtha Naphtha	.66 .55	90 [illegible]	
Erdölchemie	3	Dormagen	Naphtha	.70	[illegible]	
	4	Dormagen	Naphtha	.55	160	+ 300 (1979/80)
Esso	1	Köln	Naphtha	.55	120	close 1980
	2	Köln	Naphtha	.50		350 (1977/8)
Gelsenberg		Münchmünster	Naphtha	.50	200	
		Gelsenberg				300 (1979/80)
Hoechst		Frankfurt	Naphtha	HTP process	50	close down
[illegible]		Burghausen	Naphtha	.55 approx	[illegible]	
ROW	3	Wesseling	Naphtha	.50	200	
	4	Wesseling	Naphtha	.50	320	
	5	Wesseling	Naphtha	.50	[illegible]	
Texaco		Heide	Naphtha	.70	75	
[illegible]						
Kraftstoff	1	Wesseling	Naphtha	.60	75	
	2	Wesseling	Naphtha	.60	200	
	3	Wesseling	Naphtha		300	
Veba Chemie	1	Gelsenkirchen-Scholven	Naphtha	.61	50	

L. PRODUCT ANALYSIS : DMT/TPA

1. Overview

The primary market for DMT and TPA is in polyester fibre and film. As the demand for these products varies, so do the DMT/TPA demand levels.

The world supply/demand situation for DMT/TPA is summarised in Table IV.L.1.

TABLE IV.L.1.

DMT/TPA SUPPLY/DEMAND SUMMARY
AS SURPLUS/(DEFICIT)
(thousand tonnes)

	1974	1980	1985
USA	222	570	(1 130)
W. Europe	618	930	570
Japan	596	640	240
Latin America/Canada	(230)	(400)	(730)
E. Europe	(32)	(230)	(< 520)
Asia/Pacific	(180)	(210)	(720)
Arab World	-	(40)	-

There has been a dramatic turnaround in the worldwide DMT/TPA market in the period 1974-75 owing to the severe downturn in the textile industry which has taken place during this time.

Company		Location	Feedstock	C_2/C_3 Product Wt. Ratio	Capacity	Expansions, Year
	3	Gelsenkirchen	Naphtha	.80	600	
Total Germany					3000	
ITALY						
ANIC		Ravenna	Ref. Gas	-	100	
		Gela	Naphtha	-	240	
Montedison		Brindisi	Nap/G.O.	.65	300	+ 90 (1980's)
		Ferrara	Naphtha	.65	65	close down (1976)
		P. Marghera	Naphtha	.65	250	+ 250 (1978)
		Mantova	Naphtha	.66	60	close down (1976)
		Priolo	Naphtha	.60	285	+ 225 (1976/7) + 225 (1980's)
Rumianca		Cagliari	Naphtha	70	65	close down (1976)
		Cagliari	Naphtha	.50	-	100 (1976) + 200 (197
SIR	1	Porto Torres	Naphtha	.50	305	
	2	Porto Torres	Naphtha	.50	-	250 (1978)
Solvay		Rosignano	Naphtha	-	50	
Total Italy					1700	
NETHERLANDS						
[illegible]	1	Terneuzen	Naphtha	.50	400	+ 50 (1975) + 50 (1976
	2	Terneuzen	Naphtha	.50	400	+ 50 (1975) + 50 (1976
DSM	2	Geleen	Naphtha	.65	110	
	3	Geleen	Naphtha	.50	300	
Gulf		Rotterdam	Naphtha	.65	300	
Shell	1	Pernis	Gas	-	10	
	2	Pernis	Naphtha	70	190	
		Moerdijk	Nap/G.O.	.50	300	+ 100 (1975) + 25
Total Netherlands					[illegible]	
NORWAY						
Noretyl		Rafnes	Ethane/Propane	-	-	300 (1977)
SPAIN						
Empetrol	1	Puertollano	Naphtha	.50	70	
	2	Puertollano	Naphtha	.50	200	
	1	Tarragona	Naphtha	.50	-	300 (1976) + 125 (1
[illegible]	2	Tarragona	Naphtha	50	70	+ 300 (197
Total Spain					340	
SWEDEN						
Esso		Stenungsund	Naphtha	.60	300	
[illegible]		Stenungsund	Naphtha	.50	-	400 (1979/80)
Total Sweden					300	
UNITED KINGDOM						
B.P. Chemicals	1	Grangemouth	Naphtha	.60	60	
	3	Grangemouth	Naphtha	60	270	
	1	Baglan Bay	Naphtha	.60	50	
	4	Baglan Bay	Naphtha	50	400	
Courtaulds		Spondon	Naphtha	70	30	
Esso		Fawley	Naphtha	60	100	
ICI		Wilton	Naphtha	50	200	
		Wilton	Naphtha	[illegible]	[illegible]	
[illegible]		Wilton	Naphtha			
[illegible]		Carrington	Naphtha	[illegible]	[illegible]	[illegible]
Total United Kingdom					[illegible]	
[illegible]					[illegible]	[illegible]

b) Demand

The 1974 demand based on derivative requirements was estimated at 10 100 thousand tonnes. The breakdown by end use is given in Table IV.P.6.

TABLE IV.P.6.

1974 W. EUROPEAN ETHYLENE DEMAND, BY END USE

(thousand tonnes)

		Percent
LDPE	3 899	38.6
HDPE	1 466	14.5
VCM	1 667	16.5
Ethyl Benzene	747	7.4
Ethylene Oxide	1 404	13.9
Others	919	9.1
Total:	10 100	100

c) Supply/Demand Analysis

The supply/demand situation for ethylene in W. Europe is summarised in Table IV.P.7.

TABLE IV.P.7.

W. EUROPEAN ETHYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	11 200	11 600	14 990	18 520
Projected Demand	10 100	9 220	15 000	22 040
Surplus/(Deficit)	1 100	2 380	(10)	(3 520)

* 90% namplate

\+ estimated actual

In view of the reduced demand for many products the ethylene shortage forecast for Europe will certainly not develop as early as expected. It is anticipated that installed and planned capacity provide sufficient ethylene through to 1980. Beyond this date substantial new investment will be required, in addition to the 1980's installations mentioned in the supply section notes.

4. Japan

a) Supply

The major ethylene producers in Japan are petrochemical companies, and many of these companies are integrated with large Japanese trading companies. Ethylene production, and the construction of ethylene plants and derivative plants is co-ordinated through the Ministry of International Trade and Industry. Table IV.P.8. shows 1974 Japanese ethylene production capacity and announced new facilities and expansions. Current nameplate capacity is estimated at 4 990 thousand tonnes.

TABLE IV.P.8.

JAPANESE ETHYLENE PRODUCERS AND ESTIMATED NAMEPLATE CAPACITY, 1976

(thousand tonnes)

COMPANY	LOCATION	CAPACITY	EXPANSION PLANS, YEAR
Sumitomo Chemical	Niihama	100	
Sumitomo Chemical	Niihama	-	400 (1977) - to replace above
Sumitomo Chiba Chemical	Chiba	400	
Mitsui Petrochemical	Iwakuni	100	
Mitsui Petrochemical	Chiba	120	
Nippon Petrochemical	Kawasaki	300	
Ukishima Petrochemical	Kawasaki	300	
Ukishima Petrochemical	Chiba	-	400 (1977)
Mitsubishi Petrochemical	Yokkaichi	400	
Mitsubishi Petrochemical	Kashima	300	+ 400 (1977)
Tonen Petrochemical	Kawasaki	350	+ 10 (1976)
New Daikyowa Petrochemical	Yokkaichi	300	
Maruzen Petrochemical	Chiba	400	+ 70 (1976)
Mitsubishi Chemical	Mizushima	170	
Mizushima Ethylene	Mizushima	320	
Sanyo Ethylene	Mizushima	300	+ 40 (1976)
Idemitsu Petrochemical	Tokuyama	300	+ 64 (1976)
Showa Petrochemical	Oita	270	+ 80 (1977)
Osaka Petrochemical	Sakai	300	+ 30 (1977)
Total		6 000	+1 375

b) **Demand**

Ethylene demand in 1974 was estimated at 4 285 thousand tonnes broken down as shown in Table IV.P.9.

TABLE IV.P.9.

1974 JAPANESE ETHYLENE DEMAND, BY END USE
(thousand tonnes)

		Percent
LDPE	1 270	29.7
HDPE	690	16.1
Ethylene oxide	416	9.7
Styrene monomer	357	8.3
Acetaldehyde	430	10.0
VCM	706	16.5
Others	414	9.7
	4 285	100

Demand is expected to be down by 10 percent in 1975 and back up 15-20 percent in 1976. Thereafter growth is forecast at 7 percent through to the end of this decade and level off at around 6 percent in the 1980's.

c) **Supply/Demand Analysis**

The supply/demand situation for ethylene in Japan is summarised in Table IV.P.10.

TABLE IV.P.10.

JAPANESE ETHYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1974+	1975	1980	1985
Potential Supply*	4 490	4 613	5 730	5 730
Projected Demand	4 [illegible]	3 600	5 600	8 000
Surplus/(Deficit)	206	1 013	130	(2 270)

(* operating at 90 percent nameplate

+ estimated actual)

5. Rest of Non-Arab World

a) Supply

The existing capacity for ethylene in the Rest of the Non-Arab World is summarised in Table IV.P.11.

(thousand tonnes)

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	+ [illegible] (by [illegible])
		+ [illegible] (by [illegible])
[illegible]		
Argentina	-	+ [illegible] (by [illegible])
Brazil	[illegible]	+ [illegible] ([illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
		+ [illegible] ([illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
Total	[illegible]	+ [illegible]
[illegible]		
[illegible]	[illegible]	+ [illegible] (by [illegible])
[illegible]	[illegible]	[illegible] ([illegible])
[illegible]	[illegible]	+ [illegible]
[illegible]	[illegible]	[illegible]
Bulgaria	[illegible]	+ [illegible] ([illegible])
Poland	[illegible]	+ [illegible] ([illegible])
Hungary	[illegible]	+ [illegible] (by [illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
		+ [illegible] ([illegible])
Total	[illegible]	[illegible]
[illegible]		
[illegible]	[illegible]	+ [illegible] (by [illegible])
[illegible]		
[illegible]		
[illegible]		+ [illegible] (by [illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
		+ [illegible]
[illegible]	[illegible]	[illegible] ([illegible])
[illegible]	[illegible]	
[illegible]		
[illegible]	[illegible]	+ [illegible] ([illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
[illegible]		[illegible] ([illegible])
[illegible]	[illegible]	+ [illegible] ([illegible])
	[illegible]	+ [illegible]

b) <u>Demand</u>

- Canada
  1974 demand for ethylene was estimated at [illegible] 000 tonnes. This decreased in 1975 to [illegible] 000 but will grow steadily towards a level of 1 210 000 tonnes in 1980 and 1 [illegible] 000 thousand in 1985.

- Latin America
  The consumption level in 1974 for this area was estimated at 900 000 tonnes, with Brazil having the greatest requirement of 300 000 tonnes followed by Mexico with half this demand, 1[illegible]0 000 tonnes

- E. Europe
  Total demand for 1974 probably reached around 1.6 million tonnes with Russia taking up over a quarter of this amount

- Africa
  1974 demand for ethylene in Africa was set at 90 000 tonnes as the only requirements were for the South African LDPE and VCM plants

- Asia/Pacific
  This area of S. E. Asia consumed [illegible] 000 tonnes in 1974. Australia has one of the highest requirements of this region of around 300 000 tonnes. Demand is growing fairly rapidly in this sector as the derivative markets are going towards maturity

c) Supply/Demand Analysis

The supply demand balances for the Rest of the Non-Arab World's ethylene is given below in Table IV.P.12.

TABLE IV.P.12.

REST OF THE NON-ARAB WORLD ETHYLENE SUPPLY/DEMAND SITUATION

(thousand tonnes)

	1979*	[illegible]	[illegible]
CANADA			
Potential Supply	[illegible]	[illegible]	[illegible]
Forecast Demand	[illegible]	[illegible]	[illegible]
Surplus/(Deficit)	([illegible])	[illegible]	[illegible]
LATIN AMERICA			
Potential Supply	[illegible]	[illegible]	[illegible]
Forecast Demand	[illegible]	[illegible]	[illegible]
Surplus/(Deficit)	(115)	(10)	([illegible])
W. EUROPE			
Potential Supply	[illegible]	[illegible]	[illegible]
Forecast Demand	[illegible]	[illegible]	[illegible]
Surplus/(Deficit)	([illegible])	[illegible]	([illegible])
AFRICA			
Potential Supply	[illegible]	[illegible]	[illegible]
Forecast Demand	[illegible]	[illegible]	[illegible]
Surplus/(Deficit)	[illegible]	([illegible])	[illegible]
ASIA/PACIFIC AREA			
Potential Supply	575	[illegible]	[illegible]
Forecast Demand	[illegible]	[illegible]	[illegible]
Surplus/(Deficit)	([illegible])	210	[illegible]

* estimated actual

- **Canada**

  There is a deficit situation at present, but within the next 5 years capacity expansions of the order of 800 000 tonnes will over-compensate, and by 1980 there will be a surplus of ethylene. This will continue through the eighties as further plants are planned before 1985. These supplies based on Alberta natural gas will have a considerable effect on world markets.

- **Latin America**

  Latin America, on the other hand is short of ethylene feedstock. Large installation, due onstream mainly in Mexico and Brazil, will aid in achieving a balanced situation by 1980. Thereafter the growth of derivative industries will outpace supply.

- **Eastern Europe**

  The supply of ethylene is fairly well tailored to meet the derivative capacity requirements. There are within the community local surpluses and deficits but these are evened out by inter-Bloc movements. There is an extensive pipeline network with E. Europe for effecting this trade e.g. ethylene from Leninvaros in Hungary is shipped to Russia by this method and a cracker being built at Bohlen in E. Germany will help to augment Czechoslovakian feedstocks.

- **Africa**

  Demand is currently met by domestic production but in the early eighties there will be a substantial

Prior to 1974 there has been continuing strong growth in polyester fibre demand which lead to optimistic forecasts for DMT/TPA requirements. Based on these forecasts a good deal of new capacity was planned. However the forecasts have had to be revised downwards rather sharply and consequently a large overcapacity situation is developing, particularly in Western Europe.

It is very difficult, at this time, to forecast the timing and extent of the likely upturn in demand for polyester fibres in Western Europe. The figures shown above reflect a rather conservative view of the situation. However even if recovery occurs earlier, and to a larger degree then these figures suggest, there will still be substantial overcapacity.

The DMT/TPA business in the developed markets of USA, Western Europe and Japan is also being affected by the build up of capacity in areas such as Latin America and South East Asia. These have historically been export markets for producers in the developed countries but will increasingly supply their requirements from domestic production.

Over 90 percent of DMT and all of TPA is consumed in the production of polyester fibre. The remaining DMT goes into film and polybutylene terephthalate (PBT). Although rapid growth is forecast for PBT resins they will represent less than 5 percent of DMT/TPA requirements by 1985.

As indicated above there is a considerable volume of exports from manufacturers in the developed areas to polyester plants which are being installed in South America and South East Asia. The growing requirement of DMT/TPA in these areas is indicated import requirement building up prior to the large S. African expansions planned for the mid eighties.

- Asia/Pacific
  There is a considerable shortage of ethylene in this area at present but with most countries planning quite large capacity installations this situation will be reversed and by 1980 the area, as a whole, will be an exporter of feedstock olefin. The quantity available for export will increase through to the mid-eighties, at least.

6. The Arab World

a) Supply

The ethylene production situation in the Arab world is summarised in Table IV.P.12.

TABLE IV.P.12

ARAB ETHYLENE PRODUCTION PLANS
(thousand tonnes)

COUNTRY	PLANNED CAPACITY	PROPOSED START-UP
Algeria	120 500	1978/9 1985
Tunisia	300	1980's
Libya	300	1980's
Egypt	300 500	1979 1985
Kuwait	350 + 350	1981/2
Saudi Arabia	500 + 300	1982 + 1985
Iraq	150 + 300	1980 late 1980's
Qatar	300	1980's
Dubai	300	1985
Abu Dhabi	400	1982
Syria	300	1980's
Total	5 070	

SECTION V FEEDSTOCK ANALYSIS

Contents **Page No**

SECTION V : FEEDSTOCK ANALYSIS

V FEEDSTOCK ANALYSIS

This Section considers the characteristics and costs of the various feedstocks available in the Arab oil producing states which could be suitable for olefins and aromatics production.

These feeds may be broadly classified for present purposes as "gas" and "liquid" feeds. The gas feeds comprise ethane, propane, butane and various mixtures of these, such as can be recovered from the associated and unassociated gas available in the Arab states. These are all good olefin plant feedstocks. The liquid feeds considered are full range naphtha and atmospheric gasoil, both available from the large new coastal export refineries being planned for several Arab states. Both are common olefin plant feeds, and the catalytic reforming of naphtha is the primary route to aromatics. Other liquid feeds such as light naphtha and aromatics raffinate can also be used as olefin plant feedstock, but the economics of these are similar to the full range naphtha case.

A GAS FEEDS

1 Introduction

Vast quantities of natural gas liquids (ethane, propane and heavier) are contained in the associated and unassociated natural gas reserves of the Arab states. Associated gas production rates are seldom accurately reported unless the gas is utilised for reinjection and/or sale. Reported values of Arab gas production therefore often refer only to those quantities utilised, and not to the (far larger) total quantities actually separated from the oil and therefore available for use.

It is not the intention in this study to attempt to define the precise quantity of Arab gas available, since by any standards it may be safely assumed that supplies are more than adequate for the establishment of a large petrochemical industry. As an approximate indication only, if a conservative average gas : oil ratio of 100 cubic metres per tonne is assumed (approx. 500 standard cubic feet per barrel), a total Arab oil production of 1000 million tonnes per year (20 million barrels per day) equates to an associated gas production of 100 milliard cubic metres per year (10 billion scfd.). Table V.A.1 gives a rough indication of the quantities of gas liquids which might be recovered from this gas, using an assumed typical composition and realistic recovery levels. The numbers of world-scale ethylene plants (400 000 tpa ethylene) which could be fed by these gas liquids are also indicated.

TABLE V.A.1

ARAB ASSOCIATED GAS AS A SOURCE OF OLEFIN PLANT FEEDSTOCKS

(Basis: 100 milliard m³/year associated gas
400 000 tpa ethylene plants operating at 100% capacity)

Component	Gas Composition (Vol %)	Recovery (%)	Quantity Recovered (million tpa)	Potential number of Olefin Plants supplied
Ethane	10	80	8	14
Propane	6	90	10	10
Butanes	4	95	9	6
Pentanes +	2	95	7	3
Total			[illegible]	[illegible]

Since an olefin plant may take any combination of these feedstocks, singly or as co-feeds, it is clear that most Arab States with significant oil production are likely to have enough gas liquids available to feed an olefin complex.

In addition the vast quantities of unassociated gas available in certain Arab States (particularly Algeria) are a major complementary source of gas liquids. Although of generally leaner composition, the potential rate of production is so great that total available quantities of gas liquids from this source could be comparable to those from associated gases.

Having established that adequate supplies of gas feeds are potentially available, no further consideration will be given to this aspect of the feedstock question. The remainder of this section addresses the more important question of the price at which the various feeds could be made available to petrochemical projects.

2. The Valuation of Gas Feedstocks

The values which could be placed upon ethane, propane and other gas feeds to petrochemical projects in North Africa or the Arabian Gulf may be determined by three alternative mechanisms:

- Cost of supply
- Alternate use value
- Derivative product economics

These three mechanisms all have some merit, and are discussed below in more detail.

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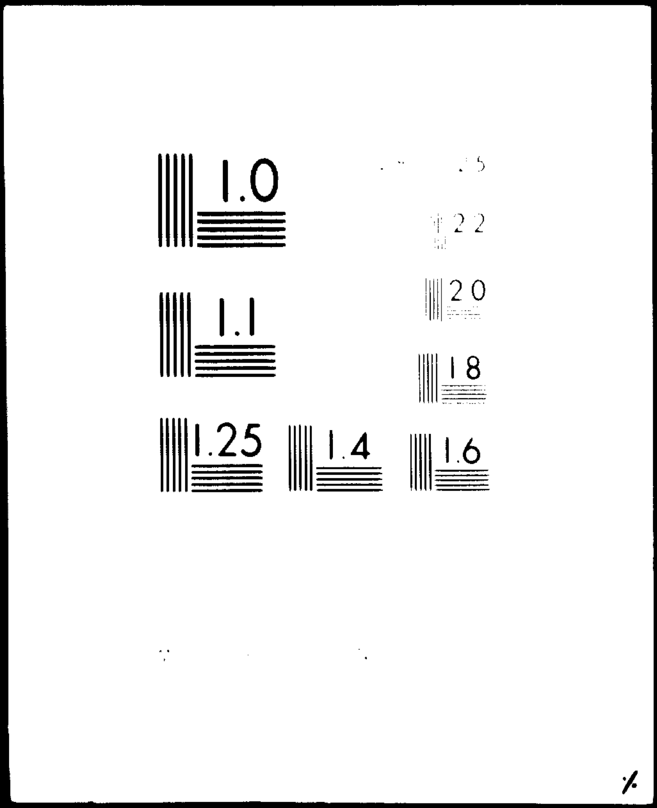

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- Ethane. If specifications on the revapourised LNG do not prevent this option, ethane may be produced as a separate sidestream product from an LNG plant. This is being done at several of the Algerian LNG trains, and is planned in Nigerian and other projects. Separating the costs attributable to the production of this separate ethane stream is not realistically possible since complete re-optimisation of the LNG circuit is involved, but an assumption of equal into-tankage costs for the LNG and the ethane on a heat-content basis is not unreasonable. It is further possible to employ the "alternate use" approach, arguing that if the ethane had not been removed it would have had the same value as LNG. Based upon equivalence with the ex-plant LNG values derived in Table V.A.4, 1980 ethane values at the Arab locations may be estimated as \$9.00 per million K cals (\$110/tonne) in N. Africa, and \$5.55 per million K cals (\$70/tonne) in the Arabian Gulf.

  It is considered probable that several ethylene plants in the Arab oil producing states will be based upon ethane taken as a sidestream from LNG plants. This "alternate value" approach to ethane pricing therefore has considerable realistic merit, and we adopt these values in the cost of production calculations in this study.

- Propane and Butanes. Propane and butane are widely traded as LPG fuel, and as such have a readily identifiable "alternative value" for export from the Arab locations. A 1980 developed - market LPG value of \$150 per tonne is predicted in the following Section V.B. Average LPG shipping costs from North African and Arabian Gulf locations are estimated in Section IX at \$40 and \$60 respectively. This results in 1980 FOB values for LPG of \$110/tonne in N. Africa and \$90/tonne in the Gulf. A few contracts have already been reported at FOB prices above these levels, but it is considered that for a really major increase in world LPG trade to develop from the Arab States, the cost of LPG delivered to the industrialised countries must be competitive with distillate fuels, and for this the above prices are realistic. These prices are therefore used in the olefin plant evaluations in Section VI.

o Pentanes and Heavier Gas Liquids. The pentanes + stream recoverable from natural gas is variously termed natural gasoline, field condensate etc. It is roughly equivalent in composition to a straight- run refinery naphtha, and is used as a low octane gasoline blendstock or as a petrochemical feed. Its value delivered to a developed market may be assumed to be approximately 10 percent below that of naphtha, estimated in Section V.B at $175/tonne in 1980. Deducting shipping costs, a pentanes + value at a North African coastal site approximates $147/tonne, and in the Arabian Gulf area will be $137/tonne, both on a 1980 basis.

c) Derivative Product Economics

One possible approach to assigning values to the Arab gas liquid feedstocks is to charge whatever price the potential consuming plant can bear. Thus if an ethylene plant could afford to pay $200 per tonne for ethane feed and still just remain a viable operation, then one could consider $200 per tonne as an acceptable ethane valuation. The disadvantages of this approach for present purposes are numerous:

o feedstock "price" would vary with derivative plant type, size, operating level etc.

- the major portion of the profit on an attractive overall scheme would be taken by the feedstock supply operation. While this could be appealing to the government of the Arab State in question, it is unlikely that foreign equity partners could be found on this basis

- this approach provides no real assistance in the problem of selecting the optimum feedstock for the petrochemical plant.

For these various reasons, the "derivative product economics" approach is not considered further here, although the sensitivity analysis in Section X, in which feedstock price is treated as variable, is one way of allowing derivative product economics to influence feedstock pricing.

d) Summary

The "alternative value" approach of Section 2b) is therefore adopted for all potential gas feedstocks. The resulting feed valuations are summarised in Table V.A.5:

TABLE V.A.5

GAS FEEDSTOCK VALUATIONS

Basis: Arab Petrochemical Projects, 1980

	Units	North Africa	Arabian Gulf
Natural gas	$/million Kcals	4.90	2.00
Ethane	$/tonne	110	70
Propane	$/tonne	110	90
Butane	$/tonne	110	90
Pentane +	$/tonne	147	137

The wide variation between these "alternate value" prices and the "cost of supply" prices (of around $32 per tonne for all products) leaves a great deal of room for argument on this important subject of feedstock pricing. Fixing feedstock prices at a low level is one obvious way in which an Arab government can improve the economic attractiveness of petrochemical ventures and thus promote industrialisation and general economic development of the country. For this reason, while the values of Table V.A.5. are used in the basic Cost of Production calculations in this study, feedstock price is treated as a variable in sensitivity calculations in Section X (Economic Evaluation).

B. LIQUID FEEDS

1. Basis for Valuation of Liquid Feeds

The values which might be placed on naphtha and gas oils as feeds to petrochemical plants in N. Africa or the Arabian Gulf may be determined by three principal mechanisms.

- Alternative use Valuation. This method evaluates what sales value the feedstock would have if sold to the open market, adjusts for any costs incurred in transporting and selling, and thus arrives at a sum of the revenue lost by not selling. This is the "opportunity cost" or "alternative use" value.
- Cost Valuation. This is the sum of all the costs of exploration, drilling, production, refining and transporting to the point of use. This is the lowest possible valuation, and is so much lower than any other method that it is not considered further.
- Crude Oil Basis. This starts from a posted price of crude oil and adds only the costs of refining. The result gives the minimum price at which sales of naphtha and other products will generate the same profit as crude oil.

Of these methods the first is the one dealt with in most detail and is believed to be the most reasonable for establishing the viability of petrochemical plant. The last method is to some extent applicable but would be more appropriate to establishing the viability of oil refining.

Since this study starts with the basis that an oil refinery is already on hand to supply feedstocks this problem does not arise. The crude oil basis is therefore dealt with only briefly.

2. The Valuation of Naphtha and Gas Oil

a) Introduction

The aim of this section is to establish the market value for light distillates as a chemical feedstock in Europe. Since selling naphtha into this market is the major alternative use to processing naphtha in the country of origin, this is used as the basis for an "alternative use" valuation.

It is assumed for both refinery and petrochemical activities the normal business economics currently found in Western Europe will continue. This will establish long term price trends on a "cost of production plus fair return on capital" basis.

Refining capacity has expanded continuously for many years at 5 - 10 percent per annum and the petrochemical industry has shown a rate of growth of 10 - 15 percent per annum. Despite the sharp rise in raw material costs these industries are expected to require additional continuing investment. To finance this expenditure it is necessary for product prices to be at an average level which gives an adequate return on capital.

b) "Typical European" Refinery

The major part of European refinery products are straight run hydrocarbons. That is, the bulk of the hydrocarbons in the crude emerge in the same molecular form, the processing having been the separation of hydrocarbons from each other, and the removal of non-hydrocarbons particularly sulphur. An exception is the catalytic reforming of naphtha to produce high octane gasoline. Thus the typical refinery consists of :

Crude Distillation
Naphtha Hydrotreating
Naphtha Catalytic Reforming
LPG Recovery
Sulphur Recovery
Kerosene Hydrotreating
Gas Oil Hydrodesulphurisation

In simpler refineries some of these facilities will be omitted; then for example, one with no kerosene treating will be unable to produce aviation kerosene, and regular kerosene only from selected crudes. In contrast other refineries add further processing units; the most notable is the addition of catalytic cracking including vacuum distillation for feed preparation and additional distillation and gas recovery for the products. When special situations and speciality products are considered the processes used run into dozens. However, these do not affect the pricing of the major products.

As a consequence of the refining pattern, the yields of products must correspond approximately to the quantities of each present in the original crude. It follows that the average crude, Arabian Light, will give the market split of products.

c) Refinery Products

The basic straight run products from the crude taken as our basis are given in Table V.B.1.

TABLE V.B.1

STRAIGHT RUN PRODUCTS FROM AVERAGE EUROPEAN CRUDE

	Range ^{o}C	Weight Percent
LPG and Gases	to C4	2
Light Naphtha	C5 - 95^{0}	7
Naphtha	95 - 175^{0}	14
Kerosene	175 - 232^{0}	8
Gas Oils	232 - 360^{0}	27
Residue	360^{0}C+	42
		100

The products actually sold from a refinery differ from the breakdown in Table V.B.1 due not only to secondary processing but also the need to blend products to meet specifications. The total yield is also less than 100 percent owing to processing losses and refinery fuel needs. From our hydroskimming "European Refinery" model, we have produced products in the proportions indicated by refinery statistics as being the average for the Northern European area. The addition of catalytic cracking increases the available gasoline and naphtha, which we have disposed of by taking a fifty percent increase in the percentage of the barrel going to naphtha and the balance to gasoline. Whilst this demand is hypothetical it is the sort of demand which must exist to justify this scheme of refining. Note that even with this refining pattern the proportion of the barrel going to gasoline is still only half that prevailing in the U.S. The resulting products for sale are shown below in Table V.B.2.

TABLE V.B.2

PRODUCTS SOLD FROM REFINERIES

	Weight Percent of Input	
	Current European Refinery	Cat. Cracker added to European Refinery
LPG	1.7	2.6
Naphtha	7.0	10.4
Gasoline	12.9	22.3
Kerosenes	4.0	4.0
Gas Oils	31.6	33.0
Residual Fuels	37.3	20.2
Total Sales	95.0	92.5
Fuel, Sulphur & Losses	5.0	7.5
	100.0	100.0

d) Refining Margins and Return on Investment

Historically the major oil companies have worked an integrated system from crude oil lifting to product selling, and have been able to adjust their crude price to take their profits in the most advantageous location. Because of this there is a paucity of published data to support a given profit margin. It is however generally considered that the oil companies plan projects and evaluate returns from individual investments using the same criteria as any capital industry.

It is certain that with oil companies no longer having access to unlimited quantities of low priced crude they will examine investments much more critically. They will no longer be able to offset a poor return on investment against the higher profit obtained on moving additional crude. This will reinforce the tendency to seek a commercial return on each investment.

As noted earlier, the refiner has at his disposal processes which enable him to produce a wide variation in product quantities from a barrel of crude. In the short term however, he has a limited ability to use this power, being constrained by specific refinery configurations, and a product in short supply cannot be dramatically increased in response to price rises. In the medium to long term he can change his product mix to meet demand at an associated cost. Thus in an equilibrium market there will be a limited price differential between products, the differential being the cost of converting one to another. It is this equilibrium situation which can be analysed, whereas short term variations are often unpredictable.

To obtain an overall satisfactory return the prices of each of the products produced from a refinery will be balanced by relative market strengths and price sensitivity. The required analysis has been indicated by the preceding paragraphs on refinery background. For the purposes of this study the naphtha scenario is of most importance, but of necessity this product is strongly affected by the demands and market strengths of the other products.

a) Cost of Supply

This is the sum of all the costs of exploration, drilling and production of natural gas (or an adjudged proportion of these costs in the case of associated gas), together with the costs of transporting the gas, and extracting and storing the gas liquids.

o Gas production costs. In the case of associated gas, an allocation must be made of the exploration, drilling and production costs between the oil and gas produced. In the general current Middle-Eastern situation, in which gas is flared or reinjected, the oil bears all these costs, and gas has generally been regarded as effectively free at the wellhead. Typical current total oil production costs are \$0.5 to \$3.5 per tonne in the major Arab oil countries, of which possibly only half relates to well-head costs. If an equal apportionment were made of these costs between oil and gas on a heat-content basis, current gas costs would only be in the range \$0.02 to \$0.15 per million K.Cals at the wellhead.

For un-associated gas, well productivities' are generally so great that costs at the wellhead are again very low. For example, a gas field development costing \$250 000 per well with a productivity of 300 000 m^3 per day would imply current costs of only \$0.09 per million K cals at the wellhead (this assumes a 25 percent annual charge on capital, and total costs equal to 150 percent of capital charges).

o Pipelining costs. Pipelining costs are also relatively low if the quantities of gas involved are

e) Naphtha

Since fuels account for the major revenue from a refinery, total crude throughput will be influenced almost entirely by fuel demand. The supply of naphtha will then be fixed within narrow limits by the quality of crude oil used and the refiner's processing flexibility. For most of the past, until less than five years ago, naphtha always emerged in surplus and was disposed of at near crude prices. Since then the supply-demand gap has narrowed such that naphtha supply is nearer a balance and shortages can be precipitated by, for example, a prolonged mild winter. Naphtha price then moved to near parity with other light distillates. Consideration of the cost of refining and the current price structure of distillates gives the value of naphtha as approximately in the range of 30 - 40 percent above the landed crude price in dollars per tonne.

The future naphtha supply-demand position is the subject of many varying forecasts. These usually omit the effects of recession which must accompany any substantial reduction in total oil supply and this item usually leads to predictions of extreme shortage and high price. Chem System's analyses lead to the conclusion that the present small surplus of naphtha is likely to be used up gradually. If all olefin projects currently in progress mature as announced this will occur by about 1978; if delays occur and olefin demand suffers a temporary plateau in growth then this may not occur until 1981. These are of course only two of the many projections possible from the current baseline, but serve to define limits to the possible range of naphtha supply-demand situations.

When a permanent deficit of straight run naphtha occurs from present day refining patterns the oil companies will respond by constructing conversion capacity; catalytic cracking or hydrocracking units. Alternatively chemical companies can reduce naphtha demand by using other feedstocks, gas oil or LPG, for olefins and aromatics manufacture. The general picture of falling projected growth rates for heavy oil fractions favours refinery conversion processes, rather than using heavy distillates for olefins. When this occurs the differential between naphtha and heavy distillates will be set by conversion economics which for a catalytic cracker at 1975 costs gives a $20/tonne differential between naphtha and heavy distillate, or for hydrocracking about $35/tonne. This margin may be escalated by the capital cost factors for future years, and would be $30 - 60/tonne in 1980.

In summary therefore, naphtha price will be set at a margin above crude oil to recoup the costs of processing in the refinery. A tendency to seasonal shortage will make naphtha price more variable than most refinery stocks but in the long term the required margin above crude is not large, and will lead to a price rise much less than fluctuations recently precipitated by shortages. In the period 1978 - 81 when conversion capacity might need to be installed stronger fluctuations in price could occur.

f) Gas Oil

Gas oil is the largest revenue product from a typical European refinery. It is therefore an instrumental factor in setting the volume of crude processed. Thus, while seasonal variations in supply and price occur, the refiner has some incentive to change crude run to balance gas oil demand. This will limit the fluctuations in gas oil price to a much smaller band than for naphtha.

The price band is also limited by technical factors. Since the other large volume product, residual fuel oil generally sells at a discount on crude oil, it is impossible for a refiner to sell gas oil below crude oil price and still remain profitable. Conversely, the premium value of gas oil, which it commands in its uses in domestic heating, light industrial uses and special heating duties is limited by the fact that for many duties heavier fuels, coal or gas could be substituted. These two limits put the long term gas oil price in a relatively narrow price band of 5 - 15 percent above crude oil price.

g) Residual Fuel

This is currently the major volume product in Europe, and whilst its price is lower than gas oil so that its contribution to total revenue is lower, it is a major influence in setting refinery runs. Unlike gas oil however, residual fuel usually stands at a discount on crude, and in times of surplus this discount may be substantial.

The competition to residual fuel is from coal interruptible natural gas supplies, and waste product incineration. In the future additional competition will arise from nuclear power for electricity generation. The outlook is therefore one of a slowly declining market share, leading to a relatively weak residual fuel price.

This we have estimated at 10 percent below crude price for medium term predictions.

h) Other Products

Kerosene is a small volume product which is generally available, with any excess being blended back into fuel oil. Its price is a little above gas oil, with special grades such as aviation fuel showing a small premium to reflect the cost of treating.

LPG varies in value according to location and supply and demand. As there is no strong established network of storage and distribution in Europe, surplus production is burned at the refinery and thus has a heavy fuel value. As a chemical feedstock however its value approaches naphtha. As naphtha supply tightens during the next decade one result will be that any available LPG will be considered for chemical use, although transport and storage costs will ensure that much of it is still used as a local fuel. The value used as a typical chemical feedstock cost approximates to 5 percent below naphtha price.

Gasoline values are set by the cost of the major feedstock, aromatic naphtha, and by-product demand relative to supply. The latter may be limited by either feedstock or plant capacity. Generally the value in Europe reflects the processing cost by catalytic reforming to give the required octane.

i) European Product Price Summary

The values which we have evolved for the major products at a N.W. European terminal, based on the considerations summarised above and a c.i.f. crude price of $120 per tonne are as follows:

	Value W. Europe 1980 $/tonne
LPG	150
Naphtha	175
Premium Gasoline	207
Kerosene	145
Gas Oil	140
Residual Fuel	108

This summary table must be regarded as a mid-range prediction only. Fluctuations around these prices will occur not only due to the uncertainty in estimating the market balance as far ahead as 1980, but also due to the fact that at any time products are traded at more than one price.

j) Value of Feedstocks to Arab Petrochemical Projects

In the preceding paragraphs the equilibrium prices of naphtha and gas oil in Western Europe have been developed. For the purposes of estimating the costs of production of Arab petrochemicals in later sections of this study we simply take the average W. European value from the table above and subtract the transport cost to W. Europe, as follows;

- N. Africa

	Naphtha	Gas Oil
Price, W. Europe 1980	175	140
Less Transport Cost	10	10
Value	$165/tonne	$130/tonne

- Arabian Gulf

	Naphtha	Gas Oil
Price, W. Europe 1980	175	140
Less Transport Cost	20	20
Value	$155/tonne	$120/tonne

3. Cost of Liquid Feedstocks

As we have noted in the basis for valuation (Section V.B.1), the cost of production of liquid feedstocks is rejected as a basis for comparing the economics of petrochemical projects. However, it is useful to compare briefly the values arrived at by this method with the valuation put forward in the preceding section.

As a basis of comparison it has been assumed that the refining cost is from a new 200,000 BPSD coastal refinery at the specified Arab location. The refinery is assumed to be an expanded hydroskimming refinery, to acknowledge that much of the output is aimed at W. Europe. Thus to be able to sell into a market liable to have a surplus of fuel and a deficit of naphtha it is desirable to increase the yield of distillates.

This is achieved by adding a catalytic cracker to give the yields shown in Table V.B.2. The refinery product revenue is adjusted to give a return of 20 percent on capital invested on an ideal year basis. The ratio of product prices is the same similar to that for a typical European refinery, with some account taken of differential transport costs and market strengths in assessing these values.

The calculation is shown in Tables V.B.3 and 4. It may be seen that the resulting naphtha and gas oil costs are slightly higher than the alternative use values, even though a larger and more efficient refinery is used as the basis. It should be noted that although the adverse margin is small, this represents an overall revenue difference of $2 500 000 per annum.

The weakness of this evaluation is that it must assume a value for all products to arrive at a value for naphtha. In this calculation it has been taken that these values are in a similar but not identical ratio as a European refinery: both residual fuel and LPG values are written down, which increases the revenue needed from distillates.

In summary therefore, the cost of refining approach to feedstock valuation will give slightly higher values to naphtha and gas oil, but the assumptions underlying this method are much less applicable than the alternative use valuation.

TABLE V.B.3

COST OF REFINING IN 1980 - N. AFRICA

Investment	Complete refinery	$400 million

200 000 BPSD crude input. Hydroskimming plus vacuum distillation and catalytic cracker.

Operating Costs	$MM p.a.
Crude oil, 10 000 000 tonne at $115/t	1150
Capital charges @ 31% of investment	123
Operating costs, excluding fuel	24
	1297

Revenue	Tonne p.a.	Price $/tonne	$MM p.a.
LPG	260 000	130	34
Naphtha	1 040 000	166	173
Gasoline	2 230 000	191	426
Kerosene	400 000	141	56
Gas Oils	3 300 000	133	439
Residual Fuel	2 020 000	84	169
	9 250 000		1297

TABLE V.B.4

COST OF REFINING IN 1980 - ARABIAN GULF

Investment	Complete refinery	$440 million

200 000 BPSD crude input. Hydroskimming plus vacuum distillation and catalytic cracker.

Operating Costs	$MM p.a.
Crude oil, 10 000 000 tonne at $107.7/t	1077
Capital charges @ 31% of investment	136
Operating costs, excluding fuel	26
	1239

Revenue

	Tonne p.a.	Price $/tonne	$MM p.a.
LPG	260 000	127	33
Naphtha	1 040 000	157	164
Gasoline	2 230 000	183	408
Kerosene	400 000	133	53
Gas Oils	3 300 000	127	419
Residual Fuel	2 020 000	80	162
	9 250 000		1239

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FEASIBILITY STUDIES FOR THE DEVELOPMENT OF OLEFIN AND AROMATICS INDUSTRIES FOR INTERNATIONAL AND NATIONAL MARKETS IN ARAB STATES

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FINAL REPORT
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large. As an indication of typical current costs, Table V.A.2. sets out a possible design basis for pipelining gas to a North African coastal site from inland oil/gas fields. The 300 km distance assumed is typical of that involved in moving Algerian unassociated gas or Libyan associated gas to a suitable coastal location. A transmission cost of $0.42 per million K cals is estimated in Table V.A.2.

Associated gas around the Arabian Gulf is typically much closer to the coast. Assuming a generous 100 km distance, reworking Table V.A.2. gives a pipelining cost for a typical Gulf situation of $0.20 per million K cals.

o Gas liquids extraction costs. Combining the perviously estimated costs of production and pipelining, a current natural gas cost at a coastal site might be generalised to be $0.50 per million K cals for North African gas and $0.25 per million K cals for Arabian Gulf gas.

To fix a cost of ethane, propane and other gas liquids (pure or mixed), costs must be estimated of plant to extract these streams from the gas. Extraction costs depend strongly upon exact gas composition, particularly regarding sulphur and other impurities, so any generalised estimate can only be regarded as very approximate.

Various processing schemes are in widespread use, the choice between which depends largely upon gas composition, recovery levels required and scale of

CONTENTS

CONTENTS

Detailed Tables of Contents of each section are included at the front of the individual sections.

SECTION VI

SECTION VI : OLEFIN PLANT

SECTION VI : OLEFIN PLANT

VI. OLEFIN PLANT

A. INTRODUCTION

This section presents technical descriptions and basic economic evaluations of the olefin production plant. The objective is firstly to describe technology and commercial practice as currently in use in the United States, Western Europe and Japan. From this base, recommendations are then developed for olefin plants to be built and operated in the very different conditions found in an Arab oil producing country.

Capital and operating costs are developed for olefin plants using various feedstocks in Western European, North African and Arabian Gulf locations. Transfer prices of ethylene and other products are then calculated for each location.

B. FEEDSTOCK OPTIONS

1. World Situation

Almost all of the World's ethylene is produced by the steam cracking of various hydrocarbon feedstocks. Any hydrocarbon or hydrocarbon mixture from ethane through to gas oil is technically acceptable as feed, but commercial and availability considerations have historically resulted in different feeds becoming dominant in different parts of the world. Prior to about 1973, the feedstock situation worldwide was relatively straightforward. Natural gas liquids feedstocks (mainly ethane and propane) were used in the United States and naphtha was used in Western Europe and Japan.

The United States was (during the 1960's) endowed with abundant supplies of natural gas, the price of which was controlled at a low level. Gas liquids were recovered by the gas producers and pipeline operators in large quantities at low cost. In addition, natural gas liquids have a high selectivity for ethylene and involve lower ethylene plant capital costs than the alternative heavier feeds. For the independant petrochemical producer, the manufacture of olefins from natural gas liquids was a more attractive operation than relying on the refining industry for supplies of alternative naphtha or other potential feeds.

By the early 1970's it was apparent that U.S. natural gas production was peaking out. As a consequence the continued growth and availability of natural gas liquids were expected to slow down and actually begin to decline. Since demand growth for ethylene was continuing at a high level, alternative feedstocks were required and a rapid trend to naphtha and (primarily) gas oil was started for all new ethylene capacity. As a consequence gas liquids are predicted to constitute less than 40 percent of total ethylene plant feed by 1985, compared to over 80 percent in 1975.

The situation in Europe and Japan has historically been very different from that in the U.S. Naphtha has been the predominant feedstock because no gas liquids were available. In addition European and Japanese gasoline consumption was only about 25 percent of that in the US (as a percentage of crude processed) so that naphtha had traditionally been in surplus from refinery operations. Refineries in Europe and Japan served primarily the industrial and utility fuels market with middle distillates and light and heavy fuel oil. With the recent steep rises in the price of energy, there is a tendancy to cut back on fuel oil consumption, while gasoline demand remains almost unchanged and petrochemical naphtha demand continues to grow. Naphtha is therefore becoming in tighter supply, and there is a very strong trend towards building new ethylene capacity with the feedstock flexibility to accept gas oil as an alternative to naphtha. Gas liquids from North Sea discoveries will be used for petrochemicals in the future, but availability will be limited.

It is now rare for a new plant in Europe or the U.S. to be designed to crack a single feed exclusively. Flexibility to crack alternate feedstocks enables an ethylene producer to continue operating at or near capacity levels when his design feed may be in short supply. He can tailor-make a product slate to fit a changing economic picture by running a different feed or by blending several feeds. Another advantage of a flexible design is the ability to accommodate the seasonal changes in a petroleum refiner's output slate (the major source

TABLE V.A.2.

GAS PIPELINING COST SUMMARY : NORTH AFRICA

Basis:

Gas quantity delivered	5 x 10^9 Nm^3/year
Pipeline length	300 km
Pipeline diameter	760 mm (30 inches)
Operating pressure	70 atm
Compressor station spacing	100 km
Installed horsepower per station	20 000 bhp
Compression at inlet to line	65 000 bhp
Pipe specification	X 60, 9.5 mm wall thickness (0.375 inches)
Terrain	Flat desert floor
Gas quality	10 500 Kcals/Nm^3

Capital Costs:	**$ million**
Installed Pipe cost (@ $500/tonne delivered)	56
Inlet compression cost	32
Intermediate station costs (2 stations)	24
Communications, controls	10
Sub-total, materials and construction	122
Engineering (4%)	5
Authorities (1%)	1
Owners costs (1.5%)	2
Sub-total	130
Contingency (10%)	13
Total estimated cost	$ 143 million

Transmission Costs:	**$ million/year**
Labour	1
Maintenance (4% station cost, 1% line cost)	3
Overheads and administration	2
Fuel @ $0.5/million Kcal	1
Capital charges (10%)	14
Insurance, taxes etc (1%)	1
Total annual cost	$ 22 million/year
UNIT TRANSMISSION COST	$ 0.42 per million Kcals.

of feed to an ethylene plant). Thus, a flexible naphtha/gas oil plant can run predominantly gas oil in the summer during the high gasoline (naphtha) demand season and then switch to mainly naphtha during the winter months, when heating oil (gas oil) is in great demand. The net result of the above options is to permit a search for the least expensive feedstock at any given time and thereby minimize the effect on the cost of ethylene production of the most important component of cost - feedstock.

Thus in the uncertain and fluctuating feedstock situation prevailing in the industrialised countries, plant flexibility is desirable. It is expensive in terms of capital cost, however, since equipment sizes must invariably be increased.

2. Arab Situation

The Arab oil and gas producing countries are not restricted in their petrochemical development by feedstock availability. The whole range of potential feedstocks could be made available to an ethylene plant if desired.

Ethane, propane, and heavier gas liquids are available in vast quantities in the associated gas, and to a lesser extent in the unassociated gas, for which collection and processing plans are presently under way in many Arab states. Enough ethane could be recovered from 20 million cubic metres per day of a typical associated gas (containing 10 percent ethane) to feed a 450 000 tonne/year ethylene plant.

Naphtha, gasoils and other liquid feeds will be produced in large quantities in the coastal export refineries which will also be developed in the Arab States during the time period of this study. A 10 million tonne/year refinery would typically produce enough full range naphtha, and more than enough gas oil, to feed a 450 000 tonne/year ethylene plant.

Since the production and supply of all of these feedstocks will be under the control of the various Arab states themselves, security of supply and availability are not factors in the selection of feed type. Accepted practice in the developed countries cannot be used as a guide, since as explained above feeds vary both by region and with time, depending upon local circumstances. Economic and technical factors alone can therefore be used to make the feedstock selection, the main considerations being

- relative olefin plant capital costs (for a given ethylene production, capital cost increases as the feedstock becomes heavier)
- relative co-product formation (an ethane cracker produces effectively only ethylene, whereas naphtha cracking also produces very large quantities of propylene, butadiene, pyrolysis gasoline etc.)
- relative costs of the various feedstocks. This question has been analysed in Section V.

Another advantage of this security of feedstock supply which an Arab olefin project should experience is that feedstock flexibility need not be incorporated into the design. As described in the previous section, this flexibility is a necessary part of new projects in the U.S., etc., so the Arab project will show a relative capital cost saving on this account.

To permit the later analysis of the technical and economic implications of these factors as listed above, a technical description of the steam cracking process for olefin production is presented in Section VI.C, below.

C. PROCESS DESCRIPTION - STEAM CRACKING

1. Introduction

Steam-hydrocarbon cracking plants designed to produce high purity olefins as the primary products all follow the same general processing scheme. A hydrocarbon feed is mixed with steam and heated to a temperature high enough to crack into lower molecular forms. The resulting cracked gas is cooled, compressed, processed for water and acid gas removal, refrigerated to a very low temperature, and subsequently separated into chemical products through a series of fractionation steps. Prior to final fractionation the C_2 and C_3 streams are treated with hydrogen for the catalytically selective removal of acetylene compounds.

The fractionation sequence varies according to the design philosophies of several contractors, but the final selection is ultimately an economic decision based on careful consideration of utility costs, product specifications, by-product utilisation, and type of feed cracked. The processing scheme employing demethanisation first and selective hydrogenation of separate concentrated streams of single carbon number olefins has become favoured.

The furnace section is the most critical design area in an olefins plant and has undergone more significant improvements in technology during the past 10 years than has any other part of the plant. The kinetics of the cracking process are better understood, resulting in carefully-defined severity levels for achieving optimum economics from a particular feedstock. The metallurgical development of improved alloy materials for furnace coil construction has made it possible to operate at these higher severity levels on a commercial scale.

The generation of high pressure steam through the indirect quenching of furnace effluent results in considerable savings in plant fuel and steam requirement. Heat recovery by high pressure steam generation is practiced in virtually all modern ethylene plant designs employing naphtha and heavier feedstock cracking.

Further downstream product upgrading is practiced in a number of new large crackers. The normal propylene product of chemical grade quality can be purified further to polymer grade with one additional fractionation step. The C_4 cut can be sent to an extraction unit where high purity butadiene is recovered, leaving a by-product stream rich in butylenes. Another processing step, which is frequently employed and is likely to be practiced regularly in the new generation gas oil crackers now under construction, is the recovery of aromatics from the pyrolysis gasoline stream. The raw gasoline is given a heavy hydrotreating to remove all olefinic and diolefinic material prior to entering the extraction unit. Benzene, toluene, and xylenes are recovered as high purity products. Part of the remaining gasoline stream is recycled back to the cracking furnaces with the remainder sold as gasoline blending stock.

The following sections discuss flowsheets used for the discrete cracking of ethane, naphtha, and gas oil. Emphasis is placed on highlighting process differences among these three feedstocks.

2. Typical Flowsheet Arrangements

Most ethylene plants have in common the production of ethylene-rich gas through pyrolysis of various hydrocarbon feedstocks, the cooling and compression of the gas to recovery pressure, the removal of water, acid gases and acetylene, and the low temperature separation of the gas into products through the use of several fractionation steps. However, the order of these various steps employed in a recovery scheme has not been constant over the years, and, in fact, many different recovery schemes have been employed. Although a complete history of ethylene recovery schemes is not important in understanding present ethylene technology, a review of some of the significant features employed in recent plant designs is useful.

The two factors that have been of paramount importance in determining the order of the process sequence are the location of the acetylene conversion step and the location of the demethanizer with its high refrigeration requirements for removing hydrogen and methane. The technology of acetylene removal, particularly through advances in catalytic hydrogenation techniques, has changed considerably over the years, and improvements in recovery plant designs have followed these changes. Several companies offer catalytic processes for the hydrogenation of acetylene and methyl acetylene. All report negligible losses of primary olefins or gains of these products upon hydrogenation. Some of the more prominent vendors are IFP, ICI, Girdler, CCI, and Dow. Optimization of the recovery flowsheet has also taken place independent of acetylene removal technology.

During the early 1960's, the technology for acetylene removal had reached a point close to its present status, however the approach of the major ethylene plant designers to the use of this technology in combination with their techniques for the demethanisation step resulted in several significantly different flow schemes. Since there were many plants built during this period employing each of these basic schemes, a short discussion of the differences is appropriate as a preamble to present technology.

The four basic locations for catalytic removal of acetylene are:

- In the total gas stream where C_4 and heavier components are present
- In the gas stream after removal of C_4 and heavier components
- In the gas stream after removal of C_3 and heavier components
- In a concentrated C_2 stream

Since higher acetylene and diolefins are partially hydrogenated in an acetylene converter system if they are present, the desirability of butadiene recovery is a major influence on the location of the conversion step. In almost all plants cracking naphtha and heavier feeds, butadiene recovery has been important. However, in many ethane-propane plants this has not been the case. As ethane-propane plants have become larger, butadiene recovery has increased in importance.

Consideration of the factors involved in selecting the acetylene converter position and the location of the demethanisation step has resulted in the basic flow sequences described below.

When butadiene recovery is not important, acetylene conversion is frequently carried out on the total gas stream with the demethaniser as the first tower. When butadiene recovery is important, acetylene conversion is carried out in one of three schemes: 1) on a C_3 and lighter gas with demethaniser following the depropaniser, 2) on a C_2 and lighter gas with the demethaniser following the deethaniser, and 3) on the concentrated C_2 stream with the demethaniser as the first tower.

Ethylene product specifications have become increasingly stringent with regard to acetylene concentration, and this has introduced a further consideration into flowsheet selection. Current acetylene specifications for polymer grade ethylene are less than 5 ppm, which is difficult to achieve when conversion is carried out in the raw gas or C_3+ streams without excessive conversion of ethylene to ethane. This factor, together with the value placed on the butadiene product, has meant that these two processing schemes have become effectively obsolete. Recently, catalysts have been developed with improved selectivity in raw gas hydrogenation, and this could cause a revival of interest in raw gas acetylene conversion in certain circumstances.

The development of these new catalysts has been one of the primary reasons behind the selection, by the European contractors, of acetylene hydrogenation in the total C_2 and lighter gas stream prior to a demethanisation step. It has now emerged that there are two distinct design philosophies in the separation area. The principal European contractors (Linde and Lurgi) favour hydrogenation of the total C_2 and lighter gas stream with deethaniser preceding demethaniser, while the U.S.

contractors (Lummus and Stone & Webster) favour hydrogenation of the concentrated C_2 stream with the demethaniser as the first tower.

Although the basic flow arrangement is likely to be constant in any given situation, the type of feedstock processed and the number of products to be recovered results in a different number of steps. For example, if the feedstock is all ethane, the only product of any consequence is ethylene, with tail gas and a small quantity of cracked gasoline as by-products. This results in a simple recovery flowsheet, shown in Figure VI.C.1, with a minimum number of fractionation steps. As the feedstock becomes heavier and more propane is processed along with ethane, more fractionation steps are added to recover propylene and other products. When a full range of materials is recovered, as in a naphtha plant or a large propane plant, the flow scheme shown in Figure VI.C.2 is employed. A plant cracking gas oil and recovering the full spectrum of products uses the typical flowsheet shown in Figure VI.C.3.

The basic flow arrangements shown in Figures VI.C.1, VI.C.2 and VI.C.3 are typical of current technology for the feed types considered. The discussion in the following sections points out the flowsheet differences among plants employing discrete cracking of ethane, naphtha, and gas oil feeds. The purpose of this exercise is to acquaint the reader with the basic processing steps of an ethylene plant. Discussion begins with an ethane cracker, since this type of plant employs the simplest flow scheme. A naphtha cracker is next followed by a gas oil cracker, the plant with the highest degree of complexity. It must be emphasised, however, that in an area of technology that is changing as rapidly as ethylene, designers of ethylene plants are continually improving and optimising their flow arrangements. Thus, the discussion on flowsheet arrangement is a design guide rather than a design handbook, and the optimum conditions for a particular situation must still be developed by experts in ethylene plant design.

a) Ethane Feed

Ethane is the lightest of all feeds which can be cracked to ethylene. Since there is only one primary reaction to consider (ethane to hydrogen and ethylene), the number of processing steps involved in purifying the ethylene product is considerably reduced compared to cracking propane and heavier feeds. A typical process flow scheme for cracking ethane is shown on Figure VI.C.1.

Ethane and dilution steam, in a steam to hydrocarbon weight ratio of approximately 0.3, are heated to a cracking temperature of approximately 900°C in a vertical tubular furnace. After the cracking reaction has progressed as far as desired to obtain the optimum yield pattern (usually in 0.5 second residence time in the furnace or less), the reaction is halted as quickly as possible by lowering of temperature in quench boilers, commonly referred to as transfer line exchangers. Heat is recovered by cooling the effluent gases to about 350 - 375°C through the generation of high pressure steam (100 atm. or higher). This steam is subsequently used to drive the process gas and refrigeration compressors, resulting in considerable savings in utility costs.

The furnace effluent is cooled further in a quench tower by a circulating water stream. Here tarry bottoms are removed from the system as a waste product, and most of the dilution steam is condensed and returned for water operation. Oil washing and refrigerated oil washing plants are the most common units currently in use worldwide, and involve scrubbing the gas with a light oil followed by recovery of the recovered gas liquids from this light oil by distillation. This type of plant is now generally regarded as outmoded and uneconomic. The choice of plant therefore lies basically between a simple cryogenic unit, which cools the gas at pressure to condense out the gas liquids, or an expander plant which incorporates a turbo expander into the cryogenic flowscheme to provide refrigeration. The choice between these latter two plant types appears fairly marginal, and we have made preliminary costings of simple cryogenic designs to give indicative recovery costs.

As with most multi-product units, there is no rational way of distributing the total costs between the various products. Butane and heavier components are the easiest to recover, and a very simple cooling plant can extract these at high recovery levels. Deeper cooling to around -40°C can recover most of the propane, whereas cooling in the range -80°C to -130°C is required for good ethane recovery. Although plant complexity and cost increase markedly as deeper refrigeration is employed, many cost items such as site development, control and administration, gas pipelining, feedgas treatment and metering, and most other offsites remain constant.

Also, recovery of ethane implies higher recovery of propane, etc. which reduces the incremental costs attributable to ethane recovery.

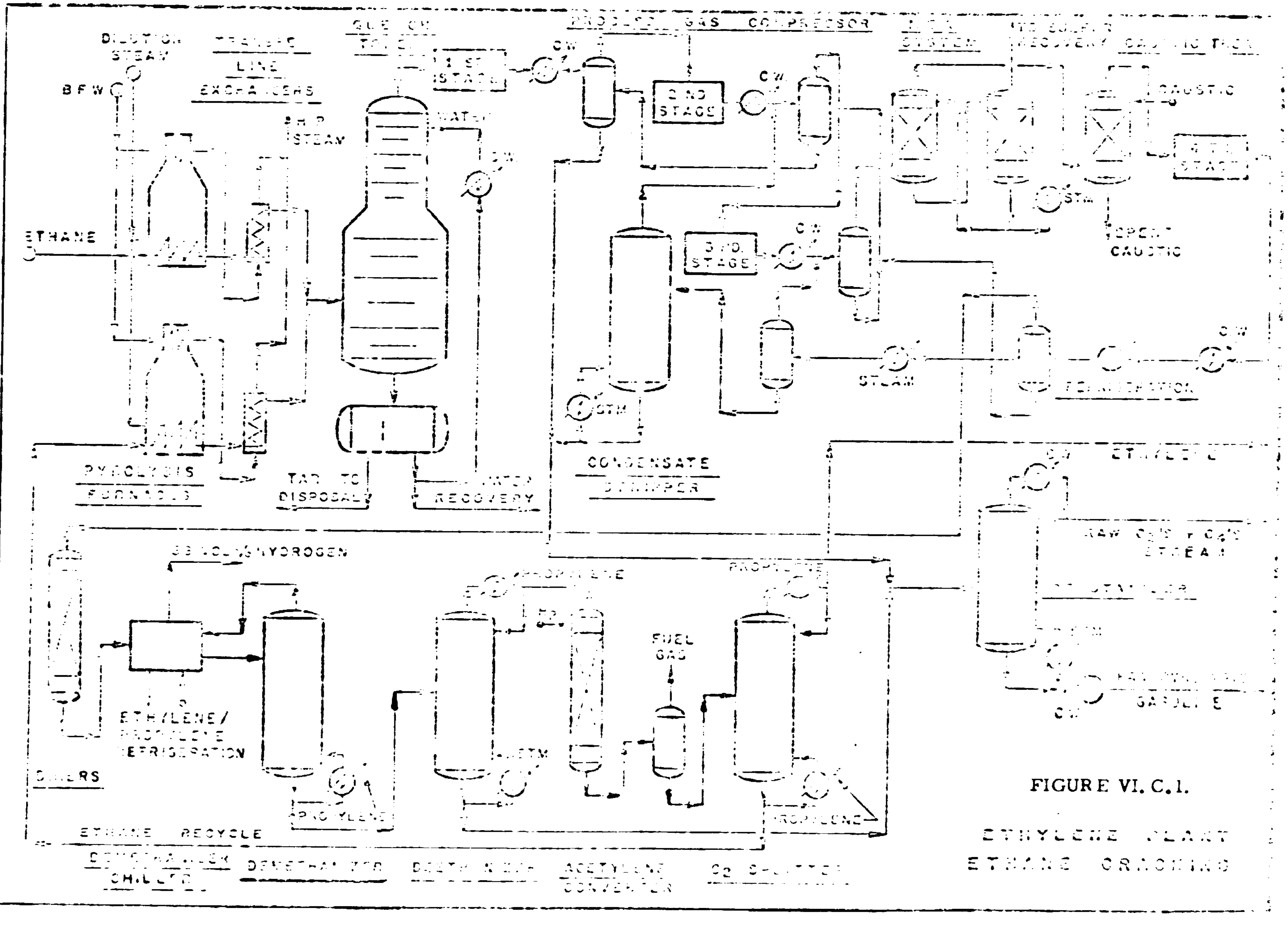

FIGURE VI. C.1.

ETHYLENE PLANT
ETHANE CRACKING

reclamation. The cracked gas leaves the tower at 40°C ready for compression and separation.

Compression is usually done in four or five stages, depending upon the particular contractor's design philosophy. The cracked gas is treated before the final compression stage in a regenerative amine system followed by a caustic wash to remove carbon dioxide and sulphur. These contaminants would render the ethylene product unsuitable for sale, foul the refrigeration system, and also poison the acetylene hydrogenation catalyst.

Following the compression step, any condensate carry-over from the quench tower is stripped to remove light ends, which are returned to the compression train. The condensate liquid is combined with deethaniser bottoms and sent to the debutaniser. The cracked gas is dried with alumina or molecular sieves to remove the last traces of water and then chilled to -75°C point in an ethylene-propylene cascade refrigeration system prior to fractional separation.

Since a pure ethane cracker produces only one major product, ethylene, the fractionation train is a relatively simple one. A demethaniser is the first tower in which hydrogen and methane are taken as an 88 volume percent hydrogen stream from a cold box system operating at a temperature of about -150°C. Part of this stream is used to hydrogenate acetylene to ethylene and ethane in the catalytic converter; the remainder is generally used as plant fuel.

Following demethanisation the gas is deethanised. Acetylene conversion is practiced on deethaniser overhead rather than on the total raw cracked gas to minimise converter size and reduce hydrogen consumption. (Finished C_3 and C_4 streams are not required). After acetylene removal the final step in producing specification grade ethylene is splitting between the ethylene product taken overhead and ethane bottoms. The ethane bottoms are either recycled back to the cracking furnaces or, in rare instances, sold as a pure product. Normally, a maximum ethylene operating mode shows an optimum economic return when recycling ethane to extinction. The ethylene product, if destined for merchant sale, is usually compressed to 100 - 140 atm. for pipeline delivery.

Bottoms from the deethaniser are combined with cracked gas condensate stripper bottoms and sent to a debutaniser. The small amount of C_3's and C_4's produced as an overhead stream do not warrant separation or hydrogenation of acetylenes prior to debutanising. These raw C_3's and C_4's are normally sent to fuel for firing of the furnaces.

The quantity of pyrolysis gasoline (sometimes called dripolene when cracking propane or lighter) removed as a bottoms stream from the debutaniser is too small to justify a hydrotreater for olefin removal. The gasoline is usually sold to local processors who collect such streams and hydrotreat the aggregate to an acceptable gasoline blending stock or feed them to an aromatics separation unit. In some instances the dripolene is blended directly to gasoline if the gasoline pool is sufficiently large to absorb the olefin and diolefin content and continue to meet maximum product specification of these constituents.

b) Naphtha Feed

By definition naphtha is thought of as any hydrocarbon boiling in the gasoline boiling range. This is generally a range of C_5 -220°C end point. Some contractors propose cutting naphthas well before the upper boiling limit to take advantage of claimed steam generation and fuel saving economies that can be realised in the transfer line exchanges when cracking stocks with 180°C end points or less. These contractors claim that higher end point naphthas begin to form significant quantities of tarry materials which accelerate coke laydown when attempting to cool the cracked gases down to boiler exit temperatures usually reserved for lighter naphthas. The decision as to the maximum naphtha endpoint to be used for a specific plant must consider the origin of the naphtha, as well as the views and experience of the contractor.

The typical flowsheet for naphtha cracking, Figure VI.C.2, follows the same processing sequence described in the preceding section for ethane cracking. In the description which follows, only those steps which differ from ethane cracking will be discussed.

The change from natural gas liquids cracking to naphtha cracking requires a dilution steam rate in a steam to hydrocarbon weight ratio of about 0.5 to achieve the proper hydrocarbon partial pressure in the cracking furnace. The reaction is carried out at a coil outlet temperature of approximately 850°C. The actual residence time/temperature relationship is highly dependent on the type of naphtha being cracked. Thus, any furnace design, particularly the coil configuration and firing technique, is unique to the particular feed under consideration.

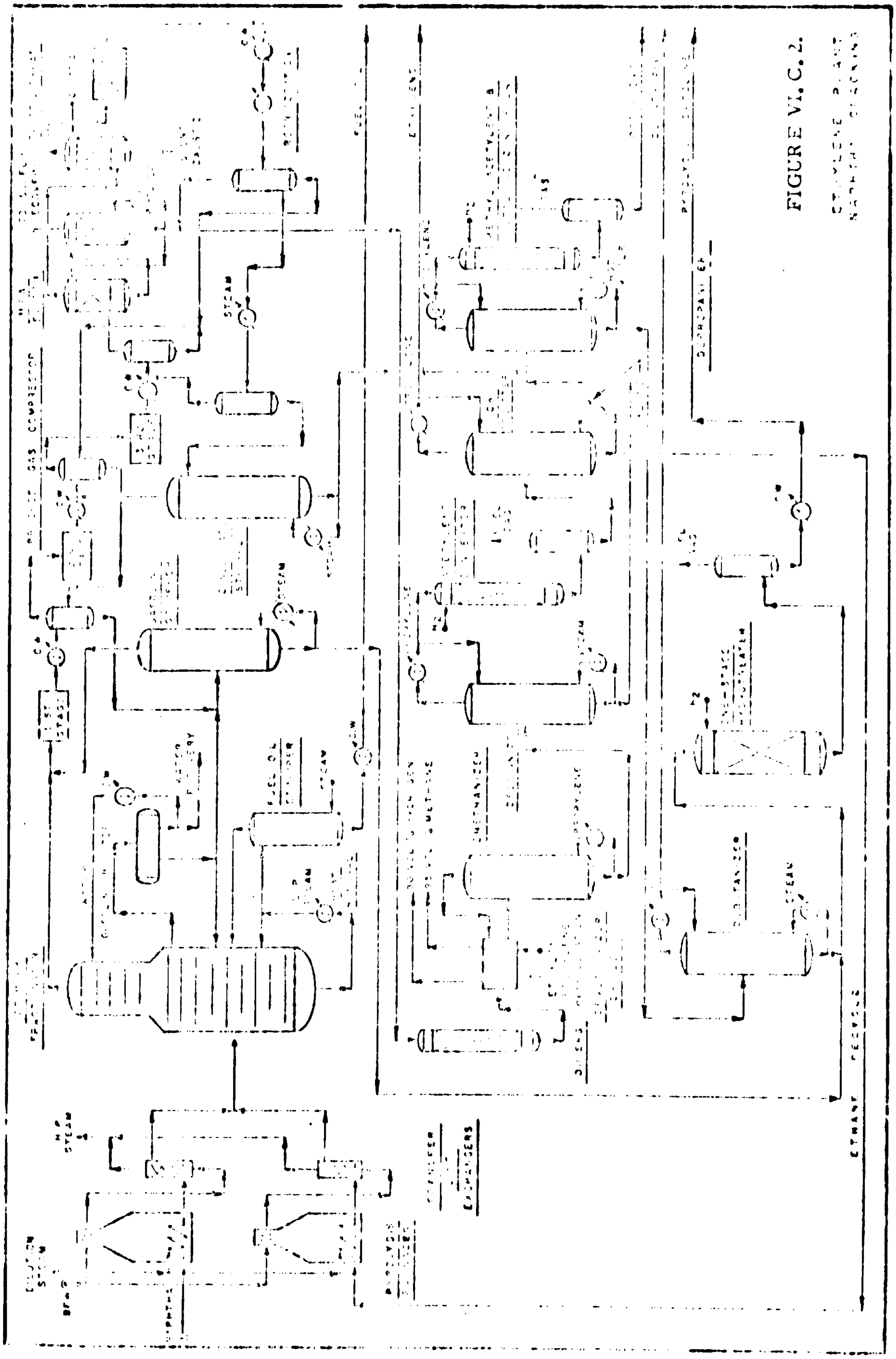

FIGURE VI.C.2.
ETHYLENE PLANT
NAPHTHA CRACKING

The initial departure of naphtha cracking from the similarity to ethane cracking occurs in the quench tower. For naphtha and heavier feedstock cracking this tower is actually a distillation column called the primary fractionator. Naphtha cracking produces considerable quantities of pyrolysis gasoline and light fuel oil which must be removed from the cracked gas prior to entering the compression train. Separation of the cracked gas into essentially C_4 and lighter, water, gasoline, and fuel oil streams is accomplished in the primary fractionator. The presence of fuel oil enables recovery of heat as medium pressure level steam (15 atm. or lower) in addition to heat recovery in the form of hot water for downstream re-boilers. The fuel oil is steam stripped to product specifications in a side stream tower next to the primary fractionator. The raw gasoline is also stripped of light ends prior to being hydrotreated.

The fractionation sequence begins with demethanisation and proceeds with successively higher carbon number product separation steps. Naphtha cracking produces a considerable amount of methane. To meet an 80 volume percent minimum hydrogen specification of the hydrogen product (for down-stream hydrotreating), a separate methane stream (95 volume percent) is recovered from the demethaniser cold box. If higher hydrogen purity levels are desired, further flashing of the 80 volume percent stream is required. To achieve a 99 percent hydrogen purity requires absorption or diffusion equipment at considerable additional capital expenditure.

Acetylene removal is practiced on the individually concentrated C_2 or C_3 streams to prevent loss of butadiene in the C_4 cut and to assure meeting the current 5 ppm maximum acetylene specification of polymer grade ethylene.

Bottoms from the deethaniser are depropanised to recover as an overhead product the large yield of propylene. If chemical grade propylene is specified as the C_3 product (minimum 92 weight percent propylene), the propane content is generally sufficiently low enough to eliminate the need for C_3 splitting.

Depropaniser bottoms contain large amounts of butadiene and butylenes. At the temperature and pressure normally used for depropanising, severe polymerisation of butadiene takes place in the tower bottom and reboiler. This problem is usually handled by sparing of reboilers and periodic burnout of the depropaniser or in some instances sparing of the bottom section of the depropaniser as well.

A C_4 cut rich in butadiene (45-60 weight percent) is recovered as an overhead product from the debutaniser. Debutaniser bottoms are combined with raw gasoline from the gasoline stripper, hydrotreated for diolefin removal in a one-stage hydrotreater, and sent to battery limits as a stream suitable for sale as a component for gasoline blending.

c) Gas Oil Feed

Gas oils are classified as either atmospheric or vacuum according to their origin as products from either the atmospheric crude tower or the crude bottoms vacuum column. The atmospheric material boils in the approximate range 200 - 425°C; the vacuum stock, in the range of 425 - 550°C+. In this report we have limited our discussion and economic analysis of gas oil cracking to atmospheric gas oils derived from several crude oils. Cracking of vacuum gas oils is not significantly practiced in the world today. Consequently, most yield data is based on laboratory runs and, therefore, not representative of expected commercial results. For these reasons we have not included the analysis of vacuum gas oil cracking in this report.

A typical flowsheet for gas oil cracking is shown as Figure VI.C.3. The only significant process variations from naphtha cracking occur in the furnace area and primary fractionator. For gas oil cracking, cooling of the cracked gases is done by a combination of indirect (transfer line exchangers) and direct (oil quench) methods. The primary fractionator is much larger than for naphtha cracking, employing more heat recovery and product fractionation. The following discussion on gas oil cracking describes the major differences between gas oil cracking and naphtha cracking.

A dilution steam to hydrocarbon weight ratio of about 0.8 - 1.0, depending on feed gravity, is required to achieve the proper hydrocarbon partial pressure at furnace cracking conditions. Furnace design is extremely critical when cracking a heavy feedstock such as gas oil. Severity must be high enough for maximum conversion of feed to valuable olefinic products, usually emphasising ethylene in preference to propylene, and low enough to prevent excessive coking in the furnace tubes and/or quench boilers. Coking tendency is mainly a function of the

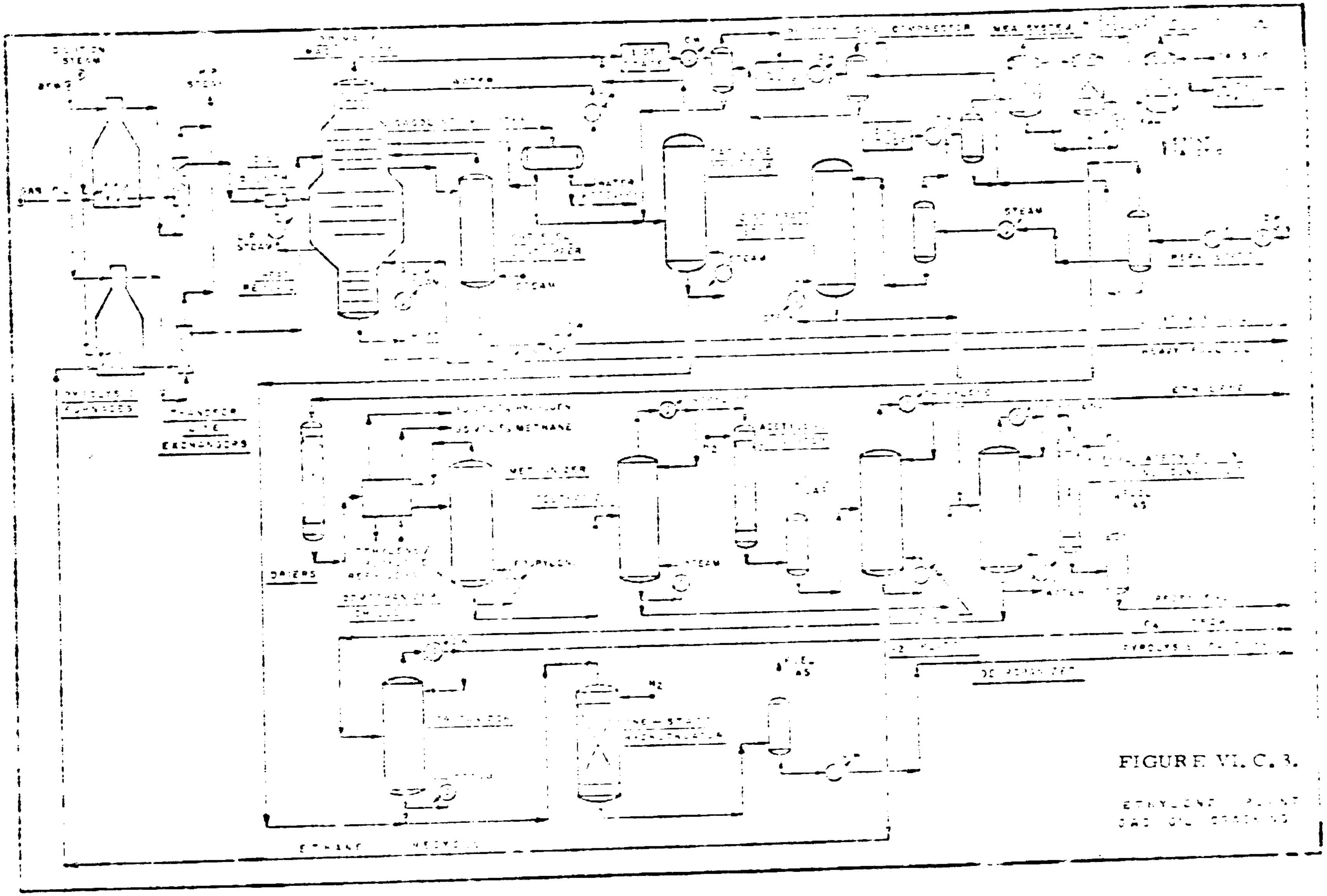

FIGURE VI.C.3.

ETHYLENE PLANT
GAS OIL CRACKING

Conradson carbon and naphthenes/aromatics content of the feed. If not properly handled in the design, it can become a very costly mistake to overcome in terms of shortened furnace run lengths necessitating frequent decoking cycles (increased thermal wear on furnace and boiler equipment and increased maintenance cost for manual decoking). In addition, if the coking rate is severe enough to foreshorten expected run lengths to the extent of exceeding any excess furnace capacity (built-in or as a space furnace), the operator is faced with the most serious problem of all - loss of production, either from a decrease in conversion to valuable products as severity is lowered to extend run time, or from a decrease in overall on-stream time if maximum yield of ethylene is maintained.

Thus, designing for the proper time/temperature relationship is of paramount importance in any gas oil cracker. A typical gas oil furnace operates at a coil outlet temperature of about $800^{o}C$ with the reaction taking place in 0.4 seconds or less.

Gas oil cracking produces a considerable quantity of a carbonaceous heavy fuel oil (in the order of 15 - 20 weight percent on feed) in addition to the usual array of products obtained from cracking naphtha and lighter feeds. It is extremely important to minimize condensation of this material during any indirect quench operation to prevent rapid coke buildup. Thus, the cracked gas temperature at the exit of the quench boiler is limited to about $550^{o}C$ prior to being sent to a second quenching step. Circulating quench oil from the primary fractionator is used as a direct quench medium to condense the heavy fuel oil and cool the cracked gases in a special fitting that

As in indication, therefore we have estimated a plant to give the recovery levels indicated in Table V.A.1, and distributed the costs between all recovered products on an equal cost per million K cal basis.

Based upon gas as specified in Table V.A.1, a typical simple cryogenic- type plant for 5 x $10^9 Nm^3$/year could be estimated as in Table V.A.3: This results in an extraction cost of $1.20 per million K cals for each gas liquid product extracted, on a current (1975) N. African basis. This could be increased to perhaps $1.30 per million K cals for the Arabian Gulf location to allow for the higher installed plant costs.

- Total cost of supply. The total cost of supplying ethane, propane and other gas liquids streams may thus be estimated as the sum of the production, pipelining and extraction costs calculated above. This gives numbers of the order of $1.75 per million K cals in North Africa and $1.55 per million K cals in the Arabian Gulf area. (i.e. around $20 per tonne for all products in both regions.) These are current (1975) numbers. Inflating to a 1980 basis using the data of Section III results in costs of around $32/tonne for all products.

  It must be stressed that very wide fluctuations around these figures can be experienced depending upon specific conditions for a particular location. Plus/minus 50 percent could be expected.

is designed to minimise coke and tarry materials accumulating on the internal surfaces of the device.

The primary difference between quenching furnace effluent from gas oil cracking and naphtha and lighter feedstock cracking is a transfer of part of the initially recovered heat from 100 atm. or higher steam to 15 atm. steam. For a given ethylene production rate, high pressure steam generation in the transfer line exchangers is about 17 percent less for gas oil cracking than for naphtha cracking, limited by the 550°C process gas exit temperature.

Plants designed for either naphtha or gas oil feeds, run either separately or simultaneously, have a choice of sacrificing some high pressure steam generating capacity as a capital-saving procedure or building a complicated quench system as proposed by some contractors to achieve maximum steam generation for either feed. Quench boilers with dual gas oil/naphtha capability can be built as two units in tandem with intermediate valving. When in the gas oil mode the cracked gases are kept above the 550°C minimum allowable temperature by utilising only the first boiler in series. The second boiler is placed in inactive service during this time by an appropriate valve arrangement. In the naphtha cracking mode the second boiler is returned to service to permit additional high pressure steam generation afforded by the lower permissible exit gas temperature.

The primary fractionator for gas oil cracking is more elaborate and larger than for naphtha cracking, resembling a crude tower in appearance and function. The main purpose of this tower is to fractionate between light and heavy fuels (sometimes referred to as cracked gas oil (light) and fuel oil (heavy)) and remove most of the gasoline and water from the cracked gases prior to compression. Another important function is to complete the removal of heat from the furnace effluent through the generation of 15 atm. and lower pressure steam. There are usually two or three heat removal sections for steam generation (more for gas oil than naphtha due to lower high pressure steam make) and a low level hot water heat removal loop. The steam is used as reboiler heat medium in the recovery section and to drive small pump turbines. Dilution steam for use in the furnaces is also generated as part of the heat recovery off the primary fractionator. This can be done as a separate steam loop or as secondary generation from primary steam from the fractionator. The purpose for a segregated dilution steam loop is to isolate the oily water from the clean boiler feed water used in the turbine drive steam system.

The process flow of the recovery section for gas oil cracking, beginning with the process gas compressor, is essentially identical to naphtha cracking. All comments made in Section 2.b for naphtha cracking are applicable for a gas oil feed.

3. Commercial Steam Cracking Yields

Tables VI.C.1, VI.C.2, and VI.C.3 present typical yields being realised in commercial tubular furnaces for several common feedstocks. The yields shown can serve as a guide to planning projects, but detailed yields derived from pilot plant data or cracking furnace computer simulations should be used for definitive designs.

From the data given in the above-mentioned tables the following general observations can be made. As the feedstock becomes heavier (measured by gravity, boiling range, carbon number, molecular weight, carbon/hydrogen ratio, etc.):

- Ethylene yield decreases
- Fuel oil yield increases
- Conversion of feed to C_3 and lighter products decreases.

Within the same feedstock type (i.e., naphthas or gas oils), selectivity to ethylene improves with increase in paraffin content and declines with increase in naphthenes. An increase in naphthenes leads to an increased yield of aromatics and, therefore, higher gasoline yield. Aromatics in the feed are essentially inert and do not crack.

a) Natural Gas Liquids

Ethane and propane, either separately or in mixtures, have been the preferred feedstocks for crackers built in the U.S. prior to approximately 1972. These feeds are recovered from natural gas, or from crude oil by distillation.

Cracking of ethane has only one primary reaction: to hydrogen and ethylene. The selectivity to ethylene increases with high temperature, short residence time, and low hydrocarbon partial pressure. Ethane is cracked in the presence of steam, at coil outlet temperatures of 840 - 880°C, at 60 - 70 percent conversion (feed disappearance) per pass. The unconverted portion is recycled to obtain maximum yields of ethylene. The exact choice of conversion is based on economics. Lower conversion per pass requires less feed per pound of ethylene produced but results in higher investments and utilities. For instance, at 60 percent conversion the once-through ethylene yield is approximately 49 wt. percent, while at 70 percent conversion the yield is about 54 wt. percent. Thus, the overall yield on fresh feed is 81 wt. percent at the lower once-through conversion and 77 wt. percent at the higher once-through conversion.

By-products are not generally a consideration with ethane cracking. Methane formation is present from the start and increases at an accelerated rate when the ethylene reaches a maximum. Some heavy ends, predominantly benzene, are formed at the higher conversion level.

Propane is cracked at about the same temperature as ethane. Because of the faster reaction rate for propane relative to ethane, a higher conversion is generally obtained. Propane conversion is 90 - 95 percent on a once-through basis with an ethylene yield of about 34 wt. percent at the lower conversion. By-products are a consideration since appreciable quantities of propylene and, to a lesser extent, butadiene and cyclic dienes are produced.

Propane and ethane can be cracked together without adverse effects. The chemical structure and cracking kinetics of the individual feedstocks are such that mixture cracking does not appear to produce a synergistic effect. In commercial operation, the furnace feed is nearly always a mixture of light hydrocarbons. In recycling operation, the actual feed composition must be determined. The feed may contain C_4 saturates or propylene.

At present, relatively few commercial plants crack butane. Ethylene yield on the order of 24 wt. percent at 90 percent once-through conversion is experienced. The propylene yield peaks at about 70 percent conversion with a 19 wt. percent yield. Contrary to expectation, butadiene and butene yields are not particularly high, peaking at 70 percent conversion with a total yield of about 7 wt. percent. Butane is not normally cracked in combination with ethane and propane because of its vastly different kinetics. Thus, the conditions under which ethane and propane co-crack efficiently would cause n-butane to overcrack, resulting in excessive coking.

By recycling the propane, ethane, and C_4 fraction, an ultimate ethylene yield of 38 wt. percent and propylene yield of 21 wt. percent are possible when cracking n-butane at a once-through conversion of 90 percent.

Mixed LPG is another light cracking feedstock which has found use for ethylene and propylene manufacture. This would be a feed recovered from natural gas, or from crude oil in primary distillation. If composed entirely of propane and/or n-butane, the cracking behavior is typically as described above. It may, however, include such components as isobutane and propylene which are basically poor cracking feedstocks. In fact, when cracking propane, the propylene content should be limited to a maximum of 15 percent because of excessive coking. Propylene in combination with ethane should be limited to 25 percent.

The performance of propylene as a feedstock relative to ethane and propane is probably based on a propylene cracking mechanism which involves first a polymerisation of the propylene, followed by cracking of the resultant polymer to ethylene. Ethylene once-through yields of about 19 wt. percent are estimated for propylene cracking at 815^{0}C and at a conversion of 70 percent. Thus, an ultimate ethylene yield of about 27 wt. percent is estimated.

Compared to propane and ethane, propylene is relatively more easily cracked at low temperatures. In the range of 815^{0}C, the order with decreasing reactivity is propane, propylene and ethane. Cracking of propylene will result in high yields of CO, benzene, CO_2, and coke. An ultimate yield of benzene of about 17 wt. percent is realised when cracking at 70 percent once-through conversion.

Iso-butane is a relatively poor feedstock for ethylene production with yields below 10 wt. percent on an ultimate basis. Propylene and isobutylene are the major products with yields of 20 and 16.5 wt. percent, respectively, at 70 percent conversion.

Normal butylenes are not particularly attractive for ethylene production with once-through yields of 15 wt. percent at 85 percent once-through conversion. Iso-butylene feed gives very low ethylene yields. The major products are methyl acetylene and propadiene (10 wt. percent) at 50 percent conversion.

Typical once-through cracking yields and furnace operating conditions are given in Table VI.C.1 for the common natural gas liquids.

TABLE VI.C.1

NATURAL GAS LIQUIDS CRACKING YIELDS AND FURNACE CONDITIONS

Feedstock Description	Ethane	Propane	70:30 Vol.% Propane:Ethane	N-Butane	I-Butane
Carbon/Hydrogen Weight Ratio	3.97	4.47	4.37	4.77	4.77
Single Pass Furnace Yields - Wt.% on Feed					
Hydrogen	3.7	1.2	1.9	1.1	1.1
Methane	4.1	23.6	20.6	19.8	14.1
Acetylene	0.3	0.4	0.4	0.2	0.1
Ethylene	48.9	34.0	39.8	24.2	5.2
Ethane	40.0	5.8	12.9	6.1	0.3
Methyl Acetylene/Propadiene	0.1	0.5	0.5	0.1	0.1
Propylene	1.1	14.9	10.3	18.1	21.2
Propane	0.2	10.0	5.0	2.3	0.8
Butadiene	0.5	1.5	1.5	2.5	1.5
Other C4's	0.4	1.1	1.0	13.8	43.6
Pyrolysis Gasoline	0.7	7.0	6.1	11.8	12.0
Total	100.0	100.0	100.0	100.0	100.0
Approximate Furnace Operating Conditions					
Coil Outlet Temperature, °C	860	860	860	860	790
Coil Outlet Pressure, Atm. g	1	1	1	1	1
Steam/Hydrocarbon Weight Ratio	0.3	0.3	0.3	0.3	0.3
% Feed Conversion	60	90	65 C_2H_6 93.5 C_3H_8	90	80

b) Naphtha

Components in the gasoline boiling range make very desirable feeds for the production of ethylene and a whole range of by-products. These types of feeds are complex hydrocarbon mixtures with yields changing dramatically as the composition is changed. The product composition from such a mixture of chemical materials can never be accurately determined from the cracking spectra of the individual components.

To understand the economics of steam cracking, it is essential first to review the general yield curves and operating limitations associated with various naphtha feedstocks. Ethylene yield increases steadily as conversion to C_3 and lighter gas increases. With a light naphtha feed, ethylene yield reaches a maximum of about 35 - 40 wt. percent at about 75 percent C_3 minus (minus meaning "and components lighter than") once-through conversion and 980°C. This is outside the capability of any current tubular type steam cracking process. Also, the concentration of ethylene in the total gas product reaches a maximum at 70 - 75 percent conversion, with hydrogen and methane increasing rapidly above this conversion.

High molecular weight olefins and diolefins peak at lower conversions since these cracked products recrack to light gases as conversion increases. Thus, whenever butadiene and/or propylene have a high by-product value, optimum conversion will be lower than when ethylene is the only valuable product.

TABLE VI.C.2.

NAPHTHA FEEDSTOCK CHARACTERIZATION, CRACKING YIELDS AND FURNACE CONDITIONS

Naphtha Number	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Feedstock Description	Typical Light Straight Run Naphtha	Typical Full Range S.R. Naphtha	Typical Full Range S.R. Naphtha	Typical Full Range S.R. Naphtha	Typical Heavy Straight Run Naphtha	Naphtha (b)	Naphtha (c)	Naphtha (d)
Cracking Severity	High	High	High	High	High	Medium	Medium	Medium
Crude Source	Lt. Arabian	Lt. Arabian	Brega (Libyan)	Saharan	Mid East			
Paraffins, Volume	93	74	60	55	60			
Naphthenes, Volume %	6	16	34	32	26			
Aromatics, Volume %	1	10	6	13	14			
Mean Average Boiling Point, °C	46	102	[illegible]	113	135			
Boiling Point Range, °C	C_5 - 70	C_5 - 175	C_5 - 175	C_5 - 180	95 - 185			
°API	85.0	65.1	62.9	61.0	58.2			
Average Molecular Weight	78	103	109	[illegible]	121			
Carbon/Hydrogen Weight Ratio	4.85	5.82	6.05	5.86	5.78			
Single Pass Furnace Yields-Wt.% on Feed								
Hydrogen	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07
Methane	14.5	13.5	12.3	16.3	15.8	11.8	12.4	12.6
Acetylene	0.8	0.7	0.5	0.4	0.5	0.2	0.1	0.1
Ethylene	29.3	28.4	27.1	[illegible]	26.9	21.3	20.7	20.1
Ethane	3.9	3.9	3.8	3.9	4.0	3.9	3.9	3.8
Methyl Acetylene/Propadiene	0.5	0.4	0.4	0.4	0.4	0.1	0.1	0.1
Propylene	17.3	16.5	16.1	14.7	13.1	16.5	15.9	16.7
Propane	0.5	0.5	[illegible]	0.7	0.6	0.7	0.7	0.7
Butadiene	5.0	4.9	5.0	3.6	3.0	3.9	4.1	3.6
Other C4's	6.4	6.3	6.5	3.1	3.2	6.6	6.8	6.1
Pyrolysis Gasoline	18.4	21.0	23.8	23.8	27.0	30.6	31.3	32.0
Fuel Oil (220-340°C)	2.5	3.1	3.2	4.5	4.8	3.2	3.3	3.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Approximate Furnace Operating Conditions								
Coil Outlet Temperature, °C	840	840	840	840	840	800	800	800
Coil Outlet Pressure, Atm. g	1	1	1	1	1	1	1	1
Steam/Hydrocarbon Weight Ratio	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Weight % Conversion to C_3 and Lighter	67.7	64.7	61.5	65.0	62.0	55.7	54.5	54.8
Raw Pyrolysis Gasoline								
Ron Clear	97.0	99.1	100.0	100.5	100.3	96.0	95.1	[illegible]
°API	45.6	44.4	46.8	37.4	37.2	47.6	47.6	45.4

Paraffinic feedstocks have the best selectivity to ethylene. Naphthenes are preferred for high butadiene and benzene yields. Aromatics are inert. Short cracking times are preferred for good selectivity to ethylene and butadiene and to avoid polymerisation of cracked products and minimise formation of coke.

The cracking yields and furnace operating conditions of a few of the common cracking naphthas are given in Table VI.C.2.

c) Gas Oil

Gas oils are classified as either atmospheric or vacuum according to their offtake origin from refinery units (viz., atmospheric or vacuum crude tower). The atmospheric material boils in the approximate range of 200 - 425°C; vacuum gas oil, from 425 - 550°C+. These types of feeds are limited to relatively low C_3 and lighter conversion levels because of coking tendencies at high conversions in a tubular furnace. Part of the ethylene yield comes from recracking products of initial cracking reactions. These intermediate products also contain aromatic coke precursors. The variables affecting the coking rate are feedstock boiling range, feed component analysis, Conradson carbon, and conversion level. Ethylene yields from 11 to 22 wt. percent have been reported for low and high severity cracking of gas oils.

The cracking yields and furnace operating conditions of a few atmospheric and vacuum gas oils are given in Table VI.C.3.

TABLE V.A.3.

GAS LIQUIDS RECOVERY PLANT COSTS

Basis:

Gas quantity processed	$5 \times 10^9 Nm^3$/year
Inlet pressure	35 atm.
Location	N. African coastal site, 1975
Process route	Simple cryogenic
Gas compositions/recovery	As Table V.A.1.

Capital Costs:	$ million
Gas treatment and drying	7
Cryogenic recovery unit	30
Product storage	14
Utilities and offsites	10
Sub-total, materials and construction	61
Engineering, owners costs, contingency (20%)	12
Total Estimated cost	$ 73 million

Extraction Costs:	$ million/year
Labour	1
Maintenance (4% BLCC)	1.5
Overheads and administration	1.5
Fuel @ $0.5/million Kcal	1
Capital charges (25%)	18
Insurance, taxes etc. (1.5%)	1
Total annual costs	$ 24 million/year

Gas Liquids Recovered:

Component	Quantity		Cost	
	(tonnes/year)	(million Kcals/year)	$/million Kcals	$/tonne
Ethane	380 000	4 700 000	1.20	15
Propane	500 000	6 000 000	1.20	14
Butanes	460 000	5 400 000	1.20	14
Pentane +	340 000	3 900 000	1.20	14
		20 000 000		

TABLE VI.C.3.

GAS OIL FEEDSTOCK CHARACTERIZATION, CRACKING YIELDS AND FURNACE CONDITIONS

Feedstock Description	Atmospheric Gas Oil	Atmospheric Gas Oil	Atmospheric Gas Oil	Atmospheric Gas Oil	Vacuum Gas Oil	Vacuum Gas Oil
Crude Source	Lt. Arabian	Brega (Libyan)	Alaskan	Saharan	Mid-East	Saharan
Mean Average Boiling Point, °C	300	305	318	296	443	443
Boiling Point Range, °C	220 - 400	220 - 400	220 - 400	230 - 370	370 - 540	370 - 540
°API	35.1	36.3	29.5	31.5	16.7	20.0
Average Molecular Weight	255	255	255	233	365	400
Carbon/Hydrogen Weight Ratio	6.44	6.35	6.97	6.91	7.79	7.33
Weight % Sulphur	1.22	0.25	0.58	0.16	2.7	0.30
Single Pass Furnace Yields-Wt.% on Feed						
Hydrogen	0.5	0.5	0.5	0.5	0.4	0.4
Methane	9.5	9.4	9.4	8.2	8.6	7.2
Acetylene	0.1	0.2	0.1	0.3	0.2	0.2
Ethylene	20.9	21.8	17.2	21.5	14.6	15.4
Ethane	4.4	4.4	4.3	4.2	4.2	3.7
Methyl Acetylene/Propadiene	0.5	0.5	0.4	0.3	0.2	0.2
Propylene	13.8	14.0	12.7	14.0	11.3	12.3
Propane	0.7	0.7	0.6	0.7	0.5	0.6
Butadiene	4.8	5.0	4.0	4.9	3.5	3.6
Other C4's	4.5	4.4	4.7	5.2	5.0	5.7
Pyrolysis Gasoline	20.5	20.3	19.2	21.9	17.5	23.4
Light Fuel Oil (220-340°C)	4.5	4.2	5.0	18.3	34.0	27.3
Heavy Fuel Oil (340°C +)	15.3	14.6	21.9			
Total	100.0	100.0	100.0	100.0	100.0	100.0
Approximate Furnace Operating Conditions						
Coil Outlet Temperature, °C	810	810	810	790	780	800
Coil Outlet Pressure, Atm. g	1	1	1	1	1	1
Steam/Hydrocarbon Weight Ratio	0.8	0.8	0.8	0.7	0.75	0.7
Weight % Conversion to C_3 and Lighter	50.4	51.5	45.2	49.7	40.0	40.0
Raw Pyrolysis Gasoline						
Ron Clear	98.4	98.0	100.1	95.0	99.7	93.4
°API	47.5	48.6	45.8	49.0	44.7	46.2

4. Effect of Key Parameters on Cracking Yields

a) Introduction

The previous section summarised typical operating conditions and product yields as presently commercially achieved in modern plants in developed countries. The selection of operating conditions and plant design details for a particular feedstock and project can be varied from these "typical" values to optimise the profitability of the specific project. Such variations from the established developed-country norm could well be important in optimising an olefin plant in the very different conditions found in an Arab oil and gas producing country. A brief analysis of the effect of the key parameters upon product yields and plant operability is therefore given in this section. The most important parameters considered are:

- Cracking severity
- Feedstock composition
- Temperature
- Residence time
- Steam/hydrocarbon ratio

Cracking severity is the most significant of these variables and, in essence, a function of all the other parameters. The optimum severity level for any given cracking situation is that time/temperature relationship that maximises yield of primary products, usually ethylene, and minimises feedstock consumption. It involves an economic consideration of feed and product values, energy consumption, and capital requirements to provide the necessary plant flexibility.

b) Cracking Severity

The definition of severity in steam cracking is somewhat ambiguous. In general, severity is measured by residence time and/or temperature and it may be represented as C_3 and lighter yield, ethylene yield, or feed disappearance. To most people in the industry, an ethylene yield of 10 - 20 percent represents low severity, 20 - 27 percent moderate, and 27+ percent high severity. The key to successful high severity operation is an optimum combination of time and temperature depending on feedstock type.

With the cracking of heavy liquid feedstocks, the problem of operability must be faced. When cracking in the 760 - 870°C range, one cannot extract the last bit of hydrogen from the feed. To assure continuous operation, the cracked liquid products (C_5+) must contain about 8 percent hydrogen by weight.

Based on this, a maximum severity in tubular crackers may be determined. For gas oils and heavier, there are other considerations in the detailed feed analysis affecting operability. Cracking of very heavy feeds is not generally carried out in tubular furnaces because of coking problems.

In general, light and heavy naphthas are commercially cracked to a maximum of 60 - 70 percent conversion to C_3 and lighter components, with ethylene yields of 25 - 30 wt. percent on feed and with considerable variation in by-products depending on feedstock characteristics.

Gas oils are cracked to 40 - 50 percent conversion to C_3 and lighter, with ethylene yields in the order of 16 - 22 wt. percent and again with considerable variation in by-products depending on feed characteristics.

The optimum severity is determined by a balance of:

- Ethylene yield
- By-product credits
- Operability limitations

In the case of light hydrocarbons (ethane, propane, butane, etc.), conversion is fairly standardised. Typical once-through cracking yield ranges were given in Table VI.C.1.

For ethane cracking, the ultimate yield of ethylene is 77 to 81 wt. percent when operating in a temperature range of 840 - 880°C. The optimum for ethane cracking is quite flat between 60 and 70 percent conversion. The higher conversion means lower investment and operating cost because less gas is processed per unit weight of ethylene, but selectivity to ethylene decreases. The operation of the transfer line exchanger is a consideration from an operability point of view. The higher conversions lead to an increased yield of polymer-forming materials which promote accelerated fouling rates. As a consequence, contractors have not designed furnaces to operate at 70 percent or higher conversion on ethane feed because of the lack of operating experience on transfer line exchangers. There are, however, some operating companies which have cracked to 75 percent conversion without adverse experiences in the transfer line exchangers. By-product credits are not a consideration with ethane cracking since once-through yield of C_3+ material is of the order of 3 - 5.5 wt. percent.

Propane cracking is generally carried out at maximum severity, i.e., 90 - 95 percent once-through conversion. By-products can become a major factor in the economics since once-through yield of C_3+ material is of the order of 30+ wt. percent. The major by-products are propylene, butadiene, cyclic diolefins and aromatics. Propylene once-through yield reaches a maximum of 20 wt. percent at low conversion of 70 - 75 percent; however, C_4's and C_5+ yields increase with conversion. Coking and operability of the transfer line exchanger generally dictates a 90 - 92 percent conversion. An ultimate ethylene yield at 92.5 percent conversion (recyclying ethane and propane to extinction) is 43+ wt. percent.

The optimum severity (conversion) is increased with an increase in coil outlet temperature because selectivity at constant conversion increases with temperature. Furnace technology prevents an ever-increasing coil outlet temperature and reduced residence time. A coil outlet temperature of about 875 - 885°C is maximum with present day materials of construction. In general, reducing the coil outlet temperature and increasing the residence time will result in lower primary products and more secondary cracked products such as aromatics and cyclic diolefins. However, the latter yields from ethane and propane cracking will still be relatively small. Operability due to coking can also become a problem when operating at high conversion (low temperature/long residence time).

TABLE VI.C.4

EFFECT OF SEVERITY ON ONCE-THROUGH YIELDS FOR A LIGHT-NAPHTHA

Naphtha Characteristics

			Vol. %
Boiling range	50 - 110°C	n-Paraffins	45
°API	79.4	i-Paraffins	32
Sulphur	200 ppm	Naphthenes	22
		Aromatics	1
			100

Average Temp., °C	740	790	800	820
Conversion, Wt. C_3 and Lighter	44.3	59.0	65.6	69.1
Component, Wt.% on Feed				
Hydrogen	0.6	1.0	1.6	2.2
Methane	9.0	14.8	20.4	23.5
Acetylene	0.3	0.6	0.8	1.1
Ethylene	16.2	24.4	29.8	31.9
Ethane	3.3	3.5	3.5	3.5
Methyl Acetylene/Propadiene	0.2	0.4	0.5	0.5
Propylene	14.3	13.8	8.5	6.0
Propane	0.4	0.5	0.5	0.4
Butanes	0.1	0.1	0.1	0.1
Butylenes	8.3	5.9	3.2	2.8
Butadiene	3.8	3.4	2.9	2.1
Pyrolysis Gasoline	42.0	28.9	22.7	16.8
Fuel Oil	1.5	2.7	5.5	9.1
Total	100.0	100.0	100.0	100.0
$C_2= + C_3=$	30.5	38.2	38.3	37.9
$C_3= / C_2=$ Ratio	0.88	0.57	0.29	0.19
C4's / $C_2=$ Ratio	0.75	0.39	0.21	0.16

The effect of severity on the yield structure from cracking naphtha and heavier feeds is much more pronounced than for light hydrocarbons. This effect is illustrated in Table VI.C.4 for a light naphtha.

The ratio of ethylene to other olefins and diolefins may also be altered by changing the residence time. This effect is shown in Table VI.C.5 for the same light naphtha at constant temperature.

TABLE VI.C.5

EFFECT OF RESIDENCE TIME ON OLEFIN RATIO - CONSTANT TEMPERATURE

Average Temperature, $^{\circ}C$	790	790
Conversion, Wt.% C_3 and Lighter	59.0	51.0
Residence Time, sec.	0.4	0.14
Wt.% on Feed		
Ethylene	24.4	22.0
Propylene	13.8	19.2
C_4's	9.4	13.0
$C_3= / C_2=$ Ratio	0.57	0.87
C_4's / $C_2=$ Ratio	0.39	0.59

From the above examples, it is apparent that as severity is increased (via time and/or temperature), conversion, as measured by C_3 and lighter, increases as does ethylene yield. However, a peak is reached beyond which further increases in severity result in reduced yield of C_3 and lighter.

Gas oil feedstocks, when cracked at varying severity levels, exhibit yield patterns directionally similar to naphthas. That is, as severity increases, C_2 + C_3 olefin yield increases and the yield of propylene and C_4's relative to ethylene decreases.

The yield of aromatics from gas oil cracking contributes significantly to the by-product offtake - either as part of the pyrolysis gasoline stream or as recovered aromatic components. Benzene is the dominant aromatic, with its yield increasing in concentration relative to the other aromatics with increase in severity. The effect of severity on C_6 - C_8 aromatic yields from cracking the same Mid-East gas oil is shown in Table VI.C.6.

TABLE VI.C.6

EFFECT OF SEVERITY ON C6 - C8 AROMATIC YIELDS
MID-EAST GAS OIL

Conversion, Wt.% C_3 and Lighter	42.5	45.9	48.4	58.1
Wt.% on Feed				
Benzene	3.1	3.6	4.1	6.4
Toluene	2.7	2.9	3.2	5.1
Xylenes	1.4	1.6	1.7	1.5
Benzene/C_7-C_8 Aromatics Ratio	0.75	0.80	0.84	0.97

c) Feedstock Composition

In addition to operating conditions, product yields vary greatly with feedstock characteristics.

A review of the data shows that the distribution between gaseous and non-gaseous products is primarily the result of the expected effect of feedstock carbon to hydrogen weight ratio on the relative abundance of a high hydrogen content gaseous hydrocarbon fraction and low hydrogen content aromatic C_6+ hydrocarbon and coke fraction.

The combined ethylene and propylene yield decreases rapidly with increase in feedstock carbon to hydrogen weight ratio with a corresponding increase in non-gaseous products.

Non-gaseous product distributions are difficult to predict, especially for heavy feedstocks and high carbon to hydrogen ratios, since a significant portion of the non-gaseous products is not the result of vapour phase pyrolysis reactions. Further, the relative formation of liquid products and coke is controlled by feedstock properties other than carbon to hydrogen ratio as well as operating conditions. In general, increase in feedstock molecular weight results in a shift from lower to higher molecular weight aromatics content of the liquid products and higher coke yields.

Laydown or deposition of coke on the internal surfaces of furnace and boiler tubes is the result of complete removal of hydrogen from a portion of the cracked gas components. The rate at which coke deposition occurs is a function of several variables, of which feedstock composition is a prime contributor. Coking is a serious and costly problem with which to contend in any cracking process. Great efforts are expended to examine all essential feed and operating parameters which significantly influence the coking rate of a given feedstock.

d) Temperature

Temperature is the reaction variable which has the greatest influence on the cracking yield spectrum of hydrocarbons.

The yield of ethylene rises with increasing temperature. Similarly, the methane and hydrogen yields rise. Part of the higher ethylene yield is at the expense of C_3 and C_4 olefins. In this way the propylene/ethylene ratio from a light naphtha feed can be varied over a wide range from 0.9 to 0.4.

The location of the peak for ethylene yield is influenced principally by the combination of time and temperature employed. As temperature is increased at a given residence time, a point is reached where further temperature increase results in a lower ethylene yield. Both the location and height of the peak is influenced by the residence time. Lower residence times shift the peaking to higher conversion levels and result in increased maximum ethylene yields.

The same effects may be noticed with heavier feedstocks. However, the ethylene peaks are generally not reached with heavy feedstocks due to the increased incidence of furnace coking even at moderate conversions. The only option open to overcome this problem is to reduce residence time and increase the temperature. However, in

This "Cost of Supply" approach is only meaningful if the methane-rich tail gas, comprising some 80 percent of total natural gas feed, can also be utilised and therefore carry its share of pipelining and other costs.

b) <u>Alternate use value</u>

The major alternative use for ethane, propane and heavier gas liquids available in Arab States is simply export to a developed market. Thus propane and butane could be exported as LPG, pentanes + could be exported as gasoline blendstock or petrochemical feed, and the main option for ethane is to leave it in the natural gas and export it as LNG. Since the value of natural gas itself (for plant fuel, etc) may also be considered to be set by LNG economics, a estimate is presented below relating natural gas prices to oil prices through the LNG route.

- Natural gas. Table V.A.4. estimates the 1980 value of natural gas at an Arab coastal location based upon LNG economics.

Thus the alternative use values of natural gas in Arab locations in 1980 are estimated at $4.90 per million K cals in North Africa, and $2.00 per million K cals in the Arabian Gulf area. These are considered to represent realistic valuations, and these numbers are used throughout the cost calculations and economics in this study to represent natural gas price and general fuel values.

conventional tubular furnaces success of this prodedure is limited by heat input restrictions dictated by tube metallurgy. This problem is receiving increased attention by ethylene plant contractors.

e) Residence Time

At low residence times secondary reactions are minimised and primary cracking is the major reaction. The yield of primary olefins (ethylene, propylene, and butadiene) is maximised at low residence time and high temperature.

In addition, as temperature increases and residence time decreases, coke is also minimised.

The residence time for maximum ethylene and total primary olefin yields decreases from 0.35 sec. at 800^{o}C cracking temperature to 0.06 sec. (60 milliseconds) at 950^{o}C. This latter temperature is beyond the maximum limit permissible in today's conventional furnace designs. But with improved technology in the area of furnace design and tube metallurgy, increased ethylene yield will show substantial improvement as cracking temperatures rise and residence times shorten.

f) Steam/Hydrocarbon Ratio

Addition of steam to the hydrocarbon feed enables the cracking reaction to proceed at workable temperatures and promotes the yield of low molecular weight olefins. The effect on the reaction lies mainly in the lowering of the hydrocarbon partial pressure. The improved olefin yields are at the expense of C_5 and higher hydrocarbons production and gas make. The decision to increase steam rate is one of economics. The following disadvantages tend to counteract the advantage of a higher ethylene yield by increasing dilution steam rate:

- Increased molar volume of the reaction mixture with an adverse effect on the time - temperature relationship.
- Increased cost of producing the extra steam
- Increased heat requirement for heating the extra steam to the cracking temperature
- Correspondingly larger condenser and cooler area requirements
- Correspondingly larger cooling water requirements

In the case of gas oil cracking dilution steam ratios are generally higher than for naphthas and lighter. This is done to reduce hydrocarbon partial pressure to a point where the cracking reaction can proceed at a temperature low enough to prevent excessive coking and still give adequate olefin yields.

D. CAPITAL COSTS AND MATERIAL BALANCES

1. Basis

The various cost factors (BLCC, offsites, working capital etc.), involved in implementing on olefin project were discussed in Section III.B.

The scope which these items cover for an olefin plant are set out below:

a) Battery Limits Capital Cost (BLCC)
This is the total erected cost of the production unit including all material, labour and engineering costs. Included where appropriate is any initial catalyst loading and solvent inventory.

The equipment included will vary depending upon the feed being considered as described earlier in Section VI.C.2

- An ethane cracker will have basically no co-product recovery equipment, all co-products being in insufficient quantities to separate economically and to recover as finished products. They are therefore used as fuel.

- Ethane/propane mixtures, and other gas liquids feedstocks, have a full fractionation section and a somewhat more complimented furnace section than for ethane alone. Chemical-grade propylene is recovered, and pyrolysis gasoline is hydrotreated to be suitable for sale to a refiner for gasoline blending. All other streams are small, and used as fuel. Butadiene recovery from the C_4 stream is not normally economic unless combined with material from other nearby plants

- Naphtha and gasoil. All by-product streams are important contributors to total production and profitability. Chemical grade propylene is recovered, butadiene is extracted from the C_4 stream, the pyrolysis gasoline is hydrotreated prior to use for gasoline blending or BTX (aromatics) recovery, and the fuel oil is collected and sold.

Thus heavier feedstocks result in far higher capital costs than ethane feeds due to increasing range, size and complexity of equipment.

BLCC costs for the olefin plant are based upon

- 454 000 tonnes per year (1 billion pounds/year) of ethylene capacity, based upon 345 days per year operation. This capacity has become a standard for new projects in Europe and the U.S., giving maximum economy of scale within the limits of available equipment sizes, feedstock availability, market growth and other factors

- Ethane recycled to extinction, propane recycled to the extent possible within propylene product minimum purity specification
- Product purities:

Ethylene	99.95	mol %
Propylene	92	wt.% (chemical grade)
Butadiene	99.5	wt.% (butadiene recovered in liquid feed cases only)

Raw Gasoline - hydrotreated to gasoline blending quality

Hydrogen 80 vol. % } both to fuel system
Methane 95 vol. % } at 4 atm.

- Ethylene product delivered as vapour at 20 atm
- Propylene product delivered as liquid at 20 atm
- Integrated self-sufficient steam system but no export across battery limits
- All other utilities available from offsites
- Average soil bearing conditions with no piling required
- Average engineering standards as applied by major oil refiners and petrochemical producers
- Mid-1980 start-up

b) Offsites

This is the total erected cost of ancillary equipment and buildings required to support the production unit. A typical list of offsite requirements for an olefin plant on a new site in a developed country was presented in Table III.B.2. No feed storage is included in the case of gaseous feeds (gas liquids) to the Arab projects.

c) Working Capital

As discussed in Section III.B.3, we use a generalised estimate of working capital requirements based upon a percentage of BLCC. For the olefin plant we use 15 percent of BLCC.

2. Capital Cost Breakdowns

Chem Systems' Ethylene Plant Linear Programme has been used to develop capital cost, operating cost and material balance data for basic olefin plants in a developed country location (North Western Europe).

Table VI.D.1 summarises the capital cost information from these computer runs. Plant design and operating parameters (e.g. cracking severity) are in line with modern commercial practice. Costs have been escalated to a 1980 basis using the inflation assumptions of Section III.B.

The liquid feeds (naphtha and gasoil) used are from Arabian light crude. Differences in both capital cost and product slate in changing to feeds from Libyan crude would be small.

The increasing capital cost which results from progressively heavier feedstocks is clearly shown. A naphtha-based plant is nearly 40 percent dearer than a comparable ethane-feed plant.

Offsites are estimated at 50 percent of battery limits capital cost for the developed country projects. This estimate assumes that the new plant is built adjacent to existing major petrochemical developments, on an existing developed site: this is the normal situation for new olefin plants in the U.S., Europe and Japan. The figure of 50 percent is based upon numerous Chem Systems studies and past experience in this area.

The BLCC costs of Arab projects are increased above these levels to reflect the location factors discussed and defined in Section III. Butadiene extraction facilities are not included for the Arab projects, and butadiene is credited at fuel value only in the by-product valuations and economic evaluations. (The reasoning for this approach is given in Section VI.E, following). Offsites costs for the Arab locations were estimated on the basis of preliminary plant

TABLE VI.D.1

OLEFIN PLANT BATTERY LIMITS CAPITAL COST BREAKDOWN

($ million, 1980, W. Europe)

Feed Equipment	Ethane	Ethane/Propane (30/70 vol.%)	Full Range Naphtha	Gas Oil
Furnaces	26.7	28.7	59.6	63.4
Steam system	21.4	22.7	23.0	26.4
Quench system	3.2	3.5	9.0	21.6
Process gas compressor	23.2	24.0	23.5	23.5
Acid gas removal	10.6	10.8	10.3	10.3
Refrigeration	21.6	22.5	21.1	21.1
Fractionation	34.8	37.8	32.2	33.0
Gasoline hydrotreater	-	4.0	6.4	9.0
Butadiene extraction	-	-	11.3	13.2
Total BLCC	141.5	154.0	196.4	221.5

layouts and calculated utility, storage and other site requirements. All local facilities specific to the olefin complex are allowed for, such as construction camp, administration buildings, power generation, sea water cooling intake system, etc. etc. General infrastructure development, such as harbour facilities, roads (other than site roads), permanent housing, etc. are excluded, however. It is considered that such infrastructure development should generally be to the account of central and local government rather than to the specific project, since such infrastructure is clearly of long term and general benefit to the national economy. The loading of such costs onto the first industrial development in an area will frequently make that development uneconomic, and thus hinder national industrialisation and growth.

3. Plant Material Balances

The product slate (i.e. range and quantities) from each of these basic olefin plants is shown in Table VI.D.2. In all cases the plants are assumed to be operating at 90 percent of their nominal 450,000 tonne/year ethylene capacity.

TABLE VI.D.2

OLEFIN PLANT PRODUCT RATES : ALTERNATE FEEDSTOCKS

(Nominal capacity 450,000 tonne/year; 90% capacity operation)

Feed Product	Ethane	Ethane/Propane (30/70 vol.%)	Full Range Naphtha	Gas Oil
Ethylene (tonnes/yr)	405,000	405,000	405,000	405,000
Chemical grade Propylene (tonnes/yr)	(1)	96,000	223,000	252,000
Butadiene (tonnes/yr)	(1)	(2)	63,000	77,000
Other C4 stream (tonnes/yr)	(1)	22,000 (2)	79,000	76,000
Pyrolysis gasoline (tonnes/yr)	7,000	51,000	261,000	334,000
Fuel Oil (tonnes/yr)	0	1,000	44,000	336,000
Fuel Gas (10^{12} Kcal/yr)	1.48	2.75	2.47	2.26
Feed Rate (tonnes/yr)	503,000	783,000	1,281,000	1,679,000

(1) Included in fuel gas

(2) Butadiene not extracted : C4 stream includes the butadiene

E. BY-PRODUCT VALUATIONS

1. Introduction

Table VI.D.2 showed the range and quantity of products obtained from the steam cracking of various feedstocks.

Examination of this table highlights the unselective nature of the ethylene production process. Although steam crackers are primarily constructed to produce ethylene, for every feedstock except ethane a large percentage of the feed is converted into by-products. The revenues obtained from the sale of these by-products obviously have important effects on the economics of ethylene production.

The second point to be emphasised is that the cracker operator has little control over the product distribution pattern. For a typical liquid feed, the operator would have enough operating flexibility to adjust the relative quantities of ethylene and propylene produced so as to match approximately his requirements for these two products. However, once the ethylene-propylene ratio (and hence cracking severity) is fixed, there is effectively no possibility of varying the yields of all the other by-products.

The major by-products affecting ethylene economics are propylene, butadiene, pyrolysis gasoline and pyrolysis fuel oil. The latter is only important when gas oil is utilised as feedstock. On the other hand, when ethane is used as a feedstock, all by-products have a very minor effect on ethylene economics.

The pricing mechanism for the by-products will vary somewhat between the major ethylene producing areas of the world.

TABLE V.A.4.

NATURAL GAS VALUATION VIA LNG ECONOMICS

	North Africa	Arabian Gulf
Basis:	Natural gas value equals gasoil at burner tip in N.W. Europe, 1980	Natural gas value equals gasoil at burner tip in Japan, 1980.
	$/ton oil equivalent	$/ton oil equivalent
Gasoil terminal price	140	140
Distribution & reception costs	38	38
Total gasoil cost to consumer	178	178
Hence gas value to consumer	178	178
Gas distribution cost	25	25
Gas value ex terminal	153	153
Shipping of LNG and revapourisation	44	82
FOB LNG value	109	71
LNG storage & loading cost	10	10
Liquefaction cost	35	35
Feed gas value allowing for 18% loss of feed as fuel	64/1.18 = $ 54/t.o.e.	26/1.18 = $ 22/t.o.e.
Thus NATURAL GAS VALUE	$ 4.90/million Kcals	$ 2.00/million Kcals

Major considerations are alternative use values, and supply-demand relationships. In particular, the by-product credits will vary widely between a typical developed-country project and a project in an Arab oil producing state. These differences have major effects upon the overall economics of an Arab project, so each by-product is considered in detail for each region in the following sections.

2. Developed Countries

a) Propylene

Propylene is a major co-product, varying from almost nothing (in the case of ethane) to 75 percent of ethylene production (in the case of low severity gas oil cracking). Propylene revenue is therefore one of the most important considerations affecting steam cracker economics, and it is unlikely that a new project based on heavy feedstocks could be economically justified without a firm chemical feedstock market for the bulk of the propylene production.

Most propylene is sold as chemical grade, which is generally classified as having a minimum content of 92 percent propylene. Polymer grade propylene (99+ percent purity) requires additional processing and will command a premium over chemical grade of around \$10 - \$20 per tonne at this time.

- United States

In the U.S., the major source of propylene is the catalytic cracker in the refineries. In 1973, refineries produced over 9 million tonnes of propylene, of which 7.5 million tonnes were recovered, while steam crackers produced about 2.7 million tonnes. The chemical industry utilised about 4.5 million tonnes or about 45 percent of the total production. Over 5 million tonnes of propylene is utilised in gasoline manufacture.

In the past, propylene price in the U.S. was determined by the highest alternate use value for refinery grade propylene plus the cost of upgrading it to chemical or polymer grade. Up to 1972, the highest value for propylene was in its relation to gasoline, as a feedstock to a propylene alkylation unit. In late 1973 and 1974, some major changes took place. Gasoline prices and consequently alkylate values increased by more than twofold. However, isobutane (a major feed to the alkylation unit) prices increased by fourfold. Based on alkylation economics, this indicates that propylene is worth only slightly more that it was prior to the energy crisis, i.e. $80/tonne for the chemical grade. In fact, however, propylene is currently selling at $130 - 175/tonne. This can be explained by a number of reasons. There is basically a shortage of propylene. The basic business of the U.S. refiner is motor gasoline; he takes the necessary decisions to maintain the volume and quality of his octane pool even at the expense of lost profits from chemical grade propylene sales. Secondly, a number of refiners have access to isobutane (either through production in reformers/hydrocrackers, or through price-controlled purchases) at below normal market prices. These factors result in higher propylene valuations, which can no longer be linked to alkylation economics.

In effect, therefore, the price of propylene for chemical use will be set by supply/demand considerations through to 1980, and a general industry consensus seems to be that propylene should sell at 60 - 70 percent of ethylene price.

o Western Europe

Since almost all European propylene is produced as a by-product of steam cracking (5.4 million tonnes in 1974), and it has no alternative use value other than fuel gas or LPG, its price has tended to be established largely by the supply/demand position. Historically, there has generally been a paper surplus of propylene in Europe. This apparent surplus is considerably reduced when logistic considerations and the general inadequacy of propylene storage and transport facilities in Europe are taken into account. Nevertheless, with ethylene supply and demand in reasonable balance, there has tended to be a modest surplus of propylene and this situation will probably continue through to 1980.

Surplus propylene is disposed of into the LPG market and this outlet accounts for about 10 percent of propylene production. Although LPG value establishes a theoretical floor price for propylene, the market price of chemical grade propylene is generally higher, reflecting a premium use value in chemical feedstock outlets.

Again the general industry consensus today is that the price of propylene should be about 60 - 70 percent of the ethylene price. Direct evidence to support this relationship is difficult to cite, but it is indirectly supported by comparison of the escalation provisions in recent ethylene and propylene contracts. Assuming that the current supply-demand situation - i.e. ethylene supply slightly shorter than propylene - continues, we expect this price relationship to prove reasonably stable. Producers, especially those with new plants, have significant flexibility to reduce propylene output in a weak market, whilst the continuing relative surplus situation makes it unlikely that propylene price can rise significantly in relation to ethylene.

- Japan

As in Europe, the primary source of propylene in Japan is as a by-product from steam crackers. In 1974, steam crackers produced about 2.9 million tonnes of propylene with a total demand of about 2.7 million tonnes for chemicals. The remainder was burned or blended into LPG. The same considerations apply as in Europe.

- Summary

In all major producing areas, therefore, propylene price is set basically by supply/demand considerations, and a value of 60 - 70 percent of ethylene price is generally accepted. We estimate that in 1980 the upper end of this price bracket will apply. As discussed in Section III.B, we take the view that for the purposes of these present evaluations production costs and prices in the various major producing regions (U.S., W. Europe, Japan) are effectively the same. The olefin plant cost of production calculations are therefore carried out on a 1980 Western European basis, and assume propylene price to be 70 percent of ethylene price.

b) Butadiene

In Western Europe and Japan, the steam cracker is the sole source of butadiene, representing approximately 13 and 17 percent of the ethylene production, respectively. In Western Europe, the current level is about 1.2 million tonnes/yr while in Japan it is 0.65 million tonnes/yr. The U.S. recovers butadiene from steam crackers as a by-product and deliberately produces butadiene from butenes and butanes via dehydrogenation.

Butadiene is an article of commerce with international trade among the three major areas. The U.S. has become a net importer of butadiene especially from Europe. Prices, therefore, tend to be established by U.S. economics plus freight cost considerations.

- United States

The major part of U.S. butadiene production is based on the dehydrogenation of n-butane and n-butenes.

With the increasing quantity of by-product butadiene becoming available from heavy liquid feed ethylene plants, supply from dehydro units is expected to decline in future. It will, however, remain the marginal source of supply and the price determining mechanism. Since the dehydro plants already exist, in large overcapacity, prices will reflect only a nominal return above the marginal cost of production, i.e. excluding depreciation and return on capital.

The major variable affecting butadiene cost is thus the price of n-butane, the major sources of which are natural gas liquids and refinery production. Refineries presently account for over 50 percent of the butane supply, natural gas liquids are the source for 40 percent, with the remainder being imported. About 50 percent of the butane supply ends up in gasoline.

With restricted availability of natural gas in the future, an increasing percentage of n-butane supply will be from refineries, and butane prices will be related to crude price. Based upon a 1980 c.i.f. crude price of $120/tonne, a n-butane valuation of around $150/tonne is predicted which would give a butadiene price of $530/tonne from a fully depreciated dehydro plant.

- Western Europe and Japan

In both these regions butadiene is entirely a by-product. Minimum price will be set by its value as a fuel plus extraction cost, placing a minimum 1980 value of around \$305/tonne. While U.S. dehydro capacity remains in operation, however, European and Japanese prices will tend to be set by U.S. prices less freight costs resulting in W. European/Japanese export price levels around \$480/tonne in 1980.

- Summary

U.S. butadiene price in 1980 is calculated to be around \$530/tonne. European and Japanese prices will tend to reflect U.S. price less freight costs. There is a tendency, however, to hold prices in Europe above these levels, and dump marginal excess material to the U.S. market at whatever price is necessary. In 1980 this would be \$480/tonne or rather lower for the export material, while prices to European consumers stayed above this. Thus the difference between U.S., European and Japanese internal market prices will not necessarily be very great.

For the purposes of the olefin plant cost of production calculations, therefore, a West European basis is used with a butadiene credit of \$510/tonne, since the overall ethylene economics will then be closely representative of the situation in all the major producing regions (U.S., Europe and Japan).

c) Butylenes

Butylenes make up 45 - 60 percent of the C_4 cut from liquid feeds. The exact composition depends on the feedstock and cracking severity. Of the butylenes, about

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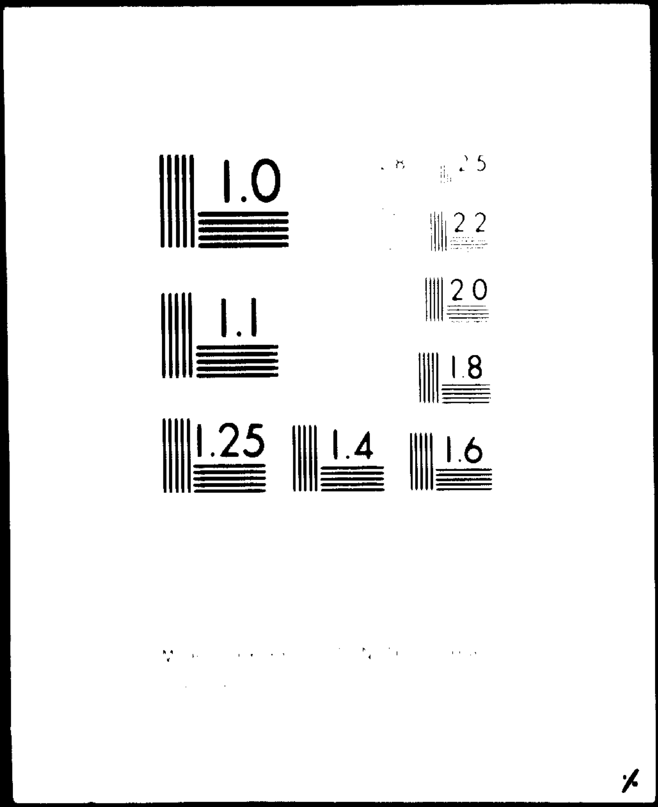

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- If propylene is also required, an ethane/propane cracker is used. The ethylene product is credited at the price calculated from the ethane cracker, and all other by-products are credited as established in the following sections.

The propylene price thus calculated will reflect the increased capital and operating cost of plant based upon the heavier feedstock.

This approach calculates chemical grade propylene values ex plant for 1980 as

North Africa	$266 per tonne
Arabian Gulf	$324 per tonne

o Summary. Due to the difficulty of assuring export markets for liquid propylene, and the artificial nature of the "70 percent of ethylene" approach, these latter "incremental production cost" values are proposed as the most meaningful propylene valuations. They are used in the subsequent economic analyses.

c) Butadiene

Butadiene valuation may be considered from the same viewpoints that the previous section adopted for propylene:

o Fuel value. In the case of both ethane and ethane/propane feed plants, the quantity of butadiene produced is too small to economically recover. Use as plant fuel is then the only option for the butadiene stream, and the relevant local fuel value is applied.

- Export. Our market analyses show that very little possibility exists for the export of butadiene to any of the major market regions during the 1980 - 85 period, due to worldwide overcapacity. As an indication of the potential export price, however, the projected U.S. 1980 price of \$530/tonne less freight and extraction costs gives a North African price of \$320/tonne, and an Arabian Gulf price of \$280/tonne.

- Developed market approach. The only real mechanisms underlying butadiene pricing in the developed markets of the U.S., Europe and Japan are the economics of dehydrogenation technology in the U.S., which sets the U.S. price referred to in the "Export" section above. A floor price for chemical use in the developed markets would be fuel value plus extraction cost, but in practice supply-demand considerations hold prices well above this level.

- Incremental production cost. Since we consider the export of butadiene to international markets to be unlikely within the time-scale of the study, the most realistic value to assign to a butadiene product is fuel value plus the cost of extraction at the Arab location. On this basis, the olefin plant would be credited only with fuel value for the butadiene contained in the mixed C_4 stream (butylenes plus butadiene). Butadiene cost to a potential downstream consuming plant (synthetic rubber, etc) may then be calculated separately on the basis of fuel value plus extraction cost.

- Summary. In all cases, butadiene will be credited to the Arab olefin project at fuel value only, due to the improbability of export possibilities and the artificial nature of any other pricing mechanism. For gaseous feed olefins plants (ethane, ethane/propane), fuel value is undoubtedly the only possible valuation. This is a conservative approach to pricing butadiene co-product from a liquid feed plant and will result in cheap synthetic rubber if such a user is incorporated with a liquid feed (naphtha, gasoil) olefins plant.

d) Butylenes

Fuel value is the only co-product valuation possible for the butylenes stream from any Arab project.

e) Pyrolysis Naphtha

The value of raw (un-hydrogenated) pyrolysis naphtha is set by its value as a gasoline blending component in an export market, as discussed in Section VII.G.1. This sets a 1980 price of $180 per tonne in North Africa and $171 per tonne in the Arabian Gulf area. These values will apply whether the pyrolysis naphtha is exported as such, or whether it is blended into gasoline at a local refinery before shipping. If no local refinery exists, this valuation may be rather high for an ethane feed olefin plant due to the small quantities of pyrolysis naphtha produced, but in this case the effect of naphtha valuation upon overall ethylene economics is very small.

f) Fuel Oil

Due to the low fuel values applicable at the Arab plant locations, the developed-country approach of using the fuel oil as plant fuel does not represent the best option. For the liquid feed olefin plants, therefore, which produce significant quantities of this fuel oil stream, a European price less freight costs is assumed. This gives a 1980 valuation of $90 per tonne in N. Africa and $84 per tonne in the Gulf. For the gas feed cases which produce negligible quantities of fuel oil, storage and shipping costs could not be justified and plant fuel value is applied ($50 per tonne N. Africa, $20 per tonne Arabian Gulf).

g) Fuel Gas

The relevant plant fuel value is applied to all gaseous by-products, i.e. $4.9 per million Kcals in N. Africa and $2.0 per million Kcals in the Gulf.

F. ETHYLENE TRANSFER PRICE VALUES

1. Developed Countries

Tables VI.F.1 to VI.F.4 present Cost of Production sheets for the four basic feedstock cases:

- ethane feed
- ethane/propane (30/70 vol %) feed
- full range naphtha feed (from Arabian Light)
- atmospheric gas oil feed (from Arabian Light)

Capital cost, operating cost and by-product credits are used as defined in preceeding sections. Ethane feed is priced at the same level as LPG on a heat-content basis. A West European location is used, on the basis that overall economics will be effectively identical for each of the three major market regions (U.S.A., Europe and Japan).

The ethylene transfer prices thus calculated for these various feeds are summarised in Table VI.F.5.

TABLE VI.F.5.

ETHYLENE TRANSFER PRICES - DEVELOPED COUNTRY, 1980

Cracker feed	Ethylene Price, $/tonne
Ethane	434
Ethane/Propane	416
Full Range Naphtha	462
Atmospheric Gas oil	428

Thus gas liquids cracking (ethane and/or propane) is shown to be an attractive option, but this will not be instrumental in setting ethylene prices due to the limited availability of these feeds. Naphtha cracking has historically set ethylene price levels in Europe and Japan, with effectively all plants using this feedstock. The large 1980 price differential (assumed and discussed in Section V.B) between naphtha and gasoil ($175 and $140/tonne respectively) results in an apparent advantage for gasoil cracking by 1980, however. In recognition of this likely trend, most new plants in the U.S. and W. Europe are now being designed and built for gasoil cracking, at least as an option or as a mixture with naphtha.

It is considered that both naphtha and gasoil cracking economics will affect U.S. ethylene pricing during the 1980's, while naphtha cracking continues the major pricing mechanism in Europe due to its present dominant position which will take many years to significantly decline. In Japan, naphtha cracking will continue to dominate, due to strong demand for gasoil for fuel applications.

As a simplification, therefore, we assume that ethylene price in the developed countries in 1980 will be basically set by naphtha cracking economics, with some downward pressure in Europe and the U.S. due to gasoil and gas liquids cracking. An average ethylene price is assumed at $450 per tonne with propylene at 70 percent of this or $315 per tonne.

2. Arab States

Tables VI.F.6 to VI.F.13 present Cost of Production sheets for the same four basic feedstock cases as were previously evaluated for the developed country locations, i.e.

- ethane
- ethane/propane
- naphtha
- gasoil

Two locations are considered, one North African and one Arabian Gulf.

Feedstock costs are used as defined in Section V. Capital costs are based upon the European costs already developed, escalated by the relevant location factors derived in Section III. By-product credits, operating costs etc. are all as defined in preceeding sections.

a) North Africa

Tables VI.F.6 to VI.F.9 show that in a typical North African location, gas liquids cracking is a far more attractive prospect than naphtha or gasoil cracking.

Basic ethylene price is considered to be set by the ethane-cracking case, which gives an ethylene transfer price of $400 per tonne.

Ethane-propane cracking gives very similar economics to the ethane cracking case. If ethylene is credited at $400 per tonne, a propylene transfer price of $266 per tonne is required. This is 67 percent of the ethylene price, an almost identical ratio to that normally prevailing in the developed countries. This is desirable, since it suggests that if local derivative plants are installed to consume both ethylene and propylene (say polyethylene and polypropylene) then the ratio of product prices from the Arab project should be roughly comparable to the ratio in developed countries. This will give comparable marketing opportunities to each product.

The choice between ethane and ethane/propane cracking can therefore be made on the basis of propylene demand. If it is considered that only ethylene derivatives present good business opportunities for a specific situation, then a simple ethane cracker should be selected: if a propylene derivative looks attractive, then the selection of an ethane/propane cracker will make nearly 100 000 tonnes per year of propylene available at a realistic price. Neither of these gas liquids crackers produce enough butadiene to support a synthetic rubber industry.

Naphtha and gasoil cracking, as expected, do not appear attractive in a North African situation. This is due to the combination of higher capital costs and lower co-product credits at the Arab locations: both of these factors have greater significance in naphtha cracking than in gas liquids cracking. If propylene price is assumed fixed at the $266 per tonne calculated from gas liquids cracking economics (above), then ethylene transfer price from these heavy liquids crackers is calculated at $577 and $528 per tonne respectively. Even these prices could prove optimistic, since they require the disposal of large volumes of fuel products onto the export market. Particularly in the case of the heavy fuel oil from gasoil cracking, this would probably be difficult in the medium-term future due to predicted depressed markets for heavy fuels in the developed countries. The one attraction of naphtha and gasoil cracking is that sufficient quantities of butadiene co-product are produced to support a major local synthetic rubber industry. Since we do not consider that this will generally be desirable in the Arab projects, due to lack of export possibilities and limited local demand, heavy liquids crackers are not in general recommended. Even assuming that butadiene was required locally, and that a premium world market-related butadiene credit was accorded to the ethylene plant, this would still only reduce the ethylene transfer price by some $40 per tonne, leaving the ethylene far more expensive than the $400 per tonne achievable from the ethane and ethane/propane crackers. Thus it must be recognised that for an Arab state (or group of states) to develop a synthetic rubber industry based upon co-product butadiene, then considerable economic penalties will be incurred by the olefin complex as a whole. If a synthetic rubber industry is considered desirable from a wider viewpoint than simple project economics (e.g. reduced import dependence, downstream industrial diversification and development, etc.) then the dangers of making the basic olefin complex uneconomic (due to higher ethylene prices) must be recognised.

The basic ethylene and propylene prices from North African projects are therefore taken to be the $400 and $266/tonne, respectively, calculated from gas cracking economics. These are not dramatically below the developed country price levels previously estimated in Section VI.F.1 ($450 and $315/tonne respectively), and in general this margin will not be large enough to produce derivatives at competitive prices for export to world markets. Variations in these basic ethylene/propylene prices will therefore be considered in sensitivity analyses in Section X (Economic Evaluation.) The simplest way of achieving these lower prices is clearly by charging feedstock (ethane, propane) at reduced prices, though if this is done it must be recognised that the feedstock supply operation will be yielding lower returns than it would if the feeds were simply sold as fuel to the export market in the form of LNG and LPG.

Variations in finance parameters (depreciation, interest rates and required return on investment) are also considered in the sensitivity analyses of Section X.

To demonstrate the effects of scale upon required Transfer Price, the N. African ethane-feed olefin plant has been recalculated at plant capacities of 300 000 and 200 000 tonnes/year. These give ethylene transfer prices of $440 and $487 per tonne respectively, compared to the base $400 per tonne calculated here for the 450 000 tonnes/year plant. The considerable incentive to use the maximum practical sized plant is thus clearly demonstrated.

b) Arabian Gulf

Tables VI.F.10 to VI.F.13 show ethylene Cost of Production calculations for the various feedstocks in a typical Arabian Gulf situation.

The basic conclusion to be drawn when comparing these calculations with the equivalent N. African values is that simple ethane cracking is relatively even more attractive. Thus the ethylene transfer price set by ethane cracking economics is $366 per tonne. If ethylene is credited at this price to an ethane/propane cracker, a propylene transfer price of $324 per tonne is calculated. This is nearly 90 percent of the ethylene price, and makes production and use of propylene and its derivatives relatively less attractive. If propylene production is particularly required, and the European "70 percent of one half is isobutylene and the remainder is split between the normal butylenes. The C_4 stream also contains between 1 and 5 percent butane.

o United States

The U.S. currently produces about 15 million tonnes/year of butylenes of which only about 4 percent comes from steam crackers. Over 80 percent of total production goes to motor gasoline manufacture. While butylenes from steam crackers will increase, its overall contribution will not exceed 10 percent. Similarly, its major use will continue to be for motor gasoline. Consequently, refinery economics in the U.S. will set butylene prices.

United States refiners have several ways of utilising butylenes. Direct blending of butylenes into gasoline represents the most profitable use of butylenes and butanes as well. However, the amount of C_4's which can be blended is limited by vapour pressure specifications. The next best way for utilising butylenes was to alkylate with relatively cheap isobutane. Isobutane prices have escalated at a faster rate than the value of the alkylate because the supply of isobutane from natural gas has not been growing. The net result has been that the value of butylenes for alkylation has not increased materially. The floor price for butylenes will be LPG values but we do not anticipate that on a long term basis butylenes will fall to this level. On the basis of projected gasoline and isobutane values ethylene price" approach is used to give reasonable propylene prices, then ethylene and propylene prices from the ethane/propane cracker would be $380 and $266 per tonne respectively. This represents only a fairly small penalty on the ethylene price, but it is nevertheless clear that unless a specific reason exists for introducing propylene, an olefins project in the Gulf will give the best economics if an ethane cracker is used, producing ethylene alone.

Naphtha and gasoil cracking are again shown to be relatively unattractive. Even with propylene price credited at the high $324 per tonne calculated from gas liquids cracking economics (above), ethylene transfer prices are calculated at $555 and $491 per tonne, respectively. The comments made in the previous section on N. Africa concerning potential fuel oil disposal problems, and butadiene supply potential, apply equal well to the Arabian Gulf situation.

The basic ethylene price from Arabian Gulf projects is therefore taken to be the $366 per tonne set by ethane cracking economics. This compares favourably with the developed country price level of $450 per tonne previously estimated in Section VI.F.1. Whether this margin will be sufficient to offset higher derivative plant costs and freight costs, and produce derivatives at competitive prices for export in world markets, is investigated in Section X (Economic Evaluation). In this section, sensitivity analyses consider variations in the ethylene price and show the effects this can have upon overall project economics.

TABLE VI.F.3

ETHYLENE VIA CRACKING ETHANE

Basis:
Location- W. Europe 1980
Capacity- 450 000 tpa ethylene
Rate - 405 000 tpa ethylene

Capital Cost	$MM
Battery Limits Capital Cost	142
Offsites Capital Cost	71
Total Fixed	213
Working	21

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethane	503 000	tonne	156	78 468 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				78 968 000	195.0
UTILITIES:					
Power	3 700	1000 KWh	43.5	161 000	
Fuel	2 270 000	10^6 Kcal	11.6	26 332 000	
Cooling Water	109 000	1000 m^3	16	1 744 000	
Boiler Feed Water	50	1000 m^3	400	20 000	
TOTAL UTILITIES COST:				28 257 000	69.8
OPERATING COSTS:					
Labour 31 men @ $ 19,000 p.a.				589 000	
Supervision 3 men @ $ 27,000 p.a.				81 000	
Maintenance Material and Labour @ 4% BLCC				5 680 000	
TOTAL OPERATING COSTS:				6 350 000	15.7
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				201 000	
General Plant Overhead - 65% Operating Costs				4 128 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				3 195 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				17 750 000	
Interest - 10% on Working Capital				2 100 000	
TOTAL OVERHEAD EXPENSES:				27 374 000	67.6
BYPRODUCT CREDIT:					
Pyrolysis gasoline	7 000	tonne	190	1 330 000	
Fuel gas	1 480 000	10^6 Kcal	11.6	17 168 000	
TOTAL BYPRODUCT CREDIT:				(18 498 000)	(45.7)
TOTAL COST OF PRODUCTION:				122 451 000	302.4
RETURN 25% ON TOTAL FIXED INVESTMENT:				53 250 000	131.5
TRANSFER PRICE:				175 701 000	433.9

* $/unit

TABLE VI.1.2

ETHYLENE VIA CRACKING ETHANE/PROPANE (30/70 VOL.%)

Basis: Location - W. Europe 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
96 000 tpa propylene

Capital Cost	$MM
Battery Limits Capital Cost	154
Offsites Capital Cost	77
Total Fixed	231
Working	23

RAW MATERIALS	QUANTITY	UNIT	PRICE*		ANNUAL COST	UNIT COST*
						($/tonne ethylene equivalent)
Ethane/Propane (30/70 vol.%)	783 000	tonne	152	(1)	119 016 000	
Catalysts & Chemicals					750 000	
TOTAL RAW MATERIALS:					119 766 000	253.6
UTILITIES:						
Power	4 500	1000 kWh	43.5		196 000	
Fuel	2 380 000	10^6 kcal	11.6		27 608 000	
Cooling Water	123 000	1000 m^3	16		1 968 000	
Boiler Feed Water	60	1000 m^3	400		24 000	
TOTAL UTILITIES COST:					29 796 000	63.1
OPERATING COSTS:						
Labour 44 men @ $ 19,000 p.a.					836 000	
Supervision 4 men @ $ 27,000 p.a.					108 000	
Maintenance Material and Labour @ 4% BLCC					6 160 000	
TOTAL OPERATING COSTS:					7 104 000	15.0
OVERHEAD EXPENSES:						
Direct Overhead - 30% (Labour & Supervision)					283 000	
General Plant Overhead - 65% Operating Costs					4 618 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital					3 465 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)					19 250 000	
Interest - 10% on Working Capital					2 300 000	
TOTAL OVERHEAD EXPENSES:					29 916 000	63.4
BYPRODUCT CREDIT:						
C_4 Stream	22 000	tonne	273	(2)	6 006 000	
Pyrolysis gasoline	51 000	tonne	190		9 690 000	
Fuel Oil	1 000	tonne	118		118 000	
Fuel Gas	2 750 000	10^6 Kcal	11.6		31 900 000	
TOTAL BYPRODUCT CREDIT:					(47 714 000)	(101.0)
TOTAL COST OF PRODUCTION:					138 868 000	294.1
RETURN 25% OF TOTAL FIXED INVESTMENT:					57 750 000	122.3
TRANSFER PRICE:					196 618 000	416.4
ie ethylene						416.4
propylene @ (70% of ethylene price)						291.5

(1) 30% ethane @ [illegible]/tonne 70% propane @ [illegible]/tonne
(2) 40% butylene @ [illegible], 60% contained [illegible] $255/tonne

* $/unit

TABLE VI.1.3

ETHYLENE VIA CRACKING FULL RANGE NAPHTHA

Basis: Location- W Europe 1980
Capacity- 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
223 000 tpa propylene

Capital Cost	$MM
Battery Limits Capital Cost	196
Offsites Capital Cost	98
Total Fixed	294
Working	29

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST(1)
Full Range Naphtha	1 281 000	tonne	175	224 175 000	
Catalyst & Chemicals				850 000	
TOTAL RAW MATERIALS:				225 025 000	401.0
UTILITIES:					
Power	27 150	1000 Kwh	43.5	1 181 000	
Fuel	3 133 000	10^6 Kcal	11.6	36 343 000	
Cooling Water	163 000	1000 m^3	16	2 608 000	
Boiler Feed Water (net)	25	1000 m^3	400	10 000	
Steam	122 000	tonne	9.6	1 171 000	
TOTAL UTILITIES COST:				41 313 000	73.6
OPERATING COSTS:					
Labour 44 men @ $19,000 p.a.				836 000	
Supervision 4 men @ $27,000 p.a.				108 000	
Maintenance Material and Labour @ 4% BLCC				7 840 000	
TOTAL OPERATING COSTS:				8 784 000	15.7
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				5 710 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 410 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				24 500 000	
Interest - 10% on Working Capital				2 900 000	
TOTAL OVERHEAD EXPENSES:				37 803 000	67.4
BY-PRODUCT CREDIT:					
Butadiene	63 000	tonne	510	32 130 000	
Other C_4	79 000	tonne	150	11 850 000	
Pyrolysis gasoline	261 000	tonne	190	49 590 000	
Fuel Oil	44 000	tonne	118	5 192 000	
Fuel Gas	2 470 000	10^6 Kcal	11.6	28 652 000	
TOTAL BY-PRODUCT CREDIT:				(127 414 000)	(227.1)
TOTAL COST OF PRODUCTION:				185 511 000	330.6
RETURN ON TOTAL [illegible] @ 25% [illegible]:				73 500 000	131.0
TRANSFER PRICE:				259 011 000	461.6

* $/unit
(1) $/ton ethylene equivalent

i.e. Ethylene:	461.6
Propylene (70% of ethylene price)	323.1

TABLE VI.F.4

ETHYLENE VIA CRACKING GAS OIL

Basis:			Capital Cost	$MM
	Location-	W. Europe 1980	Battery Limits Capital Cost	222
	Capacity-	450 000 tpa ethylene	Offsites Capital Cost	111
	Rate -	405 000 tpa ethylene	Total Fixed	333
		252 000 tpa propylene	Working	33

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST(1)
Gas Oil	1 679 000	tonne	140	235 060 000	
Catalyst & Chemicals				1 000 000	
TOTAL RAW MATERIALS:				236 060 000	406.0
UTILITIES:					
Power	34 000	1000 Kwh	43.5	1 479 000	
Fuel	3 680 000	10^6 Kcal	11.6	42 688 000	
Cooling Water	249 000	1000 m^3	16	3 984 000	
Boiler Feed Water (net)	140	1000 m^3	400	56 000	
Steam	149 000	tonne	9.6	1 430 000	
TOTAL UTILITIES COST:				49 637 000	85.4
OPERATING COSTS:					
Labour 44 men @ $19,000 p.a.				836 000	
Supervision 4 men @ $27,000 p.a.				108 000	
Maintenance Material and Labour @ 4% BLCC				8 880 000	
TOTAL OPERATING COSTS:				9 824 000	16.9
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				6 386 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 995 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				27 750 000	
Interest - 10% on Working Capital				3 300 000	
TOTAL OVERHEAD EXPENSES:				42 714 000	73.5
BYPRODUCT CREDIT:					
Butadiene	77 000	tonne	510	39 270 000	
Other C_4	76 000	tonne	150	11 400 000	
Pyrolysis gasoline	334 000	tonne	190	63 460 000	
Fuel Oil	336 000	tonne	96	32 256 000	
Fuel Gas	2 260 000	10^6 Kcal	11.6	26 216 000	
TOTAL BYPRODUCT CREDIT:				(172 602 000)	(296.9)
TOTAL COST OF PRODUCTION:				165 633 000	284.9
RETURN 25% ON TOTAL FIXED INVESTMENT:				83 250 000	143.2
TRANSFER PRICE:				248 883 000	428.1

* $/tonne

(1) $/tonne ethylene equivalent

i.e.	Ethylene	428.1
	Propylene (@ 70% of ethylene price)	299.7

TABLE VI.F.6

ETHYLENE VIA CRACKING ETHANE

Basis: Location - N Africa 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene

Capital Cost	$M
Battery Limits Capital Cost	163
Offsites Capital Cost	90
Total Fixed	253
Working	24

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethane	503 000	tonne	110	55 330 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				55 830 000	137.8
UTILITIES:					
Power	3 700	1000 Kwh	27	100 000	
Fuel	2 270 000	10^6 Kcal	4.9	11 123 000	
Cooling Water	109 000	1000 m^3	12	1 308 000	
Boiler Feed Water	50	1000 m^3	600	30 000	
TOTAL UTILITIES COST:				12 561 000	31.0
OPERATING COSTS:					
Labour	31 men @ $19 000 pa			589 000	
Supervision	3 men @ $27 000 pa			81 000	
Maintenance Material and Labour @ 4% BLCC				6 520 000	
TOTAL OPERATING COSTS:				7 190 000	17.8
OVERHEAD COSTS:					
Direct Overhead - 30% (Labour & Supervision)				201 000	
General Plant Overhead - 65% Operating Costs				4 674 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				3 795 000	
Depreciation - (10% BLCC + 5% Offsites)				20 800 000	
Interest - 10% on Working Capital				2 400 000	
TOTAL OVERHEAD COSTS:				31 669 000	78.2
BY-PRODUCT CREDIT:					
Pyrolysis Gasoline	7 000	tonne	180	1 260 000	
Fuel Gas	1 480 000	10^6 Kcal	4.9	7 252 000	
TOTAL BY-PRODUCT CREDIT:				(8 512 000)	(21.0)
TOTAL COST OF PRODUCTION:				98 738 000	243.8
[illegible]:				63 250 000	156.2
[illegible]:				161 988 000	400.0

* $/tonne

TABLE VI.F.7

ETHYLENE VIA CRACKING ETHANE/PROPANE (30/70 VOL %)

Basis:		Capital Cost	$MM
Location -	N Africa	Battery Limits Capital Cost	177
Capacity -	450 000 tpa ethylene	Offsites Capital Cost	97
Rate -	405 000 tpa ethylene	Total Fixed	274
	96 000 tpa propylene	Working	26

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethane/Propane (30/70 vol %)	783 000	tonne	110	86 130 000	
Catalyst & Chemicals		$		750 000	
TOTAL RAW MATERIALS:				86 880 000	
UTILITIES:					
Power	4 500	1000 Kwh	27	122 000	
Fuel	2 380 000	10^6 Kcal	4.9	11 662 000	
Cooling Water	123 000	1000 m^3	12	1 476 000	
Boiler Feed Water	60	1000 m^3	600	36 000	
TOTAL UTILITIES COST:				13 296 000	
OPERATING COSTS:					
Labour	44 men @ $19 000 pa			836 000	
Supervision	4 men @ $27 000 pa			108 000	
Maintenance Material and Labour @ 4% BLCC				7 080 000	
TOTAL OPERATING COSTS:				8 024 000	
OVERHEAD EXPENSES:					
Direct Overhead - [illegible] (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				5 216 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 110 000	
Depreciation - (basis: 10% BLCC + [illegible] Offsites)				22 550 000	
Interest - 10% on Working Capital				2 600 000	
TOTAL OVERHEAD EXPENSES:				34 759 000	
BYPRODUCT CREDIT:					
C_4 Stream	22 000	tonne	55	1 210 000	
Pyrolysis Gasoline	51 000	tonne	180	9 180 000	
Fuel Oil	1 000	tonne	50	50 000	
Fuel Gas	2 750 000	10^6 Kcal	4.9	13 475 000	
TOTAL BYPRODUCT CREDIT:				(23 915 000)	
TOTAL COST OF PRODUCTION				119 044 000	
RETURN ON [illegible] TOTAL FIXED INVESTMENT:				68 500 000	
TOTAL REVENUE REQUIRED				187 544 000	
LESS REVENUE FROM ETHYLENE (@ $400/tonne)				161 988 000	
PROPYLENE TRANSFER PRICE				25 556 000	266.2

* $/unit

TABLE VI.F.8

ETHYLENE VIA CRACKING FULL RANGE NAPHTHA

Basis: Location - N Africa 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
223 000 tpa propylene

Capital Cost	$MM
Battery Limits Capital Cost	213
Offsites Capital Cost	117
Total Fixed	330
Working	32

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Full Range Naphtha	1 281 000	tonne	165	211 365 000	
Catalyst & Chemicals		$		850 000	
TOTAL RAW MATERIALS:				212 215 000	
UTILITIES:					
Power	6 650	1000 Kwh	27	180 000	
Fuel	3 133 000	10^6Kcal	4.9	15 352 000	
Cooling Water	153 300	1000 m^3	12	1 839 000	
Boiler Feed Water	135	1000 m^3	600	81 000	
TOTAL UTILITIES COST:				17 452 000	
OPERATING COSTS:					
Labour 44 men @ $19 000 pa				836 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour (4% BLCC				8 520 000	
TOTAL OPERATING COSTS:				9 464 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				6 152 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 950 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				27 150 000	
Interest - 10% on Working Capital				3 200 000	
TOTAL OVERHEAD EXPENSES:				41 735 000	
BY-PRODUCT CREDIT:					
Propylene	223 000	tonne	266.2	59 363 000	
Mixed C4 (Inc Butadiene)	144 000	tonne	55	7 200 000	
Pyrolysis Gasoline	261 000	tonne	180	46 980 000	
Fuel Oil	44 000	tonne	90	3 960 000	
Fuel Gas	2 470 000	10^6Kcal	4.9	12 103 000	
TOTAL BY-PRODUCT CREDIT:				(129 606 000)	
TOTAL PRODUCTION COST:				151 260 000	
RETURN ON TOTAL FIXED INVESTMENT:				82 500 000	
SALES PRICE:				233 760 000	577.2

* $/tonne

TABLE VI.F.9

ETHYLENE VIA CRACKING GAS OIL

Basis: Location- N Africa 1980
Capacity- 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
252 000 tpa propylene

Capital Cost	$M
Battery Limits Capital Cost	240
Offsites Capital Cost	132
Total Fixed	372
Working	36

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Gas Oil	1 679 000	tonne	130	218 270 000	
Catalyst & Chemicals		$		1 000 000	
TOTAL RAW MATERIALS:				219 270 000	
UTILITIES:					
Power	8 950	1000 Kwh	27	242 000	
Fuel	3 680 000	10^6 Kcal	4.9	18 032 000	
Cooling Water	237 000	1000 m^3	12	2 844 000	
Boiler Feed Water	275	1000 m^3	600	165 000	
TOTAL UTILITIES COST:				21 283 000	
OPERATING COSTS:					
Labour	44 men @ $19 000 pa			836 000	
Supervision	4 men @ $27 000 pa			108 000	
Maintenance Material and Labour 4% BLCC				9 600 000	
TOTAL OPERATING COSTS:				10 544 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				6 854 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				5 580 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				30 600 000	
Interest - 10% on Working Capital				3 600 000	
TOTAL OVERHEAD EXPENSES:				46 917 000	
BYPRODUCT CREDIT:					
Propylene	252 000	tonne	266.2	67 082 000	
Mixed C_4 (inc Butadiene)	155 000	tonne	55	8 525 000	
Pyrolysis Gasoline	334 000	tonne	180	60 120 000	
Fuel Oil	336 000	tonne	90	30 240 000	
Fuel Gas	2 260 000	10^6	4.9	11 074 000	
TOTAL BYPRODUCT CREDIT:				(177 041 000)	
TOTAL COST OF PRODUCTION:				120 973 000	
RETURN ON [illegible] INVESTMENT:				93 000 000	
TRANSFER PRICE:				213 973 000	528.3

* $/unit

TABLE VI.F 10

ETHYLENE VIA CRACKING ETHANE

Basis: Location - Arabian Gulf 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene

Capital Cost	$ MM
Battery Limits Capital Cost	177
Offsites Capital Cost	97
Total Fixed	274
Working	27

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethane	503 000	tonne	70	35 210 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				35 710 000	88.2
UTILITIES:					
Power	3 700	1000 Kwh	22.4	83 000	
Fuel	2 270 000	10^6 Kcal	2.0	4 540 000	
Cooling Water	109 000	1000 m^3	12	1 308 000	
Boiler Feed Water	50	1000 m^3	800	40 000	
TOTAL UTILITIES COST:				5 971 000	14.7
OPERATING COSTS:					
Labour 31 men @ $19 000 pa				589 000	
Supervision 3 men @ $27 000 pa				81 000	
Maintenance Materials and Labour @ 4% BLCC				7 080 000	
TOTAL OPERATING COSTS:				7 750 000	19.1
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				201 000	
General Plant Overhead - 65% Operating Costs				5 038 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 110 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				22 550 000	
Interest - 10% on Working Capital				2 700 000	
TOTAL OVERHEAD EXPENSES:				34 599 000	85.4
BYPRODUCT CREDIT:					
Pyrolysis Gasoline	7 000	tonne	171	1 197 000	
Fuel Gas	1 480 000	10^6 Kcal	2.0	2 960 000	
TOTAL BYPRODUCT CREDIT:				(4 157 000)	(10.3)
TOTAL COST OF PRODUCTION:				79 873 000	197.2
RETURN [illegible] ON TOTAL FIXED INVESTMENT:				68 500 000	169.1
TRANSFER PRICE:				148 373 000	366.[illegible]

* $/unit

we estimate that mixed butylenes in 1980 will maintain a small premium over LPG values.

- Western Europe

In Western Europe, the supply of butylenes comes from steam crackers and refineries. Over 2.7 million tonnes/year are currently produced with equal distribution between refineries and steam crackers. About 30 percent of the butylenes is utilised in motor gasoline production while only about 15 percent is used for chemicals. The remainder goes to LPG and general fuels usage. This picture is not likely to change. Consequently, fuel value is the most realistic price for butylenes in Western Europe.

- Japan

The Japanese situation will not be much different from that of Western Europe. A large excess of butylenes will be available for LPG and fuel use. Current production is over 1.4 million tonnes/year with about 10 percent of this utilised for chemicals. Fuel value is therefore also applicable to butylenes in Japan.

- Summary

In Western Europe and Japan, LPG value is a realistic price to assign to the butylene by-product stream. This implies a value of around $150/tonne in 1980. U.S. valuation would be somewhat above

TABLE VI.F.11

ETHYLENE VIA CRACKING ETHANE/PROPANE (30/70 Vol %)

Basis: Location - Arabian Gulf 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
96 000 tpa propylene

Capital Cost	$MM
Battery Limits Capital Cost	193
Offsites Capital Cost	106
Total Fixed	299
Working	29

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethane/Propane (30/70 vol %)	783 000	tonne	84 (1)	65 772 000	
Catalyst & Chemicals				750 000	
TOTAL RAW MATERIALS:				66 522 000	
UTILITIES:					
Power	4 500	1000 Kwh	22.4	101 000	
Fuel	2 380 000	10^6 Kcal	2.0	4 760 000	
Cooling Water	123 000	1000 m^3	12	1 476 000	
Boiler Feed Water	60	1000 m^3	800	48 000	
TOTAL UTILITIES COST:				6 385 000	
OPERATING COSTS:					
Labour 44 men @ $19 000 pa				836 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				7 720 000	
TOTAL OPERATING COSTS:				8 664 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				5 632 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				4 485 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				24 600 000	
Interest - 10% on Working Capital				2 900 000	
TOTAL OVERHEAD EXPENSES:				37 900 000	
BY-PRODUCT CREDIT:					
C_4 Stream	22 000	tonne	22	484 000	
Pyrolsis Gasoline	51 000	tonne	171	8 721 000	
Fuel Oil	1 000	tonne	20	20 000	
Fuel Gas	2 750 000	10^6 Kcal	2.0	5 500 000	
TOTAL BY-PRODUCT CREDIT:				(14 725 000)	
TOTAL COST OF PRODUCTION:				104 746 000	
RETURN 25% ON TOTAL FIXED INVESTMENT:				74 750 000	
TOTAL REVENUE REQUIRED:				179 496 000	
LESS REVENUE FROM ETHYLENE (@ $366/tonne)				148 373 000	
PROPYLENE TRANSFER PRICE				31 123 000	324.2

(1) 30% ethane @ $70/tonne, 70% propane @ $90/tonne

* $/unit

TABLE VI.F.12

ETHYLENE VIA CRACKING FULL RANGE NAPHTHA

Basis:			Capital Cost	$MM
	Location-	Arabian Gulf 1980	Battery Limits Capital Cost	232
	Capacity-	450 000 tpa ethylene	Offsites Capital Cost	128
	Rate -	405 000 tpa ethylene	Total Fixed	360
		223 000 tpa propylene	Working	35

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Full Range Naphtha	1 281 000	tonne	155	198 555 000	
Catalyst & Chemicals				850 000	
TOTAL RAW MATERIALS:				199 405 000	
UTILITIES:					
Power	6 650	1000 Kwh	22.4	149 000	
Fuel	3 133 000	10^6Kcal	2.0	6 266 000	
Cooling Water	153 300	1000 m^3	12	1 840 000	
Boiler Feed Water	135	1000 m^3	800	108 000	
TOTAL UTILITIES COST:				8 363 000	
OPERATING COSTS:					
Labour 44 men @ $19 000 pa				836 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				9 280 000	
TOTAL OPERATING COSTS:				10 224 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				6 646 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				5 400 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				29 600 000	
Interest - 10% on Working Capital				3 500 000	
TOTAL OVERHEAD EXPENSES:				45 429 000	
BYPRODUCT CREDIT:					
Propylene	223 000	tonne	324.2	72 297 000	
Mixed C_4 (inc Butadiene)	144 000	tonne	22	3 168 000	
Pyrolysis gasoline	261 000	tonne	171	44 631 000	
Fuel Oil	44 000	tonne	84	3 696 000	
Fuel Gas	2 470 000	10^6Kcal	2.0	4 940 000	
TOTAL BYPRODUCT CREDIT:				(128 732 000)	
TOTAL COST OF PRODUCTION:				134 689 000	
RETURN 25% ON TOTAL FIXED INVESTMENT:				90 000 000	
TRANSFER PRICE:				224 689 000	554.8

* $/tonne

TABLE VI.F.13

ETHYLENE VIA CRACKING GAS OIL

Basis: Location - Arabian Gulf 1980
Capacity - 450 000 tpa ethylene
Rate - 405 000 tpa ethylene
252 000 tpa propylene

Capital Cost	$MM
Battery Limits Capital Cost	260
Offsites Capital Cost	143
Total Fixed	403
Working	39

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Gas Oil	1 679 000	tonne	120	201 480 000	
Catalyst & Chemicals				1 000 000	
TOTAL RAW MATERIALS:				202 480 000	
UTILITIES:					
Power	8 950	1000 Kwh	22.3	200 000	
Fuel	3 680 000	10^6 Kcal	2.0	7 360 000	
Cooling Water	237 000	1000 m^3	12	2 844 000	
Boiler Feed Water	275	1000 m^3	800	220 000	
TOTAL UTILITIES COST:				10 624 000	
OPERATING COSTS:					
Labour	44 men @ $19 000 pa			836 000	
Supervision	4 men @ $27 000 pa			108 000	
Maintenance Material and Labour @ 4% BLFC				10 400 000	
TOTAL OPERATING COSTS:				11 344 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				283 000	
General Plant Overhead - 65% Operating Costs				7 374 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				6 045 000	
Depreciation (basis: 10% BLFC + 5% Offsites)				33 150 000	
Interest - 10% on Working Capital				3 900 000	
TOTAL OVERHEAD EXPENSES:				50 752 000	
BYPRODUCT CREDIT:					
Propylene	252 000	tonne	324.2	81 698 000	
Mixed C_4 (incl. Butadiene)	155 000	tonne	22	3 410 000	
Pyrolysis Gasoline	334 000	tonne	171	57 114 000	
Fuel Oil	336 000	tonne	84	28 224 000	
Fuel Gas	2 260 000	10^6 Kcal	2.[illegible]	6 520 000	
TOTAL BYPRODUCT CREDIT:				(176 966 000)	
TOTAL COST OF PRODUCTION:				98 234 000	
RETURN 25% ON TOTAL FIXED INVESTMENT:				100 750 000	
TRANSFER PRICE:				198 984 000	491.3

* $/unit

SECTION VII

SECTION VII : AROMATICS

SECTION VII : AROMATICS

VII AROMATICS

A. INTRODUCTION

1. Sources of Aromatics

Aromatics are derived from two sources; catalytic reformate and pyrolysis naphtha. Both reformate and pyrolysis naphtha originate from petroleum naphtha which therefore is the major feedstock for all aromatics produced. A possible exception is pyrolysis naphtha derived from steam cracking gas oil, but this is not likely to be important in this context.

The three primary aromatics, benzene, toluene and xylenes are produced together in both catalytic reforming of naphtha and the thermal steam cracking of naphtha or other liquid feedstocks. The proportions of each BTX component will vary not only with the process, but also with feedstock used and severity of processing. The aromatic ring structure is chemically more stable than the alkyl side chains which differentiate between the different products so it is both possible and commercially practised to convert one product to another, by processes causing changes in the side chains. Of the many processes available some such as toluene disproportionation to benzene and xylenes and transalkylation of toluene and higher aromatics to xylenes are not practised on any large scale and are not detailed here. It is however possible that the latter process could be used to alleviate a local shortage of xylenes where excess C9 aromatics were available. The principal interconversions of aromatics practised are:

a) the isomerisation of xylenes to paraxylene

b) the dealkylation of toluene and higher aromatics to benzene.

These are considered in the appropriate following sections.

Pyrolysis gasoline is a relatively minor by-product of olefin production. Its availability will therefore depend on the market for olefins and the feedstock used. The proportion processed to aromatics will in turn depend on factors such as location of plants and the value of the feedstock if used as motor gasoline.

Catalytic reformers were originally operated primarily for the production of high octane gasoline blending stocks. The fact that the product had a high aromatics content was in itself of no significance to the refiner. For maximum aromatics content, as compared with optimum gasoline production, narrower feedstock cuts and higher severity operation are both beneficial. Thus modern aromatics plants based on reformate normally have their own catalytic reformer and are not dependent on refinery reformer capacity. The balance of aromatics demand is therefore made up by this route.

An integrated aromatics scheme including both reformer and steam cracker is shown on Figure VII.A.1.

2. Disposal of Aromatics

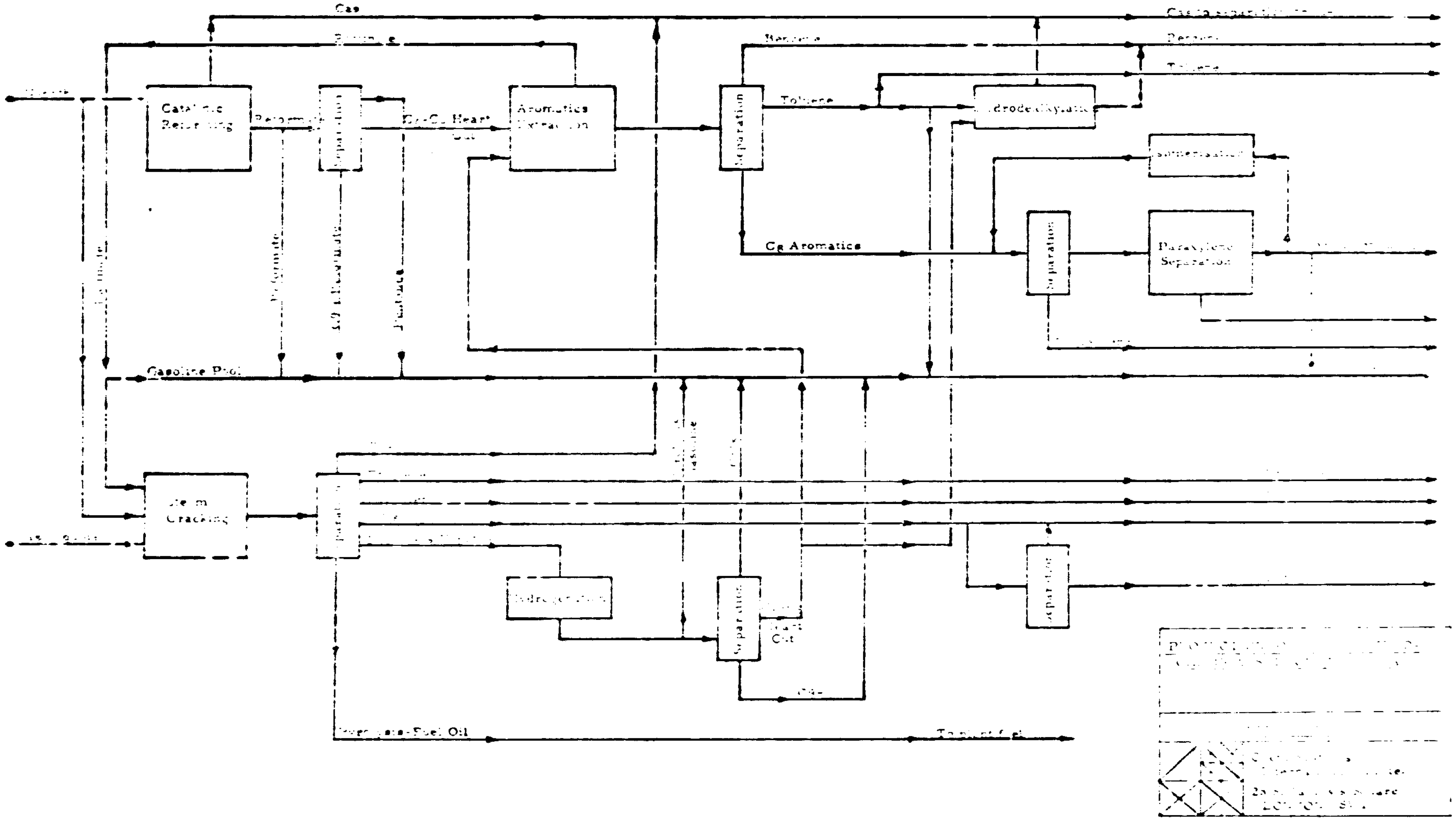
Both pyrolysis naphtha and catalytic reformate may be blended into the gasoline pool as an alternative to separating the aromatics components. Equally if the aromatics separated from a given feedstock do not match the market demand surplusses of one or more products may be blended back into gasoline. For example in Europe it is estimated that only approximately 12 percent of all xylenes and 8 percent of all the toluene this, but the W. European price is used in the cost of production calculations to give a consistent European basis. Overall ethylene economics will remain closely representative for all major producing regions.

d) Pyrolysis Naphtha

Pyrolysis naphtha (or pyrolysis gasoline) is the product fraction containing the C_5 and heavier components up to an end point of about 220°C. The markets for this material are either as a gasoline blending stock or as a source of aromatics. The choice appears to be dictated by logistic and strategic considerations, i.e. cracker operators who are basically oil companies tend to dispose of pyrolysis naphtha to the gasoline pool, whilst those with a captive benzene demand tend to process their pyrolysis naphtha for aromatics recovery.

The raw pyrolysis naphtha is generally high in Research Octane Number (RON), the exact level depending on feedstock type and cracking severity. The more naphthenic the feed in naphtha cracking plants, and the higher the cracking severity employed, the higher the gasoline RON. Numbers close to 100 are common with high severity cracking. The raw pyrolysis naphtha must be hydrotreated to convert gum forming dienes to stable compounds.

Valuation of the hydrogenated pyrolysis gasoline as a gasoline pool blendstock is related to the costs of producing an equivalent material by conventional refinery processing and precise values are a function of RON. Raw pyrolysis gasoline values are lower, the difference being equal to the cost of hydrotreating the stream.


Gas
Catalytic Reforming
Reformate
Separation
C6-C8 Heart Cut
Aromatics Extraction
Separation
Benzene
Toluene
Hydrodealkylation
Isomerisation
C8 Aromatics
Separation
Paraxylene Separation
Benzene
Toluene
Gasoline Pool
Polymerate
Alkylate
Steam Cracking
Separation
Hydrogenation
Separation
Light Cut
Fuel Oil
Transport fuel
Separation

available in reformate appear as pure products. For benzene the figure is difficult to establish because the quantity made by hydrodealkylation is not accurately known but a somewhat higher figure is estimated - in the USA the proportion estimated is approximately 50 percent. It follows therefore that gasoline is by far the major market. It is the option of blending aromatics back into gasoline which is the balancing factor on both supply and price in the developed market regions.

3. Gasoline Value of Aromatics

The alternative use value which sets the bottom of the chemical market for BTX is their value if left in the gasoline pool. This value may be calculated by a simplified blending scheme in which pure aromatics are added to regular gasoline to give premium gasoline. The calculated gasoline value may be reduced by the value of lead additive saved, but must be increased by the cost of separating aromatics to give the minimum cost at which it is worthwhile extracting BTX to sell as individual products. The gasoline values used are discussed in the section on aromatics extraction.

4. Alternative Technology

Prior to the 1945 World War, a large proportion of the aromatics production was derived from coal. Aromatics were made as by-products of coke manufacture, towns gas manufacture and tar distilling. These sources have declined and now account for only 15 percent of total production in Europe. This proportion is declining and in view of the static coal production cannot be increased readily. Coal-based aromatics are of similar low importance in most parts of the world, one exception perhaps being South Africa, where lack of oil and an abundance of coal have given rise to a coal based chemical industry. Because of the dominance of oil in both the current and foreseeable future as the major source of aromatics, this study considers only the major oil-based routes.

5. Proposed Arab Aromatics Complex

The base aromatics products considered and costed for the proposed Arab projects are benzene, orthoxylene and paraxylene: market analyses and preliminary economics show toluene and metaxylene to be completely unattractive prospects. A catalytic reformer complex producing benzene, ortho- and paraxylene end products is therefore described and evaluated for the possible Arab locations. The cost of benzene produced from the pyrolysis gasoline by product of a liquid feed olefin plant is also derived to show the economics of this route, and enable consideration of the integration of the olefin and aromatics complexes.

B. ECONOMICS OF CATALYTIC REFORMING

1. Introduction

Catalytic reforming as commercially practised is the selective conversion of naphtha fractions to increase the octane number and aromatics content of the feedstock.

Chemically naphtha contains paraffins; cycloparaffins, more usually known to a refiner as naphthenes; and aromatics. Naphtha from cracking processes such as catalytic cracking, coking or visbreaking may also contain olefins. Reforming involves four primary types of reaction:

- Dehydrocyclisation of Paraffins
  Paraffins $\rightleftharpoons$ Naphthenes + Hydrogen
- Dehydrogenation of naphthenes, including dehydro-isomerisation of alkylcyclopentanes and dehydrogenation of cyclohexanes
  Naphthenes $\rightleftharpoons$ Aromatics + Hydrogen
- Isomerisation of Paraffins
  n-Paraffins $\rightleftharpoons$ Branched Paraffins
- Hydrocracking of naphthenes and paraffins
  Naphthenes + Paraffins + Hydrogen $\longrightarrow$ Low M.W. Paraffins

The route to aromatics production is the combination of the first two reactions

Paraffins $\longrightarrow$ Naphthenes $\longrightarrow$ Aromatics

Modern catalytic reformer design is based on an analysis of the variables which favour this chain of reactions and minimise the undesirable reactions, particularly hydrocracking.

2. Modern Catalytic Reformer Design

Catalytic reformers have been operating for over twenty years with the same basic aim of maximising octane. The value of improved octane is such that an immense amount of research has been expended on process development. Advances have been made in two areas where best modern practice gives significantly higher aromatics yield than the prevailing standards of even five years ago.

a) Catalyst Development

In all catalytic reforming catalysts the active constituents are platinum, which promotes hydrogenation and dehydrogenation reactions, and the alumina support which catalyses isomerisation and cyclisation reactions.

An active catalyst is one in which the available surface area is maximised and the metal distribution is in the most favourable form. One of the major factors is the crystal size of the platinum, which is preferably as small as possible. Whilst this can be achieved by suitable preparation, the most difficult aspect is to stabilize the crystal structure in the desired form. This is because under the operating conditions in the plant the crystals tend to sinter to produce larger, less active forms. Stabilization has been achieved by:

- Removal of impurities which promote sintering. The best example is sodium, and thus modern catalyst supports are specified as low sodium alumina

- Addition of metals which stabilise the crystal structure. The first example of this to achieve commercial success was rhenium, which was used in the various bimetallic catalysts of the late 1960's.

The discovery of bimetallic catalysts led to the next major improvement, the multimetallic catalysts. These include traces of other rare earth metals which in addition to their stabilising effect also increase the selectivity to desired products.

Developments in both metal content and support have improved both the life and activity of catalysts; notable are the bimetallics which use rhenium to stabilise the platinum and the multimetallic catalysts which improve both selectivity and catalyst life.

Catalyst characteristics are closely linked with plant operating conditions. During operation cracking occurs which produces carbon. The carbon is laid down on the catalyst, impairing its activity so that eventually after, say, six months it is necessary to regenerate the catalyst by controlled combustion of the carbon. Carbon laydown is minimised by a high hydrogen partial pressure in the reactor, which adversely affects the equilibrium in the desirable reforming reactions. Hence an efficient catalyst which promotes desired reactions faster than cracking allows a lower hydrogen pressure to be used. Figure VII.B.1 compares the yield of liquid reformate for:

- a typical regenerative plant of up to five years ago using a platinum catalyst at an operating pressure of 30 atmospheres
- a recent multimetallic catalyst at an operating pressure of 13 atmospheres.

Both curves are based on a typical middle-eastern naphtha feedstock.

Figure VII.B.2 shows the hydrogen yield for the same units and feedstock. This is significant because hydrogen yield is a measure that the desired reactions which produce hydrogen are occurring and that the undesirable reactions which consume hydrogen are being suppressed. Hydrogen yield is of economic importance since this is the source on most refineries of the hydrogen to hydrotreat the naphtha feedstock and to desulphurise the distillates. If full hydrodesulphurisation is needed the reformer yield is generally fully stretched and maximisation is important. In our costings, however, we have taken the view-point that hydrogen on a refinery is an internal stream, valued as fuel gas.

b) Plant Design

For a given catalyst and operating conditions, performance has been compared on a conventional reactor system with regeneration. A simplified flow diagram of a conventional reformer is shown on Figure VII.B.3. Two recent advances have been made in plant design features which are claimed to improve yield.

FIGURE VII. B.1.

REFORMER YIELD v OCTANE

Middle East Naphtha Start of Run

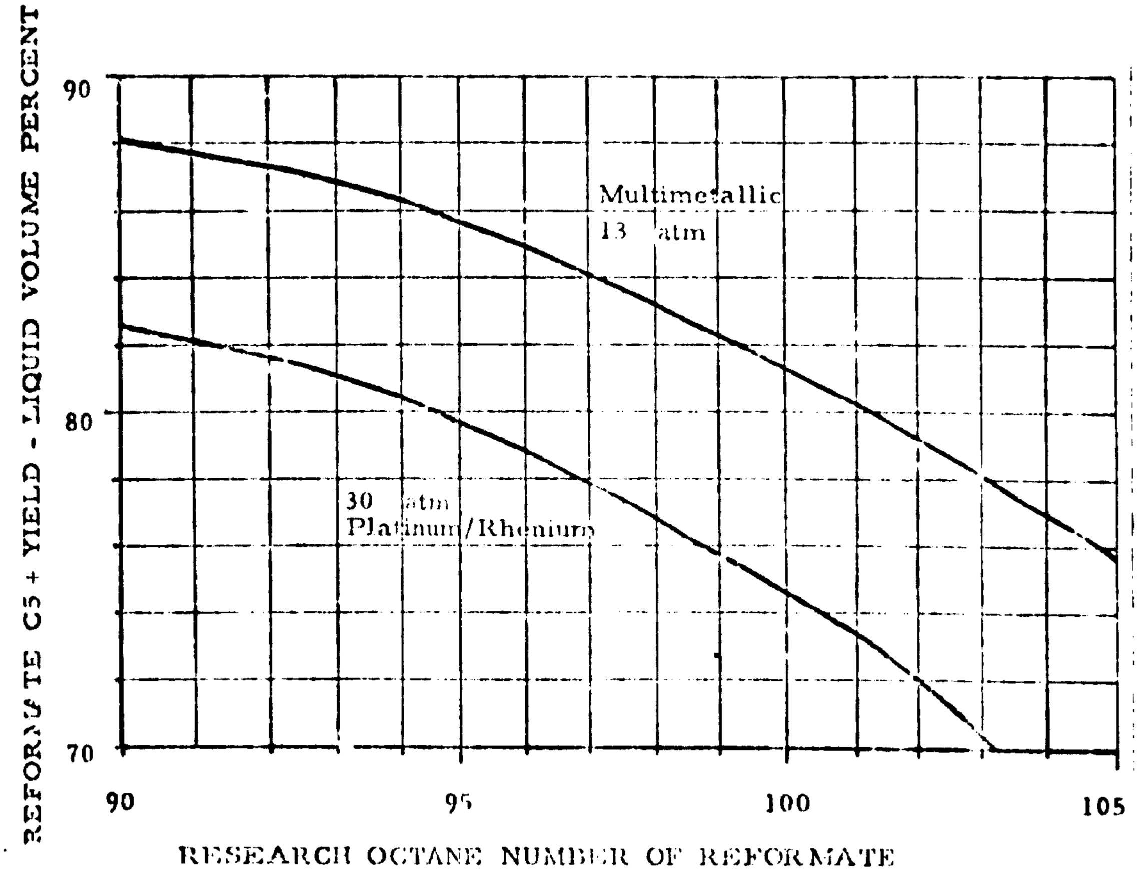


FIGURE VII. B. 2.

REFORMER HYDROGEN YIELD v OCTANE

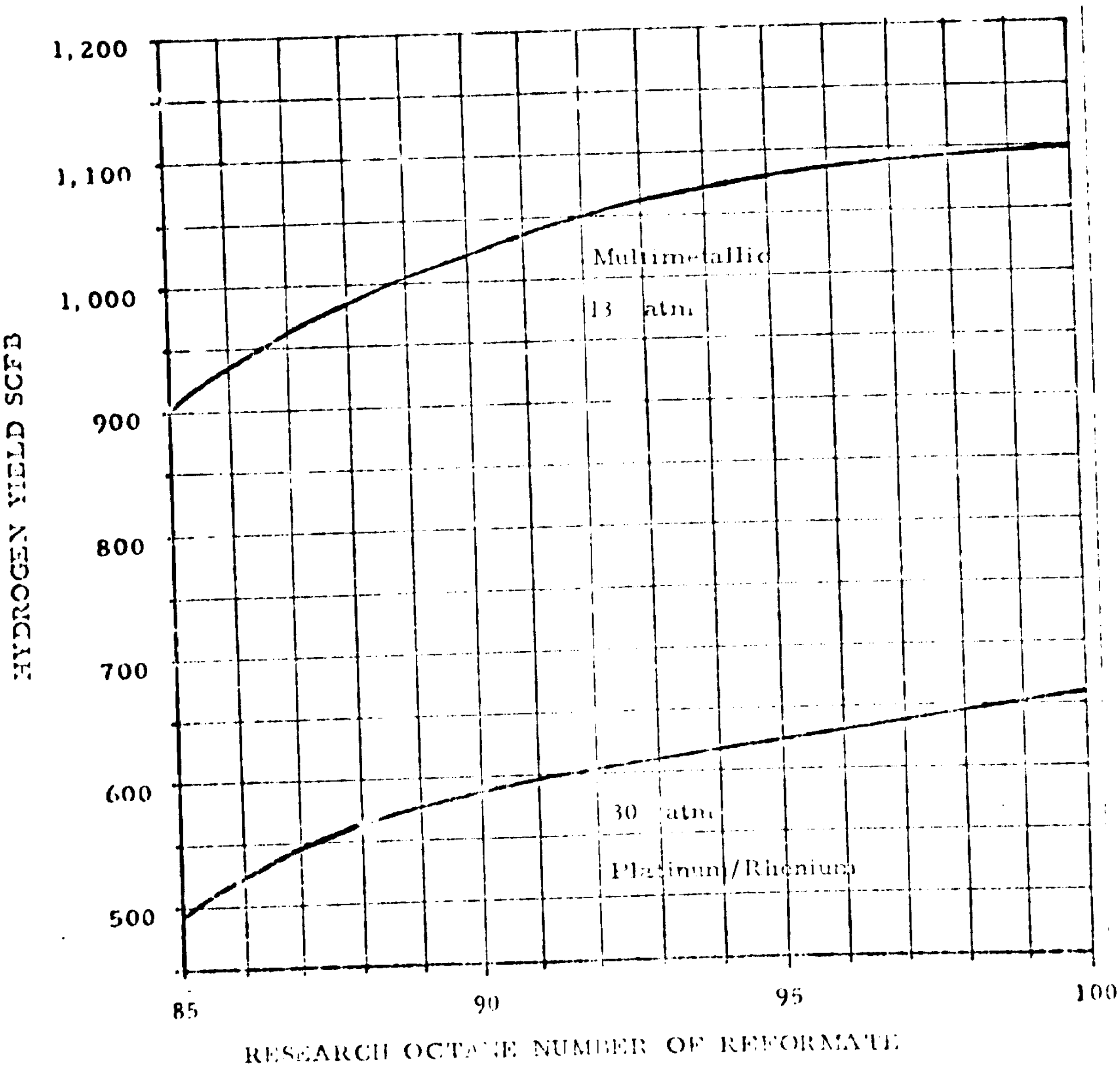
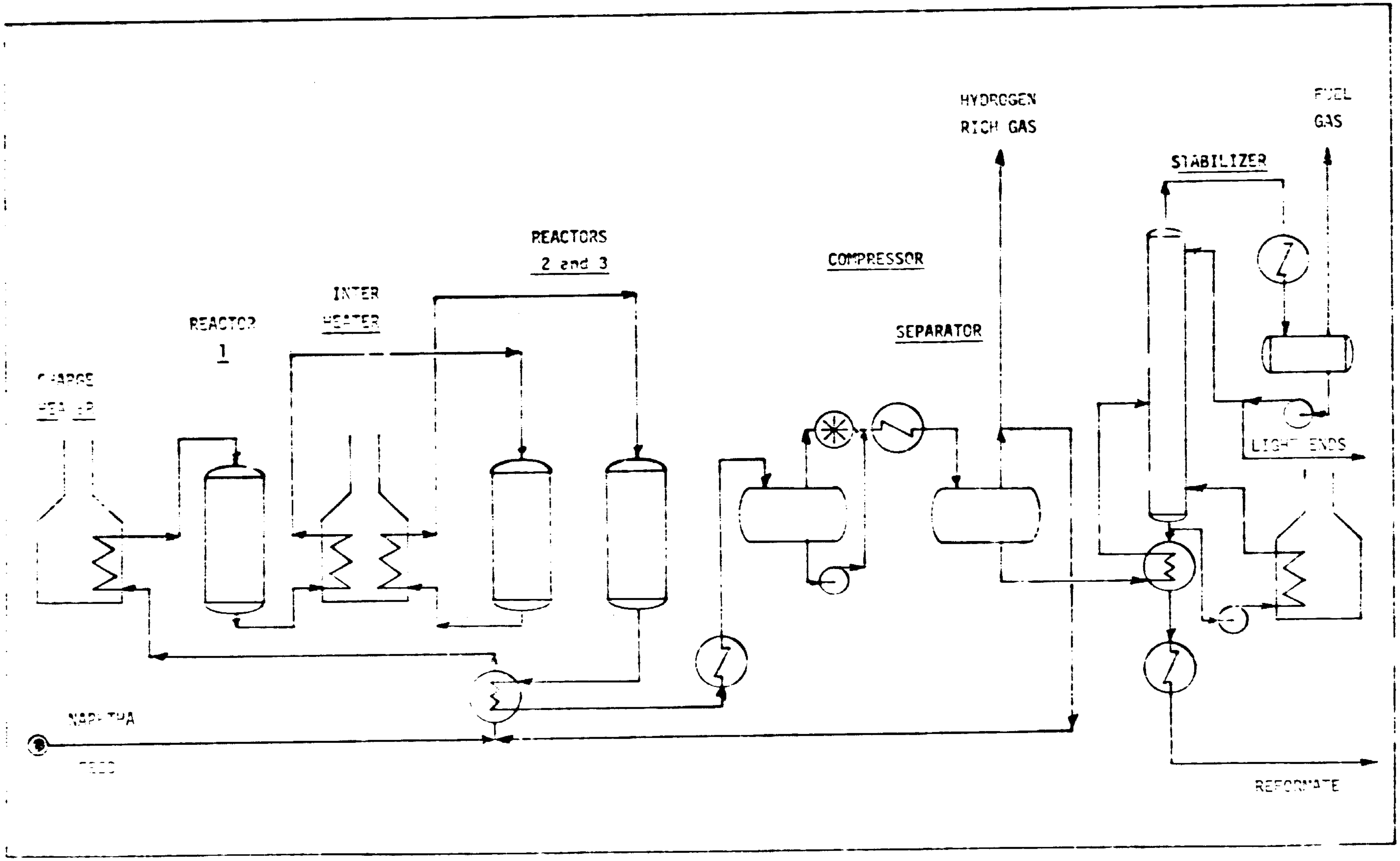


FIGURE VII.B.3.

SIMPLIFIED FLOW DIAGRAM - CONVENTIONAL CATALYTIC REFORMER



Based upon an estimated Western European 1980 naphtha price of $175/tonne, we calculate that a typical raw pyrolysis naphtha valuation in Europe will be $190/tonne. This is somewhat above likely U.S. values, and below Japanese values, due to different relative refining patterns and product valuations. The European value is used in the cost of production calculations to give a consistent W. European basis.

e) Fuel Oil

The fuel oil by-product is generally cut at 200 - 220°C and may be stripped depending on the quench tower arrangements. In some operations the fuel oil must be treated further to remove impurities such as sulphur, coke and the like. Fuel oil obtained as a by-product of high severity operations is often high in polynuclear aromatics and is, as such, a good feedstock for carbon black manufacture. Other cuts of this fuel oil may be used to manufacture low quality hydrocarbon resins. However, the most common situation is where the fuel oil is credited with fuel value and actually used as plant fuel. In the case of a gas oil feed, this use as plant fuel cannot be assumed since the quantities of heavy fuel oil produced far exceed plant fuel requirements. In this case a by-product value 10 percent below high sulphur heavy fuel oil, or approximately 20 percent below crude, is used.

The cost of production calculations therefore credit fuel oil at the same price (on a heat-content basis) as plant fuel giving a value of $118/tonne. Production in excess

Firstly, continuous catalyst regeneration is now practised. The first commercial process was the UOP continuous reformer. The reaction is carried out in three reactors with inter-heaters, which in this system are arranged vertically above each other so that catalyst can flow downwards from the first reactor to the second and thence to the third at the bottom. A stream of catalyst is continuously withdrawn from the bottom and sent to regeneration, whilst an equivalent quantity of fresh catalyst is added to the top reactor. From the performance view-point the catalyst is kept at a consistently low carbonisation level with consequent higher activity. The allowable carbonisation rate is higher so that lower hydrogen pressures may be used. These two advantages should result in better reformate yields. The system requires a free flowing and robust catalyst to withstand the new handling demands without excessive attrition. A hard spherical particle catalyst is used.

Secondly, the balancing of reactor conditions have been related to the chemical needs of the process. This is typified by the Engelhard Magnaformer. This design gives rise to several smaller reactors, usually three, with an ascending inlet temperature sequence, and a low hydrogen partial pressure followed by a large final reactor at a yet higher temperature to complete the conversion to the desired severity. The last reactor is the only one to operate at conventional severity. It therefore requires a higher hydrogen rate, obtained by adding a second recycle inlet before this reactor, and its temperature also needs to be raised as catalyst carbon deposition progresses; both are features of conventional reforming which are avoided in the three lead reactors.

Both of these developments add to the catalyst inventory and initial plant investment and obtain higher reformate yields and longer on-stream operating time. Whereas a satisfactory pay-off was claimed before 1973, current oil prices will enhance the value of extra yield and make these developments even more economic.

3. Trends in Capacity

Catalytic reformer capacity tends to follow crude unit capacity, with reforming feedstock accounting for 15 - 20 percent of crude feed. Thus a new refinery of 200 000 BPSD would have a reformer in the range of 30 000 - 40 000 BPSD. Petrochemical manufacture is unlikely to be the sole naphtha user of a refinery in the near future, hence a reformer for petrochemicals is likely to be smaller than the size range quoted. On the other hand, economics of scale indicate the very small units will not be competitive. We have selected 20 000 BPSD for the capacity; this may become typical of the two reformer refinery, one for gasoline octane and one for aromatics.

Future reformers are not expected to show much further increase in unit capacity and units of a wide range, 15 000 - 45 000 BPSD, will continue to be built. In this capacity range the economies of scale are no longer of great importance, and capacity selection will follow other requirements such as aromatics or gasoline demand.

4. Operating Severity

Severity of reforming has been increasing in recent years for three reasons:

- Lower lead levels in gasoline. Lead restrictions are in force and being tightened throughout Europe and the USA. The octane loss is being made up by higher severity reforming; the average reformer severity for lead free gasoline will need to rise to 98 RON, from the average five years ago of 94, and new capacity is being installed at this or higher severity in anticipation.

- Higher performance of reformers. The economic reforming severity used to be the minimum necessary to made the required gasoline pool. In a modern reformer the product of octane gain multiplied by yield will increase over a higher octane range and the economic choice for a refiner will depend on the availability of blending stocks rather than reformer economics.

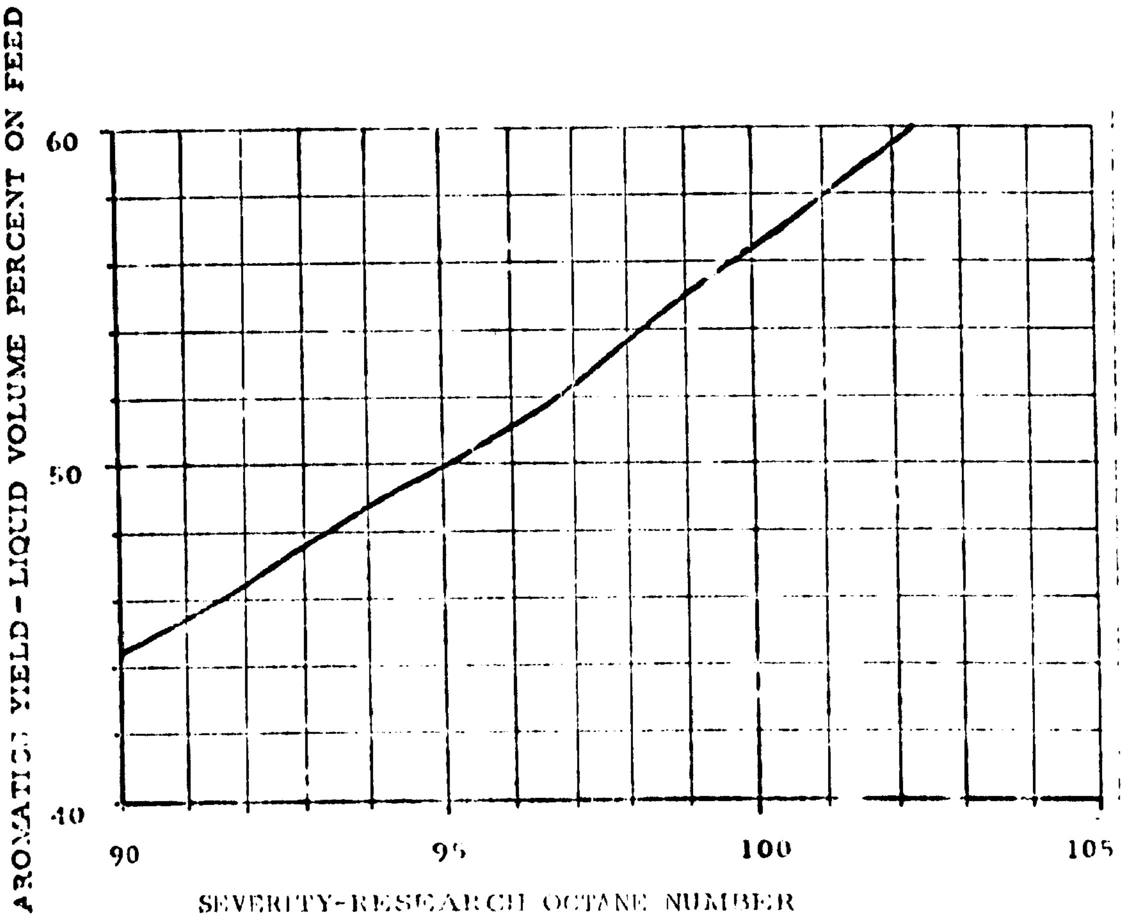
- Aromatics demand. High severity reforming is preferable for aromatics production. Severe reforming increases aromatics yield, as in Figure VII.B.4, even though it significantly reduces total liquid yield. Optimum octane for aromatics is thus higher than for gasoline production. The increasing importance of aromatics to the refiner plus the construction of reformers specifically for chemical aromatics production has therefore increased average severity.

In the future severities may increase further should there be a continued decrease in lead levels in gasoline. Improved technology and the increasing proportion of reforming capacity dedicated to chemical aromatics production will also lead to

FIGURE VII.B.4.

AROMATICS YIELD v OCTANE

From a Middle Eastern Naphtha 72-142°C Cut



an increase in the average level of severity. Future severities in the region of 100 - 106 RON will supersede the currently typical 92 - 98 RON level.

5. Economics of Reforming

From the yields noted earlier it may be seen that liquid reformate will be obtained in a yield of about 85 percent by weight on a typical naphtha feedstock. The other 15 percent is light gases, of which butane and propane together form over half and hydrogen is up to one-fifth. Since these are recoverable, only the small proportion going to ethane and methane, about 4 percent on feed is definitely of only fuel value to a refiner. The value of LPG and hydrogen to a refiner may only be for fuel but hydrogen at least is likely to be fully used in hydrotreating processes in the future. In our economic study we have ascribed fuel value to the entire stream and charged nothing for hydrogen consumed in hydrotreating. This is a realistic treatment since any enhanced value for LPG will be largely offset by recovery plant costs.

The capital and operating costs of a reformer will increase with severity. Catalyst volume for example is roughly proportional to octane increase and high severity may mean additional reactors. Heat input to the reactors is proportional to the net amount of useful reaction taking place and hence to octane increase. On an efficient reformer, the lack of heat from cracking reactions will give a higher net heat input.

The major costs however, are associated with yield loss, hence the importance of catalyst performance discussed earlier. The selection of a reforming process needs therefore to be based on choosing the correct catalyst and operating conditions i.e. the licensor. The choice of contractor, who may offer improved equipment or heat recovery schemes, is very much secondary.

6. Impact of Feedstock Quality

From the brief discussion of reaction mechanisms it is apparent that aromatics are the most desirable constituent in a reformer feedstock, followed by naphthenes and paraffins. The characteristics of a feedstock are often correlated using the index (N + 2A) where N and A are the liquid volume percentages of naphthenes and aromatics respectively. A high value of this index gives higher yield at a given octane, a higher economic severity, and greater throughput in a given unit. High naphthenes alone give greater hydrogen yield and hydrogen purity.

The qualities described here as desirable for a reformer feedstock are mostly the opposite to those noted as required for a steam cracking feedstock. It follows that the freedom to trade naphtha to match properties to use is an important economic factor. It is difficult to quantify the costs of a forced feedstock change since plant capacities, operating costs and on-stream time are also functions of feedstocks. As a simplified example, the liquid volume yield noted here for an average middle east naphtha, 82 percent wt. at 100 RON could vary plus or minus 5 percent with possible alternative feedstocks. This may be valued for the 20 000 BPSD reformer whose production costs are detailed on Table VII.G.1 at about plus or minus $4 300 000 per annum if feedstock costs only are included. If total cost of production is considered then the cost of a 5 percent yield is $11/tonne or $6 700 000 per annum.

Other feedstock characteristics such as sulphur content, nitrogen content and olefins are less important, since the feed is invariably hydrotreated to reduce these to an acceptable level.

The distillation range of naphtha for aromatics production is chosen to match the aromatic demand pattern. Normally one does not use the full range naphtha used for gasoline production but takes a narrower fraction. For example the 75 - 140°C cut would be suitable for full BTX, but a narrower cut would be preferable if only benzene (including toluene hydrodealkylation) were required.

C. BTX EXTRACTION FROM REFORMATE

1. Introduction

The separation of pure aromatics from reformate is done in three stages:

- separation by distillation of a heart cut to concentrate the required C6 - C8 aromatics
- solvent extraction to separate aromatics from non-aromatics
- separation by distillation of benzene, toluene and mixed xylenes.

How these stages link up with the reformer may be seen from Figure VII.A.1. The separation of the eight carbon atom aromatics is considered in the section following.

The initial distillation is needed to reduce the load on the extraction stage. Because of the wide range of compounds boiling in the benzene-xylenes range it is not feasible to make a sharp cut-off in the predistillation. If a narrow cut naphtha is fed to the reformer, the basic duty is to remove the 10 - 15 percent of C9 and heavier aromatics. The light ends will have been removed in the reformer stabiliser. A gasoline reformate on the other hand will need pentane removal in addition to larger quantities of heavier aromatics. If it is not required to produce mixed xylenes or toluene the cut may be narrowed still further with considerable savings in the subsequent extraction. In this study the full aromatics complex is used as the basis for costs.

The solvent extraction stage separates aromatics and non-aromatic components with high efficiency and recovery. Typical data are given in Table VII.C.1.

TABLE VII.C.1

SOLVENT EXTRACTION - TYPICAL SPECIFICATION

	Percent Recovery on Feed	Non-Aromatic Content (ppm)
Benzene	99.99	10
Toluene	99.7	100
C8 Aromatics	97.8	300

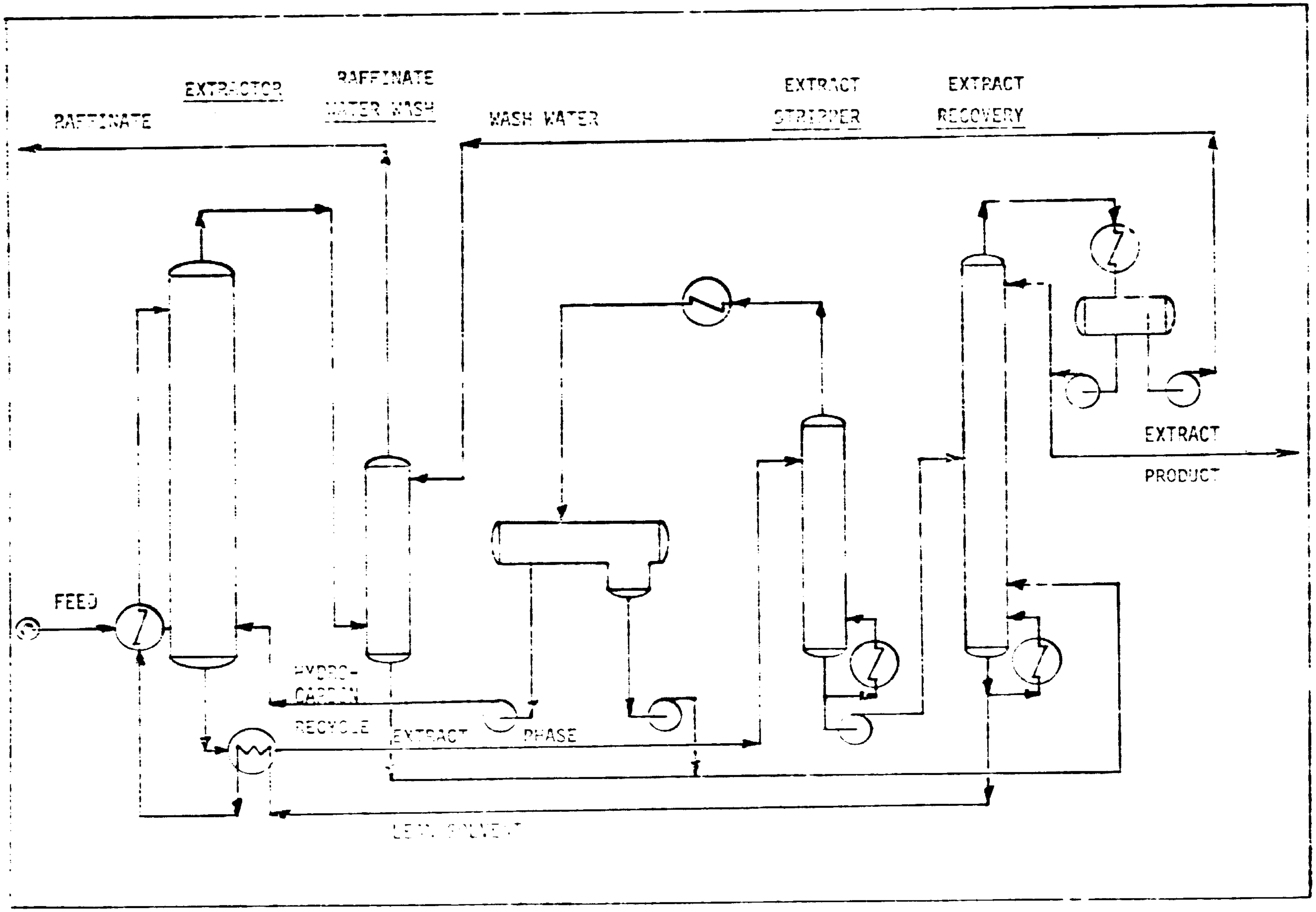
There are a number of proprietary processes available, of which the process using sulpholane as a solvent is taken here as being representative of current technology. Figure VII.C.1 presents a simplified flow diagram of a solvent extraction unit. The major process steps consist of :

- extracting the aromatics from the fresh feed by sulpholane solvent
- stripping the rich solvent mixture to remove non-aromatics
- stripping the aromatics from the sulpholane which is recycled back to extraction and stripping
- washing of hydrocarbon streams to remove trace sulpholane
- stripping of water to recover washings.

Some of these stages are dependent on the quantity of non-aromatics present, others on the total aromatics throughput. In addition the extraction of C8 aromatics is slower than toluene which is in turn slower than benzene, so that extractor size depends on the composition of the feed as well as total aromatics throughput.

FIGURE VII.C.1.

SIMPLIFIED FLOW DIAGRAM - AROMATICS EXTRACTION. (SULPHOLANE SOLVENT)



of plant fuel requirements is credited at $96/tonne (20 percent below crude).

f) Fuel Gas

These streams contain the hydrogen and methane by-products from the cracking operation. Since most plants recover separate hydrogen and methane streams, each product is discussed in turn below:

- Hydrogen Tail Gas

  In most plants a hydrogen stream containing 70 - 80 mol percent hydrogen with methane as the major impurity, is produced. Recovery at up to about 80 percent purity is relatively easy, but production of higher purity hydrogen requires additional separate process units.

  The use of hydrogen in refinery and chemical complexes is increasing, and it is reasonable to expect that in future this stream will increase in value. However, for the present exercise we have made the conservative assumption that the hydrogen stream will have only fuel value. The effect of obtaining a "chemical value" hydrogen credit on cracker economics would be relatively insignificant. A reduction of net ethylene production cost of the order of $5 per ton would be typical.

The third separation is conventional distillation. Benzene may be produced by distillation in a 65 tray tower, whence it is taken as a sidestream product five trays from the top. The top product may contain traces of water and non-aromatics and the bottoms all the heavier components. Toluene is separated in a 60 tray tower as an overhead product with xylenes as the bottoms. Traces of heavier components in the xylenes are separated in the xylenes unit. In this section the capital and operating costs are dependent on quantity of product distilled, i.e. toluene and benzene rather than total aromatics feed.

If unsaturated components are present in the feedstock, as with pyrolysis gasoline aromatics concentrate or aromatics from cracked naphthas, an additional clay treating stage is necessary before the final distillation. Trace olefins are removed by passing the aromatics down over fixed beds of clay which absorb these gum-forming impurities.

These process stages are well established and are available from a number of licensors and contractors.

2. Economics of Extraction

The products from the separation stages are the individual BTX aromatics as main products, heavy reformate and raffinate as by-products.

Raffinate will be an almost entirely paraffinic naphtha cut and as such is an ideal olefin plant feedstock. Conversely, its value to a refiner is lower owing to its low gasoline value. We have given this the same value as full range straight run naphtha on the assumption that it will be fed to a steam cracker as a replacement for naphtha. Heavy reformate will be a high octane gasoline blending stock. Its value to a refiner may be less than the same octane in a lighter stock depending on the refiner's particular blending stock availability. We have valued this relatively small quantity product at gasoline blending value.

D. TOLUENE HYDRODEALKYLATION

1. Technology Background

a) Introduction

Because of the high chemical and thermal stability of the benzene ring it is possible to subject higher aromatics to severe processing without destroying or modifying the basic ring structure. The major commercial use of this property is the hydrodealkylation of xylenes and toluene to benzene. The hydrogen is necessary in the reaction removing the side chain from the ring, shown below, and to avoid carbon forming reactions from the breaking up of the side chains. The reaction for toluene may be shown:

$$\underset{\text{Toluene}}{C_6H_5CH_3} + \underset{\text{Hydrogen}}{H_2} = \underset{\text{Benzene}}{C_6H_6} + \underset{\text{Methane}}{CH_4}$$

In this reaction environment all paraffinic hydrocarbons tend to be converted towards methane, and a complete hydrodealkylation of a mixed naphtha cut will yield benzene, methane, lesser quantities of ethane and LPG, and excess hydrogen. Such a process has been used for fuel gas production with aromatics as the by-product.

b) Processes

The hydrodealkylation (or HDA) reaction may be brought about either catalytically or thermally. Both types of process show high selectivity with ring yields over 95%, and freedom from coke formation. Thermal processes have the advantage of no catalyst with its initial expense, regeneration and associated downtime. The reaction stage is simpler and a wide range of feedstocks can be readily handled. Catalytic processes operate at lower temperature and lower hydrogen consumption. On balance however, there are a number of established processes of both types which all give comparable economics for converting toluene to benzene and no major new developments are expected. A typical hydrodealkylation flowsheet is presented in simplified form as Figure VII.D.1. Note that in using the abbreviation of HDA for this process we are not specifically referring to the licensed process known under this name.

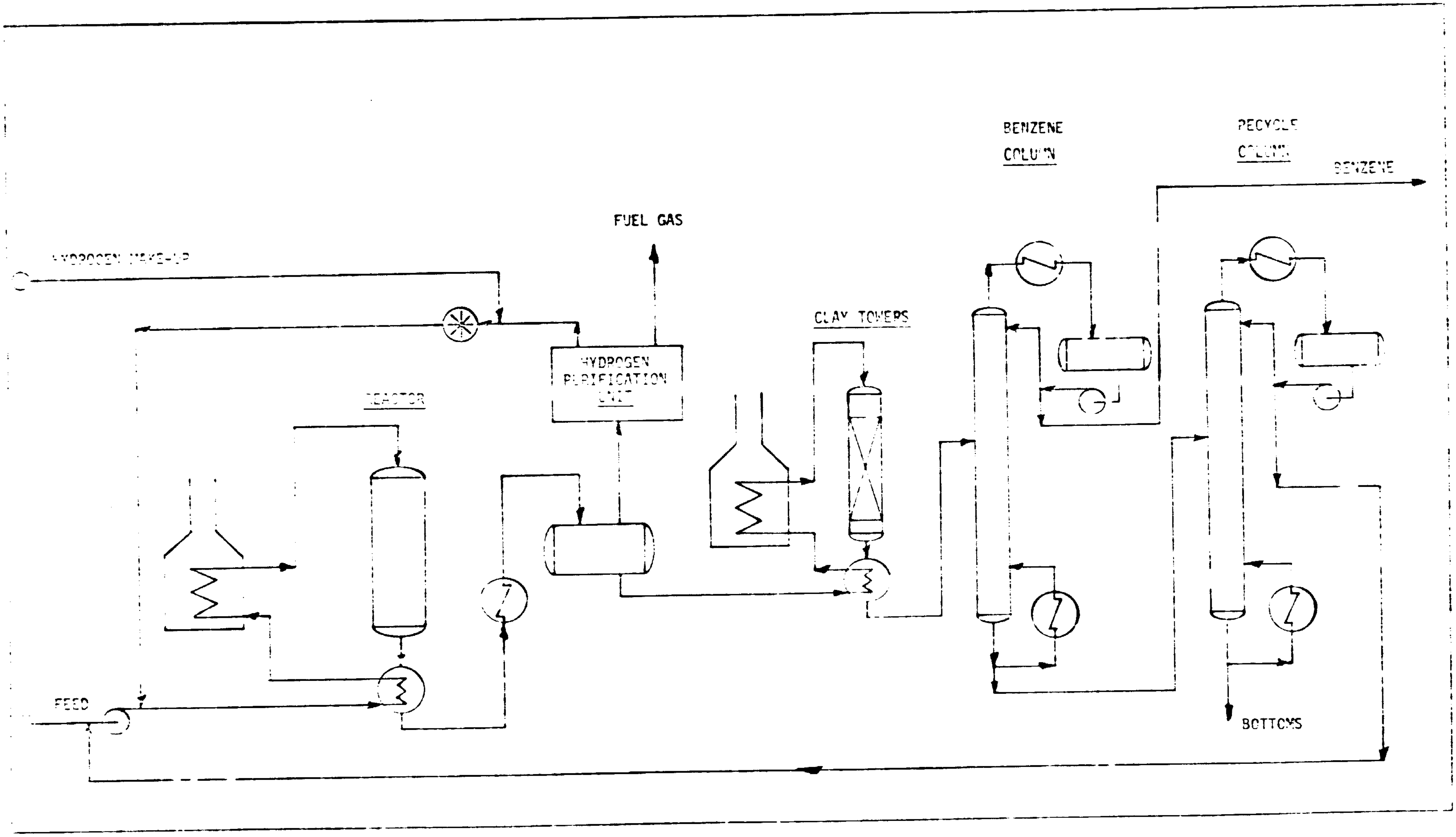
Two factors may be noted in regard to the chemistry of this process. Firstly, the non-aromatics are hydrocracked to compounds readily separated from aromatics, thus providing an alternative means to extraction of separating pure aromatics from a mixture. Secondly the non-aromatic portion of the feed, including the side chains, consumes more hydrogen per unit weight of feed than the aromatic portion. Thus hydrodealkylation of xylenes is less attractive than that of toluene not only because of the greater weight loss, 35% compared with 20%, but also because of the higher hydrogen consumption. Notwithstanding these two factors, bulk hydrodealkylation of aromatic rich cuts may be economically attractive in some situations, as discussed in the later section on pyrolysis naphtha.

2. Hydrogen Costs

Hydrogen is produced as a by-product in both the catalytic reforming and steam cracking of naphtha. In the earlier discussions on these processes it was stated that hydrogen

FIGURE VII.D.1

SIMPLIFIED FLOW DIAGRAM - HYDRODEALKYLATION



would be taken as fuel cost only. Similarly, hydrogen consumed for hydrotreating was a small quantity and was balanced out with the fuel gas produced. However, in a chemical complex it can no longer be assumed that hydrogen is in excess and assigned a fuel value cost.

For example, in a refinery the catalytic reformer will typically process 20 percent of the barrel, and the hydrogen make will be 2 percent on reformer feed, equivalent to 0.4 percent on crude. Full distillate desulphurisation, including vacuum distillates, which will be the trend in modern refineries will consume as much of this hydrogen as can be recovered without expensive cryogenic upgrading. Hence a low sulphur product refinery is self-sufficient but cannot export hydrogen. Similarly a steam cracker produces at most 1 percent by weight of hydrogen on the naphtha feed, some of which is consumed internally for acetylene hydrogenation so the quantity for export is low. Neither the refinery nor olefin complex will therefore have a substantial excess of hydrogen for export or for other chemical users.

In the present study the aromatics reformer produces enough hydrogen for the hydrodealkylation of the toluene produced. We have therefore assumed the same fuel value cost to the HDA stage as the credit to the reformer. From the preceding comments however, the validity of this assumption should be examined in the light of the overall complex hydrogen balance.

3. HDA Economics

In an integrated overall scheme for aromatics the hydrodealkylation stage would be integrated with the distillation of straight-run aromatics. Toluene from the distillation would be fed to the HDA reaction stage, the reaction product stabilised, and the product benzene plus unreacted toluene returned to the BTX separation distillation. Many HDA units are of course added as after-thoughts to previously existing aromatics complexes but if HDA is to become a feature of the complex under the present study, full integration will occur. Our economics are therefore based on this most favourable situation.

By-products are the fuel gas, sent to the plant fuel gas system, and diphenyls from the dimerisation of benzene and toluene, which are removed in a tailing column and either recycled to extinction or sent to fuel. By-products are therefore not of economic importance. Toluene feedstock is the major cost accounting for over 70 percent of the total benzene cost, and hydrogen another 10 percent. Capital charges form the bulk of the other operating costs, with other costs being minimal.

Valuation of toluene relative to benzene is therefore the major economic consideration. It is a feature of HDA plant history in the developed market areas that as demand for benzene rises faster than supply, pushing up benzene price, HDA plants have been started up to restore the supply-demand balance at a higher price which includes HDA costs, whilst when more benzene becomes available from cheaper sources, the price falls and HDA plants close down.

The cost of production of benzene by hydrodealkylation is developed in two stages on the estimates shown in this section. Firstly, the total cost of production for the combined benzene, both straight run and by dealkylation, is calculated. Toluene does not appear in this analysis at all since it is fully converted internally. Also since the sources of benzene are not distinguished this costing gives only the average price of benzene and does not show how much cost may be apportioned to each process route. Secondly, therefore, the costs of producing straight run BTX are simply deducted from the complex to give the marginal cost of adding HDA. Toluene in this case is valued at gasoline value.

E. BTX FROM PYROLYSIS NAPHTHA

1. Introduction

Pyrolysis naphtha (or pyrolysis gasoline) is defined as the steam cracker product fraction containing the C_5's and all heavier components up to about 220°C end point. In the past this material was used primarily as a motor gasoline blending stock. While this outlet still accounts for a considerable quantity of pyrolysis naphtha, increasing amounts are being processed for aromatics recovery.

For example 1973 West European production of pyrolysis naphtha is estimated to have been approximately:

Total Pyrolysis Naphtha	9.3 million tonnes
Contained Benzene	2.6 million tonnes
Toluene	1.6 million tonnes
C_8 Aromatics	0.9 million tonnes

We estimate that close to 50 percent of the contained aromatics are currently recovered for chemical use, either directly or through dealkylation processes.

2. Technical Background

Steam cracker technology is discussed in Section VI on olefin economics. The composition and quantity of the pyrolysis naphtha product is dependent on feedstock composition and on operating conditions in the cracking furnaces. In general, as cracking severity is increased, the following trends are observed:

- The overall yield of pyrolysis naphtha decreases
- The aromatics and diolefin content of the stream increases
- The paraffin and naphthene content decreases
- The olefin content reaches a peak at a relatively low cracking severity and then declines with increasing severity.

Table VII.E.1 gives yields and compositions for a number of pyrolysis naphthas. These can be considered as typical products from modern cracking furnaces.

As far as aromatics recovery is concerned, the interesting part of the stream is of course the C_6 - C_8 'heart cut'. As severity increases the aromatics content of this fraction increases from 65 - 75 percent at moderate cracking severity up to 85 - 90 percent at very high cracking severities. At the same time the non-aromatics become progressively less saturated.

3. Pyrolysis Naphtha Hydrogenation

Raw pyrolysis naphtha is an unstable material which rapidly forms gummy polymers on standing. It is normally hydrotreated to eliminate the diolefins, resulting in a stable material suitable for blending into the gasoline pool.

If aromatics recovery is carried out, a second hydrogenation operation is generally required. This second stage hydrogenation, usually carried out only on the C_6 - C_8 fraction, serves to destory thiophenic sulphur compounts which would otherwise appear in the product aromatics. The olefinic compounts are concurrently converted to saturates.

- Methane Tail Gas

This stream consists of about 96 percent methane with hydrogen and small amounts of ethylene as impurities. Its major outlet is, and will continue to be, plant fuel.

Fuel value of $11.6 per million Kcal is therefore assumed for both these gaseous by-product streams.

3. Arab Projects

a) Introduction

The co-product values applicable to an olefin project in an Arab state will be very different from the W. European situation described previously. In general, unless an adjacent derivatives plant is installed to use the co-product (propylene, butadiene etc.) then it must either be exported (to Europe, say) or burned as fuel, since suitable consuming plants do not exist. Since low-cost natural gas is available locally as fuel, the non-chemical co-product valuations are generally low.

b) Propylene

Several methods may be considered for assigning a value to the propylene from an Arab olefins plant:

- Fuel value. If the quantity of propylene produced is small, then no economic possibility exists for realising a premium chemical value. Any derivative plant (polypropylene, acrylonitrile etc.) has a certain minimum economic size below which it will be uneconomic, regardless of propylene cost, so if propylene is generally available in these minimum

TABLE VII.E.1

TYPICAL COMPOSITIONS OF PYROLYSIS NAPHTHAS

Feedstock	**Light Naphtha**	**Full Range MidEast Naphtha**		**230 - 370°C MidEast Gasoil**
Cracking Severity	High	High	Medium	Medium
Composition (wt. percent)				
C_5's	17.8	11.0	17.0	25.0
Benzene	29.9	28.5	19.5	25.5
C_6 non-aromatics	6.1	6.5	9.1	7.7
Toluene	20.1	21.1	11.7	15.3
C_7 non-aromatics	2.8	5.0	6.6	3.8
Xylenes	6.7	8.0	7.2	6.2
Ethyl benzene and Styrene	3.1	4.5	3.3	2.5
C_8 non-aromatics	1.8	4.5	5.1	2.8
C_9 - 200°C	11.7	10.9	20.5	11.2
TOTAL	100.0	100.0	100.0	100.0
BTX	59.8	62.1	41.7	49.5

a) Single Stage Hydrogenation

All the principal single stage processes are fixed bed, liquid phase. Raw gasoline from the ethylene plant is pumped up to reaction pressure of approximately 55 atmospheres, mixed with recycle product for cooling purposes and hydrogen (usually 70 mol percent purity) from the ethylene plant demethaniser overhead system. It is preheated with reactor effluent and since the reaction is highly exothermic, under normal operating conditions there is virtually no steam required for feed preheat. Feed flows downwards through the catalyst bed and reaction takes place in the liquid phase.

The temperature rise across the bed is limited to a maximum of about 30°C by recycling hydrogenated product which is usually drawn from the high pressure separator. The quantity of recycle depends upon the quality of raw gasoline and can be eliminated when treating stocks from relatively mild cracking operations. Reactor effluent is cooled and flows through a separator to the stripper where light ends are removed and recycled to the ethylene plant for recovery of hydrogen. Alternatively, if there is no incentive to recover the hydrogen, this gas may be sent to fuel.

Some heavier material is formed by polymerisation in the preheat and reactor system. In addition some material above the normal gasoline endpoint is frequently found in the raw gasoline feed, such as wash oil introduced into the cracked gas compressor of the ethylene plant. This heavy material is removed from the gasoline in a rerun tower.

All processes are affected by the presence of small quantities of polymeric material in the feed. This deposits on the catalyst resulting in a reduction of catalyst activity and an increase in pressure drop across the bed. Polymerisation occurs as a function of time and temperature, and oxidation to form peroxides occurs on contact with air. It is, therefore, desirable to minimise hold-up time and storage between gasoline recovery facilities in the ethylene plant and the first stage of hydrogenation. Where some hold-up time is unavoidable, gum formation can be minimised by holding the gasoline under an inert gas blanket and by introducing an antioxidant.

b) Two Stage Hydrogenation

A second stage hydrogenation is almost always necessary where aromatics recovery is to be carried out, otherwise the contained sulphur will appear in the benzene as thiophenes.

The processing scheme is identical to single stage hydrogenation, up to and including the high pressure separator. Liquid from this separation flows to the depentaniser which combines the function of stabiliser plus depentaniser by taking light ends overhead and C_5's as a liquid side stream. Depentaniser bottoms are then rerun to produce a C_6 - C_8 heart cut for the second stage of hydrogenation, and the C_9+ material is taken from the base of the rerun tower.

C_6 - C_8 from the top of the rerun tower is pumped to reaction pressure where it is mixed with considerable excess of hydrogen and some hydrogenated material which acts as diluent to limit temperature rise across the catalyst bed. The total stream is vaporised and preheated in a fired heater before entering the reactor at about 370°C and 55 atmospheres. Reactor effluent is cooled, condensed and unreacted hydrogen is separated and recycled. The C_6 - C_8 product is finally stabilised before flowing to storage or directly to further processing. Off-gas from the stabiliser and purge gas from the recycle circuit is generally sent to fuel, but can be recycled to the ethylene plant for hydrogen recovery if desired.

A number of proven commercial processes are available for both single and two stage hydrogenation.

4. Aromatics Recovery

The aromatics contained in the hydrogenated C_6 - C_8 fraction derived from pyrolysis naphtha can be recovered using the extraction technology discussed in previous sections.

The major differences between aromatics recovery operations based on pyrolysis naphtha and reformate feedstocks relate to the composition of the feed. Steam cracking is a more severe operation than catalytic reforming with the result that, compared to reformate:

- Total aromatics content is usually higher
- The benzene content is relatively much higher
- The ethylbenzene content of the C_8 aromatics is higher (due to hydrogenation of styrene present in the raw pyrolysis gasoline).

An alternative processing option, if benzene is the desired product, is to dealkylate the entire C_6 - C_8 cut. Processes have been developed specifically for this, but their application has been limited. The most widely used is probably the Houdry 'Pyrotol' process, with many units licensed. Processes are also offered by Hydrocarbon Research and Mitsubishi. The reactions occurring are the dealkylation of aromatics to benzene and the simultaneous hydrocracking of the non-aromatics to gaseous products. The reactor effluent is stabilised and high purity benzene recovered by distillation.

5. Economics

It is not proposed to include a separate evaluation of the economics of extraction and distillation of pyrolysis naphtha. In many respects the process is the same as described and costed for reformate. The availability of pyrolysis naphtha affords the opportunity either to construct a larger extraction stage, gaining economies of scale, or to reduce the reformer size, thus saving money.

When it is proposed to recover xylene isomers from the mixed c_8 cut, the admixture of the high ethylbenzene material from pyrolysis naphtha is a distinct disadvantage. In these circumstances the bulk hydrodealkylation route to benzene is favoured. Since this is a separate process this is costed as a different route to maximise benzene.

The value of raw pyrolysis naphtha is determined by gasoline economics. The value of hydrogenated pyrolysis naphtha is a function of octane number and it is a reasonably close approximation to assume premium gasoline value for material derived from high severity cracking (typically 98-100 RON) and regular gasoline value for the product from the moderate severity operation. The value of the raw pyrolysis naphtha is then determined by deducting the cost of the hydrogenation operation.

F. XYLENES SEPARATION

1. Introduction

The aromatics fraction separated as mixed C_8's from reformate will contain ethylbenzene and xylenes in the approximate composition given in Table VII.F.1.

TABLE VII.F.1

XYLENES DISTRIBUTION FROM REFORMATE

Isomer	Average Middle Eastern	Typical Range
Ethylbenzene	16.4	16 - 21
p-Xylene	17.8	16 - 20
m-Xylene	43.0	35 - 45
o-Xylene	22.8	16 - 26
	100.0	

Pyrolysis gasoline may also be used as a source of xylenes, but the proportion of C_8 aromatics contained is lower than in reformate and the proportion of the least desired isomer, ethylbenzene is higher, as illustrated by Table VII.F.2.

TABLE VII.F.2

XYLENES DISTRIBUTION IN PYROLYSIS GASOLINE
FULL RANGE NAPHTHA FEEDSTOCK

Isomer	High Severity	Low Severity
Ethylbenzene	51	43
p-Xylene	10	12
m-Xylene	23	26
o-Xylene	16	19
	100	100

The bulk of the ethylbenzene, about 80 percent, is formed by the hydrogenation of styrene in the original gasoline. Although a process exists for recovering styrene from the raw gasoline, it is not yet commercially established.

Whilst all four isomers are of commercial importance, paraxylene is by far the major product, with orthoxylene also significant in the economics of a xylene separation complex. Discussion is therefore concentrated on these two isomers.

2. Paraxylene Separation

Paraxylene may be separated from mixed xylenes by either crystallisation or selective absorption

a) Crystallisation

Crystallisation accounts for the bulk of paraxylene production and has been practised for many years. Licensed technology is available from many companies. Whilst different processes vary in the techniques employed, the following steps are generally employed:-

- Feedstock drying
- First stage crystallisation (to about -60°C to -70°C)
- Recovery and melting of crystals from first stage
- Second stage crystallisation (to about -20°C to -30°C)
- Recovery and melting of crystals from the second stage

The drying step is either by distillation or solid dessicant, and is fairly standard technology. The crystallisation stages show the major differences both in type of crystalliser and application of refrigerant, whilst the recovery stages are again standard centrifuge techniques. The major licensed processes have been developed over a number of years and it is probable that the economics are all similar and are not now likely to show significant changes.

In a crystallisation process the feed is cooled down and paraxylene crystals form until between 60 and 65 percent of the paraxylene in the feed is recovered. Increased recovery of paraxylene is prevented by the formation of eutectics. The composition and temperature of the limiting eutetic will vary with feed composition, but in all cases at lower temperatures ortho or metaxylene are precipated with the paraxylene. This limit occurs in all crystallisation processes, although the more efficient processes work closer to the limit than others. The crystals formed are pure apart from inclusions and retained mother liquor, which it is the object of the second stage to remove. Purity from the second stage is usually in the range 99.0 - 99.8 percent paraxylene. In some variations the recovery and purification stages are combined by using types of continuous crystalliser, but none overcomes the physical limits to recovery.

b) Selective Adsorption

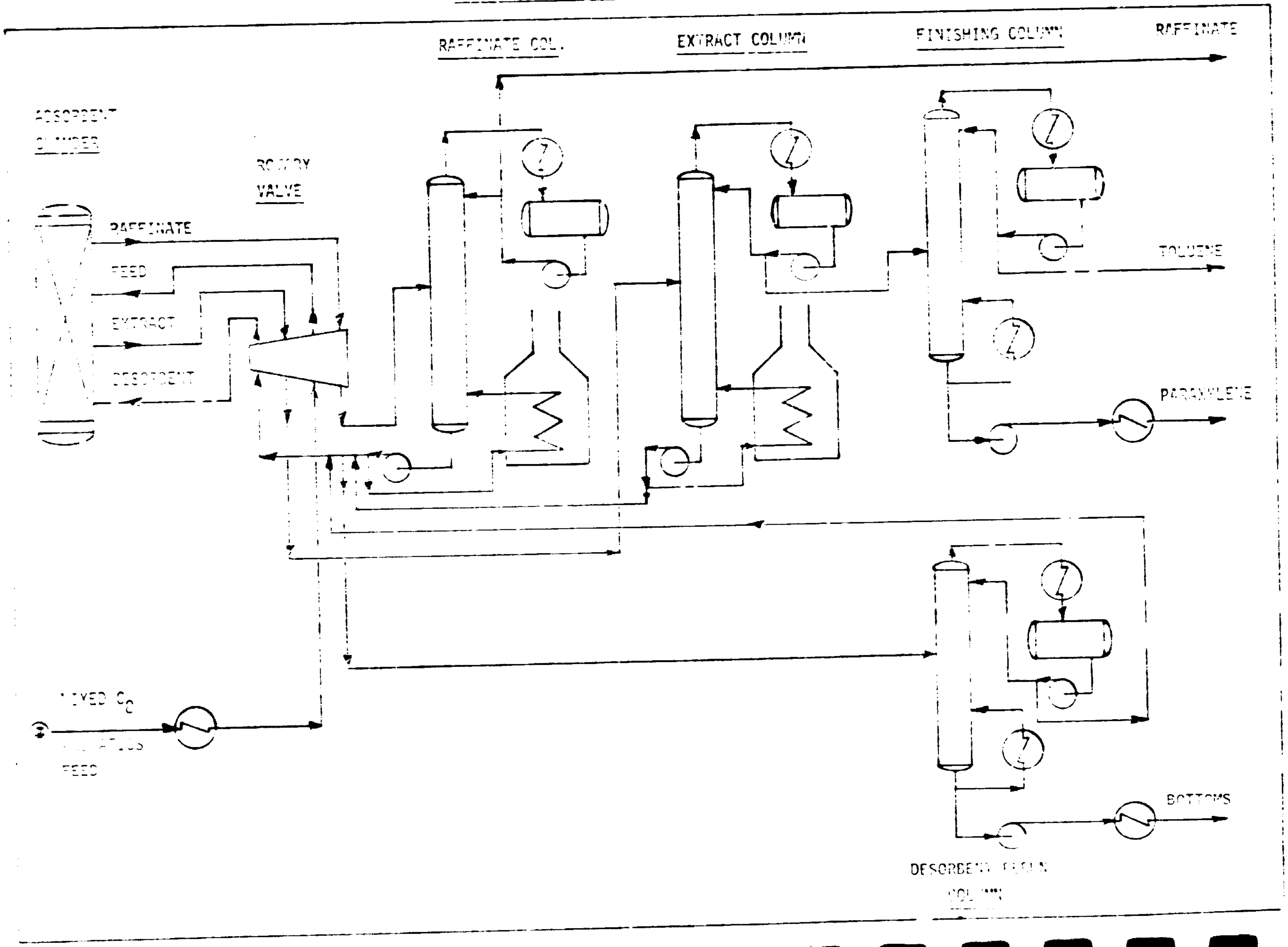
In this process mixed xylenes are passed in the liquid phase over a fixed bed of adsorbent. The adsorbent is a molecular sieve which functions here by preferential attraction to paraxylene. Paraxylene is recovered from the adsorbent by displacing it with another liquid of different boiling point. This extract is then fractionated to separate the desorbent and pure paraxylene. The major commercial process available for licence is the UOP Parex process, but other processes of similar type are known to have been developed to an earlier stage. Figure VII.F.1 presents a simplified flowsheet of the Parex process.

Selective adsorption overcomes the restriction on recovery imposed by the physical chemistry of crystallisation. Commercial units are designed for 85 - 95 percent recovery, reformate feedstocks giving the high end of this range, and product purity of 99.3 - 99.5 percent paraxylene. The UOP process has been developed further since its first commercialisation, particularly with improved solvents. The process has the flexibility to use a non-extracted feed at the expense of higher sieve requirements, which could be applicable, for example, to a pyrolysis gasoline xylene cut. The main limitation appears to be that higher purities cannot readily be achieved, although this is not a current commercial requirement.

Used by themselves, these separation processes require a very high quantity of mixed xylenes feed in relation to paraxylene product. It is therefore usual to incorporate the separation unit with isomerisation and distillation stages to maximise paraxylene yield. However, some units do operate on a once through or skimming operation, although the physical limitations on feedstock do not make this a configuration of practical economic importance.

FIGURE VII.7 1.

SIMPLIFIED FLOW DIAGRAM - PAREX PROCESS



quantities no local chemical use can be considered. The level of this minimum requirement is probably in the range of 20,000 to 50,000 tonnes per year, depending upon local circumstances.

Similarly, below a certain quantity the costs per tonne of storing and shipping will be excessive, so no export potential can be considered even if premium markets exist in, for example, Western Europe.

In these circumstances the only option is to use the propylene locally as fuel. This will generally be the case with an ethane feed plant; all other feedstocks produce far greater quantities of propylene, and higher valuations can be considered for these streams.

- Export. With quantities of 100 000 tonnes per year (or more), export of chemical or polymer grade liquid propylene can be contemplated as an economic possibility. Actual market opportunities appear very limited, however, since all three major market regions (U.S., W. Europe and Japan) are predicted to be in a balanced supply/demand situation for propylene through the early 1980's.

  On the assumption that an export market can be found, propylene valuation at the Arab olefins site will approximate to W. European price less freight costs. The European and Japanese 1980 propylene price is estimated in Section VI.F.1 to be around $315 per tonne. Freight costs are analysed in Section IX, which estimates the 1980 costs for large-scale propylene movements.

c) Isomerisation

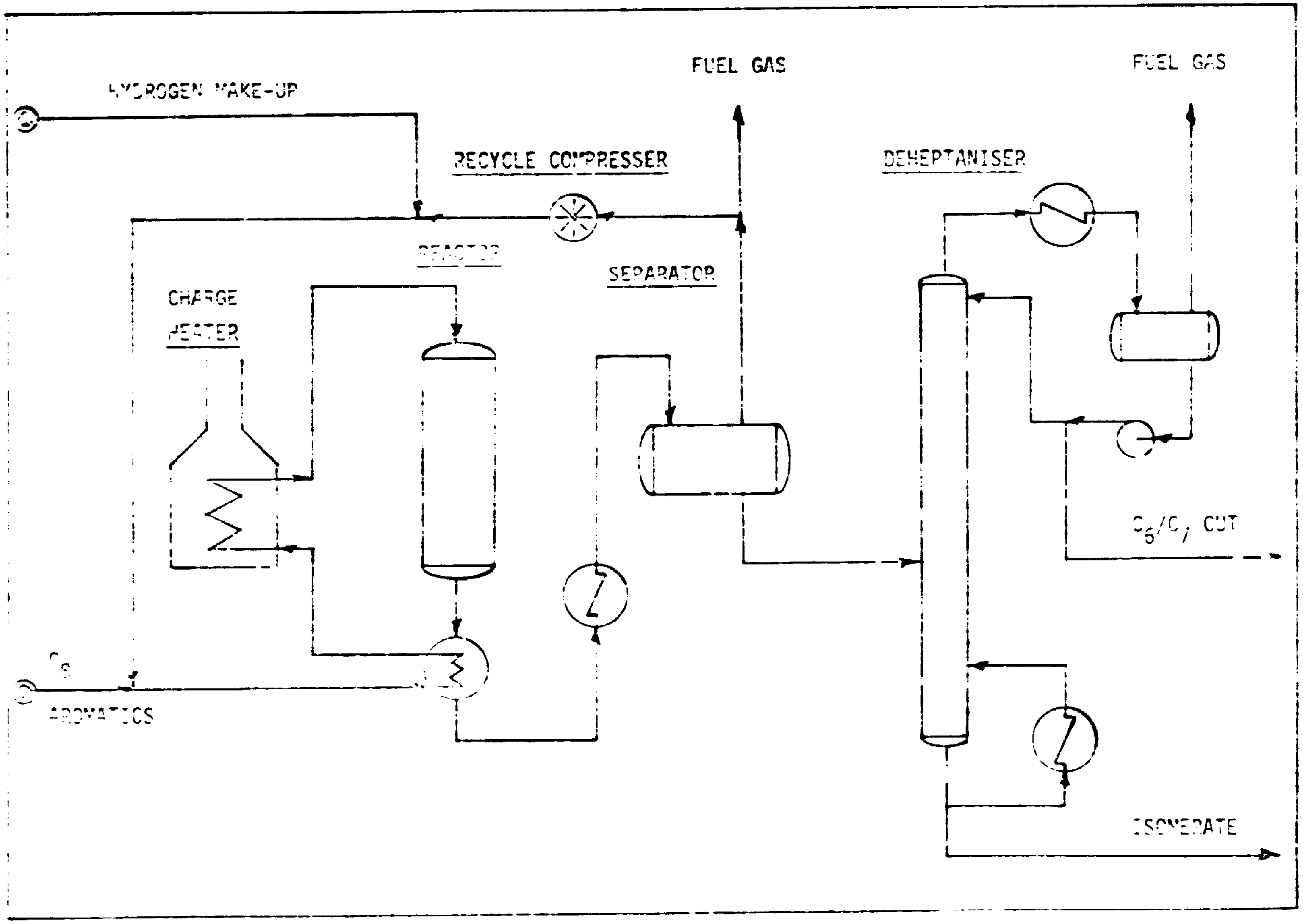
The yield of paraxylene from mixed C_8 aromatics is normally increased by isomerising the paraxylene-lean stream from the separation unit which is then recycled. Isomerisation restores the aromatics to an equilibrium ratio which varies with conditions used, but is similar to the fresh reformate feed.

About a dozen licenced processes exist for xylenes isomerisation, all catalytic, which fall into two groups according to catalyst type. Firstly, a noble metal catalyst, usually platinum, may be used in the presence of hydrogen. Noble metals act on all four isomers, although ethylbenzene is converted to a much lower extent than the xylenes, and at a much lower efficiency. The hydrogen acts as a diluent and reduces carbon laydown byproducts formed by cracking, particularly of the ethyl group of ethylbenzene. Figure VII.F.2 presents a simplified flowsheet of a noble-metal isomerisation unit. Secondly, non-noble catalysts may be used such as silica-alumina, with or without hydrogen. These act only on the xylenes, and do not change any ethylbenzene present. It is thus not possible to recycle the C_8 feed to extinction as with a noble catalyst, and ethylbenzene must be removed. This may be done by superfractionation, selective absorption or by removal of a side stream. The economics of recovering pure ethylbenzene as a product from a xylenes complex are normally unfavourable compared with the reaction of benzene and ethylene, and this route will not be considered in further detail.

A process which falls into a separate category is the Japan Gas Chemical Company route using a mixture of

FIGURE VII.F.2.

SIMPLIFIED FLOW DIAGRAM - ISOMERISATION STAGE (NOBLE METAL TYPE)



hydrofluoric acid and boron trifluoride both as an isomerisation catalyst and an extraction solvent. The solvent is used to extract metaxylene from the aromatics mixture, so that the remaining three isomers may be separated by fractionation. In this process the superfractionation of ethylbenzene is less costly owing to the prior removal of metaxylene. The metaxylene extracted plus any undesired orthoxylene may be isomerised and recycled. Little is published about the economics of this route. It would however appear to be favourable only where a substantial market for metaxylene exists, and as this is not the case in the present study, this process appears inappropriate.

d) Paraxylene Complex Economics

A route using a noble metal isomerisation catalyst is used for the evaluation of a xylenes complex. The separation unit is selective adsorption, since on available assessment data this yields slightly lower costs. This complex combines two economically competitive and proven processes which represent current technology. The capacity chosen, 142 000 tonnes p.a., is large enough to take much of the economic advantage of large scale operation, but in view of the limited size of Parex units so far in operation, a unit of larger capacity was not considered appropriate. A scheme of the units involved is shown on Figure VII.F.1.

3. Orthoxylene Separation

a) Process Description

The only commercial method of recovering orthoxylene is by fractionation of a C_8 aromatics stream. The recovery of orthoxylene in a xylenes complex is usually made ahead of the crystallisation or Parex unit, when the reduced quantity of orthoxylene reduces the cost of the paraxylene recovery which is the most expensive unit in the complex. This scheme is included on Figure VII.F.1. For maximum orthoxylene recovery the stream richest in ortho would be preferable, namely the isomeriser feed, but the overall economics which favour paraxylene made this configuration more costly.

Orthoxylene is separated from the other isomers which are all more volatile as the bottoms product of a xylenes splitting column. This conventionally contains 100-150 stages with a reflux to distillate ratio of 7 - 12. The bottoms stream is fed to the orthoxylene tower where orthoxylene is recovered overhead and C_9+ material is recovered as a bottoms product. An orthxylene tower normally is 30 - 50 stages with a reflux ratio of 2 - 4.

The cost of production of orthoxylene will vary according to the percentage recovered. Normal reformate feedstocks favour a ratio of 0.4 to 1.0 times the paraxylene product. A higher ratio will increase the xylene splitter cost or might limit the recovery of paraxylene per pass; a lower ratio will make the cost of the superfractionation expensive relative to the small throughput.

b) Process Economics

Whilst paraxylene may be recovered without any production of orthoxylene, it is unusual to produce orthoxylene by itself. By adding orthoxylene distillation to the xylenes complex one reduces the effective cost of the units making paraxylene. It is thus difficult to establish separate production costs for the two isomers from a complex, a feature which is common to many co-product process. In practice the total revenue accruing to the plant is the significant quantity, and the division of this between the two isomers is determined by the market forces. Generally the orthoisomer is lower in price by about $100/tonne, and this is the basis proposed for 1975. The margin is increased as a function of general inflation to $150/tonne in 1980. It should be noted however, that the price of orthoxylene is one of the most volatile of all aromatics and no basis for pricing remains valid over a length of time. The cost of production should therefore be used as a guide only.

G. COST OF PRODUCTION ESTIMATES

1. Discussion

The process basis for costing the production of aromatics in a North African or Arabian Gulf location has been described in the preceding sections. The economic basis including rates of inflation, relative construction costs, oil prices, and value of naphtha have also been covered in previous parts. It is only necessary here to add economic factors specific to aromatics production.

The capacity of the catalytic reformer was selected as 20 000 BPSD to be compatible with the naphtha from a crude run of 100 000 BPSD. Downstream units were chosen to use the reformer product. Thus the benzene and xylenes production are those rates which follow a reformer feed of 20 000 BPSD, and are not separately optimised. The integration is extended to include a minor recycle from the paraxylene unit to the benzene extraction plant. This integrated basis leads to non-rounded numbers for production of, for example, paraxylene of 132 000 tpa.

Because total aromatics produced from a reformer amounts to only about 40 percent of naphtha input, the value of the remaining 60 percent has a major effect on the net cost of production of the aromatics. The valuation of by-products has generally been related to their value in gasoline blending.

Thus, the value of gasoline in the plant location is calculated by deducting the transport cost from its value in an export market, following the naphtha valuation given in Section V.B. This gives the value of premium gasoline in 1980 as $197 per tonne in North Africa and $187 per tonne in the Gulf. The credit values of raw pyrolysis gasoline, toluene, mixed xylenes and higher aromatics are then found by ratio to these gasoline values.

Because the difference in value between naphtha and gasoline is relatively low compared with the cost of producing these gasoline components from naphtha in the Middle East locations, the gasoline credit values for the aromatics are likewise relatively low. This means that routes to benzene which consume these (low value) gasoline components such as hydrodealkylation of toluene or pyrolysis naphtha, appear to give low production costs. In comparison extraction from reformate which produces gasoline components appears a relatively high cost route. The conclusion must be that aromatics manufacture is more attractive than gasoline component production, but comparisons between the routes to benzene are rather artificial.

2. Estimates - N. African Location

Tables VII.G.1 to VII.G.7 inclusive show production costs for benzene and xylene isomers, on the basis described in this section, for a N. African Location.

Thus basic benzene price from reformate in an integrated extraction/toluene hydrodealkylation complex is shown to be $422/tonne. Since market studies show that there is little export potential for toluene, this integrated complex is the most likely option for a major Arab benzene operation. It is also demonstrated that benzene could be produced by bulk HDA of pyrolysis naphtha from the olefin plant at the attractive price of $345/tonne. Integration of this source of benzene into an

Arab aromatics complex is thus economically desirable. Extraction of the pyrolysis naphtha for xylenes production is not evaluated, since economics of this route are generally inferior to production from reformate due to the high percentage of ethylbenzene present in the pyrolysis gasoline.

Processing of the mixed xylenes stream from reformate to produce para-xylene alone gives a basic p-xylene price of $570/tonne. If ortho-xylene is also marketable then an integrated complex producing both para and ortho isomers can be considered; this reduces p-xylene price to $520/tonne and can then produce o-xylene at $370/tonne.

3. Estimates - Arabian Gulf Location

Tables VII.G.8 to VII.G.14 inclusive show the cost of production estimates reworked for an Arabian Gulf Location

The basic benzene price from an integrated extraction/HDA complex is $431/tonne, while benzene via pyrolysis naphtha bulk HDA is $355/tonne.

Paraxylene price is calculated at $569/tonne when produced alone, or $516/tonne when co-producing ortho-xylene at $365/tonne.

4. Estimates - Western Europe

We estimate that 1980 W. European benzene prices will be set by integrated extraction/HDA complex economics at around $420/tonne. Para-xylene price will be basically set by the economics of isomerisation plants producing p-xylene alone, giving a price level around $580/tonne. Ortho-xylene is likely to sell at around $150/tonne below this level, or $430/tonne.

TABLE VII.[illegible]

[illegible]

Basis: Location - [illegible] Africa [illegible]
Capacity - [illegible]
Rate - 640 000 [illegible] reformate
Process - naphtha hydrotreater, catalytic reformer on aromatics severity; 100[illegible] clear

Capital Cost	[illegible]
Battery Limits Capital Cost	[illegible]
Offsites Capital Cost	[illegible]
Total Fixed	4[illegible]
Working	9

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Naphtha	778 000	tonne	165	128 370 000	
Catalyst & Chemicals		$		260 000	
TOTAL RAW MATERIALS:				128 630 000	201.0
UTILITIES:					
Power	36 000	1 000 KWh	27.0	972 000	
Cooling Water	14 000	1 000 m^3	12	16[illegible]	
Steam	1 000	tonne	[illegible]	4 000	
TOTAL UTILITIES COST:				1 1[illegible]4 000	1.[illegible]
OPERATING COSTS:					
Labour	16 men @ [illegible] p.a.			304 000	
Supervision	5 men @ [illegible] p.a.			135 000	
Maintenance Material and Labour [illegible] BLCC				1 280 000	
TOTAL OPERATING COSTS:				1 71[illegible] 000	2.7
OVERHEAD EXPENSES:					
Direct Overhead - [illegible] (Labour & Supervision)				132 000	
General Plant Overhead - [illegible] Operating Costs				1 117 000	
Insurance, [illegible] Taxes - 1[illegible] Total Fixed Capital				720 000	
Depreciation - ([illegible] BLCC + [illegible] Offsites)				4 000 000	
Interest - 1[illegible] on Working Capital				900 000	
TOTAL OVERHEAD EXPENSES:				6 [illegible]	10.7
BY-PRODUCT CREDIT:					
Net Fuel Credit	1 210 000	10^6 Kcal	4.9	(5 929 000)	
[illegible]:				(5 929 000)	(9.3)
[illegible]:				1[illegible]	206.9
[illegible]:				12 000 000	18.[illegible]
[illegible]:				14[illegible]	[illegible]

* [illegible]

TABLE VII [illegible]

[illegible]

	Capital Cost	[illegible]
	Battery Limits Capital Cost	[illegible]
	Offsites Capital Cost	[illegible]
	Total Fixed	[illegible]
	Working	11

Basis: Location - N. Africa [illegible]
Capacity - [illegible] reformate
Rate - [illegible] 000 tpa Benzene
Process Route - Heart cut distillation, sulpholane extraction, [illegible] distillation, toluene HDA

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Reformate	[illegible]	tonne	225.7	144 [illegible]	
Recycle from Xylene Unit [illegible]	[illegible]	tonne	[illegible].7	2 [illegible] 000	
Hydrogen	[illegible]	10⁶ kcal	4.9	[illegible] 000	
Catalyst & Chemicals		$		[illegible] 000	
TOTAL RAW MATERIALS:				147 40[illegible] 000	65[illegible].2
UTILITIES:					
Power	[illegible]	1 000 kWh	[illegible]	[illegible] 000	
Cooling Water	[illegible]	1 000 m3	[illegible]	[illegible]	
Steam	8[illegible] 000	tonne	[illegible].3	[illegible] 000	
TOTAL UTILITIES COST:				4 [illegible]	20.[illegible]
OPERATING COSTS:					
Labour	16 men @ $19 000 p.a.			304 000	
Supervision	[illegible] men @ $27 000 p.a.			162 000	
Maintenance Material and Labour [illegible] BLCC				1 450 000	
TOTAL OPERATING COSTS:				1 [illegible] 000	8.7
OVERHEAD EXPENSES:					
Direct Overhead - [illegible] (Labour & Supervision)				140 000	
General Plant Overhead - [illegible] Operating Costs				1 2[illegible]	
Insurance, Property Tax - [illegible] Total Fixed Capital				[illegible]	
Depreciation - (Basis: [illegible] BLCC [illegible] Offsites)				4 [illegible]	
Interest - [illegible] on Working Capital				1 10[illegible]	
TOTAL OVERHEAD EXPENSES:				[illegible] 000	35.[illegible]
BY-PRODUCT CREDIT:					
Raffinate	172 [illegible]00	tonne	[illegible]	[illegible] 000	
C_9 [illegible]	67 8[illegible]	tonne	[illegible]	[illegible]	
[illegible]	1[illegible]	tonne	[illegible]	[illegible]	
Fuel Gas ([illegible])	[illegible] 000	10⁶ kcal	[illegible]	1 [illegible] 000	
TOTAL BY-PRODUCT CREDIT:				([illegible] 000)	([illegible])
TOTAL COST OF PRODUCTION:				[illegible]	[illegible]
[illegible]				13 750 000	[illegible]1.1
[illegible]				[illegible]	[illegible]

* $/unit

Assuming an average freight cost from each Arab location ($40 from North Africa, $60 from Arabian Gulf) results in chemical-grade propylene values ex-plant for 1980 as

North Africa	$275 per tonne
Arabian Gulf	$255 per tonne.

- Developed-market approach. If the propylene is to be used in an adjacent derivatives unit to produce polypropylene, acrylonitrile etc. one could adopt the European/U.S. type of approach and assign a price to the chemical-grade propylene equal to 70 percent of ethylene transfer price. The arguments for this approach are firstly that the European precedent exists, and secondly that the resulting ethylene and propylene derivatives (say polyethylene and polypropylene) will then also be in a cost ratio approximately in line with the European/U.S. situation, which should give comparable marketing opportunities to all derivatives.

- Incremental production cost. It is possible to calculate an incremental cost of producing propylene at the Arab location providing the following assumptions are made:

    - If ethylene alone is required, an ethane cracker is used and all by-products, including propylene, go to fuel

TABLE VII.[illegible]

BENZENE FROM REFORMATE BY EXTRACTION

		Capital Cost	[illegible]
Basis: Location-	N. Africa 1980	Battery Limits Capital Cost	2[illegible]
Capacity-	640 000 tpa reformate	Offsites Capital Cost	1[illegible]
Rate -	110 000 tpa extracted benzene	Total Fixed	36
Process -	Heart cut distillation, sulpholane extraction, BTX distillation	Working	7

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Reformate	640 000	tonne	225.7	144 448 000	
Recycle from p-xylene unit	9 000	tonne	225.7	2 031 000	
Catalyst & Chemicals				125 000	
TOTAL RAW MATERIALS:				146 [illegible] 000	1332.6
UTILITIES:					
Power	10 550	1 000 kWh	27.6	2[illegible]6 000	
Cooling Water	19 000	1 000 m3	1[illegible]	27[illegible] 000	
Steam	771 000	tonne	4.3	3 315 000	
TOTAL UTILITIES COST:				3 8[illegible]9 000	34.[illegible]
OPERATING COSTS:					
Labour	12 men @ $19 000 p.a.			228 000	
Supervision	5 men @ $27 000 p.a.			135 000	
Maintenance Material and Labour @ 4% BLCC				960 000	
TOTAL OPERATING COSTS:				1 323 000	12.0
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				109 000	
General Plant Overhead - 65% Operating Costs				860 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				540 000	
Depreciation - (Basis 10% BLCC + 5% Offsites)				3 000 000	
Interest - 10% on Working Capital				700 000	
TOTAL OVERHEAD EXPENSES:				5 209 000	47.4
BY-PRODUCT CREDIT:					
Raffinate	177 550	tonne	16[illegible]	[illegible] 29 000	
C8 Reformate	67 [illegible]	tonne	210	14 [illegible] 00	
Toluene	140 000	tonne	242	33 [illegible] 0 000	
C9 Aromatics	1[illegible] 300	tonne	232	3[illegible] [illegible] 00	
TOTAL BY-PRODUCT CREDIT:				(113 [illegible] 000)	(10[illegible].6)
TOTAL COST OF PRODUCTION:				43 577 000	396.2
R.O.I. [illegible] TOTAL FIXED INVESTMENT:				9 000 000	81.8
TRANSFER PRICE:				52 577 000	47[illegible].0

* $/unit

TABLE VII.C.1.

BENZENE PRODUCTION BY HYDRODEALKYLATION

Basis: Location-	N. Africa 19[illegible]	Capital Cost	[illegible]
Capacity-	140 000 tpa toluene feed	Battery Limits Capital Cost	13
Rate -	115 000 t[illegible] benzene product	Offsites Capital Cost	[illegible]
Process Route -	Catalytic hydrodealkylation of toluene	Total Fixed	1[illegible]
		Working	4

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST
Toluene	140 000	tonne	[illegible]	[illegible]	
Hydrogen	126 500	10^6 Kcal	4.9	620 000	
Catalyst & Chemicals	-	$	-	200 000	
TOTAL RAW MATERIALS:				34 700 000	301.7
UTILITIES:					
Power	9 350	1 000 kwh	[illegible]	[illegible]	
Cooling Water	5 500	1 000 m³	12.0	66 000	
Steam	124 000	tonne	4.3	533 000	
TOTAL UTILITIES COST:				[illegible]	7.4
OPERATING COSTS:					
Labour	4 men @ $19 000 p.a.			76 000	
Supervision	1 man @ $27 000 p.a.			27 000	
Maintenance Material and Labour [illegible] BLCC				[illegible]0 000	
TOTAL OPERATING COSTS:				[illegible]3 000	5.4
OVERHEAD EXPENSES:					
Direct Overhead - [illegible] (Labour + Supervision)				31 [illegible]	
General Plant Overhead - 65 [illegible] Operating Costs				40[illegible]	
Insurance, Property Taxes - 1.[illegible] Total Fixed [illegible]				[illegible]	
Depreciation - (Basis: 10 BLCC [illegible] Offsites)				1 [illegible]	
Interest - 10 on Working Capital				400 [illegible]	
TOTAL OVERHEAD COSTS:				2 721 [illegible]	23.7
BYPRODUCT CREDIT:					
Fuel Gas ([illegible])	237 000	10^6 Kcal	4.[illegible]	(1 161 [illegible])	
TOTAL BYPRODUCT CREDIT:				(1 161 [illegible])	(10.1)
TOTAL COST OF PRODUCTION:				37 735 000	[illegible].1
RETURN [illegible] ON TOTAL FIXED INVESTMENT:				4 750 000	41.[illegible]
SELLING PRICE:				[illegible]	[illegible]

* $/tonne

TABLE VII.C.[illegible]

BENZENE BY BULK HDA OF PYROLYSIS NAPHTHA

Basis: Location - N. Africa 1980
Capacity - 260 000 tpa pyrolysis naphtha
Rate - 130 000 tpa Benzene
Process Route - Hydrotreating and bulk hydrodealkylation of high severity pyrolysis naphtha

Capital Cost	$MM
Battery Limits Capital Cost	20
Offsites Capital Cost	10
Total Fixed	30
Working	6

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Pyrolysis Naphtha	260 000	tonne	180	46 800 000	
Hydrogen	245 000	10^6 Kcal	4.9	1 201 000	
Catalysts & Chemicals		$		280 000	
TOTAL RAW MATERIALS:				48 281 000	371.4
UTILITIES:					
Power	13 300	1 000 Kwh	27.0	359 000	
Cooling Water	6 300	1 000 m^3	12.0	76 000	
TOTAL UTILITIES COST:				435 000	3.3
OPERATING COSTS:					
Labour	8 men @ $19 000 p.a.			152 000	
Supervision	2 men @ $27 000 p.a.			54 000	
Maintenance Material and Labour @ 4% BLCC				300 000	
TOTAL OPERATING COSTS:				854 000	6.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				62 000	
General Plant Overhead - 65% Operating Costs				555 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				450 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				2 500 000	
Interest - 10% on Working Capital				600 000	
TOTAL OVERHEAD EXPENSES:				4 167 000	32.0
BYPRODUCT CREDIT:					
C_6 & C_9 Gasoline	64 000	tonne	197	12 608 000	
Fuel (net)	760 000	10^6 Kcal	4.9	3 724 000	
TOTAL BYPRODUCT CREDIT:				(16 332 000)	(125.6)
TOTAL COST OF PRODUCTION:				37 405 000	287.7
RETURN ON TOTAL FIXED INVESTMENT:				7 500 000	57.7
TRANSFER PRICE:				44 905 000	345.4

* $/unit

TABLE VII.[illegible]

PARAXYLENE FROM MIXED XYLENES

Capital Cost	$M
Battery Limits Capital Cost	[illegible]
Offsites Capital Cost	[illegible]
Total Fixed	87
Working	17

Basis: Location - N. Africa 1980
Capacity - 132 000 tpa paraxylene

Process Route - Distillation, parex, noble metal isomerisation, total recycle

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Xylenes	158 300	tonne	232	36 726 000	
Hydrogen	62 000	10^6 kcal	4.9	304 000	
Catalyst & Chemicals		$		1 400 000	
TOTAL RAW MATERIALS:				38 430 000	291.1
UTILITIES:					
Power	17 000	1 000 Kwh	27.0	459 000	
Cooling Water	12 700	1 000 m^3	12.0	152 000	
Fuel	465 000	10^6 kcal	4.9	2 279 000	
Steam	78 000	tonne	4.3	335 000	
TOTAL UTILITIES COST:				3 225 000	24.4
OPERATING COSTS:					
Labour	22 men @ $19 000 p.a.			418 000	
Supervision	4 men @ $27 000 p.a.			108 000	
Maintenance Material and Labour	4% BLCC			2 320 000	
TOTAL OPERATING COSTS:				2 846 000	21.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				158 000	
General Plant Overhead - 65% Operating Costs				1 850 000	
Insurance, Fire, Pty Taxes - 1.5% Total Fixed Capital				1 305 000	
Depreciation - (basis: 10% BLCC + 5% Offsites)				7 250 000	
Interest - 10% on Working Capital				1 700 000	
TOTAL OVERHEAD EXPENSES:				12 263 000	92.9
BYPRODUCT CREDITS:					
Aromatics [illegible]	9 000	tonne	225.7	2 031 000	
Heavy Aromatics	6 000	tonne	210	1 260 000	
TOTAL BYPRODUCT CREDIT:				(3 291 000)	(24.9)
TOTAL COST OF PRODUCTION:				53 473 000	405.1
RETURN 25% ON TOTAL FIXED INVESTMENT:				21 750 000	164.8
TRANSFER PRICE:				75 223 000	569.9

* $/unit

TABLE VII.6.7.
PARAXYLENE AND ORTHOXYLENE FROM MIXED XYLENES

Basis: Location - N. Africa 1980
Capacity - 100 000 tpa paraxylene
42 500 tpa orthoxylene
Process Route - Distillation, Parex, noble metal isomerisation, total recycle

Capital Cost	$MM
Battery Limits Capital Cost	75
Offsites Capital Cost	23
Total Fixed	98
Working	14

	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
RAW MATERIALS					
Xylenes	158 300	tonne	232	36 726 000	
Hydrogen	44 000	10^6 Kcal	4.9	216 000	
Catalyst & Chemicals		$		840 000	
TOTAL RAW MATERIALS:				37 782 000	
UTILITIES:					
Power	14 000	1 000 Kwh	27.0	378 000	
Cooling Water	7 500	1 000 m3	12.0	90 000	
Fuel	473 000	10^6 Kcal	4.9	2 318 000	
Steam	93 000	tonne	4.3	421 000	
TOTAL UTILITIES COST:				3 207 000	
OPERATING COSTS:					
Labour	26 men @ $19 000 p.a.			494 000	
Supervision	4 men @ $27 000 p.a.			108 000	
Maintenance Material and Labour @ [illegible] BLCC				1 800 000	
TOTAL OPERATING COSTS:				2 402 000	
OVERHEAD EXPENSES:					
Direct Overhead - 20% (Labour & Supervision)				131 000	
General Plant Overhead - 65% Operating Costs				1 561 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 020 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 650 000	
Interest - 10% on Working Capital				1 400 000	
TOTAL OVERHEAD EXPENSES:				9 812 000	
BYPRODUCT CREDIT:					
Aromatics Recycle	6 500	tonne	225.7	1 467 000	
Heavy Aromatics	4 800	tonne	210	1 008 000	
TOTAL BYPRODUCT CREDIT:				(2 475 000)	
TOTAL COST OF PRODUCTION:				50 728 000	
RETURN [illegible] ON TOTAL FIXED INVESTMENT:				17 000 000	
TOTAL REVENUE REQUIRED:				67 728 000	
Estimated division of revenue: Paraxylene				52 000 000	520
O-Xylene				15 728 000	370
				67 728 000	

* $/unit

TABLE VII.G.c.

REFORMATE FROM STRAIGHT RUN NAPHTHA

Basis: Location- Arabian Gulf 1980
Capacity- 20 000 BPSD
Rate - 640 000 tpa reformate
Process - naphtha hydrotreater, catalytic reformer on aromatics severity; 100+ RON clear

Capital Cost	$M
Battery Limits Capital Cost	35
Offsites Capital Cost	17
Total Fixed	52
Working	10

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Naphtha	778 000	tonne	155	120 590 000	
Catalyst & Chemicals		$		260 000	
TOTAL RAW MATERIALS:				120 850 000	188.8
UTILITIES:					
Power	36 000	1 000 kWh	22.4	806 000	
Cooling Water	14 000	1 000 m3	12.0	168 000	
Steam	1 000	tonne	2.7	3 000	
TOTAL UTILITIES COST:				977 000	1.5
OPERATING COSTS:					
Labour	16 men @ $19 000 p.a.			304 000	
Supervision	5 men @ $27 000 p.a.			135 000	
Maintenance Material and Labour @ 4% BLCC				1 400 000	
TOTAL OPERATING COSTS:				1 839 000	2.9
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				132 000	
General Plant Overhead - 65% Operating Costs				1 195 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				780 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				4 350 000	
Interest - 10% on Working Capital				1 000 000	
TOTAL OVERHEAD EXPENSES:				7 457 000	11.7
BYPRODUCT CREDIT:					
Net Fuel Credit	1 210 000	10^6 Kcal	2.0	(2 420 000)	
TOTAL BYPRODUCT CREDIT:				(2 420 000)	(3.8)
TOTAL COST OF PRODUCTION:				128 703 000	201.1
[illegible] ON TOTAL FIXED INVESTMENT:				13 000 000	20.3
[illegible] PRICE:				141 703 000	221.4

* $/unit

TABLE VII.G.9.

BENZENE FROM REFORMATE BY EXTRACTION AND HYDRODEALKYLATION

Basis: Location - Arabian Gulf
Capacity - 640 000 tpa reformate
Rate - 225 000 tpa benzene
Process Route - Heart cut distillation, sulpholane extraction, BTX distillation, toluene HDA

Capital Cost	$MM
Battery Limits Capital Cost	40
Offsites Capital Cost	20
Total Fixed	60
Working	12

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Reformate	640 000	tonne	221.4	141 703 000	
Recycle from p-xylene unit	9 000	tonne	221.4	1 993 000	
Hydrogen	126 500	10^6 Kcal	2.0	253 000	
Catalyst & Chemicals		$		325 000	
TOTAL RAW MATERIALS:				144 274 000	641.2
UTILITIES:					
Power	19 930	1 000 Kwh	22.4	446 000	
Cooling Water	24 500	1 000 m3	12	294 000	
Steam	895 000	tonne	2.7	2 417 000	
TOTAL UTILITIES COST:				3 157 000	14.0
OPERATING COSTS:					
Labour	16 men @ $19 000 p.a.			304 000	
Supervision	6 men @ $27 000 p.a.			162 000	
Maintenance Material and Labour @ 4% BLCC				1 600 000	
TOTAL OPERATING COSTS:				2 066 000	9.2
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				140 000	
General Plant Overhead - 65% Operating Costs				1 343 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				900 000	
Depreciation - (basis: 10% BLCC + 5% Offsites)				5 000 000	
Interest - 10% on Working Capital				1 200 000	
TOTAL OVERHEAD EXPENSES:				8 583 000	38.1
BYPRODUCT CREDIT:					
Raffinate	172 900	tonne	155	26 800 000	
C_9 Reformate	67 800	tonne	200	13 560 000	
C_8 Aromatics	158 300	tonne	223	35 301 000	
Fuel Gas (net)	237 000	106 Kcal	2.0	474 000	
TOTAL BYPRODUCT CREDIT:				(76 135 000)	(338.3)
TOTAL COST OF PRODUCTION:				81 945 000	364.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				15 000 000	66.7
TRANSFER PRICE:				96 945 000	430.9

* $/unit

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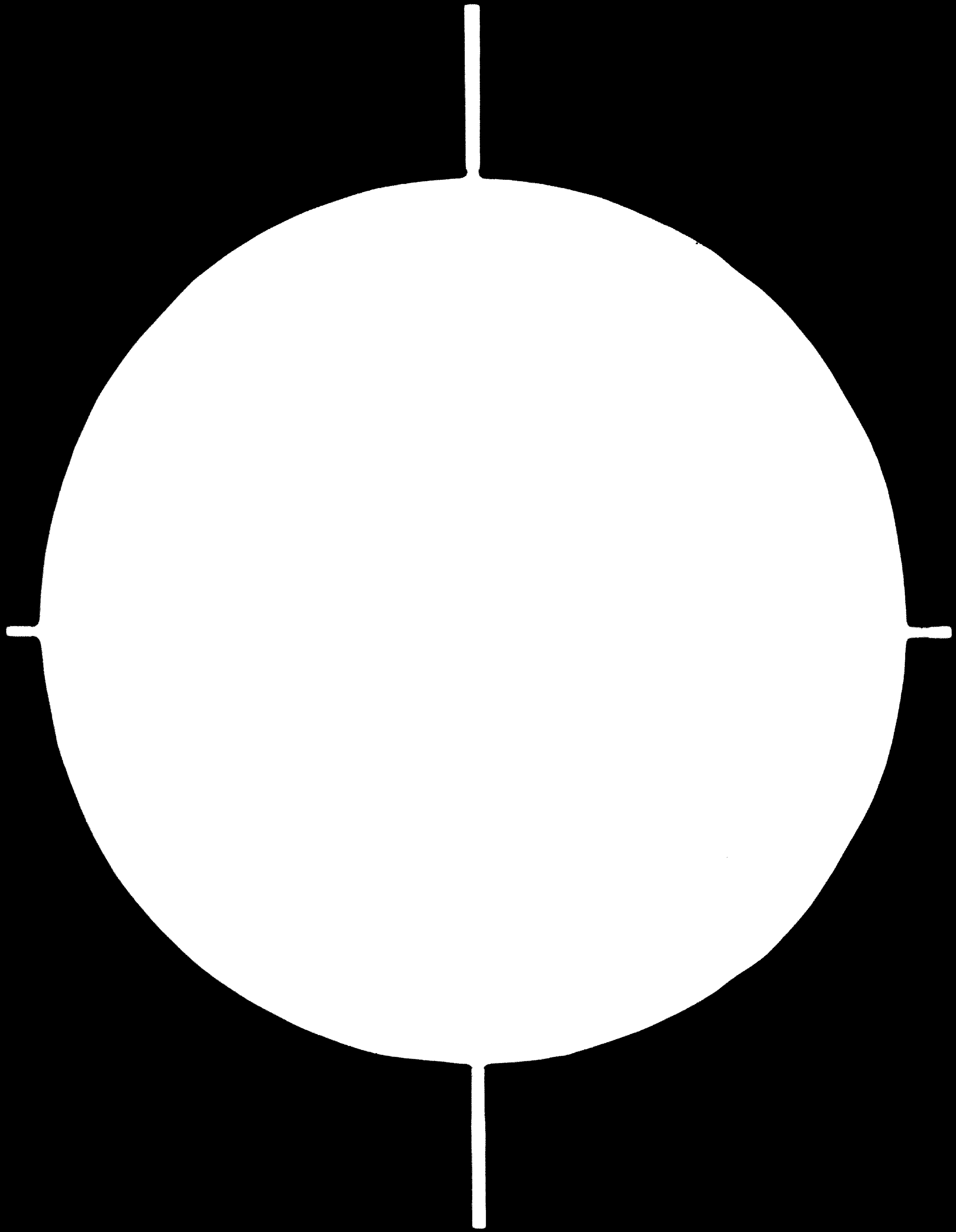

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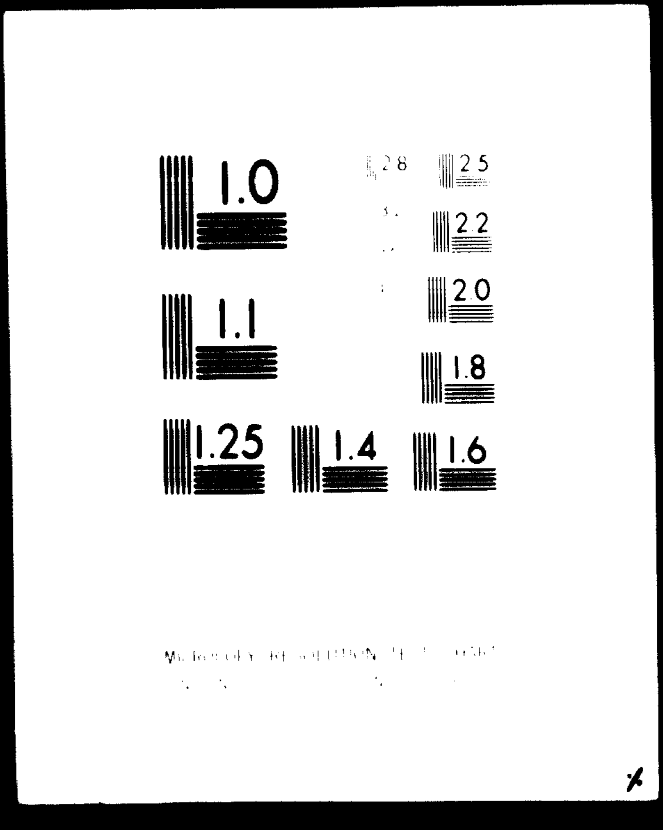

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SECTION VIII : DERIVATIVES UNITS

VIII DERIVATIVES UNITS

This Section presents technical and economic information on the various olefin and aromatics derivatives covered in Section IV. Basic process descriptions, process selection between alternative routes (where appropriate), and Cost of Production calculations for N. African, Arabian Gulf and W. European locations are presented. In each case the feedstock costs used (ethylene, benzene etc.) are the basic values calculated and selected in Sections VI and VII. Benzene price is assumed to be set by an integrated extraction/hydrodealkylation complex.

Benzene, o-xylene and p-xylene are excluded from this section since their technology and production economics have already been discussed in Section VII, which considered an integrated Aromatics complex. Ethylene is also not covered here, since ethylene production economics were dealt with in Section VI, and the costs of liquefaction and storage for export are included in the ethylene shipping economics in Section IX.E.

Identical terms of finance (depreciation, ROI, interest rates etc.) are applied throughout this Section to both Arab and European plants. This is done to present all the necessary technical and economic information in a clear and convenient manner: it is not in fact suggested that the same finance terms will be applied to Arab projects as to European projects, and this is discussed later in Section X.A.4. The concept of "minimum economic size" cannot be realistically applied to the Arab projects, since the question of what is economic depends predominantly upon feedstock price, finance terms etc. which will be different for the Arab plant and for "competing" European plants. The basic cost calculations are therefore made for Arab plant capacities generally equal to the European and US plant sizes which will set world price levels. The effects of variations in Arab plant capacity are then also indicated to demonstrate the penalties associated with selecting too small a scale of operation. Sensitivity analyses in Section X (Economic Evaluations) show the effect of variations in feedstock price, finance terms and other factors upon transfer prices and overall profitability.

A. ETHYLENE GLYCOL

1. Introduction

Ethylene glycol and ethylene oxide rank second only to polyethylene as a principal worldwide end use for ethylene. Ethylene glycol is traditionally a derivative, albeit the dominant one, of ethylene oxide. Approximately two-thirds of ethylene oxide manufacture is employed for ethylene glycol synthesis, by simple direct hydration of the oxide. The oxide in turn is manufactured by the catalytic oxidation of ethylene. Novel technology for producing ethylene glycol is being commercialised by Oxirane Corp. in the U.S. This technology provides for the direct production of ethylene glycol from ethylene without the isolation of an intermediate. The technology of both routes is described below, but the conventional route (via ethylene oxide) is used for the economic evaluations due to its worldwide dominance and operating experience.

2. Technology

a) Ethylene Oxide Route

The direct oxidation of ethylene can be carried out using air or oxygen. Almost all existing plants have now been converted to the use of oxygen, and all new plants follow this route. While there are a number of commercial processes for the manufacture of the oxide, the Shell process is used here since our evaluations show this to be generally the most attractive process currently available.

Ethylene and oxygen feeds, supplied at system pressure from outside the oxide plant battery limits, are combined with recycle gas and fed to a large tubular isothermal catalytic reactor. Ethylene dichloride moderator and methane ballast gas are also added to the recycle loop at approximately the same point. The moderator is added at about 5 ppm concentration to improve selectivity to ethylene oxide formation. Methane is added as a ballast to aid in controlling the oxidation reaction: make-up rate equals losses incurred in downstream purges only.

Reactor feed is heated to about 220°C by exchange with reactor effluent, and enters the top of the reactor at 17 atm. pressure. The reaction is carried out in the vapour phase over a silver catalyst on an inert support. The ethylene to oxygen ratio is held at 3.3. The concentration of carbon dioxide produced in the reactors is kept down to 6 mol. percent by treating part of the recycle gas with a hot potassium carbonate system to remove the carbon dioxide. Argon enters the system with the oxygen make-up and is limited to a 10 mol. percent concentration in the reactor feed by downstream purges. Methane ballast is maintained at 45 mol. percent concentration.

The reactor is a fixed-tube type heat exchanger, fabricated entirely of carbon steel. The reaction is highly exothermic, requiring carefully controlled heat removal. Selectivity to ethylene oxide formation is 75 mol. percent using the modern Shell catalysts, the balance of production being carbon dioxide, water and some carbon monoxide. Ethylene conversion is 11.1 percent per reactor pass.

Part of the heat released is absorbed by a 40°C temperature rise of the gas in the reactor, but the bulk is removed by kerosene boiling in the shell side of the reactor. This kerosene vapour is used to generate medium pressure steam for compressor drivers, reboilers etc.

After cooling against incoming feed, the reactor effluent is water scrubbed for ethylene oxide removal. After a small purge is removed and a slipstream is treated for carbon dioxide removal, the overhead vapour from this scrubbing operation is recycled to the reactors.

The crude ethylene oxide solution is steam stripped to drive off the oxide and dissolved light gases. Small quantities of ethylene glycol are formed at this stage, and in an integrated oxide/glycol plant a slipstream of the wash water is sent to the glycol plant to prevent a build-up of glycol in the oxide plant. The crude oxide is stripped for light gas removal, and the stripper bottoms, containing mainly ethylene oxide and water with a small quantity of glycol, are sent to the glycol synthesis unit.

This oxide is mixed with excess water, heated to 150°C and passed to the glycol reactor. Ethylene oxide and water react to form predominantly ethylene glycol, with lesser amounts of diethylene glycol (DEG) triethylene glycol (TEG) and a polyethylene glycol(PEG) residue. Typical glycol selectivities are 88.4 percent to monoethylene glycol, 5.2 percent to DEG and 0.17 percent to TEG. The reactor effluent is concentrated in a multi-stage evaporating system. The mixed glycols are dried and separated in a series of simple distillations under vacuum.

b) Direct (Oxirane) Route

A variety of laboratory techniques have been developed to produce ethylene glycol directly from ethylene. The impetus for this work has been the belief that in ethylene oxide synthesis the selectivity to oxide is unlikely to ever exceed 75-80 percent, so higher overall yields on ethylene have been sought via direct ethylene to glycol routes. Most techniques developed comprise acetoxylation of ethylene to mono- and diacetates followed by hydrolysis. The best available process appears to be that developed by Halcon, which is about to be commercialised in the U.S. by their associate company Oxirane.

The Oxirane process produces ethylene glycol by oxidation of ethylene in acetic acid solution in the presence of a tellurium catalyst and a bromine compound. Oxygen, ethylene and inerts (mostly ethane) are fed to the oxidation reactor. Effluent is separated into unreacted gases, which are recycled, and a liquid stream containing the catalyst and a bromoethylacetate. A series of distillations recover the acetic acid and the catalysts. The reaction products are sent to a hydrolyser, which converts monoacetate and diacetate to ethylene glycol, which is dried and purified by vacuum distillation.

The presence of a bromine compound and acetic acid dictate titanium or similar construction materials, but the high overall molar yield of up to 95 percent represents a considerable saving in feedstock costs which offsets the higher plant capital costs.

3. Cost of Production (via Oxide route)

Ethylene glycol production costs are dominated by ethylene pricing considerations. The effects of scale are not of great importance, since capital-related costs are a relatively low proportion of total transfer price. Average current W. European glycol plant capacity is around 60 000 tonnes per year, maximum is 165 000 tonnes and a typical new plant is around 100 000 tonnes per year. Plant sizes in the U.S. are larger, but market size is more relevant than economies of scale in selecting plant capacity. For the purposes of both the W. European and Arab evaluations, a glycol plant capacity of 150 000 tonnes per year is assumed, with corresponding sized oxide and oxygen plants. This capacity would absorb approximately one quarter of the output of the proposed 450 000 tpa ethylene plant. Oxygen, ethylene oxide and ethylene glycol units are included in the cost. Capital costs are based upon recent Chem Systems studies. Working capital is included as 33 percent of BLCC to allow for high catalyst silver inventory and the large product storage normally held for glycol.

Di- and tri-ethylene glycols are credited at approximately the same price as the mono-ethylene glycol (MEG), although market prices of these higher glycols are normally above MEG price. This conservative byproduct valuation allows for the higher costs of handling and marketing these smaller volume materials.

Tables VIII.A.1. to VIII.A.3. present Cost of Production sheets for Western European, North African and Arabian Gulf locations. The estimated 1980 European Transfer Price is $650 per tonne. The comparable prices from Arab plants are $628 and $622 from North African and Arabian Gulf locations respectively. Whether this marginal cost advantage is adequate to offset freight costs and permit penetration of export markets is analysed in Section X.

Sensitivity analyses in Section X consider variations in the ethylene price and in terms of project finance, and show the effects these can have upon overall economics and potential of the Arab projects.

As an indication of the effects of scale, Table VIII.A.2 (N. African location) has been reworked for capacities of 100 000 tpa and 50 000 tpa, operating at the same percentage of capacity as in Table VIII.A.2. Transfer price then increases from $628 per tonne to $670 and $774 per tonne respectively.

TABLE VIII-A-1

ETHYLENE GLYCOL PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 150 000 tpa ethylene glycol
Rate - 135 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	60
Offsites Capital Cost	30
Total Fixed	90
Working (1)	20

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	450	45 000 000	
Methane	12 000	10^6 Kcal	11.6	140 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				45 640 000	338.1
UTILITIES:					
Power	80 000	1000 Kwh	43.5	3 480 000	
Fuel	50 000	10^6 Kcal	11.6	580 000	
Cooling Water	103 000	1000 m^3	16	1 648 000	
Boiler Feed Water	1 300	1000 m^3	400	520 000	
Steam	600 000	tonne	9.6	5 760 000	
TOTAL UTILITIES COST:				11 988 000	88.8
OPERATING COSTS:					
Labour 40 men @ $19 000 pa				760 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				2 400 000	
TOTAL OPERATING COSTS:				3 430 000	25.4
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				309 000	
General Plant Overhead - 65% Operating Costs				2 230 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 350 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 500 000	
Interest - 10% on Working Capital				2 000 000	
TOTAL OVERHEAD EXPENSES:				13 389 000	99.2
BYPRODUCT CREDIT:					
Diethylene Glycol) Triethylene Glycol)	14 000	tonne	650	9 100 000	
TOTAL BYPRODUCT CREDIT:				(9 100 000)	(67.4)
TOTAL COST OF PRODUCTION:				65 347 000	484.1
RETURN 25% ON TOTAL FIXED INVESTMENT:				22 250 000	166.7
TRANSFER PRICE:				87 847 000	650.8

* $/unit

(1) includes catalyst silver

TABLE VII.6.10.

BENZENE FROM REFORMATE BY EXTRACTION

Basis: Location - Arabian Gulf 1980
Capacity - 640 000 tpa reformate feed
Rate - 110 000 tpa extracted benzene
Process Route - Heart cut distillation, sulpholane extraction, BTX distillation

Capital Cost	$'m
Battery Limits Capital Cost	26
Offsites Capital Cost	13
Total Fixed	39
Working	8

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Reformate	640 000	tonne	221.4	141 703 000	
Recycle from p-xylene unit	9000	tonne	221.4	1 993 000	
Catalyst and Chemicals				125 000	
TOTAL RAW MATERIALS:				143 821 000	1307.5
UTILITIES:					
Power	10 580	1 000 Kwh	22.4	237 000	
Cooling Water	19 000	1 000 m^3	12	228 000	
Steam	771 000	tonne	2.7	2 082 000	
TOTAL UTILITIES COST:				2 547 000	23.2
OPERATING COSTS:					
Labour	12 men @ $19 000 p.a.			228 000	
Supervision	5 men @ $27 000 p.a.			135 000	
Maintenance Material and Labour @ 4% BLCC				1 040 000	
TOTAL OPERATING COSTS:				1 403 000	12.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				109 000	
General Plant Overhead - 65% Operating Costs				912 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				585 000	
Depreciation - (basis: 10% BLCC + 5% Offsites)				3 250 000	
Interest - 10% on Working Capital				800 000	
TOTAL OVERHEAD EXPENSES:				5 649 000	51.3
BYPRODUCT CREDIT:					
Raffinate	172 900	tonne	155	26 800 000	
C_9 Reformate	67 300	tonne	200	13 560 000	
Toluene	140 000	tonne	233	32 620 000	
C_8 Aromatics	158 300	tonne	223	35 301 000	
TOTAL BYPRODUCT CREDIT:				(108 281 000)	(984.4)
TOTAL COST OF PRODUCTION:				45 140 000	410.4
RETURN ON TOTAL FIXED INVESTMENT:				9 750 000	88.6
TRANSFER PRICE:				54 890 000	499.0

* $/unit

TABLE VIII-A-2

ETHYLENE GLYCOL PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location-** N Africa 1980
Capacity- 150 000 tpa ethylene glycol
Rate - 135 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	69
Offsites Capital Cost	38
Total Fixed	107
Working (1)	23

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	400	40 000 000	
Methane	12 000	10^6 Kcal	4.9	60 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				40 560 000	300.4
UTILITIES:					
Power	80 000	1000 Kwh	27	2 160 000	
Fuel	50 000	10^6Kcal	4.9	245 000	
Cooling Water	103 000	1000 m^3	12	1 236 000	
Boiler Feed Water	1 300	1000 m^3	600	780 000	
Steam	600 000	tonne	4.3	2 580 000	
TOTAL UTILITIES COST:				7 001 000	51.9
OPERATING COSTS:					
Labour 40 men @ $19 000 pa				760 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				2 760 000	
TOTAL OPERATING COSTS:				3 790 000	28.1
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				309 000	
General Plant Overhead - 65% Operating Costs				2 464 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 605 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				8 800 000	
Interest - 10% on Working Capital				2 300 000	
TOTAL OVERHEAD EXPENSES:				15 478 000	114.7
BYPRODUCT CREDIT:					
Diethylene Glycol) Triethylene Glycol)	14 000	tonne	630	8 820 000	
TOTAL BYPRODUCT CREDIT:				(8 820 000)	(65.3)
TOTAL COST OF PRODUCTION:				58 009 000	429.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				26 750 000	198.1
TRANSFER PRICE:				84 759 000	627.9

* $/unit

(1) includes catalyst silver

TABLE VIII-A-3

ETHYLENE GLYCOL PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: Location- Arabian Gulf 1980
Capacity- 150 000 tpa ethylene glycol
Rate - 135 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	75
Offsites Capital Cost	41
Total Fixed	116
Working (1)	25

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	366	36 600 000	
Methane	12 000	10^6 Kcal	2.0	24 000	
Catalyst & Chemicals		$		500 000	
TOTAL RAW MATERIALS:				37 124 000	275.0
UTILITIES:					
Power	80 000	1000 Kwh	22.4	1 792 000	
Fuel	50 000	10^6 Kcal	2.0	100 000	
Cooling Water	103 000	1000 m^3	12	1 236 000	
Boiler Feed Water	1 300	1000 m^3	800	1 040 000	
Steam	600 000	tonne	2.7	1 620 000	
TOTAL UTILITIES COST:				5 788 000	42.9
OPERATING COSTS:					
Labour 40 men @ $19 000 pa				760 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				3 000 000	
TOTAL OPERATING COSTS:				4 030 000	29.9
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				309 000	
General Plant Overhead - 65% Operating Costs				2 620 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 740 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				9 550 000	
Interest - 10% on Working Capital				2 500 000	
TOTAL OVERHEAD EXPENSES:				16 719 000	123.8
BYPRODUCT CREDIT:					
Diethylene Glycol) Triethylene Glycol)	14 000	tonne	620	8 680 000	
TOTAL BYPRODUCT CREDIT:				(8 680 000)	(64.3)
TOTAL COST OF PRODUCTION:				54 981 000	407.3
RETURN 25% ON TOTAL FIXED INVESTMENT:				29 000 000	214.8
TRANSFER PRICE:				83 981 000	622.1

* $/unit

(1) includes catalyst silver

B. HIGH DENSITY POLYETHYLENE (HDPE)

1. Introduction

Commercially available polyethylene is broadly classified as either high or low density polymer (HDPE or LDPE). HDPE is a highly crystalline, essentially linear polymer with a specific gravity around 0.95. LDPE has a branched structure and a specific gravity around 0.92. HDPE has generally greater strength, stiffness, hardness and heat resistance. Worldwide, HDPE is produced in smaller quantities than LDPE, but still ranks as a major and rapidly growing end-use for ethylene.

HDPE technology was developed during the 1950's. In Germany, Professor Ziegler and associates at the Max Planck Institute discovered that combinations of titanium halides and aluminium alkyls would catalyse the formation of what is now known as HDPE. Simultaneously, Phillips Petroleum and Standard Oil of Indiana (Amoco) discovered that chromia/alumina systems and molybdenum oxide catalysts (respectively) could both produce HDPE.

Phillips pioneered HDPE commercialisation, and has licensed both solution and slurry versions of its technology worldwide, with the slurry route generally cheaper and therefore preferred. Phillips has traditionally offered its catalyst and process in a single licensing package. Processes based upon Ziegler catalysts are mostly slurry-type, and since a Ziegler license covers only the catalyst and not the process, there are several Ziegler-based processes in commercial use.

Although operating conditions vary widely between the various process routes, overall economics are similar, and the product quality and range of product grades are comparable.

Recently, several companies have announced the commercialisation of highly active Ziegler catalysts. Since only small quantities of these catalysts are employed it is possible to leave catalyst residues in the polymer without adversely affecting its properties. Thus although the technical description given below includes a catalyst removal stage, this may be excluded in some processes, particularly in the future as catalysts are further improved. The description below is typical of Ziegler-based slurry processes in current commercial use.

2. Technology

The first step involves the preparation of the catalyst mixture. The catalyst, $TiCl_4$, and co-catalyst, aluminium alkyl, are first blended with the process diluent in separate blend tanks, and then transferred to the hold tanks. The catalyst and aluminium alkyl solutions are then transferred to the catalyst hold tank where temperature and residence time are controlled to produce a catalyst complex consisting of a mixture of alkylaluminium chlorides and alkyltitanium chlorides.

The catalyst complex, ethylene and diluent are charged to the polymerisation reactor. Hydrogen is also charged to the reactor for molecular weight control. Mcst commercial processes employ hexane or cyclohexane as the diluent. Ethylene conversion is usually 40-50 percent. Reaction conditions are in the range of 60-80^{o}C and 4-5 atm with a residence time of one-two hours. Solids content of the reactor effluent is 25-30 wt. percent. The polymerisation reactor is usually a glass-lined or electro-polished stainless steel agitated vessel. Removal of the heat of polymerisation is probably the major problem of reactor design. Economical reactor throughputs are only obtained if the heat transfer capacity of the reactor jackets is supplemented by such operations as reflux condensation and/or the use of a recycle exchanger.

The polymer slurry passes to the flash tank where most of the ethylene flashes, and is taken overhead and charged to the ethylene purification column. Here, any heavy ends are removed in the bottoms while a purge stream from the overhead receiver removes hydrogen and light ends from the system. The purified ethylene is then recycled to the reactor.

The next processing step involves the deactivation and removal of the catalyst from the polymer. Basically, this operation involves two steps. First, the polymer slurry is treated with an alcohol and then water. The alcohol reacts with the catalyst, $TiCl_4$, and cocatalyst, aluminium alkyl, to produce soluble alkoxy compounds. The water then reacts with the alkoxy compounds to produce alumina and titania. Efficient catalyst removal is one of the most critical steps of the entire polymerisation process. Consequently, the flow scheme and equipment employed by various producers are considered highly proprietary and little definitive information has been published on this operation. A two-step deactivation process using conventional stirred tank reactors is believed to be typical. The polymer slurry from the flash tank is first centrifuged. The polymer cake is then conveyed to the catalyst extractor together with methanol and anhydrous HCl. The catalyst extractor must be designed to provide sufficient agitation and residence time for essentially complete digestion of the $TiCl_4$ and aluminium alkyl. The reaction mixture next passes to the catalyst residue precipitation tank. Water and 50 weight percent caustic for neutralisation are also charged to this vessel. The polymer slurry leaving the residue precipitation tank is separated in the centrifuge. The polymer cake and liquid phase are then transferred to the drying and methanol recovery sections of the facility.

The final processing step involves drying the polymer cake from the slurry centrifuge. The polymer cake, containing 15-20 wt. percent entrained liquid, is conveyed to the polymer dryer where the liquid content is reduced to about 0.1 wt. percent. The liquid removed in the drying operation is recycled to the methanol recovery column. The dry polymer powder is finally conveyed to the finishing section of the plant where it is extruded, pelletised and sent to storage for subsequent shipment.

3. Cost of Production

Although ethylene price obviously has a direct effect upon HDPE economics, capital charges are also of great importance, since the HPDE process is highly capital intensive. The effects of scale are therefore important in HDPE production, and a plant large enough to be competitive in world markets must be selected. Average current European capacity is around 70 000 tonnes, with new plants typically 90-100 000 tonnes. U.S. plant capacities are rather larger than these. For the purposes of both the W. European and Arab evaluations, a nominal HDPE plant capacity of 105 000 tpa is assumed which would absorb approximately one quarter of the output of the proposed 450 000 tpa Arab ethylene plant. Capital costs are based upon recent Chem Systems studies, and include an allowance for fully paid-up royalties. A slurry process using Ziegler-type catalyst is assumed. Working capital is included as 15 percent of BLCC.

Tables VIII.B.1 to VIII.B.3. present Cost of Production sheets for Western European, North African and Arabian Gulf locations.

The estimated 1980 West European Transfer Price is $1 200 per tonne. The comparable prices from Arab plants are $1 220 and $1 230 respectively, from N. African and Arabian Gulf locations. It is therefore clear that with ethylene charged at the basic rates calculated in Section VI, and with identical terms of finance applied to all locations, HDPE production for export will not be an attractive option at the Arab locations. This is due to the highly capital intensive nature of the process: the capital cost penalty associated with the Arab locations more than outweighs the lower fuel and feedstock costs.

Sensitivity analyses in Section X therefore consider variations in the ethylene price, in project finance terms, and in capital cost (locational) ratios, and show the effects these can have upon overall economics of the Arab projects.

As an indication of the effects of scale, Table VIII.B.2 (N. African location) has been reworked for capacities of 70 000 tpa and 40 000 tpa, operating at the same percentage of capacity as in Table VIII.B.2. Transfer price then increases from $1 216 per tonne to $1 323 and $1 506 per tonne respectively.

TABLE VIII-B-1

HIGH DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 105 000 tpa HDPE
Rate - 95 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	86
Offsites Capital Cost	43
Total Fixed	129
Working	13

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	450	45 000 000	
Catalyst & Chemicals		$		6 100 000	
TOTAL RAW MATERIALS:				51 100 000	537.9
UTILITIES:					
Power	80 000	1000 Kwh	43.5	3 480 000	
Cooling Water	35 000	1000 m^3	16	560 000	
Boiler Feed Water	3 100	1000 m^3	400	1 240 000	
Steam	370 000	tonne	9.6	3 552 000	
TOTAL UTILITIES COST:				8 832 000	93.0
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				3 440 000	
TOTAL OPERATING COSTS:				4 403 000	46.3
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				2 861 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 935 000	
Depreciation - (Basis. 10% BLCC + 5% Offsites)				10 750 000	
Interest - 10% on Working Capital				1 300 000	
TOTAL OVERHEAD EXPENSES:				17 135 000	180.4
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				81 470 000	857.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				32 250 000	339.5
TRANSFER PRICE:				113 720 000	1 197.1

* $/unit

TABLE VIII-R-2

HIGH DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location** - N Africa 1980
Capacity - 105 000 tpa HDPE
Rate - 95 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	99
Offsites Capital Cost	55
Total Fixed	154
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	400	40 000 000	
Catalyst @ Chemicals		$		6 100 000	
TOTAL RAW MATERIALS:				46 100 000	485.3
UTILITIES:					
Power	80 000	1000 Kwh	27	2 160 000	
Cooling Water	35 000	1000 m^3	12	420 000	
Boiler Feed Water	3 100	1000 m^3	600	1 860 000	
Steam	370 000	tonne	4.3	1 591 000	
TOTAL UTILITIES COST:				6 031 000	63.5
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				3 960 000	
TOTAL OPERATING COSTS:				4 923 000	51.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				3 200 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 310 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				12 650 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				19 949 000	210.0
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				77 003 000	810.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				38 500 000	405.3
TRANSFER PRICE:				115 503 000	1 215.9

* $/unit

TABLE VIII-B-3

HIGH DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis:		
	Location-	Arabian Gulf 1980
	Capacity-	105 000 tpa HDPE
	Rate -	95 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	108
Offsites Capital Cost	59
Total Fixed	167
Working	16

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	366	36 600 000	
Catalyst & Chemicals		$		6 100 000	
TOTAL RAW MATERIALS:				42 700 000	449.5
UTILITIES:					
Power	80 000	1000 Kwh	22.4	1 792 000	
Cooling Water	35 000	1000 m^3	12	420 000	
Boiler Feed Water	3 100	1000 m^3	800	2 480 000	
Steam	370 000	tonne	2.7	999 000	
TOTAL UTILITIES COST:				5 691 000	59.9
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				4 320 000	
TOTAL OPERATING COSTS:				5 283 000	55.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				3 434 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 505 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				13 750 000	
Interest - 10% on Working Capital				1 600 000	
TOTAL OVERHEAD EXPENSES:				21 578 000	227.1
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				75 252 000	792.1
RETURN 25% ON TOTAL FIXED INVESTMENT:				41 750 000	439.5
TRANSFER PRICE:				117 002 000	1 231.6

* $/unit

TABLE VII.C.11
BENZENE FROM TOLUENE BY HYDRODEALKYLATION

Basis:			Capital Cost	$MM
	Location	Arabian Gulf 1980	Battery Limits Capital Cost	14
	Capacity	140 000 tpa toluene feed	Offsites Capital Cost	7
	Rate	115 000 tpa benzene product	Total Fixed	21
Process Route		Catalytic hydrodealkylation of toluene	Working	4

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Toluene	140 000	tonne	233	32 620 000	
Hydrogen	126 500	10^6 Kcal	2	253 000	
Catalyst & Chemicals		$		200 000	
TOTAL RAW MATERIALS:				33 073 000	287.6
UTILITIES:					
Power	9 350	1 000 Kwh	22.4	209 000	
Cooling Water	5 500	1 000 m3	12	66 000	
Steam	124 000	tonne	2.7	335 000	
TOTAL UTILITIES COST:				610 000	5.3
OPERATING COSTS:					
Labour	4 men @ $19 000 p.a.			76 000	
Supervision	1 man @ $27 000 p.a.			27 000	
Maintenance Material and Labour @ 4% BLCC				560 000	
TOTAL OPERATING COSTS:				663 000	5.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				31 000	
General Plant Overhead - 65% Operating Costs				431 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				315 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				1 750 000	
Interest - 10% on Working Capital				400 000	
TOTAL OVERHEAD EXPENSES:				2 927 000	25.4
BYPRODUCT CREDIT:					
Fuel Gas (net)	237 000	10^6 Kcal	2.0	(474 000)	
TOTAL BYPRODUCT CREDIT:				(474 000)	(4.1)
TOTAL COST OF PRODUCTION:				36 799 000	320.0
RETURN 25% ON TOTAL FIXED INVESTMENT:				5 250 000	45.6
TRANSFER PRICE:				42 049 000	365.6

* $/unit

C. POLYPROPYLENE (PP)

1. Introduction

Polypropylene has gained market acceptance both as a plastic and as a fibre since its introduction in the late 1950's. It is a crystalline polymer, having good rigidity and hardness and a specific gravity of about 0.90. Its greatest success has been in injection moulding, and in many outlets PP competes with HDPE. PP has shown good growth in recent years, partly due to the lower price of propylene feedstock as compared to ethylene.

Technology of polypropylene production is very similar to that for HDPE described in the previous Section, VIII.B. Ziegler-Natta catalysts are used, commonly in a slurry-type process.

PP has certain advantages over HDPE in terms of physical characteristics, and hence in end-use potential. These advantages include greater rigidity, hardness and heat resistance, but it also has serious disadvantages in low-temperature impact resistance and in degradation from heat, oxygen and light. Thus in many uses PP requires the addition of antioxidants and UV stablilisers, at increased cost. Also, to improve low-temperature impact resistance to a level at which PP can compete with HDPE, some PP must be produced as a co-polymer containing up to 15 percent ethylene. This adds complexity and higher costs.

The process description given below is for a slurry process using Ziegler catalysts and capable of producing both homopolymer (all PP) and co-polymer material (PP copolymerised with ethylene.) Due to the degradation problems of PP, catalyst removal is more important and expensive than for HDPE processing. Also, in PP production a significant percentage (currently around 8 percent) of atactic or non-crystalline polymer is produced, which must be removed from the product and discarded as waste. This adds significant capital and operating costs.

2. Technology

The catalyst mixture is first prepared in a manner analogous to that used in HDPE production. The catalysts are prepared as slurries in the diluent, typically heptane, and are charged continuously to the reactors together with pure propylene (99.9 percent), hydrogen and diluent. Ethylene may also be charged at this point to produce a random co-polymer. Reaction temperature is controlled at around 60^0C and 12 atmospheres pressure. Heat removal is by jacket cooling and also by reflux condensation.

The polymer slurry passes to the flash tank where most propylene flashes off and is sent to the recycle compressors and thus to the propylene recovery section. (If block co-polymer is required, the reactor effluent is first diverted to a copolymerisation reactor into which ethylene is intermittently charged.)

The next processing step involves the deactivation and removal of the catalyst. First the polymer slurry is treated with methanol and anhydrous hydrogen chloride in deashing tanks. The catalyst and co-catalyst form soluble alk-oxides. The effluent from the deashing tank is then charged to the residue precipitation tank where it is mixed with water and dilute caustic soda. The soluble alkoxides are thus preciptated as insoluble hydroxides. The effluent from the precipitation tanks is cooled and decanted. The heavy phase contains the catalyst residue and methanol: the residue is filtered out and discarded, and methanol is recovered for recycle by fractionation.

The polymer slurry leaving the decanter is next processed for the removal of atactic polypropylene. The slurry is flashed to low pressure, thus removing most contained propylene and some heptane, which are both recovered and recycled. The slurry is centrifuged, producing a liquid heptane phase which contains effectively all the atactic propylene. This liquid is steam stripped to recover the heptane for recycle, leaving atactic polymer which is sent to disposal.

The polymer cake from the centrifuges still contains 20 percent entrapped liquid. This is reduced to about 0.1 wt. percent in the polymer driers, typically directly heated rotary units with recycled nitrogen as heating medium. The liquid thus removed is condensed and recycled to the process, and the dry polymer passes to the finishing section of the plant.

In the finishing (dry end) area of the plant the dried polymer powder is blended with additives, extruded, pelletised and packaged, with intermediate storage between these various stages. The complexity and cost of the dry end of the plant depends strongly upon the range of product grades required: it is seldom considered economic for a single plant to produce the entire range of commercially available resin grades. Dry end design philosophy also varies significantly among different producers.

3. Cost of Production

Polypropylene is extremely capital intensive, with capital costs higher even than for HDPE due to the added complexity of catalyst and atactic polymer removal. Economies of scale are therefore important and most new plants being built in Europe and the U.S. are around 100 000 tpa capacity. To have any chance of competing in world markets, an Arab plant must match these sizes, and a nominal capacity of 100 000 tpa is assumed for both Arab and European locations. This capacity will absorb all the propylene available from a 450 000 tpa ethylene plant using ethane/propane feed as considered in Section VI. Heavier feeds (naphtha, etc) will of course produce substantially greater quantities of propylene.

Polymer grade propylene is required (99.9 percent purity) as compared to the chemical grade (95 percent) produced and costed from the basic ethylene plants considered in Section VI. A price premium equal to the costs of fractionating this chemical grade to produce polymer grade material is therefore added to the propylene prices. This premium is estimated at $30/tonne in 1980 for all regions.

Capital costs are based upon recent in-depth Chem Systems evaluations, and assume a slurry process using Ziegler-Natta catalysts. An allowance for fully paid-up royalties is included in the capital cost. Flexibility to produce up to 30 percent of total output as copolymer is included in the capital costs, but operating costs and output are calculated for the case in which 100 percent homopolymer is being produced.

Tables VIII.C.1. to VIII.C.3. present Cost of Production sheets for Western Europe, North African and Arabian Gulf locations. The estimated 1980 West European Transfer Price is \$1 260 per tonne. The comparable prices from Arab plants are \$1 300 and \$1 420 per tonne from N. African and Arabian Gulf locations respectively. As for HDPE, it is therefore clear that with propylene charged at the basic rates calculated in Section VI, and with identical terms of project finance applied to all locations, PP production for export will not be an attractive option at the Arab locations. This is particularly true of the Arabian Gulf location, in which (as discussed in Section VI.F.) propylene is a relatively expensive product due to the highly favourable economics of simple ethane cracking in the Gulf which weigh heavily against production of propylene. For both Arab locations, the highly capital intensive nature of the PP process is a disadvantage due to the capital cost penalty associatad with the Arab sites. This more than outweighs the lower energy costs available.

Sensitivity analyses in Section X therefore consider variations in the propylene price, in project finance, and in capital cost (locational) ratios, and show the effects of these upon overall economics of the Arab projects.

As an indication of the effects of scale, Table VIII.C.2 (N. African location) has been reworked for capacities of 70 000 tpa and 40 000 tpa, operating at the same percentage of capacity as in Table VIII.C.2. Transfer price then increases from \$1 303 per tonne to \$1 421 and \$1 656 per tonne respectively.

TABLE VIII-C-1

POLYPROPYLENE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 100 000 tpa PP
Rate - 87 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	98
Offsites Capital Cost	49
Total Fixed	147
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Propylene	96 000	tonne	345	33 120 000	
Catalyst & Chemicals		$		8 400 000	
TOTAL RAW MATERIALS:				41 520 000	477.2
UTILITIES:					
Power	67 000	1000 Kwh	43.5	2 915 000	
Cooling Water	23 000	1000 m^3	16	368 000	
Steam	350 000	tonne	9.6	3 360 000	
TOTAL UTILITIES COST:				6 643 000	76.4
OPERATING COSTS:					
Labour 55 men @ $19 000 pa				1 045 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				3 920 000	
TOTAL OPERATING COSTS:				5 100 000	58.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				354 000	
General Plant Overhead - 65% Operating Costs				3 315 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 205 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				12 250 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				19 624 000	225.6
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:					
TOTAL COST OF PRODUCTION:				72 887 000	837.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				36 750 000	422.4
TRANSFER PRICE:				109 637 000	1 260.2

* $/unit

TABLE VIII-C-2

POLYPROPYLENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: Location- N Africa 1980
Capacity- 100 000 tpa PP
Rate - 87 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	114
Offsites Capital Cost	63
Total Fixed	177
Working	17

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Propylene	96 000	tonne	296	28 416 000	
Catalyst & Chemicals		$		8 400 000	
TOTAL RAW MATERIALS:				36 816 000	423.2
UTILITIES:					
Power	67 000	1000 Kwh	27	1 809 000	
Cooling Water	23 000	1000 m^3	12	276 000	
Steam	350 000	tonne	4.3	1 505 000	
TOTAL UTILITIES COST:				3 590 000	41.3
OPERATING COSTS:					
Labour 55 men @ $19 000 pa				1 045 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				4 560 000	
TOTAL OPERATING COSTS:				5 740 000	66.0
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				354 000	
General Plant Overhead - 65% Operating Costs				3 731 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 655 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				14 550 000	
Interest - 10% on Working Capital				1 700 000	
TOTAL OVERHEAD EXPENSES:				22 990 000	264.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				69 136 000	794.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				44 250 000	508.6
TRANSFER PRICE:				113 386 000	1 303.4

* $/unit

TABLE VIII-C-3

POLYPROPYLENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: Location- Arabian Gulf 1980
Capacity- 100 000 tpa PP
Rate - 87 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	123
Offsites Capital Cost	67
Total Fixed	190
Working	18

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Propylene	96 000	tonne	354	33 984 000	
Catalyst & Chemicals		$		8 400 000	
TOTAL RAW MATERIALS:				42 384 000	487.2
UTILITIES:					
Power	67 000	1000 Kwh	22.4	1 501 000	
Cooling Water	23 000	1000 m^3	12	276 000	
Steam	350 000	tonne	2.7	945 000	
TOTAL UTILITIES COST:				2 722 000	31.3
OPERATING COSTS:					
Labour 55 men @ $19 000 pa				1 045 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				4 920 000	
TOTAL OPERATING COSTS:				6 100 000	70.1
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				354 000	
General Plant Overhead - 65% Operating Costs				3 965 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 850 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				15 650 000	
Interest - 10% on Working Capital				1 800 000	
TOTAL OVERHEAD EXPENSES:				24 619 000	283.0
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				75 825 000	871.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				47 500 000	546.0
TRANSFER PRICE:				123 325 000	1 417.6

* $/unit

D. STYRENE

1. Introduction

Commercial processes for the production of styrene use ethylbenzene as a raw material and dehydrogenate this to styrene. Ethylbenzene does occur to a limited extent in refinery and pyrolysis naphtha fractions, and may be commercially separated from these. The majority of ethylbenzene, however, is synthesised by the direct alkylation of benzene by ethylene. Thus styrene, despite the availability of various potential routes, is in practice a two-stage process starting with ethylene and benzene, with ethylbenzene only as an intermediate. Since storage and shipping problems are encountered with styrene in a hot climate, economics of the production of ethylbenzene alone are also calculated, to permit evaluation of exporting EB instead of styrene.

2. Technology

a) Ethylbenzene Production

Processes for the alkylation of benzene are offered by a number of licensors, but the major process parameters such as overall efficiency and type of catalyst are similar in all cases. This discussion therefore applies to most commercial plants.

Fresh benzene feed plus unconverted benzene recycled from the process is azeotropically dried to reduce water to a very low concentration. Dry benzene plus ethylene is fed to a liquid phase reactor where the catalyst employed is usually aluminium chloride with ethyl chloride promoter. The reactants combine with a Friedel-Crafts type of reaction to form ethylbenzene at very high efficiency.

Small quantities of higher alkylated benzenes are formed but these are largely recycled to the reactor from the recovery train so that the net production of by-products is of the order of only 2 percent of feed. An excess of benzene is maintained in the system to minimise the formation of these by-products.

Crude ethylbenzene from the reactor is water and caustic washed to remove solubla impurities, then distilled to recover unreacted benzene. This is recycled to the feed drier. The partly purified ethylbenzene is distilled to remove higher boiling impurities and yiald the pure product. The impurities are distilled again to remove higher polyalkyl benzenes and the remainder recycled to the reactor.

Other processes which are available for ethylbenzene production are of lesser significance and are therefore listed with only brief comment:

- Separation from C_8 cuts from either pyrolysis gasoline or reformate by distillation. About 400 actual trays are required. This is practised in conjunction with xylenes processes in which ethylbenzene is not destroyed in the isomerisation stage. Two major producers use this process in Europe.

- Separation from C_8 cuts by selective adsorption. The UOP Ebex process and others can separata ethylbenzene from other C_8 aromatics if needed. The cost of the separation is comparable to distillation.

TABLE VII.C.12.

BENZENE BY BULK HDA OF PYROLYSIS NAPHTHA

Basis: Location - Arabian Gulf 1980
Capacity - 260 000 tpa pyrolysis naphtha
Rate - 130 000 tpa benzene
Process Route - Hydrotreating and bulk hydrodealkylation of high severity pyrolysis naphtha

Capital Cost	$MM
Battery Limits Capital Cost	22
Offsites Capital Cost	11
Total Fixed	33
Working	7

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Pyrolysis Naphtha	260 000	tonne	171	44 460 000	
Hydrogen	245 000	106 Kcal	2	490 000	
Catalyst & Chemicals				280 000	
TOTAL RAW MATERIALS:				45 230 000	347.9
UTILITIES:					
Power	13 300	1 000 Kwh	22.4	298 000	
Cooling Water	6 300	1 000 m3	12	76 000	
TOTAL UTILITIES COST:				374 000	2.9
OPERATING COSTS:					
Labour	8 men @ $19 000 p.a.			152 000	
Supervision	2 men @ $27 000 p.a.			54 000	
Maintenance Material and Labour @ 4% BLCC				880 000	
TOTAL OPERATING COSTS:				1 086 000	8.4
OVERHEAD EXPENSES.					
Direct Overhead - 30% (Labour & Supervision)				62 000	
General Plant Overhead - 65% Operating Costs				706 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				495 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				2 750 000	
Interest - 10% on Working Capital				700 000	
TOTAL OVERHEAD EXPENSES:				4 713 000	36.3
BYPRODUCT CREDIT:					
C_5 & C_9 Gasoline	64 000	tonne	187	11 968 000	
Fuel (Net)	760 000	106 Kcal	2	1 520 000	
TOTAL BYPRODUCT CREDIT:				(13 488 000)	(103.8)
TOTAL COST OF PRODUCTION:				37 915 000	291.7
RETURN 25% OF TOTAL FIXED INVESTMENT:				8 250 000	63.5
TRANSFER PRICE:				46 165 000	355.1

* $/unit

- Separation in paraxylene manufacture by the JGC boron trifluoride catalyst process. This route may separate all C_8 aromatics as pure products if needed. One plant has been constructed in Europe.

b) Styrene Production

Technology for producing styrene from ethylbenzene may be divided into three types;

- Direct catalytic dehydrogenation
- Oxidative dehydrogenation
- Co-product of propylene oxide manufacture

The first of these is the principal commercial route which will be described and costed in detail. This description is representative of all the major licensors' processes.

Fresh feed ethylbenzene is mixed with recycle and vapourised. Water is vapourised with the feed to reduce fouling and provide part of the reaction steam. The mixed vapours are heated and fed to the reactor with additional superheated steam. Steam is necessary for two reasons - it minimises coking of the catalyst, and it is a convenient diluent which is needed to improve reaction selectivity. The reactor effluent is heat exchanged and condensed. Water is separated in a decanter whilst the ethylbenzene-styrene mixture is sent to purification.

Crude styrene is distilled to remove overhead the light ends, principally benzene and toluene, which may be fed to an aromatics recovery plant. The bottoms from the first column are fed to the EB-styrene column where, under a high vacuum, ethylbenzene is removed overhead and recycled to the reaction stage. In both this and the final column vacuum is used to reduce the temperature and hence minimise styrene polymerisation. The styrene from the second column is redistilled to remove polymeric residues and make high purity polymer grade styrene.

The other processes available for production of styrene from ethylbenzene are briefly mentioned below:

- Oxidative dehydrogenation processes seek to increase conversion per pass and reduce the quantity of dilution steam needed by the addition to the reactor of oxidizing agents. Suggested agents are sulphur dioxide, which reduces to hydrogen sulphide and water, or halides. The processes have yet to attain commercial importance.

- Co-product styrene from propylene oxide plants will be produced only as Oxirane-type processes are used to meet propylene oxide demand. It will therefore not form a large proportion of styrene capacity. Normally such plants will be operated to meet propylene oxide market requirements and therefore in certain circumstances could contribute to an oversupply of styrene, and hence to depressed prices.

3. Cost of Production

Production costs of styrene are dominated by ethylene and benzene feed costs, with capital-related costs accounting for a relatively small proportion of the total. The effects of scale are therefore not of great importance. Average current West European styrene plant capacity is around 160 000 tonnes per year, maximum is 400 000 tpa, and a typical new plant is around 300 000 tpa.

For both the European and Arab locations, a styrene capacity of 360 000 tonnes/year is evaluated. This is equivalent to an ethylbenzene capacity of 415 000 tpa, and would absorb approximately one quarter of the proposed 450 000 tpa ethylene production. Benzene consumption would be 277 000 tpa which is somewhat greater than the total production from the Aromatics complex considered in Section VII, but the effects of scale (beyond this size range) upon benzene price are minimal. The benzene price from an integrated extraction/hydrodealkylation plant as calculated in Section VII is therefore used here. By-product aromatics are valued at a mean of benzene and toluene gasoline values less 1980 extraction cost of approximately $60 per tonne.

Capital costs are based upon recent Chem Systems studies. Working capital is allowed at 33 percent of BLCC for both EB and styrene plants. This assumes that these plants are part of an integrated olefins/aromatics complex, so excessive feed storage is not required. Separate Cost of Production calculations are presented for intermediate ethylbenzene as well as finished styrene. This is to permit the evaluation of exporting ethylbenzene to a styrene facility located in a developed market region, thus avoiding the storage and shipping problems associated with styrene in hot climates.

Tables VIII.D.1. to VIII.D.6. present Cost of Production sheets for ethylbenzene and styrene for Western European, North African and Arabian Gulf locations. The estimated 1980 W. European transfer prices thus calculated are \$480 and \$720 per tonne for EB and styrene respectively. The comparable prices from Arab plants are \$466 and \$657 per tonne from a N. African location; \$463 and \$645 per tonne from an Arabian Gulf location.

At the basic feedstock prices used in these evaluations, therefore, and applying identical financial requirements to all locations, ethylbenzene production at the Arab locations for export is barely viable. Styrene production, however, is attractive, with more than enough cost differential to offset freight charges. The attraction of styrene production is, of course, due to its high energy and utility input, which gives a significant cost advantage to the low energy-cost Arab locations. Capital costs are also low.

Although storage and shipping problems can arise with styrene in hot climates, due to potential polymerisation in the tanks, the cost advantage is large enough that some allowance can be made for cooling the storage tanks to avoid these problems without affecting the overall economic attractiveness of the venture.

As an indication of the effects of scale, Tables VIII.D.3 and VIII.D.4 (N. African location) have been reworked for styrene capacities of 200 000 tpa and 100 000 tpa, with corresponding ethylbenzene capacities. Operating rates are at the same percentage of capacity as in Tables VIII.D.3 and VIII.D.4. Styrene transfer prices then increase from \$658 per tonne to \$696 and \$755 per tonne respectively.

TABLE VIII-D-1

ETHYLBENZENE PRODUCTION COST ESTIMATE: W EUROPE

Basis:
Location- W Europe 1980
Capacity- 415 000 tpa EB
Rate - 370 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	15
Offsites Capital Cost	7
Total Fixed	22
Working	5

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	450	45 000 000	
Benzene	277 000	tonne	420	116 340 000	
Catalyst & Chemicals		$		1 500 000	
TOTAL RAW MATERIALS:				162 840 000	440.1
UTILITIES:					
Power	10 700	1000 Kwh	43.5	465 000	
Cooling Water	30 700	1000 m^3	16	491 000	
Fuel	370 000	10^6Kcal	11.6	4 292 000	
TOTAL UTILITIES COST:				5 248 000	14.2
OPERATING COSTS:					
Labour 10 men @ $19 000 pa				190 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				600 000	
TOTAL OPERATING COSTS:				898 000	2.4
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				89 000	
General Plant Overhead - 65% Operating Costs				584 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				330 000	
Depraciation - (Basis: 10% BLCC + 5% Offsites)				1 850 000	
Interest - 10% on Working Capital				500 000	
TOTAL OVERHEAD EXPENSES:				3 353 000	9.1
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				172 339 000	465.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				5 500 000	14.9
TRANSFER PRICE:				177 839 000	480.7

* $/unit

TABLE VIII-D-2

STYRENE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 360 000 tpa styrene
Rate - 325 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	35
Offsites Capital Cost	17
Total Fixed	52
Working	12

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylbenzene	370 000	tonne	480.7	177 839 000	
Catalyst & Chemicals		$		3 900 000	
TOTAL RAW MATERIALS:				181 739 000	559.2
UTILITIES:					
Power	33 000	1000 Kwh	43.5	1 436 000	
Cooling Water	80 000	$1000\ m^3$	16	1 280 000	
Fuel	475 000	10^6Kcal	11.6	5 510 000	
Steam	2 750 000	tonne	9.6	26 400 000	
TOTAL UTILITIES COST:				34 626 000	106.5
OPERATING COSTS:					
Labour 16 men @ $19 000 pa				304 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				1 400 000	
TOTAL OPERATING COSTS:				1 839 000	5.7
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				132 000	
General Plant Overhead - 65% Operating Costs				1 195 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				780 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				4 350 000	
Interest - 10% on Working Capital				1 200 000	
TOTAL OVERHEAD EXPENSES:				7 657 000	23.6
BYPRODUCT CREDIT:					
Benzene/Toluene Cut	25 000	tonne	197	4 925 000	
TOTAL BYPRODUCT CREDIT:				(4 925 000)	(15.2)
TOTAL COST OF PRODUCTION:				220 936 000	679.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				13 000 000	40.0
TRANSFER PRICE:				233 936 000	719.8

* $/unit

TABLE VIII-D-3

ETHYLBENZENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location-** N Africa 1980
Capacity- 415 000 tpa EB
Rate - 370 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	17
Offsites Capital Cost	9
Total Fixed	26
Working	6

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	400	40 000 000	
Benzene	277 000	tonne	422.5	117 033 000	
Catalyst & Chemicals		$		1 500 000	
TOTAL RAW MATERIALS:				158 533 000	428.5
UTILITIES:					
Power	10 700	1000 Kwh	27	289 000	
Cooling Water	30 700	1000 m^3	12	368 000	
Fuel	370 000	10^6 Kcal	4.9	1 813 000	
TOTAL UTILITIES COST:				2 470 000	6.7
OPERATING COSTS:					
Labour 10 men @ $19 000 pa				190 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				680 000	
TOTAL OPERATING COSTS:				978 000	2.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				89 000	
General Plant Overhead - 65% Operating Costs				636 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				390 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				2 150 000	
Interest - 10% on Working Capital				600 000	
TOTAL OVERHEAD EXPENSES:				3 865 000	10.4
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				165 845 000	448.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				6 500 000	17.6
TRANSFER PRICE:				172 345 000	465.8

* $/unit

TABLE VIII-D-4

STYRENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location** - N Africa 1980
Capacity - 360 000 tpa styrene
Rate - 325 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	40
Offsites Capital Cost	22
Total Fixed	62
Working	14

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylbenzene	370 000	tonne	465.8	172 345 000	
Catalyst & Chemicals		$		3 900 000	
TOTAL RAW MATERIALS:				176 245 000	542.3
UTILITIES:					
Power	33 000	1000 Kwh	27	891 000	
Cooling Water	80 000	1000 m^3	12	960 000	
Fuel	475 000	10^6Kcal	4.9	2 328 000	
Steam	2 750 000	tonne	4.3	11 225 000	
TOTAL UTILITIES COST:				16 004 000	49.2
OPERATING COSTS:					
Labour 16 men @ $19 000 pa				304 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				1 600 000	
TOTAL OPERATING COSTS:				2 039 000	6.3
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				132 000	
General Plant Overhead - 65% Operating Costs				1 325 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				930 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 100 000	
Interest - 10% on Working Capital				1 400 000	
TOTAL OVERHEAD EXPENSES:				8 887 000	27.3
BYPRODUCT CREDIT:					
Benzene/Toluene Cut	25 000	tonne	187	4 675 000	
TOTAL BYPRODUCT CREDIT:				(4 675 000)	(14.4)
TOTAL COST OF PRODUCTION:				198 531 000	610.7
RETURN 25% ON TOTAL FIXED INVESTMENT:				15 500 000	47.7
TRANSFER PRICE:				214 031 000	658.4

* $/unit

TABLE VIII-D-5

ETHYLBENZENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: Location- Arabian Gulf 1980
Capacity- 415 000 tpa EB
Rate - 370 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	19
Offsites Capital Cost	10
Total Fixed	29
Working	6

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	366	36 600 000	
Benzene	277 000	tonne	430.9	119 359 000	
Catalyst & Chemicals		$		1 500 000	
TOTAL RAW MATERIALS:				157 459 000	425.6
UTILITIES:					
Power	10 700	1000 Kwh	22.4	240 000	
Cooling Water	30 700	1000 m^3	12	368 000	
Fuel	370 000	10^6 Kcal	2.0	740 000	
TOTAL UTILITIES COST:				1 348 000	3.6
OPERATING COSTS:					
Labour 10 men @ $19 000 pa				190 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				760 000	
TOTAL OPERATING COSTS:				1 058 000	2.9
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				89 000	
General Plant Overhead - 65% Operating Costs				688 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				435 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				2 400 000	
Interest - 10% on Working Capital				600 000	
TOTAL OVERHEAD EXPENSES:				4 212 000	11.4
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				164 077 000	443.5
RETURN 25% ON TOTAL FIXED INVESTMENT:				7 250 000	19.6
TRANSFER PRICE:				171 327 000	463.1

* $/unit

TABLE VIII-D-6

STYRENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: **Location-** Arabian Gulf 1980
Capacity- 360 000 tpa styrene
Rate - 325 000 tpa tpa

Capital Cost	$MM
Battery Limits Capital Cost	44
Offsites Capital Cost	24
Total Fixed	68
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylbenzene	370 000	tonne	463.1	171 327 000	
Catalyst & Chemicals		$		3 900 000	
TOTAL RAW MATERIALS:				175 227 000	539.2
UTILITIES:					
Power	33 000	1000 Kwh	22.4	739 000	
Cooling Water	80 000	1000 m^3	12	960 000	
Fuel	475 000	10^6 Kcal	2.0	950 000	
Steam	2 750 000	tonne	2.7	7 425 000	
TOTAL UTILITIES COST:				10 074 000	31.0
OPERATING COSTS:					
Labour 16 men @ $19 000 pa				304 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				1 760 000	
TOTAL OPERATING COSTS:				2 199 000	6.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				132 000	
General Plant Overhead - 65% Operating Costs				1 429 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 020 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 600 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				9 681 000	29.8
BYPRODUCT CREDIT:					
Benzene/Toluene cut	25 000	tonne	177	4 425 000	
TOTAL BYPRODUCT CREDIT:				(4 425 000)	(13.6)
TOTAL COST OF PRODUCTION:				192 756 000	593.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				17 000 000	52.3
TRANSFER PRICE:				209 756 000	645.5

* $/unit

TABLE VII.6.13

PARAXYLENE FROM MIXED XYLENES

Basis: Location- Arabian Gulf 1980
Capacity- 132 000 tpa paraxylene
Process Route - Distillation, parex, noble metal isomerisation, total recycle

Capital Cost	$MM
Battery Limits Capital Cost	63
Offsites Capital Cost	31
Total Fixed	94
Working	19

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Xylenes	158 300	tonne	223	35 301 000	
Hydrogen	62 000	10^6 Kcal	2	124 000	
Catalyst & Chemicals		$		1 400 000	
TOTAL RAW MATERIALS:				36 825 000	279.0
UTILITIES:					
Power	17 000	MWh	22.4	381 000	
Cooling Water	12 000	1 000 m^3	12.0	152 000	
Fuel	465 000	10^6 Kcal	2.0	930 000	
Steam	78 000	tonne	2.7	211 000	
TOTAL UTILITIES COST:				1 674 000	12.7
OPERATING COSTS:					
Labour	22 men @ $19 000 p.a.			418 000	
Supervision	4 men @ $27 000 p.a.			108 000	
Maintenance Material and Labour @ 4% BLCC				2 520 000	
TOTAL OPERATING COSTS:				3 046 000	23.1
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				158 000	
General Plant Overhead - 65% Operating Costs				1 980 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 410 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 850 000	
Interest - 10% on Working Capital				1 900 000	
TOTAL OVERHEAD EXPENSES:				13 298 000	100.7
BYPRODUCT CREDIT:					
Aromatics recycle	9 000	tonne	221.4	1 993 000	
Heavy Aromatics	6 000	tonne	200	1 200 000	
TOTAL BYPRODUCT CREDIT:				(3 193 000)	(24.2)
TOTAL COST OF PRODUCTION:				51 650 000	391.3
RETURN 25% ON TOTAL FIXED INVESTMENT:				23 500 000	178.0
TRANSFER PRICE:				75 150 000	569.3

* $/unit

E. VINYL CHLORIDE MONOMER (VCM)

1. Introduction

Vinyl chloride monomer is used almost exclusively for production of polyvinyl chloride (PVC). PVC is one of the most versatile plastics, and now ranks as the third largest consumer of ethylene worldwide, after polyethylenes and ethylene oxide/glycol.

VCM or PVC is generally considered as a potential product in most petrochemical projects considered for an oil-producing country, due to the high energy consumption of VCM manufacture (which favours production in a location with cheap energy), the comparatively high demand for PVC in developing countries, and the large world market. In this study, we consider the production of VCM for export rather than further processing into PVC. This is due to the restriction of the total number of products which this study can consider (see Appendix I), and our assessment that the economics of VCM production will be more attractive than PVC due to the high capital costs and low energy input involved in upgrading the monomer to PVC polymer. The establishment of local PVC units as a subsequent development would, however, be a logical stage in industrialisation, and could draw upon economically priced VCM as required.

Chlorine production is an integral part of a VCM complex, and the economics of chlorine together with valuation for the caustic soda by-product are also analysed in this section.

2. Technology

The oldest and simplest route to VCM is the vapour phase addition reaction of acetylene to hydrogen chloride. The reaction is simple and of high yield, but high acetylene costs have made this route generally uneconomic. Current plants employ ethylene-based technology, with the balanced oxychlorination process predominating.

The production of VCM via this route consists basically of the following steps:

- a reaction section in which ethylene dichloride (EDC) is produced by reacting ethylene with chlorine, called the direct chlorination section
- a reaction section in which EDC is produced by reacting ethylene with hydrogen chloride and oxygen, called the oxychlorination section.
- a fractionation section in which the crude EDC from both reaction sections is purified to a pyrolysis grade specification
- a pyrolysis section in which the purified EDC is thermally cracked to yield VCM, HCl and unreacted EDC
- a fractionation section in which pure VCM is separated from the other pyrolysis products, which are recycled

These sections may be conveniently considered to form two process plants, one producing EDC and the other producing VCM from this EDC feedstock. These plants are described in more detail below:

a) Ethylene Dichloride (EDC)

In the direct chlorination section, ethylene and chlorine, both of high purity (99 percent +), are fed to a liquid phase non-catalytic reactor operating at about 10 atmospheres and 50°C. The addition reaction to EDC is highly selective and conversion is essentially complete. Effluent liquid EDC is caustic and water washed prior to being sent to the EDC fractionation section. Small amounts of non-condensables are vented from the scrubbing system.

In the oxychlorination section, ethylene, air or oxygen, and hydrogen chloride (recycled from the VCM plant) are fed to the oxychlorination reactor. This is a vapour phase catalytic reaction and can be carried out in either fixed or fluidised bed equipment. Reactor operation is at 260-310°C and a pressure of 1-7 atmospheres, the higher pressures being used in fixed bed systems. EDC and water are formed, over a copper chloride catalyst. Conversion is highly selective and essentially complete. Gaseous reaction products are caustic and water washed to produce a crude EDC which is fed to the EDC purification facilities for removal of small amounts of light and heavy ends.

The EDC fractionation train consists of a three tower system which successively separates water, other light ends and heavy ends to produce an EDC of sufficient purity (approximately 99 percent) for effective pyrolysis.

b) Vinyl Chloride Monomer (VCM)

Pure EDC from the fractionation section of the EDC plant is fed to the pyrolysis section of the VCM plant, where it is thermally cracked to VCM and hydrogen chloride. Operating conditions are in the region of 10 atmospheres and 480^{0}C. Conversion is about 50-60 percent per pass. Furnace effluent is quenched by direct contact cooling in a quench tower prior to being fed to the VCM fractionation section.

The VCM fractionation train consists of a three tower system. The first tower separates by-product hydrogen chloride for recycle to the oxychlorination reactor. VCM is separated from unreacted EDC in the second tower, and the EDC is recycled to the EDC fractionation section. VCM is further purified in the third tower.

3. Cost of Production

a) Chlorine

Chlorine is produced almost exclusively by the electrolysis of brine. Historically this has been mostly by the use of mercury cells, but increasingly diaphragm cells are superceding these to eliminate mercury contamination and pollution problems. Chlorine production is accompanied by 1.1 tonnes of caustic soda for each tonne of chlorine. The caustic is generally produced as a 50 percent solution which may be sold in this form, or further concentrated and purified from residual chlorides and other contaminants.

For a viable electrolysis unit both chlorine and caustic need to be sold. Since the supply is in a fixed ratio and the demand independent there have been cycles of caustic excess/shortage. The relative pricing of chlorine and caustic has therefore also fluctuated, and to predict relative prices at any time in the future requires analysis of the supply/demand balances for both chlorine and caustic in each of the major market regions. Chem Systems has recently carried out such market analyses, and based upon these analyses we have taken caustic as 50 percent solution as equal in value to chlorine for the West European location.

This is equivalent to pure anhydrous flake caustic about 1.15 times chlorine value. For the Arab locations, these same ratios of chlorine/caustic solution/flake caustic prices are assumed. The main target markets for Arab caustic in the 1980's appear to be Australia and South America, with potential spot business throughout the developing countries. Further analysis of the world caustic supply/demand balance would be essential in the detailed planning of any Arab project, however, since disposal of this material could prove difficult in the expected oversupply situation of the early 1980's. Certainly coordination between any planned Arab projects would be essential.

Chlorine production costs are dominated by power costs and by caustic soda by-product valuation. The effects of scale are of limited importance, since capital-related costs are a relatively low proportion of total transfer price. A plant capacity of 140 000 tonnes per year chlorine is used as the basis of the evaluations for both the European and Arab locations. This capacity is consistent with the VCM plant capacity selected. Power cost is taken to be the value previously derived (Section III) for each location, as used in other product evaluations. In practice, however, it should be recognised that chlorine plants frequently enjoy a preferential power tarif due to the scale of their demand. Discounts of 10-20 percent below normal values can be achieved. Salt price is assumed to be the same for all locations: this is not a major component of chlorine costs, and plants are generally sited close to suitable salt beds or brine wells.

Tables VIII.E.1. to VIII.E.3. present Cost of Production sheets for Western European, North African and Arabian Gulf locations. The estimated 1980 W. European Transfer Price of chlorine is $234 per tonne. The comparable prices from Arab plants are $216 and $215 per tonne from N. African and Arabian Gulf locations respectively.

b) Vinyl Chloride Monomer (VCM)

Although it is possible to separate the costs of ethylene dichloride production from those of VCM production, this is usually of academic interest only. The economics of an integrated EDC/VCM complex are superior to those of separate, remote plants, since only in an integrated scheme can by-product hydrogen chloride from the VCM plant be effectively utilised by recycling to the EDC plant.

VCM production cost is dominated by raw material charges for ethylene and chlorine. Scale of manufacture is therefore not critical in a cost analysis. We use here a VCM capacity of 230 000 tonnes per year, which is typical of current European and U.S. plants. This capacity would absorb approximately one quarter of the ethylene output from the proposed 480 000 tpa Arab olefins plant.

Capital and operating costs are based upon recent Chem Systems studies. Working capital is taken as 50 percent of BLCC.

Tables VIII.E.4. to VIII.E.6. present Cost of Production sheets for VCM for Western European, N. African and Arabian Gulf locations. The estimated 1980 W. European transfer price is thus calculated as $545 per tonne. Comparable prices from Arab plants are $517 and $508 per tonne from N. African and Arabian Gulf locations respectively. These margins below European prices are not large enough to cover freight costs and permit penetration of the developed markets. Sensitivity analyses in Section X therefore consider variations in feedstock prices and project finance, and show the effects these can have upon overall economics and potential of the Arab projects.

As an indication of the effects of scale, Tables VIII.E.2 and VIII.E.5 (N. African location) have been reworked for VCM capacities of 150 000 tpa and 100 000 tpa, with corresponding chlorine capacities. Operating rates are at the same percentage of capacity as in Tables VIII.E.2 and VIII.E.5. VCM transfer prices then increase from $517 per tonne to $553 and $593 per tonne respectively.

TABLE VIII-E-1
CHLORINE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 140 000 tpa chlorine
Rate - 125 000 tpa chlorine
138 000 tpa caustic soda

Capital Cost	$MM
Battery Limits Capital Cost	50
Offsites Capital Cost	25
Total Fixed	75
Working	8

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST#
Salt	217 000	tonne	20	4 340 000	
Chemicals & Consumables		$		750 000	
TOTAL RAW MATERIALS:				5 090 000	19.4
UTILITIES:					
Power	436 000	1000 Kwh	43.5	18 966 000	
Cooling Water	2 600	1000 m³	16	42 000	
Steam	650 000	tonne	9.6	6 240 000	
TOTAL UTILITIES COST:				25 248 000	96.0
OPERATING COSTS:					
Labour 20 men @ $19 000 pa				380 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				2 000 000	
TOTAL OPERATING COSTS:				2 515 000	9.5
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				155 000	
General Plant Overhead - 65% Operating Costs				1 635 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 125 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 250 000	
Interest - 10% on Working Capital				800 000	
TOTAL OVERHEAD EXPENSES:				9 965 000	37.9
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				42 818 000	162.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				18 750 000	71.3
TRANSFER PRICE:				61 568 000	234.1

* $/unit

\# $/tonne (chlorine plus caustic)

TABLE VIII-E-2

CHLORINE PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location-** N Africa 1980
Capacity- 140 000 tpa chlorine
Rate - 125 000 tpa chlorine
138 000 tpa caustic soda

Capital Cost	$MM
Battery Limits Capital Cost	58
Offsites Capital Cost	32
Total Fixed	90
Working	9

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST#
Salt	217 000	tonne	20	4 340 000	
Chemicals & Consumables		$		750 000	
TOTAL RAW MATERIALS:				5 090 000	19.4
UTILITIES:					
Power	436 000	1000 Kwh	27	11 772 000	
Cooling Water	2 600	1000 m^3	12	31 000	
Steam	650 000	tonne	4.3	2 795 000	
TOTAL UTILITIES COST:				14 598 000	55.5
OPERATING COSTS:					
Labour 20 men @ $19 000 pa				380 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				2 320 000	
TOTAL OPERATING COSTS:				2 835 000	10.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				155 000	
General Plant Overhead - 65% Operating Costs				1 843 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 350 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 400 000	
Interest - 10% on Working Capital				900 000	
TOTAL OVERHEAD EXPENSES:				11 648 000	44.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				34 171 000	130.0
RETURN 25% ON TOTAL FIXED INVESTMENT:				22 500 000	85.6
TRANSFER PRICE:				56 671 000	215.6

* $/unit

\# $/tonne (chlorine plus caustic)

TABLE VIII-E-3

CHLORINE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: **Location-** Arabian Gulf 1980
Capacity- 140 000 tpa chlorine
Rate - 125 000 tpa chlorine
138 000 tpa caustic soda

Capital Cost	$MM
Battery Limits Capital Cost	63
Offsites Capital Cost	34
Total Fixed	97
Working	10

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST #
Salt	217 000	tonne	20	4 340 000	
Chemicals & Consumables		$		750 000	
TOTAL RAW MATERIALS:				5 090 000	19.4
UTILITIES:					
Power	436 000	1000 Kwh	22.4	9 766 000	
Cooling Water	2 600	1000 m^3	12	31 000	
Steam	650 000	tonne	2.7	1 755 000	
TOTAL UTILITIES COST:				11 552 000	43.9
OPERATING COSTS:					
Labour 20 men @ $19 000 pa				380 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				2 520 000	
TOTAL OPERATING COSTS:				3 035 000	11.5
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				155 000	
General Plant Overhead - 65% Operating Costs				1 973 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 455 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				8 000 000	
Interest - 10% on Working Capital				1 000 000	
TOTAL OVERHEAD EXPENSES:				12 583 000	47.8
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				32 260 000	122.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				24 250 000	92.2
TRANSFER PRICE:				56 510 000	214.8

* $/unit

\# $/tonne (chlorine plus caustic)

TABLE VII.G.1[illegible].
PARAXYLENE AND ORTHOXYLENE FROM MIXED XYLENES

		Capital Cost	$MM
Basis: Location-	Arabian Gulf 1980	Battery Limits Capital Cost	49
Capacity-	100 000 tpa paraxylene 42 500 tpa orthoxylene	Offsites Capital Cost	25
		Total Fixed	74
Process Route -	Distillation, parex, noble metal isomerisation total recycle	Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Xylenes	158 200	tonne	223	35 301 000	
Hydrogen	44 000	10^6 Kcal	2	88 000	
Catalyst and Chemicals		$		840 000	
TOTAL RAW MATERIALS:				36 229 000	
UTILITIES:					
Power	14 000	Mwh	22.4	314 000	
Cooling Water	7 500	1 000 m^3	12.0	90 000	
Fuel	473 000	10^6 Kcal	2.0	946 000	
Steam	98 000	tonne	2.7	265 000	
TOTAL UTILITIES COST:				1 615 000	
OPERATING COSTS:					
Labour	26 men @ $19 000 p.a.			494 000	
Supervision	4 men @ $27 000 p.a.			108 000	
Maintenance Material and Labour @ 4% BLCC				1 960 000	
TOTAL OPERATING COSTS:				2 562 000	
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				181 000	
General Plant Overhead - 65% Operating Costs				1 665 000	
Insurance, Property Taxes - 1.5 Total Fixed Capital				1 110 000	
Depreciation - (basis: 10% BLCC + 5% Offsites)				6 150 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				10 606 000	
BYPRODUCT CREDIT:					
Aromatics Recycle	6 500	tonne	221.4	1 439 000	
Heavy Aromatics	4 800	tonne	200	960 000	
TOTAL BYPRODUCT CREDIT:				(2 399 000)	
TOTAL COST OF PRODUCTION:				48 613 000	
RETURN 25% ON TOTAL FIXED INVESTMENT:				18 500 000	
TOTAL REVENUE REQUIREMENT:				67 113 000	
Estimated division of revenue:	Paraxylene			51 600 000	516
	O-Xylene			15 513 000	365
				67 113 000	

* $/unit

TABLE VIII-F-4

VCM PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 230 000 tpa VCM
Rate - 210 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	45
Offsites Capital Cost	23
Total Fixed	68
Working	23

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	450	45 000 000	
Chlorine	215 000	tonne	234.1	29 263 000	
Catalysts & Chemicals		$		1 000 000	
TOTAL RAW MATERIALS:				75 263 000	358.4
UTILITIES:					
Power	46 000	1000 Kwh	43.5	2 001 000	
Cooling Water	55 000	1000 m^3	16	880 000	
Process Water	1 700	1000 m^3	400	680 000	
Fuel	210 000	10^6Kcal	11.6	2 436 000	
Steam	315 000	tonne	9.6	3 024 000	
TOTAL UTILITIES COST:				9 021 000	43.0
OPERATING COSTS:					
Labour	25 men @ $19 000 pa			475 000	
Supervision	5 men @ $27 000 pa			135 000	
Maintenance Material and Labour @ 4% BLCC				1 800 000	
TOTAL OPERATING COSTS:				2 410 000	11.5
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				183 000	
General Plant Overhead - 65% Operating Costs				1 567 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 020 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 650 000	
Interest - 10% on Working Capital				2 300 000	
TOTAL OVERHEAD EXPENSES:				10 720 000	51.0
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				97 414 000	463.9
RETURN 25% ON TOTAL FIXED INVESTMENT:				17 000 000	81.0
TRANSFER PRICE:				114 414 000	544.9

* $/unit

TABLE VIII-E-5
VCM PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location-** N Africa 1980
Capacity- 230 000 tpa VCM
Rate - 210 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	52
Offsites Capital Cost	29
Total Fixed	81
Working	26

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	400	40 000 000	
Chlorine	125 000	tonne	215.6	26 950 000	
Catalysts & Chemicals		$		1 000 000	
TOTAL RAW MATERIALS:				67 950 000	323.6
UTILITIES:					
Power	46 000	1000 Kwh	27.0	1 242 000	
Cooling Water	55 000	1000 m^3	12	660 000	
Process Water	1 700	1000 m^3	600	1 020 000	
Fuel	210 000	10^6 Kcal	4.9	1 029 000	
Steam	315 000	tonne	4.3	1 354 000	
TOTAL UTILITIES COST:				5 305 000	25.3
OPERATING COSTS:					
Labour 25 men @ $19 000 pa				475 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				2 080 000	
TOTAL OPERATING COSTS:				2 690 000	12.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				183 000	
General Plant Overhead - 65% Operating Costs				1 749 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 215 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 650 000	
Interest - 10% on Working Capital				2 600 000	
TOTAL OVERHEAD EXPENSES:				12 397 000	59.0
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				88 342 000	420.7
RETURN 25% ON TOTAL FIXED INVESTMENT:				20 250 000	96.4
TRANSFER PRICE:				108 592 000	517.1

* $/unit

TABLE VIII-E-6

VCM PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: **Location-** Arabian Gulf 1980
Capacity- 230 000 tpa VCM
Rate - 210 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	56
Offsites Capital Cost	31
Total Fixed	87
Working	28

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	366	36 600 000	
Chlorine	125 000	tonne	214.8	26 850 000	
Catalysts & Chemicals		$		1 000 000	
TOTAL RAW MATERIALS:				64 450 000	306.9
UTILITIES:					
Power	46 000	1000 Kwh	22.4	1 030 000	
Cooling Water	55 000	1000 m^3	12	660 000	
Process Water	1 700	1000 m^3	800	1 360 000	
Fuel	210 000	10^6Kcal	2.0	420 000	
Steam	315 000	tonne	2.7	815 000	
TOTAL UTILITIES COST:				4 321 000	20.6
OPERATING COSTS:					
Labour 25 men @ $19 000 pa				475 000	
Supervision 5 men @ $27 000 pa				135 000	
Maintenance Material and Labour @ 4% BLCC				2 240 000	
TOTAL OPERATING COSTS:				2 850 000	13.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				183 000	
General Plant Overhead - 65% Operating Costs				1 852 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 305 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 150 000	
Interest - 10% on Working Capital				2 800 000	
TOTAL OVERHEAD EXPENSES:				13 290 000	63.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				84 911 111	404.4
RETURN 25% ON TOTAL FIXED INVESTMENT:				21 750 000	103.6
TRANSFER PRICE:				106 661 000	508.0

* $/unit

F. POLYSTYRENE

1. Introduction

Polystyrene is the dominant end-use for styrene monomer, currently consuming around two-thirds of global styrene production. This ranks polystyrene as a major commodity petrochemical in its own right, with worldwide tonnage production greater than either HDPE or polypropylene.

The range of end-uses for polystyrene is very large, with packaging representing the major application area. The three main classifications of polystyrene are as follows:-

- general-purpose or "crystal" resins are glossy and clear, and are generally supplied as granules. A range of grades are produced.
- "impact" resins contain a few percent polybutadiene to improve final product impact strength. Around 50 percent of all polystyrene is produced as "impact" grades.
- expandable beads, which are used for production of moulded foam products.

The technology of polystyrene production is relatively simple, and plant capital costs are low compared to those of the other thermoplastics (polyethylene, etc).

The description below is for a plant capable of producing crystal and impact grades.

2. Technology

Polystyrene is readily obtained by free-radical polymerisation of styrene monomer. This can be initiated simply by heating, but the addition of free-radical initiator accelerates the polymerisation. The polymerisation is highly exothermic.

The most common reaction system is a mass or solution polymerisation carried out in a series of stirred, cooled reactors.

Ethylbenzene diluent is mixed with the styrene monomer: if under 15 percent diluent is used the process is generally considered a modified mass polymerisation process. If greater amounts of diluent are used the process becomes a solution process. Typically the heated mixture of styrene, diluent and initiator is pumped through a series of agitated polymerisation reactors, each equipped with several heat exchange systems. Temperature typically rises from 120°C to around 160°C over the course of the reaction line. The hot product is then pumped into a reduced pressure, heated flash tank. Unreacted styrene and diluent are flashed off, condensed and recycled. The hot, viscous polymer is fed directly to the extrusion and packaging units.

To produce "impact" or "rubber-modified" grades a quantity of an elastomer (usually polybutadiene) is dissolved in the styrene feed. The rubber level is typically 2 - 15 percent by weight in the final product, up to 5 percent being termed medium-impact grades and 8 - 12 percent being typical high-impact grades.

3. Cost of Production

Polystyrene costs are dominated by styrene monomer price. Capital charges are of lower importance than with most other thermoplastics due to the relative simplicity and low cost of polystyrene plants. Economies of scale are therefore of less importance. A plant capacity of 100 000 tonnes per year, typical of US and European practice, is assumed here for both Arab and European locations. The plants have the flexibility to produce impact grades if required, but the economics are calculated here on the basis of producing all crystal grades. Under these conditions, effectively one tonne of styrene is consumed per tonne of polystyrene produced. Thus a 100 000 tpa capacity plant would absorb approximately one quarter of the output of the proposed Arab styrene plant.

Tables VIII.F.1. to VIII.F.3. present Cost of Production sheets for Western European, North African and Arabian Gulf locations. The 1980 West European Transfer Price thus estimated is $1 045 per tonne. The comparable prices from Arab plants are around $1 010 per tonne from both locations, rising to $1 090 per tonne at a capacity of 50 000 tpa (N. African location.)

The cost advantage of the Arab plants is therefore very nominal, and will not offset freight costs at the basic feedstock prices and financial parameters assumed above. This is despite the superior economics (previously demonstrated in Section VIII.D.) of styrene monomer production at the Arab locations. This would be expected, since the relatively high capital costs and low energy input of the polymerisation stage will weigh against the Arab plants. Since styrene itself is a marketable basic commodity, there is little incentive to process further to polystyrene for export from the Arab locations, bearing in mind also the smaller, more diffuse market for polystyrene and the technical support required.

TABLE VIII-F-1
POLYSTYRENE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 100 000 tpa polystyrene
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	25
Offsites Capital Cost	13
Total Fixed	38
Working	13

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Styrene	90 000	tonne	719.8	64 782 000	
Catlayst & Chemicals		$		8 800 000	
TOTAL RAW MATERIALS:				73 582 000	817.6
UTILITIES:					
Power	10 000	1000 Kwh	43.5	435 000	
Cooling Water	50 000	1000 m^3	16	800 000	
Steam	30 000	tonne	9.6	288 000	
TOTAL UTILITIES COST:				1 523 000	16.9
OPERATING COSTS:					
Labour 60 men @ $19 000 pa				1 140 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				1 000 000	
TOTAL OPERATING COSTS:				2 410 000	26.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				423 000	
General Plant Overhead - 65% Operating Costs				1 567 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				570 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				3 150 000	
Interest - 10% on Working Capital				1 300 000	
TOTAL OVERHEAD EXPENSES:				7 010 000	77.9
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				84 525 000	939.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				9 500 000	105.6
TRANSFER PRICE:				94 025 000	1 044.8

* $/unit

TABLE VIII-F-2

POLYSTYRENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: Location - N Africa 1980
Capacity - 100 000 tpa polystyrene
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	29
Offsites Capital Cost	16
Total Fixed	45
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Styrene	90 000	tonne	658.4	59 256 000	
Catalyst & Chemicals		$		8 800 000	
TOTAL RAW MATERIALS:				68 056 000	756.2
UTILITIES:					
Power	10 000	1000 Kwh	27	270 000	
Cooling Water	50 000	1000 m^3	12	600 000	
Steam	30 000	tonne	4.3	129 000	
TOTAL UTILITIES COST:				999 000	11.1
OPERATING COSTS:					
Labour 60 men @ $19 000 pa				1 140 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				1 160 000	
TOTAL OPERATING COSTS:				2 570 000	28.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				423 000	
General Plant Overhead - 65% Operating Costs				1 671 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				675 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				3 700 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				7 969 000	88.5
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				79 594 000	884.4
RETURN 25% ON TOTAL FIXED INVESTMENT:				11 250 000	125.0
TRANSFER PRICE:				90 844 000	1 009.4

* $/unit

TABLE VIII-F-3

POLYSTYRENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: **Location-** Arabian Gulf 1980
Capacity- 100 000 tpa polystyrene
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	31
Offsites Capital Cost	17
Total Fixed	48
Working	16

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Styrene	90 000	tonne	645.5	58 095 000	
Catalyst & Chemicals				8 800 000	
TOTAL RAW MATERIALS:				66 895 000	743.3
UTILITIES:					
Power	10 000	1000 Kwh	22.4	224 000	
Cooling Water	50 000	1000 m^3	12	600 000	
Steam	30 000	tonne	2.7	81 000	
TOTAL UTILITIES COST:				905 000	10.1
OPERATING COSTS:					
Labour 60 men @ $19 000 pa				1 140 000	
Supervision 10 men @ $27 000 pa				270 000	
Maintenance Material and Labour @ 4% BLCC				1 240 000	
TOTAL OPERATING COSTS:				2 650 000	29.4
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				423 000	
General Plant Overhead - 65% Operating Costs				1 723 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				720 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				3 950 000	
Interest - 10% on Working Capital				1 600 000	
TOTAL OVERHEAD EXPENSES:				8 416 000	93.5
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				78 866 000	876.3
RETURN 25% ON TOTAL FIXED INVESTMENT:				12 000 000	133.3
TRANSFER PRICE:				90 866 000	1 009.6

* $/unit

G. TEREPHTHALIC ACID/DIMETHYLTEREPHTHALATE (TPA/DMT)

1. Introduction

Terephthalic acid (TPA) and its dimethyl ester, dimethyl terephthalate (DMT), became available as industrial chemicals in the early 1950's. They are virtually inseparable insofar as their major applications are concerned. DMT and TPA are, together with ethylene glycol, the principal raw materials for the manufacture of polyester fibres and films. This use consumes well over 90 percent of all DMT and TPA production.

DMT was the first material to be used as a feedstock for the manufacture of polyethylene terephthalate. The polymer was first manufactured on a commercial scale in England by Imperial Chemical Industries (ICI) in 1949 and in the United States by DuPont in 1953. In both cases the starting material was para-xylene which was oxidised to TPA by dilute nitric acid. Modifications by ICI and DuPont have refined the process but the disadvantages still existed. These are primarily (1) the need for an auxiliary HNO_3 plant to utilise the nitrogen oxides produced in the oxidation, (2) the need to operate under explosive temperature and HNO_3 concentrations for realisation of adequate yields and (3) the difficulty in purifying the TPA. TPA is a refractory material and is insoluble in most common solvunts making it difficult to produce fibre grade product by the common purification procedures.

The latter point is the reason why DMT became the established raw material for polyesters. Manufacture of the dimethyl ester offered ease of purification by conventional processes such as crystallisation and distillation.

SECTION VIII

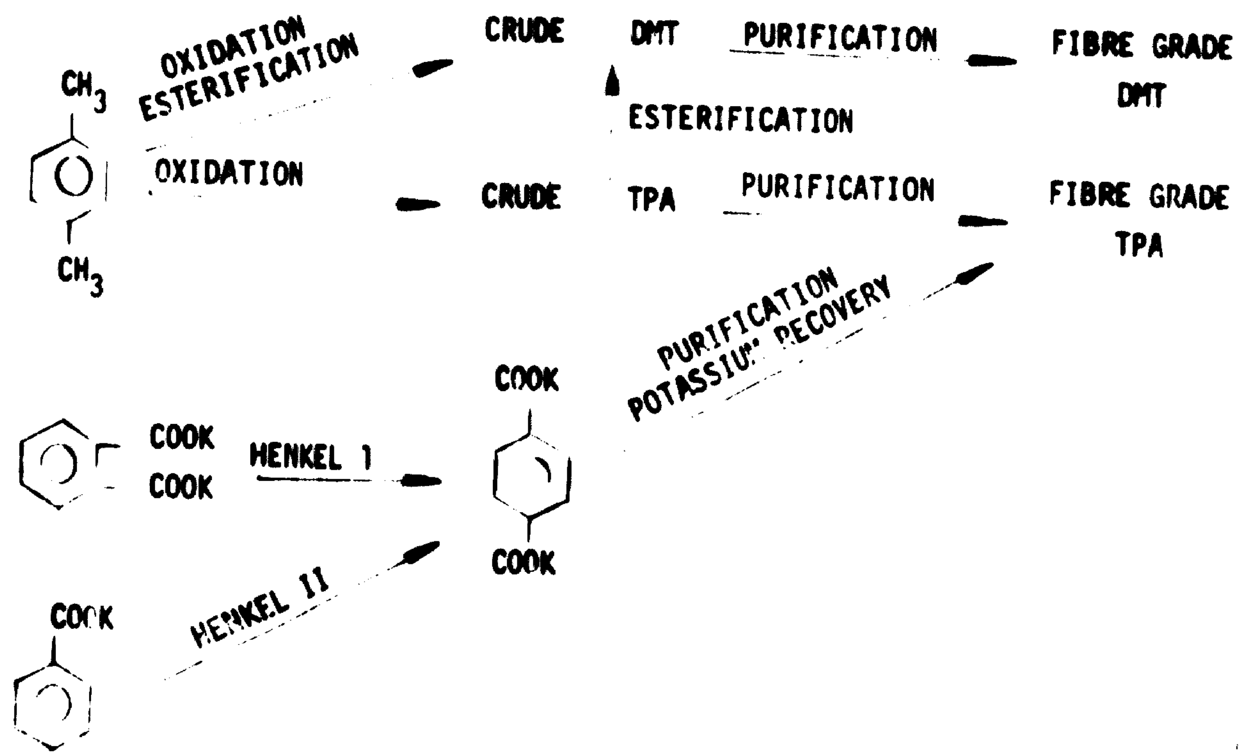
The phenomenal growth of DMT/TPA condumption is the direct result of the rapid penetration of most major textile markets by polyester fibres. The consumer appeal of easy-care and durable press fabrics has led to the general acceptance of polyester as an apparel fibre.

Most of the DMT and TPA produced in the world today are based on para-xylene feedstock. Older technologies that begin with other feedstocks such as toluene or phthalic anhydride are available, but these processes have not remained economically competitive.

If useful polyester products are to be manufactured from DMT or TPA they must meet very stringent purity requirements. As mentioned previously, this is the reason why historically DMT was the preferred starting material. A comparison of some physical properties suggests why DMT is purified more easily. Terephthalic acid does not melt under normal conditions and sublimes at about 400°C, is insoluble in water and only slightly soluble in most organic solvents at room temperatures. In contrast, DMT melts at about 141°C and boils at 288°C. It is soluble in ether and hot methanol. Consequently, while DMT can be distilled at relatively moderate temperatures, TPA purification requires such steps as treatment with solvent mixtures and successive crystallisations, hydrogenation, or sublimation.

2. Technology

The production routes for fibre grade DMT and TPA are outlined below:



Starting with para-xylene, two main routes are considered. The first route, involving oxidation and esterification directly to DMT without intermediate production of TPA, is the route employed by the Hercules-Witten-Dynamit process. The crude DMT must then be purified to fibre grade DMT. The second route involves oxidation to crude TPA and is the basis for several process. These include the Amoco, Mobil, Henkel I and II, and other processes. Once the crude TPA is produced it may be purified to fibre grade TPA or esterified to DMT.

The Henkel I process involves starting with ortho-xylene through phthalic anhydride to the potassium salt. Henkel II involves conversion of toluene through benzoic acid to the potassium salt. In both versions these are transformed to dipotassium terephthalate which is purified to fibre grade TPA or alternatively converted to crude TPA for subsequent processing to DMT.

The business has basically settled down to a competition between the Hercules-Witten-Dynamit Process for the manufacture of DMT, and the Amoco process for the manufacture of fibre-grade TPA. These two processes are described in detail below, together with brief summaries of the other process.

a) Hercules-Witten-Dynamit Process

The process employs a liquid phase reaction which produces DMT directly from para-xylene and cannot be employed for the production to TPA.

The basic process was originally developed by Chemische Werke Witten GmbH and engineered by Imhausen International Co. of West Germany. Simultaneous development was carried out by the California Research Corporation, a division of Standard Oil of California. Hercules, Inc., which is currently the world's largest producer of DMT, further modified the process under license from California Research and Witten. The basic patents were granted to California Research and Imhausen in 1953 with further patents to Witten and Hercules. Modification of the process continues and it is understood that under a technical exchange agreement with Dynamit Nobel AG of West Germany, process features developed by that company are being incorporated into the Hercules process. These include modifications in the catalyst system and in the air oxidation and purification steps. The bulk of world production of DMT is based on the Hercules-Imhausen-Witten technology and is currently used in addition by Teijin, Montedison, Hoechst and Rhone-Poulenc.

The process involves the oxidation of para-xylene to toluic acid as an intermediate. The toluic acid is esterified with methanol to methyl toluate which is then oxidised further to monomethyl terephthalate. The monomethyl terephthalate is finally esterified with methanol to DMT.

The oxidation steps are reportedly catalysed by about 0.5-1 wt. percent cobalt naphthenate or cobalt toluate and take place at about 170°C and 15 atm. Recent information indicates that the current catalyst is a cobaltous-manganese salt mixture, used as the acetate. The esterification reactions are carried out at about 150°C with the use of para-toluene sulfonic acid as the catalyst. Although higher esterification temperatures generally lead to the production of unwanted methyl ethers, some reports indicate a non-catalytic esterification reaction at higher temperatures. There is no need for the use of special solvents for either the oxidation or esterification steps. Instead, excess para-xylene and methanol are used. Both of these are ultimately recovered and recycled. Only two reactors are needed - one for oxidation and one for esterification.

The intermediate oxidation and esterification products are separated and recycled to the appropriate reactors. In this design an overall yield of 81 percent of theoretical on p-xylene has been used, although overall yields of approximately 85 percent of theoretical on p-xylene have been reported as a result of processing improvements.

While the reactions may be carried out either batchwise or continuously, it is expected that new installations would be designed for continous operation. The catalyst is mixed with some para-xylene in the catalyst preparation tank before being pumped to the feed mix tank where it is mixed with additional para-xylene. This is then fed to the oxidation reactor together with recycle methyl toluate from the crude ester column. Air is introduced in the bottom of the oxidation reactor and the highly exothermic reaction takes place. The heat of reaction is removed by the vaporisation and external condensation of excess para-xylene. The oxidation reactor is maintained at 15 atm. and approximately 180°C. The oxidate is fed to the esterification reactor where it is contacted with methanol and catalyst at a temperature of approximately 150°C. The catalyst, para-toluene sulfonic acid, mixed with methanol is pumped from the catalyst preparation tank. The resulting crude ester, containing excess methanol and water, is pumped to the methanol column where the methanol and water are taken overhead and sent to the dehydration column. The bottoms are sent to the crude ester column. The methyl toluate and excess para-xylene are taken overhead and recycled to the oxidation reactor. The bottoms product, crude DMT, is sent to a vacuum crystalliser in which methanol is used as a solvent. To further purify the DMT a second crystallisation step has conventionally been used. However, an improvement in the purification section involving a countercurrent washing column has been incorporated in this design. This improvement, disclosed recently by Dynamit Nobel, permits the elimination of two centrifuges, a washing vestle and a dissolving tank. The slurry effluent from the crystalliser is pumped to the top of the washing column where it is contacted countercurrently with high purity recycle methanol from the dehydration column and makeup methanol from storage. The impure mother liquor passes into the washing liquid as is withdrawn at the top of the washing column and recycled to the crystalliser and esterification reactor. The purified DMT is withdrawn at the bottom of the washing column together with pure washing liquid. The DMT at this point is free of mother liquor as well as all adhering impurities at the surface of the DMT crystals.

The crystals are separated from the methanol in a centrifuge. The methanol is recycled to the washing column and the wet solid conveyed to a melting tank. In the melting tank the DMT is liquefied and the methanol vaporised off and sent back to the dehydration column. The liquefied DMT is sent to a DMT column for final purification. Fibre grade DMT is taken overhead and any high boiling impurities from the bottom of the DMT column are discarded or recycled to the crude ester column.

It is possible to store and ship the DMT in the molten state, but here we include a flaker and an inert gas conveying system to produce a solid product and transfer the DMT product to storage.

It must be emphasized that this is a continously changing process in which many of the improvements are kept secret. The subsequent economic evaluation is based on our judgment of a modern viable design which incorporates many of the modern process improvements that have been developed.

b) Amoco (Mid-Century) Process

In this process para-xylene is oxidised to terephthalic acid in the presence of acetic acid, a bromine promoter and a heavy metal catalyst. This process was originally developed by the Mid-Century Corporation, now a wholly owned subsidiary of Standard Oil Co. (Indiana) but previously a joint venture with Halcon International, Inc. It covers air oxidation techniques for various alkylated benzenes. Originally, the work concentrated on oxidising para-di-isopropyl benzene to terephthalic acid but later development efforts were based on para-xylene because of higher weight yields. Mixed xylenes can also be oxidised and the products separated to obtain TPA, phthalic anhydride, isophthalic acid and benzoic acid. Because of the use of bromine and acetic acid construction with expensive alloys is required.

In 1958 Amoco Chemical began operating a mixed xylenes oxidation plant at Joliet, Illinois. The Amoco process has been widely licensed (e.g. ICI, Mitsui, Maruzen, Montedison) and virtually all world production of fibre grade TPA is based on this technology.

This process is a liquid phase air oxidation, involving as catalysts heavy metal and a form of bromine. It is known that oxidation of alkyl benzenes with oxygen occurs by means of a free-radical chain mechanism. Formation of the dicarboxylic acid is possible if an organic acid medium such as acetic acid and a metal catalyst are used. Cobalt and manganese are the most common metals used.

Details of the actual plants are kept secret. This description has been synthesised from information available in the literature, primarily patents, and the application of engineering judgment. It represents what we believe to be a reasonable operating scheme for this process.

The catalyst and some recycle acetic acid are mixed in the catalyst dissolving tank before being pumped to the feed mix tank. The preferred catalyst is apparently a combination of a manganous and cobaltous salt. In addition, bromine, either elemental or in the form of a bromine compound, is added as a promoter.

The catalyst solution is mixed in the feed mix tank with para-xylene and acetic acid before being pumped to the oxidation reactors. Recycle acetic acid is added at this point. The amount of catalyst and solvent used, as well as operating conditions, must be tailored for optimum yields and product quality.

The oxidation can be conducted batchwise, semi-continuously, or continuously, but it is expected that newer installations of substantial size will probably be continuous. In a continuous process the feed would enter the top of the reactor and the reaction mixture leave the bottom. The air would enter at the bottom of the reactor and the unreacted gas leave the top. The oxidation reaction is highly exothermic and the heat of the reaction is removed by condensing and refluxing solvent para-xylene and water vapours. Temperature and pressure in the reactor are held at 200°C and 14 atm. The pressure is required to maintain the liquid phase. Reaction time is 1/2 to 1 hour and yield for this step is reported to be close to 95 mole percent. Overall yield of 87 percent of theoretical based on p-xylene was assumed in this design. Oxygen absorption is extremely rapid. A limitation of oxygen availability to the propagating free-radical chains can lead to undesirable by-products, some of them coloured. Oxygen must, therefore, be supplied to the reaction zone in excess of the stoichiometric requirements.

The reactor products are continuously discharged from the reactor as a hot slurry into a crystalliser where cooling takes place by flashing off part of the acetic acid, unreacted para-xylene, and water of reaction. Further cooling takes place in the cooling vessel before the slurry is sent to a centrifuge. The crude TPA is dried and conveyed to a storage hopper for further purification to fibre grade TPA.

The liquid from the centrifuge is sent to a surge drum prior to recovery of the acetic acid for recycle. The recovery process involves a two tower system. In the acetic acid recovery column the acetic acid and water are taken overhead and the higher boiling bottoms either disposed of or treated to recover useful material. This stream contains the catalyst and promotor, other products and tars. The acetic acid is separated from the water in the acetic acid dehydration column. The pure acetic acid from the bottom of the column is recycled to the oxidation reactors. The gases from the reactors, crystallisers and cooling vessel are contacted with water in an absorber to recover any acetic acid and the absorber bottoms sent to the acetic acid dehydration column. No provision is made in this design for the recovery of the catalyst.

There are a number of procedures available for the purification of the crude TPA to fibre grade TPA. In this design use is made of a hydrogenation step to remove impurities which would result in discolouration of the final fibre. The crude TPA is conveyed to a slurry vessel where it is contacted with hot water. The resulting slurry is centrifuged and the solid washed with additional hot water. The filtrate and wash water are discarded. The crystals are conveyed to the slurry vessel where it is reslurried with hot water and fed to the dissolver. The dissolver is maintained at a pressure of approximately 40 atm and a temperature of 250°C. The aqueous solution of TPA with colour impurities are contacted with hydrogen in the hydrogenation reactor. The catalyst, palladium on carbon which has adsorbed hydrogen, reacts with the impuritities. The small hydrogen stream is necessary to replace the hydrogen removed from the catalyst surface by reaction. The reactor effluent is sent to the crystalliser and then is centrifuged. The mother liquor is partly recycled and partly sent to disposal. After a further wash with hot water the wet crystals are dried, cooled and the final fibre grade TPA conveyed to storage.

Because of the corrosive nature of the process, careful attention must be paid to materials of construction. Hastelloy C or titanium is required in all equipment that is in contact with more than a trace amount of bromine.

SECTION VIII : DERIVATIVES UNITS

Contents **Page No.**

Equipment handling acetic acid and water requires 316 SS. In the purification of TPA, titanium is specified in many areas to reduce contamination of the final product with iron.

Comments made previously for the Hercules-Witten-Dynamit process are equally valid for this process. Continual modifications are made and in many cases are kept secret. For example, Maruzen has altered the manganese-to-cobalt ratio in the catalyst and the method of purifying crude TPA. Mitsubishi has reportedly developed a new method for purifying crude TPA which employs an aqueous catalyst system.

c) Mobil Process

The Mobil process for manufacture of fibre grade TPA was in successful operation for several years at Mobil Chemicals' Beaumont, Texas petrochemical complex, but it has recently been shut down. In early 1963, Mobil purchased exclusive worldwide rights to certain patents and know-how developed by the Olin-Mathieson Chemical Co. related to the liquid phase oxidation of alkyl aromatics to polybasic acids and the partial purification of these acids. Mobil continued development work to improve the process and to purify further the product to fibre grade TPA. In 1966 Mobil began operation of a fibre grade TPA plant. Initial capacity was about 35 000 tonnes/year, and was continually expanded until Mobil went out of the business recently.

The basic chemistry for this process involves the conversion of para-xylene to terephthalic acid with either air or oxygen in an acetic acid liquid medium in the presence of a soluble cobalt catalyst and an activator. As practiced by Mobil, oxygen of 95+ percent purity and methyl ethyl ketone as the activator were employed.

The process consists of six basic steps:

- A catalytic liquid-phase oxidation using gaseous dissolved oxygen with all reactants held in a mutual solvent
- Separation of crude TPA crystals from the solvent phase
- Removal of gross impurities from the crude crystals by partially dissolving them in purified solvent
- Separation of TPA solids from the solvent and drying to produce technical grade TPA. This material is suitable for DMT manufacture but unsuitable without further purification for polyester fibre manufacture.
- Separation of the reactor solvent phase by means of distillation into purified solvent, some unreacted xylene and MEK, and intermediate products for recycle to the oxidation step. Water of reaction and by-product acetic acid are separated.
- Final purification of the semi-pure TPA crystals by sublimation followed by catalytic treatment in the vapour phase and subsequent crystallisation.

d) Henkel I (Teijin) Process

The Henkel processes were invented and piloted in Germany but the only substantial production has been in Japan. Basically, toluene, ortho-xylene or naphthalene, which are converted to benzoic or phthalic acids, are used. The processes are based on the general principle that the potassium salt of a carboxylic acid attached to the benzene ring can be moved to another location in the ring - the more stable molecule being the para dicarboxylic potassium salt. Henkel I, in which phthalic anhydride feedstock is used, has been employed by Teijin and Kawasaki.

The Henkel I Process, as practiced by Teijin, is divided into the following three steps:

- Isomerisation - Isomerisation of the dipotassium phthalate into dipotassium terephthalate
- Purification - The isomerisation products are dissolved in water and are separated from water-insoluble impurities. The separated isomerised products are then purified into high purity TPA
- Potassium Recovery - Used potassium is recovered almost quantitatively

e) Henkel II (Mitsubishi) Process

The Henkel II process, as practiced by Mitsubishi, employs the disproportionation of potassium benzoate into dipotassium terephthalate and benzene. As with Henkel I the process is based on the general principle that the potassium salt of a carboxylic acid attached to a benzene ring can be moved to another location in the ring. In the Henkel II process benzoic acid is employed as the feedstock. Phillips Petroleum is involved in developmental work on variations of this process.

f) Nitric Acid Oxidation Process

The nitric acid oxidation process was a development of Imperial Chemical Industries and is currently employed by

DuPont in the United States. It involves a two stage oxidation of p-xylene. Yields are good but it has generally been used where a nitric acid plant is in close proximity so that the lower oxides of nitrogen produced in the process can be reconverted to nitric acid. The product from this process is not of fibre grade. It is usually converted to dimethyl terephthalate by reaction with methanol. ICI has licensed this process in a number of countries including Germany and Japan. At present, ICI, DuPont, Hoechst, Rhone-Poulenc and Montedison use this process.

The process involves a two step oxidation. In the first stage p-xylene is rapidly oxidised to p-toluic acid. The second stage involves the further oxidation of p-toluic acid to TPA. During the oxidation, the nitric acid decomposes to gaseous nitrogen oxides which are recycled to the nitric acid plant.

The first stage of oxidation is operated at about 130-160°C using 30-40 wt. percent nitric acid. The relatively low temperature prevents oxidation to terephthalic acid at this stage. This is necessary so that the TPA precipitate does not occlude the p-toluic acid. In the second stage the temperature is raised to about 220°C and the nitric acid concentration adjusted to about 30 wt. percent. Careful pressure control is required to avoid buildup of potentially explosive nitrogen oxides within the reactor. The technique may be varied to use air oxidation in the first stage to obtain p-toluic acid followed by nitric acid oxidation to terephthalic acid.

Nitric acid and p-xylene are fed to the first of a two stage reaction system arranged in series. In the first stage, operated at a temperature of about 140°C the p-xylene is converted to p-toluic acid. In the second stage reactor, the temperature is increased to about 220°C, and at this temperature the p-toluic acid is further oxidised to terephthalic acid. The reactor product is sent to a crystalliser where TPA is crystallised out. The slurry is separated into wet crystals of crude TPA and aqueous HNO_3. The wet crystals are washed and dried before being sent to storage. Major impurities are nitrogen compounds which are extremely difficult to remove, thus making this process unsuitable for the production of fibre grade TPA.

The mother liquor and wash water from the centrifuge is sent to a series of three distillation columns. In the flash column, dissolved TPA is separated from the nitric acid and recycled to the crystalliser. In the second column the nitric acid is concentrated and the water taken overhead and recycled to the first stage reactor and the bottoms recycled to the crystalliser.

3. Cost of Production

Typical DMT and TPA plant sizes in Europe are in the range 50-150 000 tonnes/year, with US plants being around the upper end of this size range. For the purposes of these evaluations we assume a capacity of 100 000 tonnes/year. For the Hercules or Amoco processes this would absorb around 50 percent of the maximum paraxylene available from the Arab aromatics complex described in Section VII.

Capital and operating costs are based upon recent in-depth Chem Systems studies. Working capital is included as 20 of BLCC for all processes.

Cost of Production sheets for all processes are first presented on a W. European basis. These clearly demonstrate that the Amoco process has superior economics as compared to the other commercial fibre-grade TPA processes. In addition, its absence of co-feeds and co-products, and its extensive commercial experience are substantial advantages. It is also shown that DMT production cost is lower than that of TPA even via the Amoco process. Licensing fees are excluded from all evaluations, since these are believed to vary widely and can only be defined by direct negotiations with the licensor at the project planning stage.

In all developed market regions, TPA price is at approximately the same level as DMT, mainly due to the pricing policy of Amoco who set TPA merchant market prices equal to the current DMT price. Thus a company considering production for the merchant market would realise greater profits from DMT rather than TPA. An operation including polyester production can favour the TPA route, however. Approximately 17 percent more DMT than TPA is required to produce a tonne of polyester fibre. In addition capital investment for a polyester fibre plant based on TPA is said to be substantially less than that of one based on DMT. Since most companies considering DMT or TPA production for the first time are generally planning to integrate backward from the fibre or forward to the fibre (and this would presumably include - in the long term - any Arab project) these advantages of TPA can often make a TPA complex the prefered option even though DMT production costs are lower than those of TPA.

Due to the entrenched market positions of Hercules, Amoco and others in the US/European merchant markets, and due also to the projected worldwide overcapacity, it seems unlikely that an Arab project could penetrate these markets on a large scale. The main justification for an Arab project would therefore only come from an operation integrated into polyester fibre production. Since polyester plant economics, royalty payments and technical expertise in this area can only be defined by further detailed studies outside the scope of this report, we present Cost of Production sheets for both the Hercules DMT process and the Amoco TPA process for the two Arab locations.

For the DMT process, methanol price at the Arab locations is arbitrarily set at the same level as the European value. If local large-scale production based upon cheap natural gas were available a lower methanol price would apply: if no local production existed, methanol would have to be shipped in from developed market regions at higher prices.

Tables VIII.G.1. to VIII.G.6. present Cost of Production sheets of the six processes considered for a West European location. The results are summarised in Table VIII.G.11, below:

TABLE VIII-G-1

FIBRE-GRADE DMT PRODUCTION COST ESTIMATE: W EUROPE

HERCULES - WITTEN - DYNAMIT PROCESS

Basis:			Capital Cost	$MM
	Location-	W Europe 1980	Battery Limits Capital Cost	40
	Capacity-	100 000 tpa DMT	Offsites Capital Cost	20
	Rate -	90 000 tpa	Total Fixed	60
			Working	8

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	60 750	tonne	580	35 235 000	
Methanol	40 000	tonne	200	8 000 000	
Catalyst & Chemicals		$		900 000	
TOTAL RAW MATERIALS:				44 135 000	490.4
UTILITIES:					
Power	54 000	1000 Kwh	43.5	2 349 000	
Cooling Water	43 000	1000 m^3	16	688 000	
Fuel	125 000	10^6 Kcal	11.6	1 450 000	
Steam	360 000	tonne	9.6	3 456 000	
TOTAL UTILITIES COST:				7 943 000	88.3
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				1 600 000	
TOTAL OPERATING COSTS:				2 278 000	25.3
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				1 481 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				900 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 000 000	
Interest - 10% on Working Capital				800 000	
TOTAL OVERHEAD EXPENSES:				8 384 000	93.2
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				62 740 000	697.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				15 000 000	166.7
TRANSFER PRICE:				77 740 000	863.9

* $/unit

TABLE VIII-G-2

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: W EUROPE

AMOCO PROCESS

Basis: **Location** - W Europe 1980
Capacity - 100 000 tpa TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	60
Offsites Capital Cost	30
Total Fixed	90
Working	12

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	65 250	tonne	580	37 845 000	
Catalyst & Chemicals				3 300 000	
TOTAL RAW MATERIALS:				41 145 000	457.2
UTILITIES:					
Power	85 000	1000 Kwh	43.5	3 698 000	
Cooling Water	33 000	1000 m^3	16	528 000	
Fuel	160 000	10^6 Kcal	11.6	1 856 000	
Steam	60 000	tonne	9.6	576 000	
Others		$		1 400 000	
TOTAL UTILITIES COST:				8 058 000	89.5
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 400 000	
TOTAL OPERATING COSTS:				3 078 000	34.2
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				2 000 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 350 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 500 000	
Interest - 10% on Working Capital				1 200 000	
TOTAL OVERHEAD EXPENSES:				12 253 000	136.1
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				64 534 000	717.0
RETURN 25% ON TOTAL FIXED INVESTMENT:				22 500 000	250.0
TRANSFER PRICE:				87 034 000	967.0

* $/unit

TABLE VIII-G-3

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: W EUROPE

MOBIL PROCESS

Basis:	**Location-**	W Europe 1980	
	Capacity-	100 000 tpa TPA	
	Rate -	90 000 tpa	

Capital Cost	$MM
Battery Limits Capital Cost	54
Offsites Capital Cost	27
Total Fixed	81
Working	11

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	61 200	tonne	580	35 496 000	
MEK	21 600	tonne	740	15 984 000	
Oxygen	90 000	tonne	40	3 600 000	
Catalyst & Chemicals		$		400 000	
TOTAL RAW MATERIALS:				55 480 000	616.4
UTILITIES:					
Power	22 000	1000 Kwh	43.5	957 000	
Cooling Water	10 000	1000 m^3	16	160 000	
Fuel	275 000	10^6 Kcal	11.6	3 190 000	
Steam	900 000	tonne	9.6	8 640 000	
Others		$		1 000 000	
TOTAL UTILITIES COST:				13 947 000	155.0
OPERATING COSTS:					
Labour 26 men @ $19 000 pa				494 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 160 000	
TOTAL OPERATING COSTS:				2 762 000	30.7
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				181 000	
General Plant Overhead - 65% Operating Costs				1 795 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 215 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 750 000	
Interest - 10% on Working Capital				1 100 000	
TOTAL OVERHEAD EXPENSES:				11 041 000	122.7
BYPRODUCT CREDIT:					
Acetic acid (glacial)	23 400	tonne	580	13 572 000	
TOTAL BYPRODUCT CREDIT:				(13 572 000)	(150.8)
TOTAL COST OF PRODUCTION:				69 658 000	774.0
RETURN 25% ON TOTAL FIXED INVESTMENT:				20 250 000	229.0
TRANSFER PRICE:				89 908 000	1 003.0

* $/unit

TABLE VIII-G-4

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: W EUROPE

HENKEL I PROCESS

Basis: **Location-** W Europe 1980
Capacity- 100 000 tpa TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	61
Offsites Capital Cost	31
Total Fixed	92
Working	12

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Orthoxylene	85 500	tonne	430	36 765 000	
Catalyst & Chemicals				7 200 000	
TOTAL RAW MATERIALS:				43 965 000	488.5
UTILITIES:					
Power	222 000	1000 Kwh	43.5	9 657 000	
Cooling Water	38 000	1000 m^3	16	608 000	
Fuel	175 000	10^6 kcal	11.6	2 030 000	
Steam	403 000	tonne	9.6	3 869 000	
Other		$		1 500 000	
TOTAL UTILITIES COST:				17 664 000	196.3
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 440 000	
TOTAL OPERATING COSTS:				3 118 000	34.6
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				2 027 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 380 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				7 650 000	
Interest - 10% on Working Capital				1 200 000	
TOTAL OVERHEAD EXPENSES:				12 460 000	138.4
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				77 207 000	857.8
				23 000 000	255.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				100 207 000	1 113.4
TRANSFER PRICE:					

* $/unit

TABLE VIII-G-5

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: W EUROPE

HENKEL II PROCESS

Basis: **Location-** W Europe 1980
Capacity- 100 000 tpa TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	55
Offsites Capital Cost	28
Total Fixed	83
Working	11

RAW MATERIALS	**QUANTITY**	**UNIT**	**PRICE***	**ANNUAL COST**	**UNIT COST***
Toluene	121 500	tonne	257	31 226 000	
Potassium Hydroxide	72 000	tonne	230	16 560 000	
Sulphuric Acid	65 000	tonne	80	5 200 000	
Catalyst & Chemicals		$		8 500 000	
TOTAL RAW MATERIALS:				61 486 000	683.2
UTILITIES:					
Power	200 000	1000 Kwh	43.5	8 700 000	
Cooling Water	57 000	1000 m^3	16	912 000	
Fuel	250 000	10^6 kcal	11.6	2 900 000	
Steam	1 080 000	tonne	9.6	10 368 000	
Others		$		1 400 000	
TOTAL UTILITIES COST:				24 280 000	269.8
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 200 000	
TOTAL OPERATING COSTS:				2 878 000	32.0
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				1 871 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 245 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 900 000	
Interest - 10% on Working Capital				1 100 000	
TOTAL OVERHEAD EXPENSES:				11 319 000	125.8
BYPRODUCT CREDIT:					
Benzene	44 000	tonne	420	18 480 000	
Potassium Sulphate	108 000	tonne	90	9 720 000	
TOTAL BYPRODUCT CREDIT:				(28 200 000)	(313.3)
TOTAL COST OF PRODUCTION:				71 763 000	797.5
RETURN 25% ON TOTAL FIXED INVESTMENT:				20 750 000	230.6
TRANSFER PRICE:				92 513 000	1 028.1

* $/unit

TABLE VIII-G-6

CRUDE TPA PRODUCTION COST ESTIMATE: W EUROPE

NITRIC ACID OXIDATION PROCESS

Basis: **Location-** W Europe 1980
Capacity- 100 000 tpa Crude TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	50
Offsites Capital Cost	25
Total Fixed	75
Working	10

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	63 200	tonne	580	36 656 000	
Nitric Acid	73 800	tonne	290	21 402 000	
Catalyst & Chemicals				200 000	
TOTAL RAW MATERIALS:				58 258 000	647.3
UTILITIES:					
Power	20 000	1000 Kwh	43.5	870 000	
Cooling Water	89 000	1000 m^3	16	1 424 000	
Fuel	125 000	10^6 Kcal	11.6	1 450 000	
Steam	2 075 000	tonne	9.6	19 920 000	
TOTAL UTILITIES COST:				23 664 000	262.9
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 000 000	
TOTAL OPERATING COSTS:				2 678 000	29.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				1 741 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 125 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 250 000	
Interest - 10% on Working Capital				1 000 000	
TOTAL OVERHEAD EXPENSES:				10 319 000	114.7
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				94 919 000	1 054.7
RETURN 25% ON TOTAL FIXED INVESTMENT:				18 750 000	208.3
TRANSFER PRICE:				113 669 000	1 263.0

* $/unit

TABLE VIII-G-7

FIBRE-GRADE DMT PRODUCTION COST ESTIMATE: N AFRICA

HERCULES-WITTEN-DYNAMIT PROCESS

Basis: **Location-** N Africa 1980
Capacity- 100 000 tpa DMT
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	46
Offsites Capital Cost	25
Total Fixed	71
Working	9

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	60 750	tonne	569.9	34 621 000	
Methanol	40 000	tonne	200	8 000 000	
Catalyst & Chemicals		$		900 000	
TOTAL RAW MATERIALS:				43 521 000	483.6
UTILITIES:					
Power	54 000	1000 Kwh	27	1 458 000	
Cooling Water	43 000	1000 m^3	12	516 000	
Fuel	125 000	10^6 Kcal	4.9	613 000	
Steam	360 000	tonne	4.3	1 548 000	
TOTAL UTILITIES COST:				4 135 000	45.9
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				1 840 000	
TOTAL OPERATING COSTS:				2 518 000	28.0
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				1 637 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 065 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				5 850 000	
Interest - 10% on Working Capital				900 000	
TOTAL OVERHEAD EXPENSES:				9 655 000	107.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				59 829 000	664.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				17 750 000	197.2
TRANSFER PRICE:				77 579 000	862.0

* $/unit

TABLE VIII-G-8

FIBRE-GRADE DMT PRODUCTION COST ESTIMATE: ARABIAN GULF

HERCULES-WITTEN-DYNAMIT PROCESS

Basis: **Location-** Arabian Gulf 1980
Capacity- 100 000 tpa DMT
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	50
Offsites Capital Cost	28
Total Fixed	78
Working	10

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	60 750	tonne	569.3	34 585 000	
Methanol	40 000	tonne	200	8 000 000	
Catalyst & Chemicals		$		900 000	
TOTAL RAW MATERIALS:				43 485 000	483.2
UTILITIES:					
Power	54 000	1000 Kwh	22.4	1 210 000	
Cooling Water	43 000	1000 m^3	12	516 000	
Fuel	125 000	10^6 Kcal	2	250 000	
Steam	360 000	tonne	2.7	972 000	
TOTAL UTILITIES COST:				2 948 000	32.8
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material **and Labour @ 4% BLCC**				2 000 000	
TOTAL OPERATING COSTS:				2 678 000	29.8
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				1 741 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 170 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				6 400 000	
Interest - 10% on Working Capital				1 000 000	
TOTAL OVERHEAD EXPENSES:				10 514 000	116.8
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				59 625 000	662.6
RETURN 25% ON TOTAL FIXED INVESTMENT:				19 500 000	216.7
TRANSFER PRICE:				79 125 000	879.3

* $/unit

TABLE VIII-G-9

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: N AFRICA

AMOCO PROCESS

Basis: Location- N Africa 1980
Capacity- 100 000 tpa TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	69
Offsites Capital Cost	38
Total Fixed	107
Working	14

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	65 250	tonne	569.9	37 186 000	
Catalyst & Chemicals				3 300 000	
TOTAL RAW MATERIALS:				40 486 000	449.8
UTILITIES:					
Power	85 000	1000 Kwh	27	2 295 000	
Cooling Water	33 000	1000 m^3	12	396 000	
Fuel	160 000	10^6 Kcal	4.9	784 000	
Steam	60 000	tonne	4.3	258 000	
Others		$		1 400 000	
TOTAL UTILITIES COST:				5 133 000	57.0
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				2 760 000	
TOTAL OPERATING COSTS:				3 438 000	38.2
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				2 235 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 605 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				8 800 000	
Interest - 10% on Working Capital				1 400 000	
TOTAL OVERHEAD EXPENSES:				14 243 000	158.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				63 300 000	703.3
RETURN 25% ON TOTAL FIXED INVESTMENT:				26 750 000	297.2
TRANSFER PRICE:				90 050 000	1 000.5

* $/unit

TABLE VIII-G-10

FIBRE-GRADE TPA PRODUCTION COST ESTIMATE: ARABIAN GULF

AMOCO PROCESS

Basis: **Location-** Arabian Gulf 1980
Capacity- 100 000 tpa TPA
Rate - 90 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	75
Offsites Capital Cost	41
Total Fixed	116
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Paraxylene	65 250	tonne	569.3	37 147 000	
Catalyst & Chemicals				3 300 000	
TOTAL RAW MATERIALS:				40 447 000	449.4
UTILITIES:					
Power	85 000	1000 Kwh	22.4	1 904 000	
Cooling Water	33 000	1000 m^3	12	396 000	
Fuel	160 000	10^6Kcal	2	320 000	
Steam	60 000	tonne	2.7	162 000	
Others		$		1 400 000	
TOTAL UTILITIES COST:				4 182 000	46.5
OPERATING COSTS:					
Labour 30 men @ $19 000 pa				570 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				3 000 000	
TOTAL OPERATING COSTS:				3 678 000	40.9
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				203 000	
General Plant Overhead - 65% Operating Costs				2 391 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 740 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				9 550 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				15 384 000	170.9
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				63 691 000	707.7
RETURN 25% ON TOTAL FIXED INVESTMENT:				29 000 000	322.2
TRANSFER PRICE:				92 691 000	1 029.9

* $/unit

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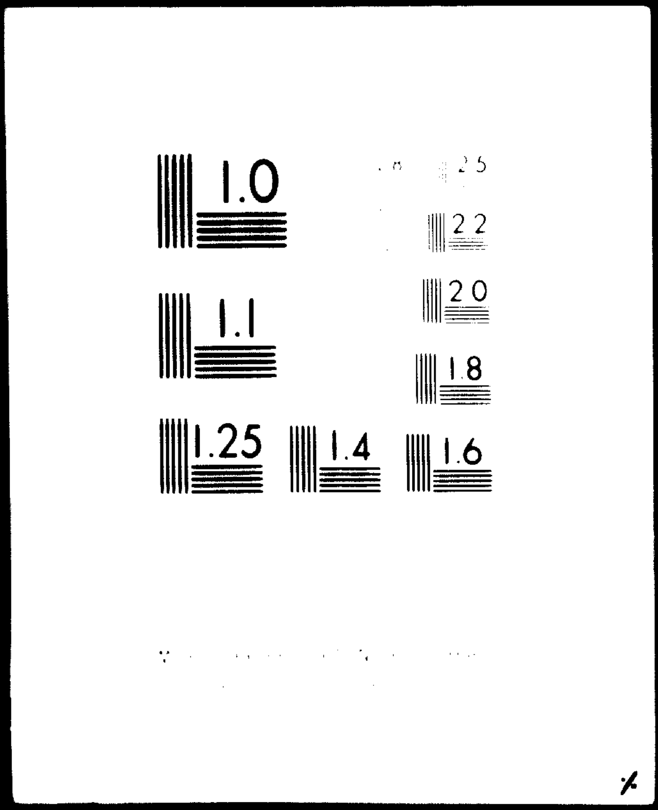
8 OF 9



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SECTION IX

SECTION IX : SHIPPING ANALYSES

Contents **Page No**

Page No

SECTION IX : SHIPPING ANALYSES

IX SHIPPING ANALYSES

A. INTRODUCTION

This section presents analyses of the methods and costs of shipping each of the selected products. In the case of highly specialised shipping requirements (e.g. liquid ethylene) the availability of suitable shipping facilities is estimated with projections made up to 1990.

Typical North African and Arabian Gulf producing locations are assumed and shipping distances from each to various market regions are tabulated. Based upon a judgement of likely markets and volumes for each product from each producing location, typical costs of shipping to market are calculated. These costs are used in Section X (Economic Evaluations) to calculate the average achievable Transfer Prices of the various products from the Arab projects, based upon shipping to world markets.

The various feedstocks and petrochemical products can be grouped into categories, based upon the type of ship required. These categories are as follows:

- LPG - includes propane, butane, propylene, VCM, butadiene and mixed C_4 streams
- Ethylene

- LNG - included to substantiate natural gas economics in Section V
- Clean products - includes "white" oil products such as naphtha and gasoil. Also, for cost purposes, includes liquid chemicals such as ethylene glycol, benzene, pyrolysis gasoline, p-xylene etc., which use similar ships
- Dirty products - includes "black" oil products, primarily heavy fuel oil and pyrolysis fuel oil
- Crude oil
- Dry products - includes resin products such as polyethylene and polystyrene

B. METHOD OF COST CALCULATIONS

1. General

Shipping costs are generally considered and discussed in terms of "spot" or "time charter" rates for the hire of a vessel for a certain period.

Spot fixtures are arrangements made at short notice and generally cover the hire of a vessel for only a single voyage. The costs of such fixtures are therefore very sensitive to the supply/demand situation for the type of ship in question at a particular moment, which for oil and oil products is itself greatly influenced by political factors. Spot rates are thus extremely volatile, with variations by a factor of three over the course of a year being quite common. As such, they are almost completely unpredictable with any degree of certainty, and are of no use in long-term forecasting.

Time charters are medium/long-term arrangements typically covering periods of one to five years. The price levels at which such charters are fixed are more stable than the spot market, but are still heavily influenced by the state of the market at the time of fixing the contract. Only when the length of the charter period for a new ship is of the order of ten years or more does a relatively stable price situation emerge. For periods of this order, the arrangement is not really a time charter in the accepted sense, but becomes more of a leasing arrangement over the working life of the vessel. Against such a long-term contract, the shipowner can arrange finance for the cost of the new ship (newbuilding cost). The contract is then insulated to a large extent from fluctuations in the shipping market, since profitability to the owner can be assured by setting the charter rate at a level which will cover operating costs and capital repayments, and allow an acceptable margin for profit.

The most realistic way to estimate future shipping costs, however, is to analyse the various components of the total cost, and estimate these individually for the particular product, time, location and scale. The structure of the freight market is logical, and on average the long-term cost of shipping will be a true reflection of the various cost elements involved. These cost elements are

- capital charges - includes loan repayments, interest and profit
- bunker costs - this is the cost of ship's fuel
- operating costs - includes crew wages, food, stores/supplies, repair/maintenance, insurance and administration costs
- port costs - includes port charges, pilotage fees, towage and boatmen, and agency charges

All vessels are assumed to operate for 340 working days per year (8160 hours p.a.).

2. Capital Charges

Since shipowning is an international industry it is difficult to generalise about standard terms which shipowners obtain in financing vessels, and about the return on investment which they expect to receive from shipping. However, all the different owners who build vessels in various countries, with different finance, and operate them under different flags and tax systems, must eventually compete in the same market. It is therefore reasonable for our present purposes to consider the situation of a typical independant shipowner, buying new ships in a stable balanced market in 1976-77 for delivery at the beginning of 1980, with operation under a "flag of convenience" such as Liberian.

a) Financing

Under OECD financing, which covers the vast majority of independantly owned shipping not operating on preferential trades (e.g. domestic Japanese, French or US trades), loan terms available to shipowners in recent years have been as follows:

- payment of the vessel's capital cost to the building yard on a 25/25/25/25 basis; the first and last payments on ordering and delivery respectively, the other two equally spread out during the building programme

- 70-80 percent of total cost covered by the loan, with the rest to be paid by the owner before the bank assists with loan payments

- loan repayable over 7-8 years at 7-8 percent per annum interest.

At certain times, governments of the major shipbuilding nations are forced to support their shipbuilding industries with competitive subsidies of one form or

TABLE VIII.G.11.

W. EUROPEAN 1980 TRANSFER PRICES FOR DMT AND TPA VIA ALTERNATE PROCESS ROUTES

Process	Product	$/tonne
Hercules-Witten-Dynamit	Fibre-grade DMT	864
Amoco	Fibre-grade TPA	967
Mobil	Fibre-grade TPA	1 003
Henkel I	Fibre-grade TPA	1 113
Henkel II	Fibre-grade TPA	1 028
Nitric Acid Oxidation	Crude TPA	1 263

Tables VIII.G.7. to VIII.G.10. present Cost of Production sheets of the two preferred processes (Hercules and Amoco) for Arab locations. The DMT and TPA transfer prices thus calculated are $862 and $1 000 per tonne respectively for the N. African location; $879 and $1 030 per tonne for the Arabian Gulf location.

These results confirm that there is little possibility of production in the Arab states for export to developed markets, even if overcapacity in these markets did not exist. The desirability of DMT/TPA production therefore depends upon the demand for and economics of an Arab polyester fibre complex, which is outside the scope of this present study.

another. Such subsidies generally occur at times of depressed markets, but occasionally a particular country decides to regenerate its shipping industry by giving very competitive subsidies at any time. However, the OECD terms, above, represent a good approximation to typical shipbuilding finance terms.

b) Profit

A discussion of typical shipping profit levels is even more difficult than of typical financing terms. Different shipowners use various accounting procedures, and each owner is in an individual tax situation depending upon flags of the vessels, etc. Under flags of convenience company tax may be very low, and restrictions on how the owner insures, crews and maintains vessels can be flexible.

In general, it is found that the market accepts on average a net profit to owners of at least 10-15 percent (on a discounted cash flow basis). This means that after tax an owner can expect to make 10-15 percent (minimum) on his investment in a new ship.

c) Summary

Assuming typical OECD financing, a capital charge of 15 percent per year during an assumed 15 year operating life will give the desired DCF return of nearly 15 percent per year. An annual capital charge of 15 percent of capital cost is therefore assumed in all shipping cost analyses in this study. Capital costs of the different ship types and sizes are listed in the following sections.

3. Bunker Costs

Different types and sizes of ship can burn different grades of fuel oil and sometimes a mixture of grades for various services (main power unit, auxilliary services etc). In general, however, heavy high sulphur fuel oil will be the dominant fuel for the ships under consideration in this study.

Fuel consumption at sea will be far greater than consumption when in port, at which time basically only auxilliaries are required. Consumption rate in port is typically 15-25 percent of "at sea" consumption. Since time at sea for the routes under consideration in this study is normally 90 percent or more of total round-trip time, a simplifying assumption is made that average bunkers consumption is 95 percent of the "at sea" rate. These average consumption rates are listed for each ship type and size in the following sections.

A bunkers price of 10 percent below crude oil price is assumed, equal to the average residual fuel price predicted in Section V.B of $108 per tonne in 1980.

4. Operating Costs

This comprises the following items:

- Wages, which includes all wages, salaries and bonuses payable to the ship's crew. The number of crew required by modern ships varies only very slightly between one ship type and another, and between one size and another. We make the simplifying assumption here that crew costs for all ship types will be $800 000 in 1980, based upon an average complement of 32 men. Two thirds of this total is for certificated deck and engine officers, so the addition of a few extra unskilled crew will have little effect on this total wages bill.

- Victualling, which includes the purchase of foodstores and provisions for consumption by the ship's crew (whose service is on an "all found" basis), and the replenishment of captain's stores, used for entertaining. A cost equal to 10 percent of crew wages is assumed.

- Stores and Supplies, which relates basically to engine and auxilliary machine parts, consumable supplies such as lube oil, greases and paint. An average cost equal to ½ percent p.a. of ship capital cost is assumed.

- Repair and Maintenance; costs vary widely with vessel type and also with supply/demand for drydocking facilities. A simplifying assumption is made that R and M costs equal 1 percent p.a. of the newbuilding cost, which is about right for tankers and bulk carriers, and somewhat conservative for sophisticated types such as LNG carriers.

- Insurance; this comprises hull and machinery insurance, (covering loss and damage to the vessel itself), plus protection and indemnity insurance (covering loss of life of crew and third parties, cargo loss or damage and damage to other property or vessels). A simplifying assumption of 2 percent p.a. of the newbuilding cost is used.

- Administration and other costs; these vary widely from vessel to vessel reflecting internal accounting procedures operated by various owners. Typical allowances for a large independant shipowner are used in this study, based upon 40 percent of crew wages.

5. Port Costs

Charges made by port authorities, or those providing services within ports are of two kinds; one component being the dues and charges on the vessel arising from port entry and berthing, payable by the shipowner, the other being the costs arising from the actual discharge of the vessel's cargo, this being to the charterer's or cargo recipient's account. Here we are only concerned with charges on ships. The major constituents of the port costs payable by ship owners are as follows:

a) Port Charges

These charges vary widely between countries and ports, and include conservancy charges, ship dues, berth dues, harbour dues etc. They are generally based on one or other of the vessel's tonnage measurements, and are payable to the port authority, who use the derived revenue to maintain the harbour and approach channels, berthing facilities, and navigational aids.

b) Pilotage

Pilotage charges are established by the individual port authorities. They are generally based on vessel draft, NRT, GRT, or length (or combinations thereof) and are payable to the relevant port authority.

c) Towage and Boatmen

These services are generally provided by private companies operating within particular ports, although the port authority usually approves the tariff scales. Towage is invariably based on an NRT scale per tug, whilst boatmen's fees for mooring, unmooring and fendering are derived similarly on a 'per gang' basis.

d) Agency Charges

These payments are standardized by the various national associations of ship's agents. Payment to the particular port agent is on a standard national scale dependent on vessel size, for services and assistance rendered to the vessel whilst in port.

Estimation of the total of these costs is complex, since it varies with vessel tonnage, length, time in port, number of trips per year and other factors. For present purposes we base our estimates upon gross registered tonnage, number of trips and days in port only, as follows:

Annual port charges = $2 000 per port visit plus
$ 100 per 1 000 GRT
per day in port

6. Terminal Costs

Terminal charges are not generally included in these shipping costs. Loading costs are already included in the offsites estimates for the various Arab projects. Discharge/reception terminal charges are excluded since in general the Arab material will not be at any disadvantage in this respect compared to (say) European material: product will generally be discharged directly into tankage at the coastal petrochemical site in (say) Europe which will consume the product. Storage charges will thus be little different from charges on material produced in an adjacent plant. For simplicity, therefore, terminal costs are excluded for most products. Exceptions to this general treatment are ethylene and LNG. In these cases, terminal costs are very significant due to the high costs of cryogenic storage. Furthermore, these are costs which would not be incurred if the ethylene or natural gas were consumed local to the production site. The ethylene and LNG shipping analyses therefore include allowance for these terminal costs.

C. LOCATIONS AND DISTANCES

1. North Africa

The shipping distances from the prospective N. African petrochemicals complex to various world markets are tabulated below (Table IX-C-1) assuming a location near Tripoli. It must be stressed that this does not imply any recommendation regarding actual plant location: Tripoli merely represents a suitable mid - N. African location which will reflect an average of the shipping distances from Algerian, Libyan and Egyptian ports to world markets.

TABLE IX.C.1.

SHIPPING DISTANCES FROM N. AFRICAN LOCATION TO WORLD MARKETS

Southern Europe (e.g. Fos/Lavera)	750 n. miles
Northern Europe (e.g. Rotterdam)	2 500 n. miles
U.S. (average of East Coast & Gulf Coast)	5 000 n. miles

2. Arabian Gulf

On the same basis as above, the plant location assumed in the Arabian Gulf is around Ras Tanura. Table IX.C.2. gives the shipping distances involved. Passage via the Suez Canal is assumed for all routes to Europe and the U.S. Suez Canal dues are ignored since these are currently low compared to the total shipping costs for the main products considered here.

TABLE IX.C.2.

SHIPPING DISTANCES FROM ARABIAN GULF LOCATION TO WORLD MARKETS

Southern Europe (e.g. Fos/Lavera)	4 750 n. miles
Northern Europe (e.g. Rotterdam)	6 500 n. miles
U.S. (average of East Coast & Gulf Coast)	9 000 n. miles
Japan (e.g. Yokohama)	6 500 n. miles

D. LPG SHIPPING

1. General

Vessels capable of carrying liquified petroleum gas (LPG) and similar products may be of various specialised designs. At normal ambient temperature and pressure these products are gases. To enable economic shipment, either low temperatures or high pressures (or a combination of the two) must be employed to keep the product in the liquid state.

In general, small vessels (up to 5 000 cubic metres cargo capacity) are of the pressurised or semi-refrigerated type, whereas large vessels are fully refrigerated. Since the quantities of products involved in the present study are large, only fully refrigerated vessels will be considered here.

The LPG shipping business is presently extremely depressed, with many vessels inactive and low charter rates prevailing. The costs used in this analysis look beyond the present oversupply situation, and assume a newbuilding ordered under stable market conditions and delivered for use in 1980.

2. Sizes and Capital Costs

Vessel sizes ranging from 5 000 to 50 000 m^3 are considered, with costs as given below:

5 000 m^3	\$16 million
20 000 m^3	\$33 million
50 000 m^3	\$60 million

These vessels will be capable of carrying two or more grades of LPG-type products at the same time. Thus propylene and VCM could be carried in the same ship.

3. Shipping Costs

The various items relevant to cost calculations are summarised below for the three vessel sizes:

TABLE IX.D.1.

LPG SHIPPING COST ITEMS

	5 000 m^3	20 000 m^3	50 000 m^3
Av. speed (knots)	15	17	17
Av. bunkers consumption (tonnes/day)	16	45	60
Loading/unloading time (days each end)	1	1	1
Gross registered tonnage (tonnes)	4 200	14 000	32 000

The costs of shipping may now be calculated for any specified shipping distance, assuming that the vessel is fully utilised. Typical calculations are presented in Tables IX.D.2. and IX.D.3. for a route of 5 000 n. miles each way.

H. LOW DENSITY POLYETHYLENE (LDPE)

1. Introduction

LDPE production was pioneered by ICI in the U.K. during the 1930's. It has a branched structure with a specific gravity of around 0.92, and is produced at very high pressures of around 1 700 atmospheres.

LDPE is by far the largest outlet for ethylene in all major market regions, and despite market maturity is still showing good growth.

Either tubular or autoclave reactors can be used for LDPE production. Investment and operating costs for the two reactor types are similar, and any grade of resin can be produced in either reactor. The description below is of an ICI-type autoclave process, which is representative of most modern units.

2. Technology

Polymer grade ethylene (99.9 percent minimum purity) is compressed from supply pressure to 250 atmospheres in a reciprocating supply compressor. This fresh feed is then combined with recycle ethylene and compressed in a secondary compressor to the reaction pressure of around 1 700 atmospheres. Suitable quantities of a chain transfer agent (to control product molecular weight) and a reaction initiator are also added to the ethylene before or after compression. The ethylene is then fed to the stirred autoclave reactor. The autoclave is essentially adiabatic, with the heat required

TABLE IX.D.2.

CARRYING CAPACITY OF 20 000 m^3 LPG CARRIER

OVER 5 000 MILE RUN

Time at sea (per round trip) = $\frac{5\,000 \times 2}{17}$

= 588 hours

Contingency for bad weather, waiting time etc. = 5 percent

Time in port (per round trip) = 48 hours

Total round-trip time = (588 x 1.05) + 48

= 666 hours

Round trips per year = $\frac{8\,160}{666 \text{ hours}}$

= 12.25

Total carrying capacity per year = 12.25 x 20 000

= <u>245 000 m^3 p.a.</u>

(Port visits per year = 24. 5

Days in port per year = 24. 5)

TABLE IX.D.3.

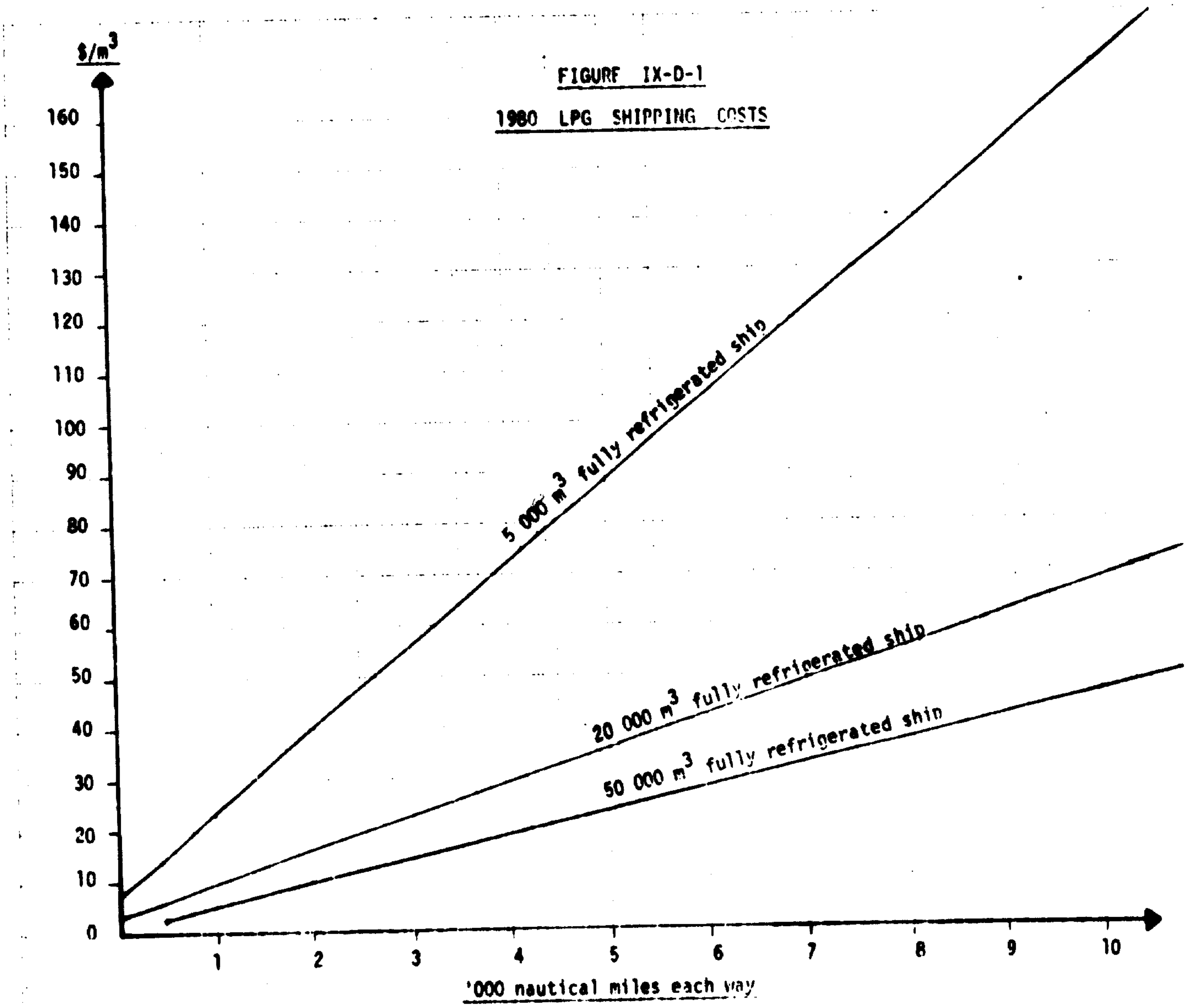
COSTS OF SHIPPING IN 20 000 m^3 LPG CARRIER OVER 5 000 MILE RUN

		$ million p.a.	
Capital charges (15% of $33 million)		4.95	
Bunkers costs		1.65	
Operating costs -	wages		0.80
	victualling		0.08
	stores		0.17
	R & M		0.33
	insurance		0.66
	admin.		0.32
		2.36	
Port Costs		0.08	
Total Annual Costs		$9.04 million p.a.	
Total product carried per year (Table IX.D.2.)		245 000 m^3 p.a.	
Unit shipping cost		$36.9 per m^3	

These calculations have been carried out for the various ship sizes over different voyage lengths. The results are shown on Figure IX.D.1.

FIGURE IX-D-1

1980 LPG SHIPPING COSTS



Variation in ship size is thus seen to have a very dramatic effect upon shipping costs. Over half of the total world LPG fleet (existing and on order) is of 50 000 m^3 capacity or greater. Above 50 000 m^3 cost savings are relatively small, and the quantities of material transported are so great that these vessels are only appropriate to the large volume "energy" trades, typically LPG from the Arabian Gulf to Japan, rather than the chemical products of prime interest in this study.

Judgement must therefore be made of the likely ship size to be used on a particular route for a particular product. Since these ships are capable of carrying several different products in separate tanks, even relatively small quantities of a particular product (e.g. butadiene or mixed cracker C4's) could benefit from large-ship economics provided large volumes of another LPG-type product (e.g. VCM) are being carried on the same run (it is seldom possible, however, to combine small volume chemicals such as C4's with large "energy" movements of LPG, since even a single tank of the large LPG tankers will be too large for the chemical material. Also different destinations will commonly be involved). Thus shipping costs for most products may depend upon the final selection of products and markets for the Arab projects. Since shipping cost data is required to assist in making this selection of products, a considerable degree of approximation is inevitable in these shipping cost numbers, but we believe them to be of sufficient accuracy for present purposes.

Table IX.D.4 summarises the shipping costs for the different products on various routes, using Figure IX.D.1 together with the considerations discussed above. The specific gravity (S.G.) of each product is indicated in the Table. Also included in the Table is an "average" cost of shipping each product from each Arab location (N. Africa and Arabian Gulf), based upon judgement of the most likely market distribution of the particular product from each location.

It is clear from Table IX.D.4 that shipping costs are by no means proportional to distance, since as distance increases so larger vessels can economically and logistically be used, with corresponding very large economies of scale.

TABLE IX.D.4.

1980 SHIPPING COSTS OF LPG-TYPE PRODUCTS ($/tonne)

	N. Africa					Arabian Gulf				
	LPG	Propylene	BN	VCM	C4's	LPG	Propylene	BN	VCM	C4's
S. Europe	20	40	50	30	50	40	80	100	55	100
N. Europe	35	70	80	45	80	50	100	120	65	120
U.S.	50	100	120	65	120	70	120	140	75	140
Japan	-	-	-	-	-	50	100	120	65	120
Weighted average	40	70	80	45	80	60	100	120	65	120

Notes

LPG includes propane, butane, and mixtures of these S.G. = 0.59

BN is butadiene S.G. = 0.65

VCM is vinyl chloride monomer S.G. = 0.96

C4's are the mixed C4 olefins from an ethylene plant S.G. = 0.63

Propylene S.G. = 0.60

E. ETHYLENE SHIPPING

1. General

Transportation of ethylene by sea is a relatively new development. Although 250 000 tonnes/yr. ethylene are being shipped around Europe at the present time, these movements are almost all in relatively small lots for balancing purposes. Outside Europe, liquid ethylene transportation is even less developed.

For regular deliveries, terminals should have approximately twice the capacity of the ships. Almost all existing liquid ethylene terminals in Europe and elsewhere are relatively small (5 000-20 000 tonnes) which means that large ships cannot be regularly used. Liquid ethylene transportation has therefore developed in a rather haphazard manner, with little coordination between ship and terminal construction. There is thus no indication, at the present time, that any major contract sales of ethylene are being planned on the basis of maritime transportation.

Several of the olefin projects being considered for the oil-producing states, however, have included proposals for the direct export of liquid ethylene to the industrialised countries, using large ships and new terminals. A few large ships have already been speculatively built, with the capability of carrying LPG or LNG as alternate cargoes to permit chartering flexibility. The costs used in this analysis assume a newbuilding ordered under stable market conditions, delivered for use in 1980.

2. Sizes and Capital Costs

Vessel sizes of 10 000 and 30 000 m^3 are considered, with costs as given below:

10 000 m^3	\$33 million
30 000 m^3	\$54 million

3. Shipping Costs

The various items relevant to cost calculations are summarised below for the two vessel sizes:

TABLE IX.E.1.

ETHYLENE SHIPPING COST ITEMS

	10 000 m^3	30 000 m^3
Av. speed (knots)	17	18
Av. bunker consumptions (tonnes/day)	35	80
Loading/unloading time (days each end)	1	1
Gross registered tonnage (tonnes)	8 000	28 000

The costs of shipping may now be calculated for any specified shipping distance, assuming that the vessel is fully utilised. Typical calculations are presented in Tables IX.E.2 and IX.E.3 for a route of 5 000 n. miles each way.

Unlike the products included in the previous Section IX.D, however, an analysis of ethylene shipping costs must make some allowance for extra terminal and storage costs associated with liquid ethylene transportation. Ethylene is normally produced from a steam cracker as a gas at around 20 atmospheres pressure. If it is to be shipped it must all be liquefied, and stored in cryogenic tanks. Likewise, large cryogenic tanks and re-vaporisation facilities must be installed at the reception point for delivery of ethylene gas to the pipeline or consuming plant. Since ethylene handling facilities are expensive due to the low temperatures involved, the costs associated with these terminals cannot be ignored. If it is assumed that the shipping project employs two equal-sized, fully utilised ships, and that terminal capacities (each end) are twice ship capacity, then total terminal costs may be approximated by an additional 10 percent p.a. capital charge on the ship newbuilding cost. This is included in Table IX.E.3 and in Figure IX.E.1. If only a single ship is used on a particular run, terminal charges per tonne of product increase; this case is also indicated on Figure IX.E.1.

TABLE IX.E.2.

CARRYING CAPACITY OF 30 000 m^3 ETHYLENE CARRIER OVER 5 000 MILE RUN

Time at sea (per round trip) = $\frac{5\,000 \times 2}{18}$

= 556 hours

Contingency for bad weather, waiting time etc. = 5 percent

Time in port (per round trip) = 48 hours

Total round-trip time = (556 x 1.05) + 48

= 632 hours

Round trips per year = $\frac{8\,160}{632}$

= 12.91

Total carrying capacity per year = 12.91 x 30 000

= 387 000 m^3 p.a.

= <u>220 000 tonnes p.a.</u>

(Port visits per year = 25.8

Days in port per year = 25.8)

to bring the feed to reaction temperature being provided by the heat of reaction. Gas is fed to the reactor at several points, including a large proportion which enters through the stirrer motor housing to act as a coolant.

Conversion to polyethylene in the reactor is controlled in the range 15-23 percent to minimise heat removal problems. The ethylene/polyethylene mixture leaving the reactor is cooled, using a high-temperature heat transfer fluid as the intermediate coolant, which is itself air cooled. This intermediate coolant is used, and held above a certain minimum temperature in the range of 100-120^{0}C, to avoid polymer formation on the walls of the cooler.

After cooling, the mixture is flashed to a separator at 250 atmospheres. Most of the ethylene flashes off and is recycled via water coolers and a stock tank to the secondary compressor. Low molecular weight waxes present in the ethylene gas gradually build up on the walls of these coolers. Periodically this wax is melted off and sent to disposal.

The liquid polyethylene from the 250 atm separator is flashed into a low pressure, heated hopper at around 0.3 atmospheres gauge pressure. In this the remaining dissolved ethylene is flashed off, and is recycled via a booster compressor, stock tank and primary compressor back into the 250 atm suction of the main secondary compressor.

The molten polyethylene from the L.P. hopper is fed to the extruder line. This includes the extruder, die, water bath for cooling and hardening the polymer strands, pelletiser, and pellet de-watering system (centrifuge). The pellets are then screened to remove over- and under-sized material.

TABLE IX.E.3.

COSTS OF SHIPPING IN 30 000 m^3 ETHYLENE CARRIER OVER 5 000 MILE RUN

(including terminal costs)

		$ million p.a.	
Shipping			
Capital Charges (15% of $54 million)		8.10	
Bunkers Costs		2.94	
Operating Costs -	wages		0.80
	victualling		0.08
	stores		0.27
	R & M		0.54
	insurance		1.08
	administration		0.32
		3.09	
Port Costs		0.12	
Total Annual Shipping Costs		$14.25 million p.a.	
Terminals			
Total annual terminal costs (based upon 10% of ship cost of $ 54 million)		$5.40 million p.a.	
Total Transportation Cost			
Sum of shipping and terminal costs		$19.65 million p.a.	
Total product carried per year (Table IX.E.2.)		220 000 tonnes p.a.	
Unit transportation cost		$89.3/tonne	

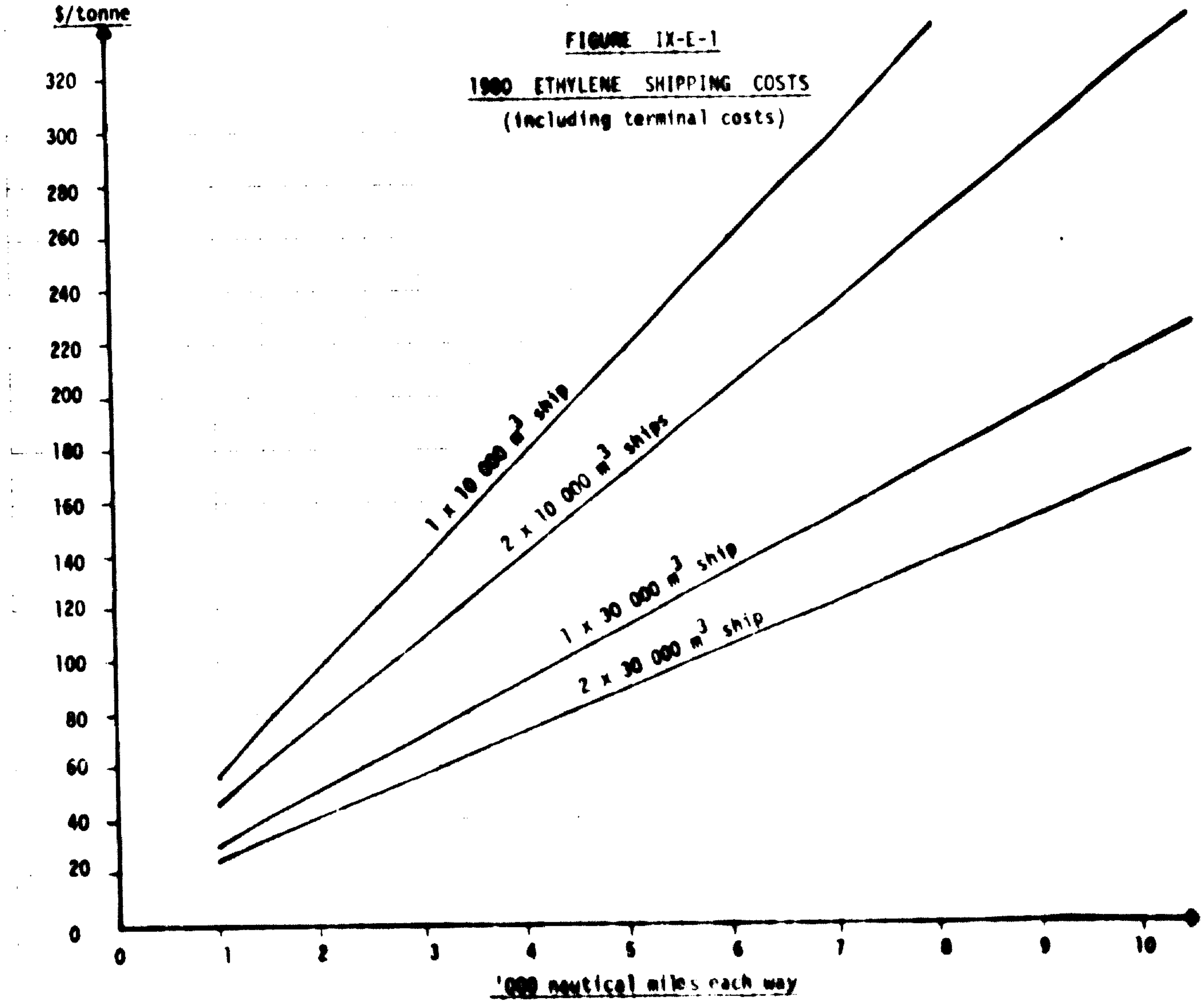


FIGURE IX-E-1

1980 ETHYLENE SHIPPING COSTS

(including terminal costs)

These calculations have been carried out for the two ship sizes over different voyage lengths. The results are shown in Figure IX.E.1.

As in the cast of LPG shipping, ship size is again seen to have a very dramatic effect upon shipping costs. Ethylene ships up to 30 000 m^3 already exist, and larger vessels present only logistic - not technical - problems, since ethylene ship design is very similar to the LNG technology which is already well proven up to 75 000 m^3 capacity and above.

Assuming a total ethylene movement of 300 000 tonnes per year (two thirds of the capacity of the proposed Arab plant capacity), only the very long runs (Arabian Gulf to U.S.) could fully utilise a large 30 000 m^3 ship, and even then only a single ship would be required. The runs from the Gulf to Europe and Japan, and from North Africa to the U.S., could use two ships with capacity of the order of 10 000 m^3, whereas shorter runs would need only one ship in the 10 000 m^3 range.

Table IX.E.4 summarises large volume ethylene shipping costs on various routes, using Figure IX.E.1 together with the considerations on capacity limitations discussed above. Also included in the Table is a weighted "average" cost of shipping ethylene from each Arab location (N. Africa and Arabian Gulf) based upon judgement of the most likely market distribution.

TABLE IX.E.4.

1980 SHIPPING COSTS OF ETHYLENE ($/tonne)

(including terminal costs)

	N. Africa	Arabian Gulf
S. Europe	60	150
N. Europe	100	190
U.S.	170	200
Japan	-	190
Weighted Average	80	180

As for LPG, it is again clear from Table IX.E.4 that ethylene shipping costs are by no means proportional to distance. As distance increases, so larger vessels and multiple vessels can be used, with corresponding large economies of scale.

F. LNG SHIPPING

1. General

The cost of LNG shipping is the most important component in the overall economics of the LNG chain from wellhead to consumer. For this reason a brief analysis of LNG shipping economics is given here, to substantiate the natural gas valuation economics previously presented in Section V.

2. Sizes and Capital Cost

125 000 m^3 has become the standard size of new LNG tankers. Over 40 vessels of this size were on order in January 1975, comprising over 80 percent of the total prospective world LNG fleet. It is estimated that such a vessel could be ordered at present for 1978 delivery at a price of around $145 million, escalating to perhaps $175 million for 1980 delivery. However, LNG shipping is an area particularly susceptible to government subsidies, finance and control, and this price can only be regarded as an approximation.

3. Shipping Costs

The various items relevant to cost calculations are summarised below:

TABLE IX.F.1.

LNG SHIPPING COST ITEMS
(125 000 m^3 ship)

Average speed (knots)	20
Average bunkers consumption (tonnes/day)	175 (when using bunkers only)
Loading/unloading time (days each end)	1
Gross registered tonnage (tonnes)	90 000
Boil-off rate (percent/day)	0.2

This boil-off gas is used as fuel in the ships main boilers, providing approximately 80 percent of total fuel demand. Actual consumption of fuel oil is therefore only around 35 tonnes/day when at sea, and zero when in port, giving an average demand of around 30 tonnes/day.

Typical LNG shipping costs are presented in Tables IX.F.2 and IX.F.3 for a route of 5 000 n. miles each way. Reception terminal costs are included in these analyses: loading terminal costs are included in LNG plant costs.

TABLE IX.F.2.

CARRYING CAPACITY OF 125 000 m^3 LNG TANKER OVER 5 000 MILE RUN

Time at sea (per round trip) = $\frac{5\ 000 \times 2}{20}$

= 500 hours

Contingency for bad weather, waiting time etc. = 5 percent

Time in port (per round trip) = 48 hours

Total round trip time = (500 x 1.05) + 48

= 573 hours

Round trips per year = $\frac{8\ 160}{573}$

= 14.24

Cargo loss due to boil-off = $\frac{573 \times 0.2}{24}$

= 4.8 percent of capacity

Delivered capacity per year = 14.24 x 125 000 x 0.952

= $\underline{1\ 695\ 000\ m^3\ \text{p.a.}}$

(Port visit per year = 28. 5

Days in port per year = 28. 5)

TABLE IX.F.3.

COSTS OF SHIPPING IN 125 000 m^3 LNG CARRIER OVER 5 000 MILE RUN

(including terminal costs)

	$ million p.a.	
Shipping		
Capital charges (15% of $175 million)	26.25	
Bunker Costs (fuel oil)	1.10	
Operating Costs - wages		0.80
victualling		0.08
stores		0.88
R & M		1.75
insurance		3.50
administration		0.32
	7.33	
Port Costs	0.31	
Cost of boil-off (at assumed FOB price of $9.0/million Kcals.)	4.31	
Total Annual Shipping Costs	$39.30 million p.a.	
Total product carried per ship per year (Table IX.F.2.)	1 695 000 m^3 LNG	
Unit Shipping Cost	$23. 2/m^3 = $ 3.83/million Kcals.	

Reception Terminal (based upon total terminal throughput of 5 milliard Nm^3 p.a.)

Capital charges (25% of $220 million)	55.00	
Operating Costs	15.00	
Cost of gas used as fuel (1½% of throughput @ $13/million Kcals.)	9.17	
Total annual terminal costs	$79.17 million p.a.	
Total terminal throughput	5 x 10^9 Nm^3 p.a. gas = 47 x 10^{12} Kcals. p.a.	
Unit terminal cost	= $ 1.68/million Kcals.	

Total Shipping & Reception

Total unit cost of shipping, reception & revaporisation	$ 5.51/million Kcals.	

These calculations have been carried out for various voyage lengths and the results are shown on Figure IX.F.1.

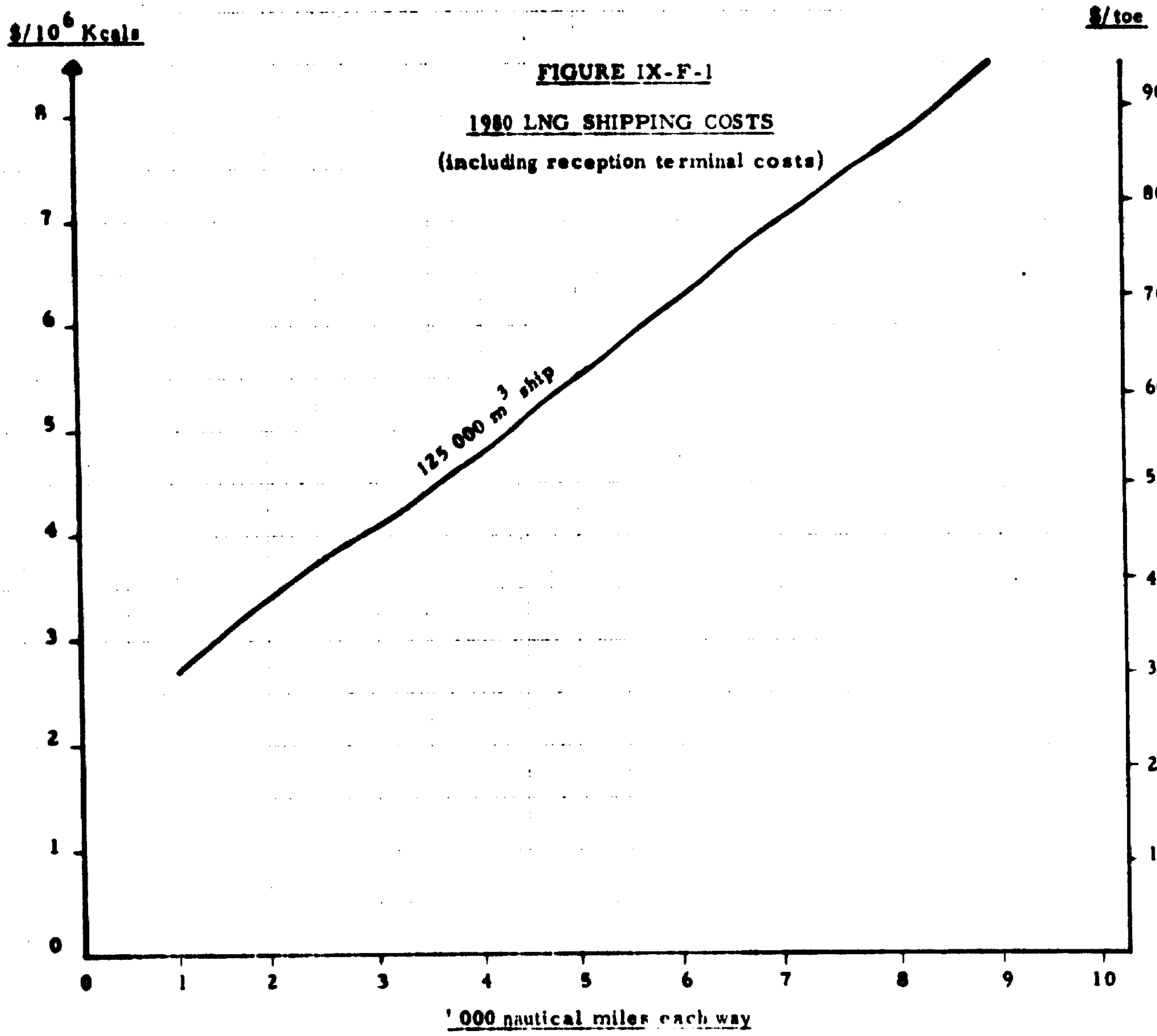


FIGURE IX-F-1

1980 LNG SHIPPING COSTS

(including reception terminal costs)

Table IX.F.4 summarises LNG shipping and reception costs for various routes. Also included in the Table is an estimate of the weighted "average" costs of shipping LNG from each Arab location (N. Africa and Arabian Gulf). Thus while FOB LNG value in N. Africa is expected to be basically set by the North European market, the U.S. market will also be very significant. This more remote market incurs higher shipping costs, and can therefore afford a lower FOB LNG value (and therefore a lower natural gas price). Shipping costs to the U.S. are therefore a factor in depressing N. African natural gas valuation.

TABLE IX.F.4.

1980 LNG SHIPPING COSTS ($/10⁶ Kcals.)

(including terminal costs)

	N. Africa	Arabian Gulf
S. Europe	2.50	5.30
N. Europe	3.80	6.60
U.S.	5.50	8.60
Japan	-	6.60
Weighted average	4.00 ($44/toe)	7.50 ($82/toe)

Antioxidants and other additives can be added either before extrusion or after pelletising. The finished pellets then pass via pneumatic or hydraulic conveyor to a series of sampling, weighing, deodorising, blending and storage silos. Finally, the pellets are conveyed to bagging facilities prior to shipment.

3. Cost of Production

Although ethylene price obviously has a direct effect upon LDPE production economics, capital charges are also of great importance, since the LDPE process is highly capital intensive. Effects of scale are therefore of great importance in LDPE production and a plant large enough to be competitive in world markets must be selected. Typical capacities in a single production line in Europe and the U.S. are generally in the range 50-80 000 tonnes per year, with one line in the U.S. over 110 000 tpa. Plant sizes, comprising multiple production lines, are typically over 100 000 tpa.

For the purposes of both the European and Arab evaluations, a nominal LDPE plant capacity of 105 000 tpa in a single line is assumed. This would absorb approximately one quarter of the output of the proposed 450 000 tpa Arab ethylene plant.

Capital costs are based upon recent in-depth studies by Chem Systems, and include an allowance for fully paid-up royalties. An ICI-autoclave process is assumed. Working capital is included as 15 percent of BLCC.

Tables VIII.H.1. to VIII.H.3. present Cost of Production sheets for Western European, North African and Arabian Gulf locations. The estimated 1980 West European Transfer Price is

G. CLEAN PRODUCTS

1. General

"Clean" petroleum products include "white" fractions such as naphtha, gasoil and gasoline. Vessels designed for this service are generally capable of carrying several grades in separate tanks. Typical vessel sizes are currently 15 000 to 35 000 tonnes product capacity, and larger sizes are becoming more attractive as the volumes of world product trade increase.

Liquid chemical carriers for large volume movements are effectively identical to these oil product carriers, except that tanks are always internally coated to prevent corrosion and contamination. The economics presented in this section are therefore applicable to clean oil products and also to chemicals such as ethylene glycol, para-xylene, benzene, pyrolysis gasoline, etc.

2. Sizes and Capital Costs

Vessel sizes of 20 000 and 50 000 tonnes carrying capacity are considered. These capacities are based upon product specific gravities in the range 0.80 ± 10 percent, i.e. oil products from gasoline to gasoil. This range also covers all of the chemical products of interest except ethylene glycol, which has a S.G. of 1.11. Assuming that cargo weight would not be limiting in a multi-product carrier, glycol shipping costs could be lower than for the other products due to the higher tonnage carrying capacity of a given ship/tank; but it is not considered that such precision is justified in the present generalised study due to the large number of assumptions made concerning ship size, likely markets etc. The same unit costs are therefore used for all products.

Vessel costs are as follows:

20 000 tonnes capacity	$20 million
50 000 tonnes capacity	$30 million

3. Shipping Costs

The various items relevant to cost calculations are summarised below for the two vessel sizes.

TABLE IX.G.1.

"CLEAN" PRODUCT SHIPPING COST ITEMS

	20 000 tonnes	50 000 tonnes
Av. speed (knots)	15	16
Av. bunkers consumption (tonnes/day)	30	100
Loading/unloading time (days each end)	1½	1½
Gross registered tonnage (tonnes)	13 000	30 000

The costs of shipping may now be calculated for any specified shipping distance, assuming that the vessel is fully utilised. Typical calculations are presented in Tables IX.G.2. and IX.G.3. for a route of 5 000 n. miles each way.

TABLE IX.G.2.

CARRYING CAPACITY OF 20 000 TONNE "CLEAN" PRODUCTS CARRIER OVER 5 000 MILE RUN

Time at sea (per round trip) = $\frac{5\ 000 \times 2}{15}$

= 667 hours

Contingency for bad weather, waiting time etc = 5 percent

Time in port (per round trip) = 72 hours

Total round-trip time = (667 x 1.05) + 72

= 772 hours

Round trips per year = $\frac{8\ 160}{772}$

= 10.57

Total carrying capacity per year = 10.57 x 20 000

= 211 000 tonnes p.a.

(Port visits per year = 21. 1

Days in port per year = 31. 7)

TABLE IX.G.3.

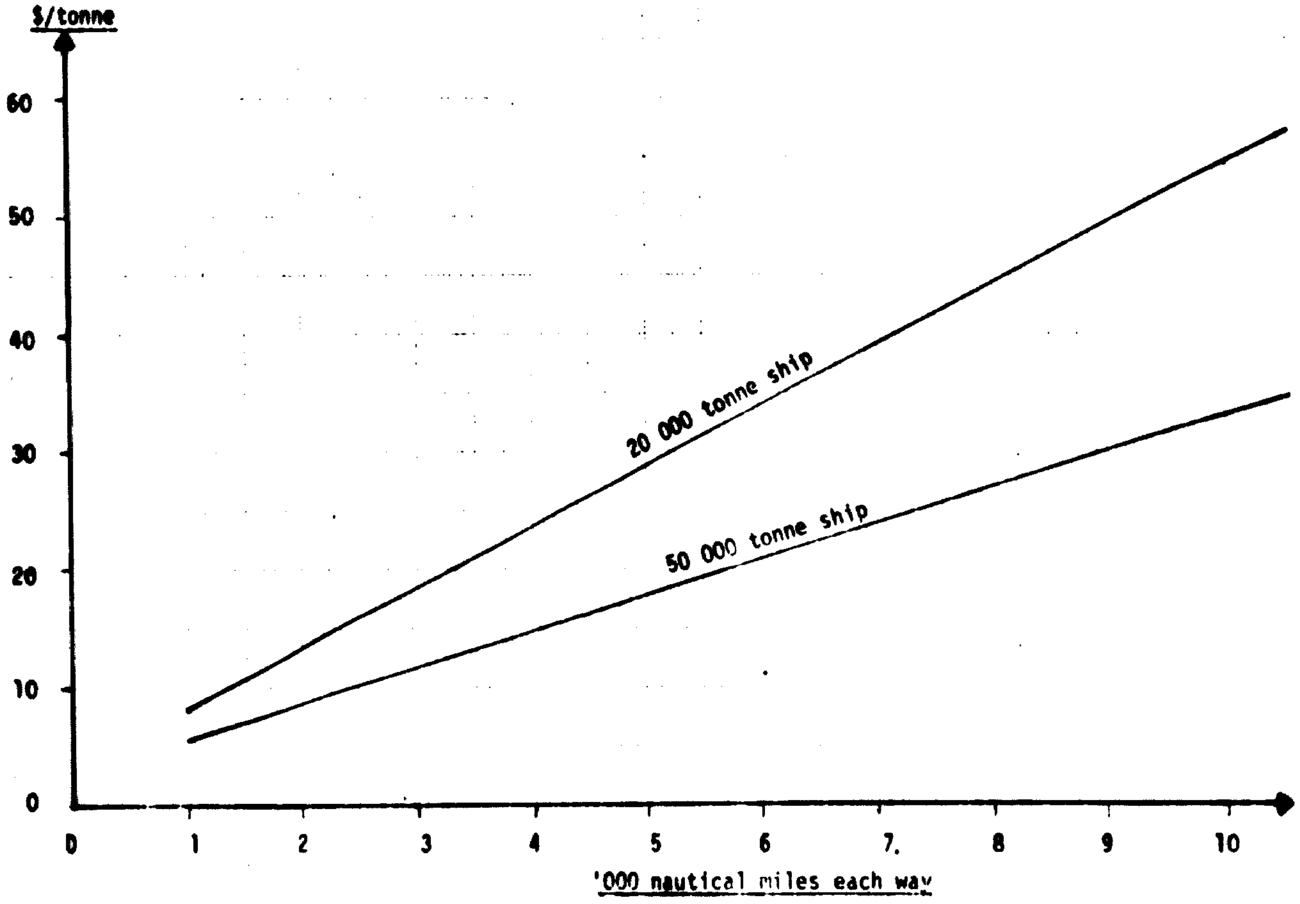
COSTS OF SHIPPING IN 20 000 TONNE "CLEAN" PRODUCTS CARRIER OVER 5 000 MILE RUN

		$ million p.a.	
Capital charges (15% of $20 million)		3.00	
Bunker costs		1.10	
Operating costs-	wages		0.80
	victualling		0.08
	stores		0.10
	R & M		0.20
	insurance		0.40
	admin.		0.32
		1.90	
Port costs		0.08	
Total annual shipping costs		$6.08 million p.a.	
Total product carried per year (Table IX.G.2.)		211 000 tonnes p.a.	
Unit shipping cost		$28. 8 per tonne	

These calculations have been carried out for the different ship sizes over a range of voyage lengths. The results are shown on Figure IX.G.1.

FIGURE IX-G-1

1980 "CLEAN" LIQUID PRODUCTS SHIPPING COSTS



The effects of scale are thus rather less dramatic for conventional products carriers than for the highly capital-intensive specialised shipping (ethylene, etc) analysed in previous sections.

Scale of operation dictates that the smaller vessels (20 000 tonne range) will be more appropriate to runs of up to 2-3 000 miles. For the very longest runs (Gulf to U.S., etc) vessels of more than 50 000 tonnes could be used.

Table IX.G.4. summarises large-volume products shipping costs on various routes, using Figure IX.G.1 together with the capacity considerations discussed above. A weighted "average" cost of shipping products from each Arab location is also indicated in the Table, based upon judgement of the most likely market distributions:

TABLE IX.G.4.

1980 SHIPPING COSTS OF "CLEAN" LIQUID PRODUCTS ($/tonne)

	N. Africa	Arabian Gulf
S. Europe	7	18
N. Europe	13	24
U.S.	19	30
Japan	-	24
Weighted Average	10	20

H. "DIRTY" PRODUCTS

This classification includes the "black" products such as heavy fuel oil and the pyrolysis fuel oil from naphtha cracking. In tanker terminology, it also includes crude oil.

Spot charter rates for "dirty" tankers are invariably lower than for "clean" products tankers. This is a reflection of typical scales of operation and also of the need to thoroughly clean tanks before white products can be carried in a vessel previously carrying crude or other black products. Actual costs of building and operating tankers are, however, very similar for white and black products.

Shipping costs of black products are peripheral to the main topics of this study. We therefore take costs of shipping heavy fuel oils, etc, to be equal to the "clean" products costs calculated in the preceding Section, G. Costs of crude oil transport are taken at 50-60 percent of these values to reflect the greatly increased scale of operations and the overcapacity situation in large tankers (VLCC'S) which is expected to persist into the 1980's.

Thus average costs predicted are as follows, weighted according to likely market distribution:

TABLE IX.H.1.

AVERAGE 1980 SHIPPING COSTS FOR "DIRTY" PRODUCTS ($/tonne)

	N. Africa	Arabian Gulf
Heavy fuel oils	10	20
Crude	5	12

J. DRY PRODUCTS

1. General

Dry products include all resin products such as polyethylene and polystyrene. It is assumed that all such products will be moved in bags rather than in bulk, since the range of resin grades produced and the range of market locations involved would make the logistics of bulk shipping very dubious in most cases. Conventional dry cargo vessels with full lifting gear are therefore assumed for this costing exercise.

2. Sizes and Capital Costs

Vessel sizes of 10 000 and 20 000 tonnes carrying capacity are considered. This covers the upper range of sizes of multi-purpose vessels available. Above 20 000 tonnes, dry cargo vessels are generally single-product bulk carriers, which would not be applicable to the present project. Costs are as follows:

10 000 tonnes cargo capacity	$11 million
20 000 tonnes cargo capacity	$14 million

3. Shipping Costs

The various items relevant to cost calculations are summarised below for the two vessel sizes:

TABLE IX.J.1.

DRY PRODUCT SHIPPING COST ITEMS

	10 000 Tonnes	20 000 Tonnes
Av. speed (knots)	13	14
Av. bunkers consumption (tonnes/day)	17	25
Loading/unloading time (days each end)	4	5
Gross registered tonnage (tonnes)	7 000	15 000

The costs of shipping in fully utilised dry cargo vessels over a range of distances may now be calculated. Typical calculations are presented in Tables IX.J.2 and IX.J.3 for a route of 5 000 n. miles each way.

TABLE IX.J.2.

CARRYING CAPACITY OF 10 000 TONNE DRY CARGO VESSEL OVER 5 000 MILE RUN

Time at sea (per round trip) $= \frac{5\,000 \times 2}{13}$

$= 769$ hours

Contingency for bad weather, waiting time etc. = 5 percent

Time in port (per round trip) = 192 hours

Total round trip time $= (769 \times 1.05) + 192$

$= 999$ hours

Round trips per year $= \frac{8\,160}{999}$

$= 8.17$

Total carrying capacity per year $= 8.17 \times 10\,000$

= <u>81 700 tonnes p.a.</u>

(Port visits per year = 16. 3
Days in port per year = 65. 4)

$1 090 per tonne. The comparable prices from Arab plants are around $1 110 per tonne from both N. African and Arabian Gulf locations.

As for both HDPE and Polypropylene, therefore it is clear that with feedstock charged at the basic rates calculated in Section VI, and with identical terms of finance applied to all locations, LDPE production for export will not be an attractive option at the Arab locations. This is due to the highly capital intensive nature of all the polyolefin resin processes, including LDPE: the capital cost penalty associated with the Arab locations more than outweighs the advantage of the lower fuel and feedstock costs.

Sensitivity analysis in Section X therefore consider variations in the ethylene price, finance terms and capital cost (locational) ratios, and show the effects these can have upon overall economics of the Arab projects.

As an indication of the effects of scale, Table VIII.H.2 (N. African location) has been reworked for LDPE capacities of 70 000 and 40 000 tpa, operating at the same percentage of capacity as in Table VIII.H.2. Transfer price then increases from $1 106 per tonne to $1 208 and $1 371 per tonne respectively.

TABLE IX.J.3.

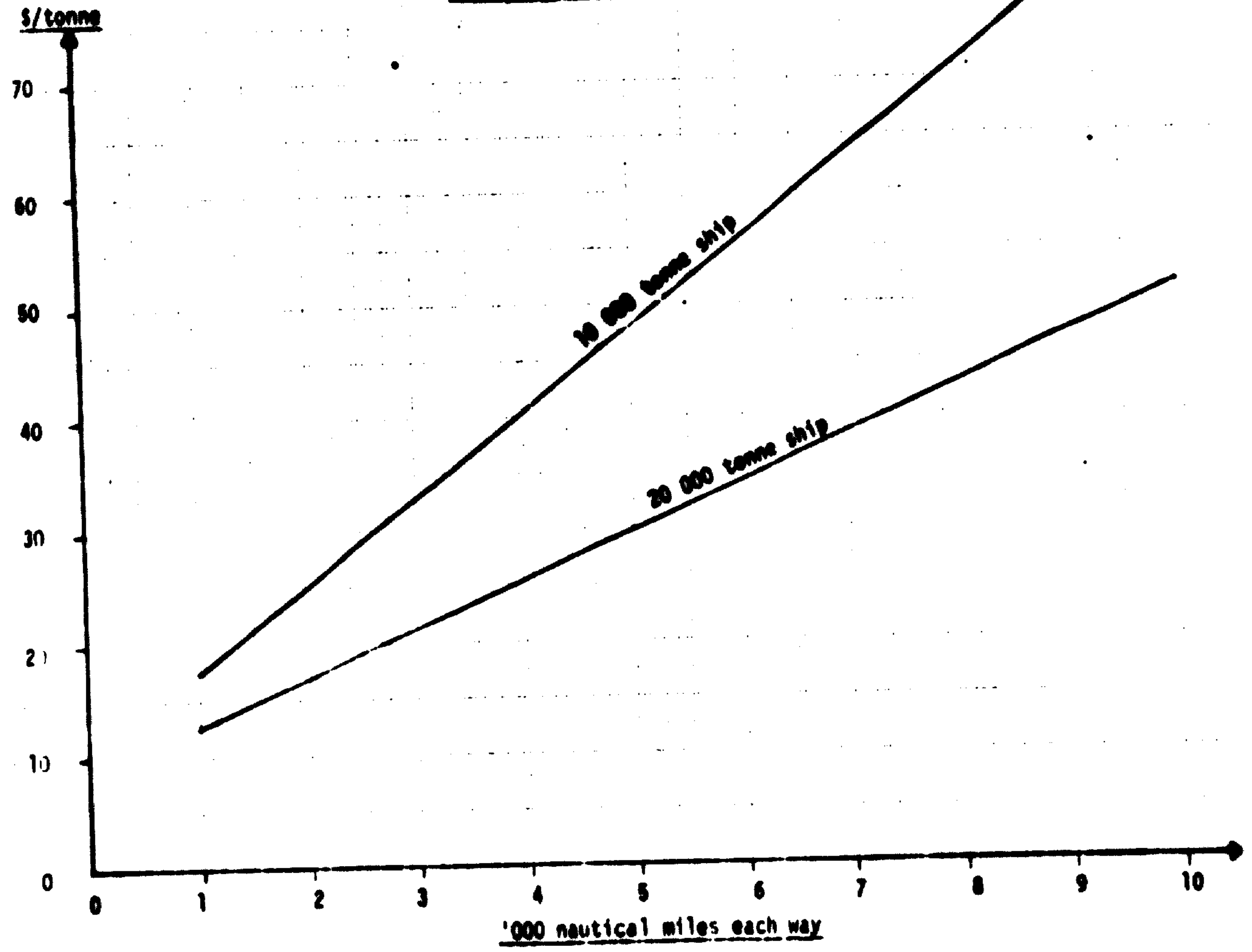
COSTS OF SHIPPING IN 10 000 TONNE DRY CARGO VESSEL OVER 5 000 MILE RUN

		$ million p.a.	
Capital Charges (15% of $11 million)		1.65	
Bunker Costs		0.62	
Operating Costs -	wages		0.80
	victualling		0.08
	stores		0.06
	R & M		0.11
	insurance		0.22
	administration		0.32
		1.59	
Port Costs		0.08	
Total annual shipping costs		$3.94 million p.a.	
Total product carried per year (Table IX.J.2)		81 700 tonnes p.a.	
Unit shipping cost		$48 per tonne	

These calculations have been carried out for the different ship sizes over a range of voyage lengths. The results are shown in Figure IX.J.1.

FIGURE IX-J-1

1980 DRY CARGO SHIPPING COSTS



Assuming a total resin export volume in the range 100 000-200 000 tonnes/year from the proposed Arab projects, the larger ships could be used on the longest runs provided all produce was being moved to the same destination. This is unlikely, however, and costs are assumed to be primarily based upon vessels in the 10 000 tonne range. Vessels of this type and size are currently regular visitors to Arabian Gulf and North African ports. Since more general cargo moves into these ports than is shipped out, it is conceivable that some early petrochemical projects could benefit from "backhaul" shipping rates in vessels that would otherwise return empty to Europe, etc. Since the prospects for this can only be evaluated for a specific project when all local circumstances are known, no credit is taken here for this possible economy.

Table IX.J.4 summarises dry cargo shipping costs on various routes, using Figure IX.J.1 together with the vessel size considerations discussed above. A weighted "average" cost of shipping products from each Arab location is also indicated, based upon judgement of the most likely market distributions:

TABLE IX.J.4.

1980 DRY CARGO SHIPPING COSTS ($/TONNE)

	N. Africa	Arabian Gulf
S. Europe	17	45
N. Europe	30	60
U.S.	47	75
Japan	-	60
Weighted Average	30	60

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SECTION X : ECONOMIC EVALUATION

Contents **Page No.**

SECTION X : ECONOMIC EVALUATION

Figures

X ECONOMIC EVALUATION

A. SCOPE AND METHODOLOGY

1. Scope

This Section assembles all the market, shipping cost and production cost information from previous sections, and uses this to select the most likely products for Arab olefin and aromatics projects. The net-back prices achievable for the Arab materials are calculated, and overall economic evaluations are then carried out for a number of credible complexes. Sensitivity analyses are carried out on these complexes to show the effects of variations in capital costs and feedstock prices upon the overall profitability and attractiveness of the potential Arab projects.

Discussion is also presented on the indirect benefits to the local Arab economies of petrochemical developments in general, and of the manufacture of certain products in particular.

Based upon these analyses, one apparently attractive complex is selected and used as the basis for staffing schedules, material and utility balances, offsites estimates, construction timetables, etc. Infrastructure requirements are also discussed in the context of this selected complex.

2. Markets

For each product an estimate is made of the target market distribution. This is not a prediction of the actual market penetration which could be achieved by a particular Arab project; rather it is a judgement on the relative target market sizes which would have to be developed to move the total proposed Arab production. This distribution is broken down into three groupings:

- developed markets, i.e. W. Europe, US and Japan
- developing markets, comprising generally the rest of the non-Arab world
- local Arab markets, assumed to include not only the producing country but also other Arab markets.

3. Net-back Prices

Net-back prices which may be realised by an Arab project will be basically set by the economics of competing plants in the developed countries together with freight cost and tariff considerations.

The transfer prices in developed countries have been calculated in previous sections, using the simple Return on Investment (ROI) approach at a rate of 25 percent ROI. This is equivalent to an after-tax return on total capital of around 20 percent on a DCF basis, using inflation accounting assumptions applied to a typical W. European/US location. This is the sort of level of return needed by the major integrated oil and chemical companies to generate adequate cash flows to finance their development programmes in the current business environment of high inflation and capital shortages. We believe, therefore, that this simple ROI method gives a good approximation to the price levels which the developed markets will have to reach to provide adequate

TABLE VIII-H-1

LOW DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: W EUROPE

Basis: Location- W Europe 1980
Capacity- 105 000 tpa LDPE
Rate - 96 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	80
Offsites Capital Cost	40
Total Fixed	120
Working	12

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	450	45 000 000	
Catalyst & Chemicals				3 500 000	
TOTAL RAW MATERIALS:				48 500 000	505.2
UTILITIES:					
Power	115 000	1000 Kwh	43.5	5 003 000	
Cooling Water	16 000	1000 m^3	16	256 000	
Steam	80 000	tonne	9.6	768 000	
TOTAL UTILITIES COST:				6 027 000	62.8
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				3 200 000	
TOTAL OPERATING COSTS:				4 163 000	43.4
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				2 706 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				1 800 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				10 000 000	
Interest - 10% on Working Capital				1 200 000	
TOTAL OVERHEAD EXPENSES:				15 995 000	166.6
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				74 685 000	778.0
RETURN 25% ON TOTAL FIXED INVESTMENT:				30 000 000	312.5
TRANSFER PRICE:				104 685 000	1 090.5

* $/unit

incentive for the major companies to invest in new plant. These prices are assumed to increase every year in line with cost inflation in the developed countries. Thus it is assumed that prices in each year are set by the economics of a new plant starting operation in that particular year. For the purposes of escalating these costs forward from 1980, the inflation assumptions of Section III are used, i.e. plant and labour costs increasing at 10 percent p.a., and feedstock/energy costs increasing at 7½ percent p.a. Freight costs are also assumed to increase at 7½ percent p.a. Three net-back price levels will be considered here, corresponding to the three market groupings listed above.

a) <u>Developed markets</u>

The average shipping costs of the various products to the most likely developed regions were estimated in Section IX. These costs must be deducted from prevailing developed-market "offshore" prices (i.e. market price less import duties) to give the net-back FOB price at the Arab locations when supplying these developed markets.

An analysis of the effects of developed country import duties on material from the Arab states is complicated here by the generalised nature of this study. The tariff structures of the US, Japan and the European Economic Community (EEC) are all widely different. In addition, the rates of duty charged depend upon the country of origin.

Thus for imports into the EEC, most of the Arab states are classified as "developing countries," and as such are liable to the standard rates of duty (Common Customs Tariff or CCT) indicated below in Table X.A.1. Egypt, however, has negotiated a separate agreement which in effect reduces the duty payable to 45 percent of the CCT levels. Algeria in practice, pays no duty at present on exports to the EEC due to its past inclusion in the EEC as a part of metropolitan France.

The tariff structure of the United States is applied uniformly to almost all countries of the world, including all of the Arab states. The basic rates are given in Table X.A.1.

The import duty into Japan is presently zero on the relevant products from all Arab states, which are classified as "developing countries".

All tariff levels are liable to change over the years, however, either as part of a general international agreement (generally a reduction, such as the 50 percent reductions of the so-called Kennedy Round of negotiations) or as a result of a specific agreement between two countries or groups.

It is conceivable, however, that in the event of a continued world recession a protectionist policy could be adopted by the major developed regions. If this attitude coincided with the arrival on world markets of large quantities of Arab petrochemicals, then the possibility of the creation of higher tariff barriers by the EEC, USA and Japan to protect their domestic industries cannot be totally ignored, though in view of their heavy continued dependence upon Arab oil the scope for such punitive tariffs appears limited.

Due to the generalised nature of this study we can only allow for import duties in a generalised way, by assuming that current rates of developed country duty continue (basic EEC rates, etc), and by assuming an approximate split of the market between US, Japan and W. Europe. The effects of variations in average net-back prices are then evaluated subsequently in the sensitivity analyses.

TABLE X.A.1.

TARIFF SCHEDULE ON IMPORTS TO DEVELOPED REGIONS FROM THE ARAB STATES

	US	EEC	Japan
Ethylene	Free	Free	Free
Ethylene glycol	$33.1/tonne + 7½%	16.4%	Free
VCM	$27.6/tonne + 6 %	15.2%	Free
LDPE	$28.7/tonne +10 %	16 %	Free
HDPE	$28.7/tonne +10 %	16 %	Free
Polypropylene	$28.7/tonne +10 %	18.4%	Free
Polystyrene	$30.9/tonne + 9 %	16 %	Free
Styrene	$30.9/tonne + 9 %	6.4%	Free
Benzene	Free	Free	Free
Xylenes	Free	Free	Free

Note Duty is normally based upon the CIF price of the material.

b) Developing markets

Shipping costs to the various developing markets, and import duties into those markets, are ignored in calculating Arab net-back FOB prices for material exported to these developing markets. This is because the Arab material will not in general be at any disadvantage in terms of import duty or freight costs when compared to the developed countries, which are the traditional suppliers of petrochemicals to these developing regions. In a generalised study of this type it is not possible to be precise about such matters because both shipping distances and applicable rates of duty will vary depending upon which particular Arab state and which particular market country is being considered. The general approach of assuming equal costs for both Arab and developed country material is therefore a necessary and reasonable simplification. The net-back FOB price for Arab material when supplying these developing markets is thus taken to be the same as the developed country transfer price.

c) Local Arab markets

When supplying the local Arab markets, net-back price to the Arab plant may be taken to be developed country transfer price plus freight costs, since these are the local price levels which would exist if no local production were undertaken. Local Arab import duties could also be added to this price, as a measure of protection and encouragement for local production; we do not add such duties in these evaluations, however, for various reasons:

- They would raise the local market prices, thus making downstream manufacturing operations less attractive. Since downstream integration and general industrialisation is a basic intention of most Arab petrochemical plans, this seems illogical. Protection against unfair foreign competition could be given by anti-dumping legislation, and adequate assistance can be given to the Arab petrochemical project by low taxation rather than by inflating market prices.

- Since the Arab projects will rely for most of their markets upon export to the developed nations, it is very much in the Arab interest to promote a general reduction in tariff levels. This is unlikely to be assisted by protective Arab tariffs against imported material.

- Present import duties imposed by the various Arab states on the products of interest are very variable and frequently very low; e.g. Saudi Arabia - all free; Kuwait - all at 4 percent; Abu Dhabi - all at 1 percent; Libya at 10 percent on most products, but resins free.

4. Product Selection

As discussed above in Section X.A.3, the transfer prices of all products in the developed countries are estimated by a simple Return on Investment approach, which approximates to a

DCF return of around 20 percent on total capital when tax is levied at standard rates (e.g. US at 48 percent).

In Section VIII, this same 25 percent ROI-approach was also applied to the Arab plants as a simple method of obtaining a "ranking list" of potential Arab plants. On this basis, very few products could be exported competitively from Arab projects to world markets. However, a 25 percent ROI is not necessarily required to give adequate returns and incentives to investors in an Arab project, for several reasons:

- as an incentive to development, Arab governments will frequently be prepared to set up tax-free zones for petrochemical projects, or at least to offer extended tax holidays and concessions

- since the Arab states are beginning to provide a substantial part of the world's loan capital, finance could presumable be made available to local Arab development projects at concessionary rates, "short-circuiting" the established money markets

- since the Arab states will themselves control their feedstock supplies, one of the risk elements is removed from planning considerations. Higher risks require higher returns as an incentive to incur the risk

- the unquantifiable benefits of industrialisation in terms of employment, training, infrastructure development etc. make petrochemical development a political objective in most Arab states. Under such circumstances a project may be considered acceptable by a state-owned Arab company at much lower rates of return than those normally considered commercially necessary

- many major oil and chemical companies will be prepared to take equity in Arab petrochemical and refining projects to gain guaranteed access to feedstocks and products, even if rates of return on the project are low: feed will thus be assured to their downstream plants in the developed countries, and it is these downstream units which generally give the highest profitability. Also, participation by the major oil companies in such Arab projects would be in line with the companies general desire to be seen as a "good citizen" in all countries in which they operate. Thus participation in a petrochemical project (even of limited profitability) might be considered acceptable in the interests of good relations with the host government, thus preserving access to valuable crude oil supplies.

For these various reasons, lower capital charges will often be applicable to the Arab projects as compared to projects in the developed countries.

Furthermore, the "alternate value" (i.e. world market price) approach to feedstock pricing used in previous sections will not always be applied to Arab petrochemical projects. This is particularly true of the lighter "gas" feedstocks such as ethane, and to associated natural gas itself. Under some circumstances actual costs of production could be used to estimate feedstock price, which as shown in Section V results in far lower prices for feed and thus for ethylene.

To assist in making the selection of products for inclusion in the Arab complexes, simple sensitivity analyses are therefore first presented for each individual product showing the effect upon transfer price of lower feedstock prices and of lower capital charges.

5. DCF Analyses

Several credible and apparently attractive combinations of plants are selected as potential Arab complexes on the basis of the transfer price economics of the individual products, the simple sensitivity analyses described above, and the worldwide product market potentials.

Overall DCF returns on these possible complexes are then calculated, using the following assumptions and considerations.

The final target market volumes, discussed in Section X.A.2., are estimated for each product in the following sections. This ultimate average plant production (generally assumed to be 90 percent of nominal capacity) will not be achievable immediately after plant completion, due to non-productive start-up period, initial operating problems, market build-up considerations, and the time-lags involved in shipping products to market and receiving payment. For these DCF analyses we assume sales build-up for all products as follows:

Year of operation	Sales volume as % of capacity
1st	40%
2nd	75%
3rd & subsequent	90%

Sales into the various regions (developed markets, local markets, etc.) are all assumed to build up at these same rates. For the DCF evaluations an eleven (11) year operating life is assumed (i.e. 1980-1990 inclusive). Available net-back prices in 1980 are calculated as described in Section X.A.3, above, and escalated forward using the inflation assumptions of that section.

Operating costs of the Arab plant are also assumed to increase at the rates as given in Section X.A.3.

The total fixed investment (BLCC plus offsites) of each Arab plant is given in the Cost of Production sheets of previous sections. For purposes of the DCF analysis this expenditure is assumed to be incurred as follows:

percentage of total expenditure	during year before operation
10%	3
50%	2
40%	1

The DCF rate of return on each complex is then calculated using the basic costs and revenues as described above.

Sensitivity analyses are then carried out to show the effects upon these DCF returns of variations in key parameters such as feedstock prices and capital costs.

On the basis of these analyses, one complex is selected as a representative attractive project, and further sensitivity analyses are carried out on this to show the effect of variations in prices, and - most important - in terms of finance and taxation. Variations in the debt/equity ratio are considered in these latter analyses.

B. PRODUCT ANALYSIS

1. Ethylene Glycol

a) Markets

The potential for long-term contract sales of glycol to the developed regions of Europe, US and Japan appears very limited, due to projected overcapacity in all these areas during the early 1980's. If ethylene shortages develop in these regions, then glycol is likely to be one of the first products to suffer as ethylene is diverted to more profitable outlets such as polyethylene and styrene. Under these circumstances spot shipments from an Arab project could be sold, but this is a very uncertain basis upon which to commit capital to an Arab ethylene glycol venture.

The deficits likely to occur in the developing regions of Latin America, Southern Africa and the Far East are very small in comparison to the projected overcapacity in the developed countries. Limited amounts of glycol could probably be sold to these areas from an Arab plant, however, generally resulting in higher net-backs to the Arab project due to more favourable relative freight costs and tariffs.

Local Arab markets for glycol will remain very small until polyester fibre industries are established locally. The timing of such fibre development is very uncertain. A fibre production of 150 000 tonnes/year would absorb half of the output of the proposed 150 000 tpa Arab glycol plant, thus providing a good base demand. Since

TABLE VIII-H-2

LOW DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: N AFRICA

Basis: **Location-** N Africa 1980
Capacity- 105 000 tpa LDPE
Rate - 96 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	92
Offsites Capital Cost	51
Total Fixed	143
Working	14

RAW MATERIALS	**QUANTITY**	**UNIT**	**PRICE***	ANNUAL COST	**UNIT COST***
Ethylene	100 000	tonne	400	40 000 000	
Catalyst & Chemicals				3 500 000	
TOTAL RAW MATERIALS:				43 500 000	453.1
UTILITIES:					
Power	115 000	1000 Kwh	27	3 105 000	
Cooling Water	16 000	1000 m^3	12	192 000	
Steam	80 000	tonne	4.3	344 000	
TOTAL UTILITIES COST:				3 641 000	37.9
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				3 680 000	
TOTAL OPERATING COSTS:				4 643 000	48.4
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				3 018 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 145 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				11 750 000	
Interest - 10% on Working Capital				1 400 000	
TOTAL OVERHEAD EXPENSES:				18 602 000	193.8
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				70 386 000	733.2
RETURN 25% ON TOTAL FIXED INVESTMENT:				35 750 000	372.4
TRANSFER PRICE:				106 136 000	1 105.6

* $/unit

evaluation of the establishment of local fibre industries is outside the scope of this study, we base the evaluations here on the assumption that all glycol would have to be exported.

Assumed distribution of product target sales is thus as follows:

Developed markets	120 000 tpa
Developing (non-Arab) markets	15 000 tpa
Local Arab markets	0 tpa
Total	135 000 tpa

b) Prices and Costs

Table X.B.1. presents calculated net-back glycol prices to the Arab plants. Also included are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and ethylene price:

TABLE X.B.1.

ETHYLENE GLYCOL NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	585 (1)	575 (1)
To developing markets	651	651
In local Arab markets	661	671
Weighted average	592	583
Transfer prices achievable		
Basic case (2)	628	622
20% ROI (3)	588	579
15% ROI	549	536
10% ROI	509	493
Ethylene @ $250/tonne (4)	517	536

(1) For purposes of import duty calculations assumes market split equally between US, W. Europe and Japan

(2) 25 percent ROI; ethylene price $400/tonne in N. Africa, $366/tonne in Arabian Gulf

(3) Ethylene price kept fixed, i.e. still at 25 percent ROI on ethylene plant

(4) With 25 percent ROI on glycol plant

c) Conclusions

Thus under the basic assumptions detailed above, glycol from Arab plants would not be competitive with material produced in the developed countries. With any concessions on required return on capital or on ethylene transfer price, however, glycol from the Arab plants could be made available at prices to match world market price levels.

Our market evaluations suggest that it will be difficult for an Arab project to penetrate world glycol markets and actually obtain the target sales suggested above even with substantial price cutting, however.

We therefore consider that this product should only be included in an Arab complex if a prospective Joint Venture partner is prepared to guarantee offtake of most or all of the product on long-term contracts at adequate prices.

2. High Density Polyethylene (HDPE)

a) Markets

There seems to be reasonable potential for Arab penetration of the HDPE markets in the developed countries during the early 1980's. Substantial new investment will be required for HDPE to meet growing worldwide demand forecast in both developed and developing countries during the early 80's, and a portion of this investment could be made in Arab states.

The major target market among the developed countries appears to be North America, though W. Europe will also offer good prospects. Southern Africa and the Asia/Pacific region will require either substantial plant capacity or large imports, and a portion of these markets could be captured by an Arab project, though competition from the Japanese would be severe.

There is also a significant local Arab market potential for HDPE, which could be fully exploited and expanded if local production were established.

Assumed distribution of HDPE target sales is thus as follows:

Developed markets	50 000 tpa
Developing (non-Arab) markets	30 000 tpa
Local Arab markets	15 000 tpa
Total	95 000 tpa

b) <u>Prices and Costs</u>

Table X.B.2. presents calculated net-back HDPE prices to the Arab plants. Also included are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and ethylene price:

TABLE X.B.2.

HDPE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	1 032 (1)	1 002 (1)
To developing markets	1 197	1 197
In local Arab markets	1 227	1 257
Weighted average	1 115	1 104
Transfer prices achievable		
Basic case (2)	1 216	1 232
20% ROI (3)	1 135	1 144
15% ROI	1 054	1 056
10% ROI	973	968
Ethylene @ $290/tonne (4)	1 058	1 109

(1) Duty calculated assuming US market

(2) 25 percent ROI; ethylene price $400/tonne in N. Africa, $366/tonne in Arabian Gulf

(3) Ethylene price kept constant

(4) With 25 percent ROI on HDPE plant

c) Conclusions

Thus it is clear that under the basic assumptions detailed above (Note (1)) HDPE from the Arab projects will not be competitive in world markets. Reducing the ethylene price can just give a viable HDPE project, but even more important (due to the capital-intensive nature of the HDPE process) is the ROI applied to the project. Provided that some reasonable concessions are made in terms of finance or taxation, therefore, an Arab HDPE project can be viable.

Market potential exists in all regions (developed, developing and local markets), though it will be necessary to have as a Joint Venture partner a company well established in the HDPE business in the developed countries, to provide the necessary technical support and marketing network.

3. Polypropylene

a) Markets

Polypropylene has a strongly growing market in both the developed and the developing countries. Substantial new investment will be required in the US by 1980, and in W. Europe by the early 1980's, to avoid shortages. Growing imports will be required in certain developing regions, particularly the Asia/Pacific area and Latin America, and a portion of these could be supplied from the Arab states.

Local Arab demand will remain fairly low, polethylenes generally being preferred and better established. The costs of UV stabilisation, required in Middle Eastern and other hot sunny areas, generally hurt the competitiveness of polypropylene as compared to HDPE and LDPE.

Assumed target market distribution for polypropylene is thus as follows:

Developed markets	50 000 tpa
Developing (non-Arab) Markets	30 000 tpa
Local Arab markets	7 000 tpa
Total	87 000 tpa

b) Prices and Costs

Table X.B.3. presents calculated net-back polypropylene prices to the Arab plants. Also included are simple sensitivity analyses showing the transfer price achievable from the Arab plants using various assumptions on capital charge (ROI) and ethylene price:

TABLE X.B.3.

POLYPROPYLENE NET-BACK PRICES AND TRANSFER PRICES (1990)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	1 089 (1)	1 059 (1)
To developing markets	1 260	1 260
In local Arab markets	1 290	1 320
Weighted average	1 164	1 149
Transfer prices achievable		
Basic case (2)	1 303	1 418
20% ROI (3)	1 202	1 308
15% ROI	1 100	1 199
10% ROI	998	1 080
Propylene @ $206/tonne (4)	1 203	1 263

(1) Duty calculated assuming US market

(2) 25 percent ROI; Polymer-grade propylene price $296/tonne in N. Africa, $354/tonne in Arabian Gulf

(3) Propylene price kept fixed i.e. still at 25 percent ROI on olefins plant

(4) With 25 percent ROI on polypropylene plant

c) Conclusions

Thus with the feedstock price and financial requirements applied to the basic case (Note (1), above) polypropylene production at the Arab locations is not attractive. This is particularly true of the Arabian Gulf location, due to the relatively high propylene price (caused by the favourable economics of simple ethane cracking in the Gulf, which weighs against propylene production) and to the high capital cost penalty. Even reducing the propylene feedstock price cannot alone give a viable project. Quite substantial concessions on the required return on capital are necessary to enable an Arab polypropylene plant to penetrate world markets.

Market potential exists for sale of Arab material into both developed and developing countries during the 1980's, though a Joint Venture partner would be required who is well established in the polypropylene markets in the developed countries.

Basically, the fiscal and other concessions required to establish a viable Arab polypropylene project are greater than those required for the ethylene-based polymers (HDPE, etc). There is thus little incentive to produce propylene for polypropylene production, particularly in the Gulf area, and in general simple ethane cracking producing ethylene alone is the best option for the first Arab olefin complexes unless there is a shortage of ethane feedstock.

4. O-xylene

a) Markets

It appears likely that a tight global supply/demand situation will develop for o-xylene during the early 1980's, giving opportunities for the export of some Arab material. W. Europe in particular will be a major target market. Surplus capacity in Japan would compete with any Arab plant for the continuing import markets in Asia/Pacific and Africa.

Local Arab demand will develop for production of phthalic anhydride-based plasticisers, used in flexible PVC, as the Arab PVC industry develops in the late 1980's.

Assumed average target market distribution for o-xylene over the early years of plant operation is thus:

Developed markets	30 000 tpa
Developing (non-Arab) markets	7 500 tpa
Local Arab markets	5 000 tpa
Total	42 500 tpa

b) Prices and Costs

Table X.B.4. presents calculated net-back o-xylene prices to the Arab plants. The price of o-xylene is one of the most volatile of all the aromatics, and these estimated net-back prices should be considered as indicative only.

The viability of an Arab export-oriented o-xylene plant would be more than usually at the mercy of fluctuating world market forces. Also included in the Table are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI):

TABLE X.B.4.

O-XYLENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	420 (1)	410 (1)
To developing markets	430	430
In local Arab markets	440	440
Weighted average	424	418
Transfer prices achievable		
Basic case (2)	370	366
20% ROI (3)	361	346
15% ROI	333	326
10% ROI	315	306

(1) xylenes are free of duty into all major market regions

(2) 25 percent ROI; xylenes feedstock price fixed by gasoline valuation

(3) Constant feedstock price

TABLE VIII-H-3

LOW DENSITY POLYETHYLENE PRODUCTION COST ESTIMATE: ARABIAN GULF

Basis: Location- Arabian Gulf 1980
Capacity- 105 000 tpa LDPE
Rate - 96 000 tpa

Capital Cost	$MM
Battery Limits Capital Cost	100
Offsites Capital Cost	55
Total Fixed	155
Working	15

RAW MATERIALS	QUANTITY	UNIT	PRICE*	ANNUAL COST	UNIT COST*
Ethylene	100 000	tonne	366	36 600 000	
Catalyst & Chemicals				3 500 000	
TOTAL RAW MATERIALS:				40 100 000	417.7
UTILITIES:					
Power	115 000	1000 Kwh	22.4	2 576 000	
Cooling Water	16 000	1000 m^3	12	192 000	
Steam	80 000	tonne	2.7	216 000	
TOTAL UTILITIES COST:				2 984 000	31.1
OPERATING COSTS:					
Labour 45 men @ $19 000 pa				855 000	
Supervision 4 men @ $27 000 pa				108 000	
Maintenance Material and Labour @ 4% BLCC				4 000 000	
TOTAL OPERATING COSTS:				4 963 000	51.7
OVERHEAD EXPENSES:					
Direct Overhead - 30% (Labour & Supervision)				289 000	
General Plant Overhead - 65% Operating Costs				3 226 000	
Insurance, Property Taxes - 1.5% Total Fixed Capital				2 325 000	
Depreciation - (Basis: 10% BLCC + 5% Offsites)				12 750 000	
Interest - 10% on Working Capital				1 500 000	
TOTAL OVERHEAD EXPENSES:				20 090 000	209.3
BYPRODUCT CREDIT:					
TOTAL BYPRODUCT CREDIT:				-	
TOTAL COST OF PRODUCTION:				68 137 000	709.8
RETURN 25% ON TOTAL FIXED INVESTMENT:				38 750 000	403.6
TRANSFER PRICE:				106 887 000	1 113.4

* $/unit

c) Conclusions

Thus o-xylene production appears an attractive proposition for an Arab aromatics complex, even under the basic assumptions on finance and feedstock pricing. More favourable terms of finance improve the economics still further. Another incentive for o-xylene production is that it also improves the economics of p-xylene production.

The uncertainties regarding future o-xylene prices are greater than for some other commodity petrochemicals, which are far more closely governed by cost of production. Also, the shortages envisaged in certain market regions during the 1980's could well be reduced or eliminated by increased local production, either from new facilities or by increasing o-xylene production at the expense of p-xylene from existing integrated facilities. The economics of Arab o-xylene are so attractive, however, that provided long-term contracts for export of at least a portion of the production can be established, either with a Joint Venture partner or with aromatics merchants, o-xylene appears a relatively low-risk addition to an Arab aromatics complex.

5. Styrene

a) Markets

Styrene has very large and strongly growing markets in all regions, and substantial new investment will be required to avoid shortages in all regions during the early 1980's. Large imports will be required by Latin America, and a growing volume by the Asia/Pacific countries. Since ethylene and benzene feedstocks could be short in all developed regions, there is considerable scope for supplying styrene from an Arab plant to established producers in the developed countries.

Local Arab demand for styrene will develop later, as polystyrene, synthetic rubber and other polymer industries develop. For the first few years of a styrene venture, it is assumed here that all product would be exported, with target market distribution approximately as follows:

Developed markets	225 000 tpa
Developing (non-Arab) markets	100 000 tpa
Local Arab markets	0 tpa
Total	325 000 tpa

b) Prices and Costs

Table X.B.5. presents calculated net-back styrene prices to the Arab plants. Also included are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and feedstock prices:

TABLE X.B.5.

STYRENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	666 (1)	656 (1)
To developing markets	720	720
In local Arab markets	730	740
Weighted average	683	676
Transfer prices achievable		
Basic case (2)	660	645
20% ROI (3)	644	630
15% ROI	631	615
10% ROI	617	600
Ethylene @ $250/tonne (4)	612	609
Benzene @ $350/tonne (4)	596	577
Lowest practical case (5)	523	511

(1) For purposes of import duty calculations, assumes market split equally between US, W. Europe and Japan

(2) 25 percent ROI on both ethylbenzene and styrene plants; ethylene at $400/tonne (N. Africa) and $366/tonne (Arabian Gulf); benzene at $422.5/tonne (N. Africa) and $430.9/tonne (Arabian Gulf)

(3) On both EB and styrene plants. Feedstock prices kept constant

(4) All other cost items still as in basic case (25 percent ROI, etc)

(5) 15 percent ROI; $250 ethylene; $350 benzene

c) **Conclusions**

Thus styrene production is shown to be a very attractive proposition for an Arab petrochemical venture. This is due largely to the energy-intensive nature of the styrene process, which favours the Arab locations with their cheap energy.

Export markets will be available during the 1980's, and provided that a Joint Venture partner is selected who will guarantee offtake of a large portion of the production, styrene production should be included in any integrated Arab petrochemical project to which both ethylene and benzene are available. Cheap, locally-produced styrene will then be available to Arab synthetic rubber and polymer plants when these are established later as a subsequent stage of industrialisation.

c Vinyl Chloride Monomer (VCM)

a) **Markets**

Despite recent worries about health problems associated with VCM and PVC, strong growth is expected in these major markets during the 1980's, requiring significant investment in all market regions. Of the developed regions, the US will present the most attractive market opportunities for Arab VCM during the early 1980's, due to the large projected deficit and the relative lack of integration in the US industry. With the planned installation of polymerisation facilities in various developing nations, there will be a shift towards supplying these countries with VCM rather than PVC, and large markets will develop in Southern Africa, Latin America and elsewhere. Local Arab PVC plants will undoubtedly be established to use a portion (and ultimately perhaps all) of the VCM.

Target market distribution for VCM is thus assumed to be:

Developed markets	100 000 tpa
Developing (non-Arab) markets	50 000 tpa
Local Arab markets	60 000 tpa
Total	210 000 tpa

b) Prices and Costs

Table X.B.6. presents calculated net-back VCM prices to the Arab plants. Also included are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charges (ROI) and feedstock price:

TABLE X.B.6.

VCM NET-BACK PRICES AND TRANSFER PRICES (1990)
($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	443 (1)	423 (1)
To developing (non-Arab) markets	546	546
In local Arab markets	590	610
Weighted average	509	506
Transfer prices achievable		
Basic case (2)	517	508
20% ROI (3)	488	476
15% ROI	459	445
10% ROI	429	413
Ethylene @ $200/tonne (4)	446	453

(1) Duty calculated assuming US market

(2) 25 percent ROI on VCM and chlorine plants; ethylene price $400/tonne in N. Africa, $366/tonne in Arabian Gulf

(3) Ethylene price kept constant; 20 percent ROI on both chlorine and VCM plants

(4) With 25 percent ROI on VCM and chlorine plants

c) Conclusions

VCM production in an Arab petrochemical development is thus shown to be a viable proposition, requiring only very nominal concessions on feedstock pricing or financial requirements to enable the Arab material to undercut world market price levels. This conclusion is based upon the target market distribution assumed above, which requires significant sales in local and/or developing country markets. Production exclusively for the US or European markets is barely viable, however, due to freight costs and tariff barriers. Thus while markets will be available in all regions during the 1980's, it is important that long-term supply contracts be established in these developing markets to ensure good profitability.

The availability of local Arab VCM will undoubtedly lead to local PVC facilities, either as an integrated development or as a separate phase of industrialisation.

7. Polystyrene (PS)

a) Markets

Polystyrene consumption has contracted significantly during the last two years, due to the combined effects of feedstock supply problems, higher prices and industrial recession. Even with the projected resumption of strong growth, therefore, a worldwide surplus is projected into the early 1980's. Beyond that time, significant investment will be required to supply the growth in this large market.

Japan in particular seems to be a likely target market during the early 1980's, with the US a possible target a few years later. The developing countries in the Asia/Pacific region also offer good market potential during the early 1980's, particularly since Japan will apparently not be in a position to supply these markets.

Local Arab demand could be significant by the early 80's, but it seems possible that several Arab plants could be installed during this period which will have to share the limited available local market.

Target market distribution is thus assumed as follows:

Developed markets	60 000 tpa
Developing (non-Arab) markets	20 000 tpa
Local Arab markets	10 000 tpa
Total	90 000 tpa

b) <u>Prices and Costs</u>

Table X.B.7. presents calculated net-back polystyrene prices to the Arab plants. Also included in the Table are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and styrene feedstock price:

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9 OF 9

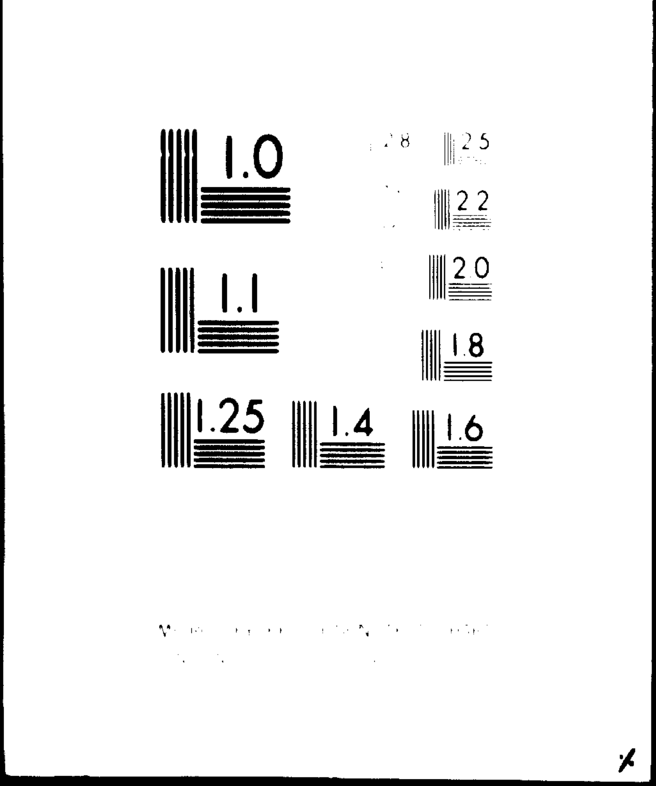

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TABLE X.B.10.

LDPE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	935 (1)	905 (1)
To developing markets	1 090	1 090
In local Arab markets	1 120	1 150
Weighted average	996	981
Transfer price available		
Basic case (2)	1 106	1 113
20% ROI (3)	1 032	1 032
15% ROI	957	952
10% ROI	883	871
Ethylene @ $250/tonne (4)	950	992

(1) Duty calculated assuming US market

(2) 25 percent ROI; ethylene price $400/tonne in N. Africa, $366/tonne in Arabian Gulf

(3) Ethylene price kept constant

(4) With 25 percent ROI on LDPE plant

c) Conclusions

Thus it is clear that under the basic assumptions detailed above (Note (2)) LDPE from the Arab projects will not be competitive in world markets. Reducing the ethylene price can just give a viable LDPE project, but - as for the other polyolefin resins - due to the capital intensive nature of the process the ROI applied to the project is even more important.

Provided that some reasonable concessions are made in terms of finance and taxation, therefore, an Arab LDPE project can be viable.

Market potential exists in all regions (developed, developing and local markets). It will be necessary to have as a Joint Venture partner a company well established in the LDPE business in the developed countries to provide the necessary technical support and worldwide marketing network.

LDPE is expected to play a major role in most Arab petrochemical plans, due to the very large worldwide market.

11. Benzene

a) Markets

Benzene is a widely traded commodity, and the vast size of the market together with projected overall deficits in Japan and the US make benzene a prime prospect for Arab production.

In addition to capacity shortages in certain developed regions, feedstocks supply problems and competition for aromatics from the gasoline pool may cause further pressure on benzene supplies. These will increase the attractiveness of imports of Arab material.

The developing regions of Asia/Pacific and Latin America are also installing extensive benzene capacity, so export of Arab material to these regions appears unlikely.

Local Arab consumption of benzene will undoubtedly develop, particularly for styrene production, and later also for cyclohexane, cumene and the other commodity-type aromatics derivatives.

Target market distribution is thus assumed to be as follows:

Developed markets	125 000 tpa
Developing (non-Arab) markets	0 tpa
Local Arab markets	100 000 tpa
Total	225 000 tpa

b) Prices and Costs

Table X.B.11. presents calculated net-back benzene prices to the Arab plants. Also included in the Table are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and process route:

TABLE X.B.11.

BENZENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	410 (1)	400 (1)
To developing markets	420	420
In local Arab markets	430	440
Weighted average	419	418
Transfer prices achievable		
Basic case, from reformate (2)	422	431
20% ROI	410	418
15% ROI	398	404
10% ROI	386	390
From pyro. naphtha (3)	345	355
From pyro. naphtha, 15% ROI	322	330

(1) Benzene is free of duty into all major market regions

(2) 25 percent ROI; integrated extraction and HDA complex

(3) 25 percent ROI; bulk HDA of pyrolysis naphtha. Feedstock price set by gasoline economics

c) Conclusions

Benzene production from pyrolysis naphtha from an Arab ethylene plant is an extremely attractive proposition, though adequate quantities of pyrolysis naphtha will only be available from ethylene plants using naphtha or gas oil feedstocks. As discussed elsewhere, such feedstocks will not in general represent the best economic choice for the initial Arab petrochemical projects.

Benzene production via naphtha reforming is viable provided some concessions are made on finance and/or taxation terms. Also, local Arab benzene production is essential as a cornerstone in the eventual development of an integrated petrochemical industry. In particular, if coordinated with ethylene production it permits styrene production, and subsequently styrene-based polymers and rubbers.

12. <u>Liquid Ethylene</u>

a) Markets

The total ethylene demand in the developed countries is growing rapidly, and very substantial investment in new crackers will be required throughout the 1980's in all regions. The possibility of supplying a part of this incremental demand with liquid ethylene shipped in from the Arab states is considered in this Section.

Due to the role of ethylene as the fundamental building block of the petrochemical industry, security of supply is of prime importance in consideration of potential new sources. It seems unlikely that an ethylene consumer in the developed countries would be prepared to rely entirely for his feedstock upon material imported from a new Arab project though this situation could change in time with increasing volume of maritime transportation and demonstrated reliability. In the meantime, it appears that the most promising method of marketing would be to several customers all of whom have flexibility in their sources of supply. This effectively means selling through one of the pipeline systems.

There are two prinicpal systems in Europe. One system traverses the centre of France running from Lavera, near Marseilles, northwards to Dijon. The second and larger system connects Belgium, Holland and Germany. Two smaller lines exist in the UK. The biggest system in the world is in the US Gulf coast area. There are no systems on the US West coast. Limited local systems exist in Japan.

All consumers connected to the major pipeline systems are potential consumers of Arab ethylene. These are the only credible target export markets for this material.

b) Prices and Costs

Table X.B.12. presents calculated net-back ethylene prices to the Arab plants when exporting liquid ethylene to the developed markets. Shipping costs, taken from Section IX.E. include the costs of liquefaction, storage, shipping, reception terminal and revaporisation. The average costs are heavily weighted towards the shortest available routes (i.e. N. Africa to Southern Europe, Arabian Gulf to Southern Europe/Japan), since the very high costs of ethylene shipping will generally make the more remote markets (e.g. US) uneconomic.

Also included in the Table are simple sensitivity analyses showing the effects of variations in capital charges and feedstock price upon ex-plant ethylene price achievable. These sensitivities are also used to fix the range of ethylene transfer prices considered as feed to the local derivatives units in previous sections.

TABLE X.B.12.

ETHYLENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	370	270
Transfer prices achievable		
Basic case (1)	400	366
20% ROI	369	332
15% ROI	338	298
10% ROI	306	264
Ethane feed at production cost (2)	307	323
Ethane at production cost, 15% ROI	245	255
Naphtha feed, 25% ROI	577	555
Naphtha feed, 15% ROI	496	466

(1) 25 percent ROI; ethane feedstock at $110/tonne in N. Africa, $70/tonne in Arabian Gulf (based upon alternate value economics)

(2) As derived in Section V.A.; $35/tonne for both locations. ROI on olefin plant at 25 percent.

c) Conclusions

Export of liquid ethylene to developed market areas (primarily Southern Europe) is a viable possibility from a North African project, requiring only nominal concessions on required return on capital or on ethane feedstock price. From an Arabian Gulf location, the economics of liquid ethylene export are distinctly unattractive, requiring both very cheap ethane feed and also substantial concessions on terms of finance and required return on capital.

For the purposes of sensitivity analyses on the various ethylene derivatives, the lowest possible ethylene transfer price may be taken to be around $250/tonne from both Arab locations. This requires cheap ethane feedstock (at production cost) and low capital charges (15 percent ROI, which covers basically only the cost of finance when unscheduled production losses are taken into account). The only situation in which ethylene could be made available at this price is when the Arab state wishes to promote the viability and establishment of derivative and downstream industries and is prepared to regard the basic olefin plant effectively from an "infrastructure" or "utility" viewpoint, and thus be prepared to heavily subsidise the ethylene to gain the benefits from rapid and extensive downstream development.

C. ANALYSES OF ALTERNATIVE COMPLEXES

1. Introduction

Most of the products analysed in the previous section were demonstrated to be viable possibilities for inclusion in an Arab petrochemical venture. It is not possible to select one particular complex and state that this is the recommended combination of plants and products. This selection will be heavily influenced for each location by specific local circumstances, e.g.

- technical and market position of Joint Venture partners. If a particular foreign oil or chemical company is desired as a JV partner, possibly due to its existing committments in the Arab state, then the capabilities and preferences of this partner will strongly influence the selection of products

- size of local market and existing downstream industry, e.g. plastics fabrication. Although we generally assume throughout this study that the Arab markets can be regarded as a coordinated whole, the existence of (or potential for) large markets in the actual country of production will be an incentive to manufacture those products.

- existing market contacts. If an Arab state already has good contacts and connections in a particular area (e.g. through existing refinery product exports) then there will be an incentive to develop in this area.

- o government objectives. If specific 5-year Plans or other national objectives have already been defined in the Arab state, with a view to developing a particular area of industry, this will obviously be of dominant importance in finalising the product range of a petrochemical complex.

This section therefore presents overall economic analyses of a number of credible complexes. A discounted cash flow approach is used.

2. Complexes Considered

Even from the relatively few products finally indicated in Section X.B. as desirable components of initial Arab petrochemical complexes, a very large number of different combinations are possible, even without varying the capacities selected in Section VIII. The following Table X.C.1. indicates a representative range of the more credible possibilities, which are then evaluated for overall profitability:

TABLE X.B.7.

POLYSTYRENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developing markets	1 045	1 045
In local Arab markets	1 075	1 105
Weighted average	988	971
Transfer prices achievable		
Basic case (2)	1 009	1 011
20% ROI (3)	984	984
15% ROI	959	957
10% ROI	934	931
Styrene @ $250/tonne (4)	871	884
$250 styrene, 15% ROI	821	830

(1) Duty calculated assuming 50 percent US, 50 percent Japanese markets

(2) 25 percent ROI; styrene price $658/tonne in N. Africa, $645/tonne in Arabian Gulf

(3) Styrene price kept constant

(4) With 25 percent ROI on polystyrene plant

TABLE X.C.1.

COMPLEXES CONSIDERED IN DCF ANALYSES

	Olefin Complex						Aromatics Complex		
Case	EG	LDPE	HDPE	VCM	Liquid Ethylene	Styrene	Benzene	P-X	O-X
a.	*	*	*	*					
b.	*	*		*	*				
c.		*	*	*	*				
d.	*	*	*		*				
e.							*	*	
f.							*	*	*
g.	*	*		*		*			
h.		*		*	*	*			
j.		*	*	*		*			

Complexes "a" to "d" are exclusively ethylene-based, and assume a coastal 450 000 tpa ethane cracker supplying four different derivatives units/sales outlets.

Complexes "e" and "f" are exclusively for direct sale of basic aromatics, benzene and xylenes. They are based upon the catalytic reformer capacity and processing schemes as described in Section VII. Integration with a new large coastal export refinery is assumed.

Complexes "g" to "j" show the effects of combining olefin and aromatics facilities by production of styrene. The olefin plant and other olefin derivatives are as in complexes "a" to "d". The reformer and benzene production units are scaled-up slightly to produce the quantities of benzene required by the styrene capacity selected, though no economies of scale are assumed in this scale-up to enable valid comparisons to be made between the various complexes "a" to "j".

3. Cost and Revenue Data

The following tables present calculated sales revenue, out-of-pocket costs and net revenue for each of the considered complexes. "Sales revenue" is the total annual revenue to the project obtained from sales (on an FOB or equivalent basis) of all products. "Out-of-pocket costs" are the sum of all raw material, utility, operating and overhead costs, less by-product credits, but excluding any depreciation or return on capital investment. "Net revenue" is sales revenue less out-of-pocket costs.

Data is presented here for 1980, 1985 and 1990 though each year during the operating life of the plant has been calculated to permit the DCF analyses to be carried out. The basic 1980 data and capital costs are taken from the Cost of Production sheets of earlier sections. Revenue and operating costs are escalated forwards using the inflation assumptions of Section X.A.3.

Out-of-pocket costs do not include depreciation or any return on capital. Also, they do not include any cost/revenue of ethylene or benzene feedstock transferred from the olefin/benzene plants to derivatives units.

a) Complex "a"

This comprises the olefin plant together with ethylene glycol, LDPE, HDPE and VCM derivatives units. The VCM capital costs include the relevant proportion of caustic/chlorine plant costs.

TABLE X.C.2.

REVENUE AND COST DATA FOR COMPLEX "a" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	158.17	388.48	230.31	268.02
1985	220.25	608.17	387.92	442.23
1990	313.07	951.85	638.78	716.50
1980 net revenue @ actual sales level of 40% capacity:			14.49	52.20
1981 net revenue @ actual sales level of 75% capacity:			184.74	225.32

Capital cost of complex $781 million

(1) ethane at "cost of production" price level of $35/tonne

TABLE X.C.3.

REVENUE AND COST DATA FOR COMPLEX "a" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	134.68	383.96	249.28	266.88
1985	186.82	601.62	415.80	441.14
1990	263.63	942.51	678.88	715.14
1980 net revenue @ actual sales level of 40% capacity:			35.97	53.57
1981 net revenue @ actual sales level of 75% capacity:			206.39	225.31

Capital cost of complex $845 million : note that this (and other complexes including VCM) excludes the proportion of the caustic/chlorine unit which attributable to production of the caustic soda. (This is assumed to be carried by the sales price of the caustic.)

(1) ethane at "cost of production" price level of $35/tonne

b) Complex "b"

This comprises the olefin plant together with glycol LDPE and VCM units. Direct export of part of the ethylene, as liquid, is also included in this scheme.

TABLE X.C.4.

REVENUE AND COST DATA FOR COMPLEX "b" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	133.82	319.55	185.73	223.44
1985	186.69	499.96	313.27	367.58
1990	265.41	780.22	514.81	592.53
1980 net revenue @ actual sales level of 40% capacity:			8.20	45.91
1981 net revenue @ actual sales level of 75% capacity:			147.82	188.40

Capital cost of complex $627 million

(1) ethane at "cost of production" price level of $35/tonne

TABLE X.C.5.

REVENUE AND COST DATA FOR COMPLEX "b" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	109.78	306.07	196.29	213.89
1985	151.79	480.52	328.73	354.07
1990	215.55	752.43	536.88	573.14
1980 net revenue @ actual sales level of 40% capacity:			26.25	43.86
1981 net revenue @ actual sales level of 75% capacity:			161.86	180.77

Capital cost of complex $678 million

(1) ethane at "cost of production" price level of $35/tonne

c) Complex "c"

This includes the olefin plant with LDPE, HDPE and VCM derivatives units. Remaining ethylene is exported as liquid.

TABLE X.C.6.

REVENUE AND COST DATA FOR COMPLEX "c" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	148.98	345.55	196.57	234.28
1985	209.48	539.19	329.71	384.02
1990	299.76	841.46	541.70	619.42
1980 net revenue @ actual sales level of 40% capacity:			4.60	42.31
1981 net revenue @ actual sales level of 75% capacity:			155.40	195.98

Capital cost of complex $674 million

(1) ethane at "cost of production" price level of $35/tonne

TABLE X.C.7.

REVENUE AND COST DATA FOR COMPLEX "c" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	125.85	332.23	206.38	223.98
1985	175.75	519.97	344.22	369.56
1990	251.43	813.99	562.56	598.82
1980 net revenue @ actual sales level of 40% capacity:			21.81	39.41
1981 net revenue @ actual sales level of 75% capacity:			168.36	187.27

Capital cost of complex $729 million

(1) ethane at "cost of production" price level of $35/tonne

d) **Complex "d"**

This comprises the olefin plant with LDPE, HDPE and glycol derivatives units. Remaining ethylene is exported as liquid.

TABLE X.C.8.

REVENUE AND COST DATA FOR COMPLEX "d" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	130.70	318.53	187.83	225.54
1985	183.08	497.71	314.63	368.94
1990	260.89	778.26	517.37	596.00
1980 net revenue @ actual sales level of 40% capacity:			10.87	48.58
1981 net revenue @ actual sales level of 75% capacity:			180.20	190.78

Capital cost of complex $657 million

(1) ethane at "cost of production" price level of $35/tonne

TABLE X.C.9.

REVENUE AND COST DATA FOR COMPLEX "d" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue	Net Revenue with cheap ethane feed (1)
1980 (@ 90% capacity)	109.84	304.80	194.96	212.56
1985	152.33	477.91	325.58	350.92
1990	216.57	749.95	533.38	569.64
1980 net revenue @ actual sales level of 40% capacity:			25.63	43.23
1981 net revenue @ actual sales level of 75% capacity:			160.51	179.43

Capital cost of complex $712 million

(1) ethane at "cost of production" price level of $35/tonne

e) Complex "e"

This is an aromatics complex, based upon a catalytic reformer taking naphtha feedstock from an adjacent refinery. Benzene is produced directly by extraction from reformate, and also by the dealkylation of all extracted toluene. Total benzene output is 225 000 tpa. Para-xylene alone is produced from the extracted mixed xylenes in an adsorption/isomerisation sequence.

c) Conclusions

Thus polystyrene is shown to offer a viable opportunity provided some concessions are made on required return on investment or styrene feedstock price. However, since production of styrene itself for direct export to the developed countries seems to be a very attractive proposition (Section X.B.5.), there appears little incentive to process further to polystyrene during the initial phase of an Arab petrochemical development. If large-scale styrene facilities are first successfully installed, polymerisation plant can and undoubtedly will be added later, but the economic logic of including it initially for export purposes seems doubtful.

Economies of scale are of less importance for the relatively inexpensive polystyrene plants than for the highly capital-intensive polyethylene and other thermoplastics. The installation of small plants to serve mainly local Arab demand is therefore possible as a subsequent stage of industrialisation.

8. Para-xylene

a) Markets

Worldwide p-xylene capacity appears adequate to meet demand through to the early 1980's. This comfortable supply situation has arisen due to the sudden drop in current demand and growth expectations for polyester fibres, and hence for DMT/TPA and p-xylene. In addition a large surplus is likely in the Asia/Pacific region as p-xylene plants come on stream while the planned DMT/TPA

TABLE X.C.10.

REVENUE AND COST DATA FOR COMPLEX "e" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	107.73	169.62	61.89
1985	153.89	256.43	104.54
1990	220.45	387.07	166.62

1980 net revenue @ actual sales level of 40% capacity:	(32.34)
1981 net revenue @ actual sales level of 75% capacity:	37.80

Capital cost of complex $190 million

TABLE X.C.11.

REVENUE AND COST DATA FOR COMPLEX "e" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	103.15	168.19	65.04
1985	147.07	254.35	107.28
1990	210.42	383.80	173.38
1980 net revenue @ actual sales level of 40% capacity:			(28.40)
1981 net revenue @ actual sales level of 75% capacity:			41.50

Capital cost of complex $206 million

f) Complex "f"

This aromatics complex is identical to Complex "e" except that ortho-xylene is also produced along with the para-xylenes. This reduces overall costs and improves economics.

TABLE X.C.12.

REVENUE AND COST DATA FOR COMPLEX "f" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	105.61	169.37	63.76
1985	150.77	256.06	105.29
1990	215.71	386.56	170.85

1980 net revenue @ actual sales level of 40% capacity: (30.33)

1981 net revenue @ actual sales level of 75% capacity: 39.86

Capital cost of complex $171 million

TABLE X.C.13.

REVENUE AND COST DATA FOR COMPLEX "f" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	101.81	167.98	66.17
1985	145.25	254.04	108.79
1990	207.84	383.48	175.69

1980 net revenue @ actual sales level of 40% capacity:	(27.15)
1981 net revenue @ actual sales level of 75% capacity:	42.78

Capital cost of complex $186 million

g) Complex "g"

This is a combined olefins and aromatics complex. The olefin plant supplies ethylene glycol LDPE and VCM units, and also feeds an ethylbenzene/styrene plant. The benzene feed to this EB/Styrene unit comes from a reformer-based extraction and toluene hydrodealkylation complex, scaled-up to produce exactly the benzene quantity required by the styrene plant. Xylenes separation is not included.

TABLE X.C.14.

REVENUE AND COST DATA FOR COMPLEX "g" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	236.06	504.40	268.34
1985	329.59	779.63	450.04
1990	466.65	1 202.20	716.50

1980 net revenue @ actual sales level of 40% capacity: (11.88)

1981 net revenue @ actual sales level of 75% capacity: 205.90

Capital cost of complex $841.8 million

TABLE X.C.15.

REVENUE AND COST DATA FOR COMPLEX "g" ARABIAN GULF, 1980 START UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	204.40	498.67	294.27
1985	283.60	771.34	487.74
1990	400.94	1 190.36	789.42

1980 net revenue @ actual sales level of 40% capacity:	17.23
1981 net revenue @ actual sales level of 75% capacity:	235.04

Capital cost of complex $912.9 million

h) **Complex "h"**

This combined olefins/aromatics complex is similar to Complex "g", except that liquid ethylene export replaces the glycol plant.

TABLE X.C.16.

REVENUE AND COST DATA FOR COMPLEX "h" N. AFRICA,
1980 START-UP
($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	226.87	461.47	234.60
1985	318.82	710.65	391.83
1990	453.34	1 091.81	638.47

1980 net revenue @ actual sales level of 40% capacity:	(21.77)
1981 net revenue @ actual sales level of 75% capacity:	177.03

Capital cost of complex $734.8 million

TABLE X.C.17.

REVENUE AND COST DATA FOR COMPLEX "h" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	195.57	443.94	248.37
1985	273.53	689.69	416.16
1990	388.74	1 061.84	673.10

1980 net revenue @ actual sales level of 40% capacity:	1.74
1981 net revenue @ actual sales level of 75% capacity:	194.73

Capital cost of complex $769.9 million

j) Complex "j"

This combined olefins/aromatics complex is also similar to Complex "g", except that on HDPE plant replaces the glycol unit.

TABLE X.C.18.

REVENUE AND COST DATA FOR COMPLEX "J" N. AFRICA, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	251.22	530.40	279.18
1985	352.38	818.86	466.48
1990	501.00	1 263 44	762.44

1980 net revenue @ actual sales level of 40% capacity:	(15.49)
1981 net revenue @ actual sales level of 75% capacity:	213.67

Capital cost of complex $888.8 million

TABLE X.C.19.

REVENUE AND COST DATA FOR COMPLEX "J" ARABIAN GULF, 1980 START-UP

($ millions)

	Out-of-pocket costs	Sales Revenue	Net Revenue
1980 (@ 90% capacity)	220.47	524.83	304.36
1986	307.56	810.79	503.23
1990	436.82	1 251.92	815.10
1980 net revenue @ actual sales level of 40% capacity:			12.79
1981 net revenue @ actual sales level of 75% capacity:			241.91

Capital cost of complex $963.9

and polyester fibre facilities are delayed. Thus with the inevitable addition on p-xylene expansions in the developed countries by integrated producers committed to this business area, little obvious potential exists for export of Arab p-xylene. However, p-xylene is a widely traded commodity on which no tariff barriers exist, so it is probable that if material can be delivered at below world market price levels then outlets can be secured.

Since the timing of the development of Arab polyester fibre industries is uncertain and outside the scope of this report, we base the evaluations here on the assumption that all p-xylene would have to be exported during the early years of operation.

Assumed distribution of target sales is thus as follows:

Developed markets	90 000 tpa
Developing (non-Arab) markets	10 000 tpa
In local Arab markets	0 tpa
Total	100 000 tpa

b) Prices and Costs

Table X.B.8. presents calculated net-back p-xylene prices to the Arab plants. Also included in the Table are simple sensitivity analyses showing the transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and process route:

4. Results of Evaluations

Each complex has been evaluated using a discounted cash flow approach to calculate the "internal rate of return" of the project. This method of evaluation is considered to be the most meaningful in analyses of this type.

Table X.C.20 summarises the results of these calculations, including the sensitivity analyses which consider variations in feedstock price and in capital costs.

TABLE X.C.20

INTERNAL RATE OF RETURN ON ALTERNATIVE COMPLEXES

(percent per annum)

Complex	North Africa			Arabian Gulf		
	Base Case	High Capital(1)	Cheap Ethane(2)	Base Case	High Capital(1)	Cheap Ethane(2)
a	26.1	22.3	28.6	26.4	22.8	28.0
b	26.1	22.4	30.5	25.9	22.4	27.8
c	25.7	21.9	29.6	25.3	21.7	27.2
d	25.5	21.7	29.7	24.8	21.0	26.7
e	24.9	21.5	-	24.8	21.4	-
f	27.5	24.0	-	26.9	23.5	-
g	27.1	23.2	-	27.6	23.9	-
h	26.8	23.0	-	26.8	23.2	-
j	26.6	22.9	-	27.2	23.5	-

Notes: (1) "High Capital" cases assume that the locational ratios (i.e. costs relative to W. Europe) for the N. African plants are increased from 1.15 to 1.40, and for the Arabian Gulf from 1.25 to 1.50.

(2) "Cheap Ethane" cases assume that ethane is charged in at the calculated production cost of $35/tonne, rather than at the "alternate value" prices, used in the base case, of $110/tonne in N. Africa and $70/tonne in the Arabian Gulf.

In general, the likely profitability of a petrochemical complex in North Africa is shown to be very similar to the profitability of a similar project in the Arabian Gulf, despite the variations in costs and revenues between the two regions. In both regions, integrated olefin and aromatics complexes offer the best economics, though any of the complexes could be considered acceptable.

By comparing the returns on one complex with another, the following general comments on the potential profitability and desirability of each product can be made.

In both locations, styrene is shown to be the most attractive major option, with ortho-xylene also very favourable, though long-term uncertainties on o-xylene price mechanisms cloud this judgement somewhat. VCM, para-xylene and benzene also offer good economics in both regions. LDPE economics are not particularly attractive at either Arab location, but export and local market considerations suggest that this should be included in any complex as a reliable base-load product. HDPE economics are in fact marginally more attractive than LDPE, due to the higher energy and utility consumption of the process, but marketing prospects are less favourable and the economics are still less attractive than any other ethylene derivative considered. Inclusion of HDPE in the initial Arab complexes, therefore, seems less clearly beneficial. Ethylene glycol economics are quite favourable, but again marketing prospects are relatively poor.

Direct export of liquid ethylene from the North African location is quite an attractive prospect in terms of straight economics. Detailed sales discussions on the basis of firm project plans will be particularly necessary in the case of liquid ethylene sales, however, to identify specific sales opportunities and confirm the acceptability of large-volume imports to the European consumers and pipeline companies. The economics of liquid ethylene export from an Arabian Gulf location look distinctly unattractive, due to the high costs of shipping over the long distances involved, when compared to the alternative approach of using the ethylene locally and exporting derivatives.

The effects of higher capital costs are roughly equally damaging, in terms of returns on investment, to all complexes, though obviously the effect is marginally greater upon the highly capital intensive styrene, VCM, etc.

Cheap feedstock, i.e. charging in ethane at production cost rather than the higher "alternate value" price, has a major effect upon returns of the N. African complexes. This is particularly true of those complexes involving liquid ethylene export, in which cases the benefits of cheap ethane can more than outweigh the potential penalties of higher capital costs. For the Arabian Gulf complexes, the benefits of lowering ethane price to a production cost level are less marked, since the "alternate value" price in the Gulf is already quite low, due to the high costs of shipping gas or light gas liquids to market.

To show the magnitude of the penalties involved in selecting naphtha as opposed to ethane as cracker feedstock, complex "a" has been reworked for the Arabian Gulf location for naphtha feed. All cracker co-products are credited at the values given in Table VI.F.12, and only the net feedstock cost (naphtha minus co-product credits) is charged to the ethylene. This reduces the DCF return on the ethylene-based complex from the 26.4 percent of case "a" (ethane feed) to 20.5 percent for the naphtha feed case.

5. Acceptability of Returns

The general conclusion that can be drawn from these evaluations is that any of these Arab petrochemical complexes can be viable from the viewpoint of a state-owned Arab petrochemical company.

That is to say that all projects can yield net cash flows adequate to repay loans and interest charges, while leaving a reasonable surplus for profit and return on equity. If the project is based entirely upon loan finance, and a ten-year depreciation period is assumed, then a rate of return around 15 percent p.a. on total project costs is adequate to cover all debt service charges over the project's life at current commerical interest rates. The minimum rate acceptable to an Arab National Petrochemical company is thus probably in the range of 15 to 20 percent, allowing a margin over loan costs to cover overheads and profit, and to provide some safety factor against failing to reach operating or sales revenue targets.

The range of returns available from the various complexes listed in Table X.C.20. are generally 21 to 30 percent, with the most-likely cases around 25 percent. These rates of return are based upon two major considerations, however, in addition to all the detailed cost and market assumptions set out in previous sections. These two key assumptions are that

- the project will be located in a tax-free zone, and will thus pay no local corporate income tax, and
- world inflation will continue approximately at the rates set out in Section III, i.e., a long-term average of 7½ percent p.a. in general inflation and 10 percent p.a. in labour and capital costs.

This inflation assumption is obviously impossible to justify with any great degree of confidence: it represents a current consensus view, but could be very wrong. Higher rates of inflation in the developed regions of the world after the Arab project has been built will generally benefit the Arab venture by more rapidly raising the level of product prices in the export markets. Conversely, a reduction of inflation to the historical levels of the 1950's and 1960's (say 3-4 percent p.a.) could reduce the returns listed in Table X.C.20. by 2 or 3 percentage points.

Corporate taxation could obviously greatly reduce the net returns on all projects, depending upon the tax rate and the system of depreciation allowances applied. The amount of taxation which any project could bear and still remain viable depends largely upon factors specific to the individual situation. It should however be noted that there are many "development regions" in, for example, Western Europe in which major taxation concessions and capital grants are available to compensate companies for investing in these less developed and/or more remote regions. These concessions indicate the size of the incentives necessary to offset the relative economic advantages of the highly developed production centres, such as Rotterdam and the US Gulf Coast.

It is to be expected therefore that heavy corporate taxation on the early Arab petrochemical projects will not be feasible if the returns even to the National Petrochemical Company (say) are to remain adequate.

The returns required by an international chemical or oil company will generally be significantly greater than those acceptable to the Arab organisation itself. This is because the State-owned Arab company will be basically motivated by a national political directive to develop the petrochemical industry: the considerations involved in formulating this directive are largely long-term economic and social factors, as discussed in Section X-D on "Indirect Benefits". They include such factors as employment and training benefits, generation of increased foreign exchange revenue by processing basic feedstocks ("value added"), and the intangible long-term national benefits of infrastructure development. While these indirect benefits are of prime importance in formulating Arab national policies, they are of little relevance to a foreign chemical company evaluating an investment decision in the Arab country. The company will view the proposed project as a separate entity, and apply only commerical criteria in evaluating it. (This is also true in the developed countries, where governments offer financial inducements to companies to invest in regions and industries which the government regards as desirable, for social reasons, but which are less attractive to the company than some other alternative.)

The main commercial criteria which the foreign company will apply are

- alternative uses for its available money, manpower and expertise.
- assessment of the commercial, political and other risks involved in the project, as compared to other projects in which it could invest.

The alternative use for the financial resources of an international company is basically investment in similar facilities in the developed countries. As was demonstrated in Section VIII, there are very few petrochemical products which can be manufactured in the Arab states to yield gross returns on capital equal to those achieved in the developed countries, assuming comparable taxation levels. Certainly a large multi-product Arab facility will not be able to achieve the same gross returns as a comparable integrated facility in a developed country. On inflation and other assumptions comparable to those used in evaluating the Arab projects in Table X.C.20, we calculate that the after-tax DCF returns on most W. European petrochemical projects will be around 20-22 percent p.a. if prices are set by the simple 25 percent ROI approach of Section VIII. This 20-22 percent after tax corresponds to 27-30 percent before tax. (It should be noted that the historical value of 15 percent DCF return after tax, which many companies have long used as a minimum acceptable return in project planning, was not based upon inflation accounting principles, i.e., it did not take full credit for future increases in product prices after plant start-up, and calculated the returns on the price levels predicted for the time of start-up. This 15 percent rate is roughly equivalent to 22-23 percent on the inflation-accounting basis used throughout this report and we believe that most major companies are presently looking for returns of this order in evaluating new projects.)

The rates of return on the better complexes, indicated in Table X.C.20 therefore appear to be in line with the requirements of the foreign chemical companies. A complete absence of corporate income tax should therefore ensure adequate incentives to a potential foreign equity partner. Some of the more attractive complexes indicated in the table could bear some tax and still remain marginally viable.

The assessment of risk which a potential foreign equity partner will make of an Arab project depends upon many factors, most of them specific to the project and the company.

Firstly, the lack of experience with comparable projects in the Arab States increases the uncertainties regarding the actual time required to build a plant and the final costs involved. This uncertainty is widespread, and the "high capital cost" data included in Table X.C.20 represents our assessment of maximum likely impact of such risks. Many European and US companies believe that these "high capital" figures are closer to reality than our base case data, and would therefore be looking for returns higher than the 22-23 percent discussed above as insurance against the possibility of these higher costs actually being realised.

Secondly, the history of nationalisation of foreign assets and concessions by the oil-producing states over the past few years has made many major oil and chemical companies acutely aware of the political risks involved in investing outside their domestic regions. Very secure long-term agreements, on a government level as well as between companies, will generally be necessary to reduce the political risks to a level acceptable to the foreign companies and their financial backers. Also, any such risk (real or imagined) tends to increase the returns a company expects from a project, as an incentive to incur this higher risk.

Thirdly, project development costs and corporate overheads will be higher for a company developing and supporting a project outside its traditional areas of operation, and somewhat higher returns will be required to cover these costs. This factor varies from company to company, since some major international chemical companies already have well-established marketing operations in the Arab regions and in neighbouring areas.

Fourthly, there is one major factor which will tend to counteract the disincentives previously discussed. This is the attraction of guaranteed availability of feedstocks.

The oil embargo and shortages of 1974 made many integrated international companies acutely aware of the importance of security of supply for feedstocks and energy, and participation in a project in the Arab oil-producing states is one way in which a company could secure access to reliable feedstocks supplies. This incentive could lead the company to regard investment in an Arab petrochemical project as acceptable at a rather lower return on investment than it would otherwise accept. An associated factor is the desire of the major oil companies to be seen to be "good citizens" in the countries in which they have established oil production operations: participation in a petrochemical venture (even of limited profitability) might be considered acceptable in the interests of good relations with the host government, thus preserving access to valuable crude oil supplies.

On a balance of the factors discussed above, a foreign major chemical company will generally require a higher rate of return on its investment in the project than will the State-owned Arab Petrochemical Company. If it is desired to attract foreign equity participation in the project, it will therefore generally be necessary to offer the project (or the foreign investor) more generous concessions on taxation, etc. than would be necessary from the viewpoint of the state participation. On this consideration, it may be regarded as undesirable to have any foreign equity participation in the project at all: in this case, some other form of joint venture would have to be entered into, possibly combining a technical service and management contract together with a product marketing contract.

We believe it to be very important, however, that an experienced major international company should be deeply involved in all phases of the implementation of the Arab petrochemical development, since the expertise of such companies can have a dominant impact upon the efficiency and profitability of the project. The most certain way to ensure total long-term commitment is for the foreign company to have an equity stake in the Joint Venture company; this ensures their interest in maximising project profitability, and also makes it inconceivable that they would abandon the project in the event of future difficulties of operation or marketing. If the Arab country does not wish to obtain foreign equity partners, due either to political inclination or to economic considerations, such as the required return on capital as discussed above, then the foreign expertise will have to be bought in some other way, and the risks of such alternate approaches must be considered.

A major international chemical company will not be prepared to involve itself in an Arab project, thereby associating its technical and commercial reputation with that project, and committing management services to it, without adequate incentive. Thus a simple technical service and management contract to execute and operate the project for a fee will not generally be desirable, since it offers little incentive to the foreign company to maximise project profitability. A contract based upon a fixed or reimbursable fee plus a percentage of profits would seem to be necessary to ensure adequate commitment of the foreign company. Even this arrangement is in some ways less certain than having foreign equity participation, since it is still conceivable that under certain adverse circumstances of operating

TABLE X.B.8.

P-XYLENE NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
To developed markets	570 (1)	560 (1)
To developing markets	580	580
In local Arab markets	590	600
Weighted average	571	562
Transfer prices achievable		
Basic case (2) p-xylene only	570	569
20% ROI (3)	537	533
15% ROI	504	498
10% ROI	471	462
Integrated with o-xylene prodn. (4)	520	516
15% ROI (5)	468	459

(1) Xylenes are free of duty into all major market regions

(2) 25 percent ROI; xylenes feedstock price fixed by gasoline valuation. All o-xylene isomerised to p-xylene

(3) Constant feedstock price

(4) Relative productions as in Section VIII

(5) On integrated ortho/para unit

problems coupled with badly depressed markets, a foreign company without equity involvement might abandon the project and concentrate upon the plants in its home area.

Risks and factors such as this must be weighed by the planners of each Arab project when deciding whether to invite foreign equity participation in the venture. We believe that in most cases this firm equity-based Joint Venture approach will offer the safest method of "buying" the necessary committed expertise from foreign companies.

D. INDIRECT BENEFITS OF PETROCHEMICAL DEVELOPMENTS TO THE ARAB STATES

The development of a petrochemical industry within the Arab States has obvious direct economic advantages in upgrading indigenous feedstocks. However, such developments also have a much wider impact upon the overall aims of the Arab States to reduce their dependence upon oil exports, bring about an increase in general industrial activity and improve the standard of living and economic well being of their people.

To this end the economic plans of the various States call for a good deal of investment in various industries and social services including:-

agriculture and foodstuffs
general manufacturing
housing
education
transport
communications
health
textiles

The development of these sectors will bring about a rapid increase in the demand for a large variety of basic materials and fabricated products. Thus increases in agriculture and foodstuffs will lead to a demand for packaging materials for both bulk transport (sacks) and also for retail sales (film, boxes, etc.). Improvements in health and educational services, as well as housing, will lead to rapidly increasing requirements for building materials of all kinds. Improvements in the level of general manufacturing will necessitate provision of tools, handling equipment, etc. The textile industry, in order to expand and diversify its product range will require synthetic fibres. In the Arab States polyester fibres will be of particular importance for blending with locally produced cotton.

In all these examples the products of the petrochemical industry contribute towards the effective realisation of the plans for new industrial development. Thus LDPE film is of major importance in both bulk and retail packaging in the agricultural and foodstuffs industry. It is also important in various new developments for mulching and water conservation which is of particular importance in the Arab regions. Irrigation is vital to improved agricultural production and PVC and HDPE piping provides the most economic means for water distribution. Polystyrene has wide applications in food conservation and packaging.

The building industry is one of the major outlets for petrochemical derivatives in the developed countries. PVC in particular has many applications in piping, flooring, roofing, walls, windows, etc., etc. Clearly this will be appropriate not only in housing but also for hospitals, schools and offices.

General industry provides an outlet for many plastics mouldings as components, casings etc. HDPE and polystyrene are of special interest in this area with PVC also having applications in wiring and cables.

Development of the textile industry will be greatly expanded by the use of synthetic fibres which have wide applications in clothing, household fabrics and industrial textiles. The polyester fibres referred to above will bring about demand for dimethylterephthalate and ethylene glycol.

Thus apart from being an important activity in its own right, the petrochemical industry provides products which are essential for the satisfactory development of a wide range of other industries. Availability of such products, from a domestic source of supply will not only decrease the reliance on imports but will stimulate further demand. In addition, the conversion and fabrication of petrochemical derivatives will provide an industrial activity of its own, producing added value to basic products and further opportunities for employment.

E. ANALYSIS OF TYPICAL SPECIFIC PROJECT

1. Introduction

As has been argued in previous sections, it is not realistic for a generalised study such as this to conclude that one specific complex is preferable to all others for all Arab projects. Obviously if many major Arab petrochemical projects are realised, it will be essential that there is some coordination between the planning of these to avoid excessive conflict and competition in world markets: it is therefore clear that a range of different products and complexes must be and will be implemented. The choice of products and processes for a particular Arab project will be heavily influenced by many local factors, as discussed in Section X-C-1.

For the purposes of presenting further analysis and information on the scale and execution of a typical major petrochemical project of the type discussed in this study, we select now Complex "a", comprising an ethylene plant with glycol, LDPE, HDPE and VCM derivatives units. This is not intended to be a judgment on the "best" available project either in terms of economics or market potential; it is merely selected as being typical of the type of project which will be implemented in the Arab countries.

Indicative material and utility balances, manpower requirements, offsites cost estimates, and construction schedules are presented for this representative project in an Arabian Gulf location.

2. Operating and Utility Requirements

Tables X-E-1 to X-E-3 summarise the utility, manpower and other operating requirements of the complex to give an impression of the scale of the project.

TABLE X-E-1

SUMMARY OF NET UTILITY REQUIREMENTS FOR COMPLEX

Plant	BLCC ($million)	Power (1000 Kwh)	Cooling Water (1000 m^3)	Process Water (1000 m^3)	Fuel (10^6 Kcal)	Steam (tonne)
Ethylene	177	3 700	109 000	50	790 000	-
E. Glycol	75	80 000	103 000	1 300	50 000	600 000
LDPE	100	115 000	16 000	-	-	80 000
HDPE	108	80 000	35 000	3 100	-	370 000
VCM	56	46 000	55 000	1 700	210 000	315 000
Chlorine	63	436 000	2 600	-	-	650 000
Annual Total	579	760 700	320 600	6 150	1 050 000	2 015 000
Hourly Rate		95 mw	40 000 m^3/hr	750 m^3/hr	$130x10^6$ Kcal/hr	250 tonnes/hr

TABLE X-E-2

SUMMARY OF OPERATING REQUIREMENTS FOR COMPLEX

Plant	BLCC ($million)	Labour	Supervision	Catalyst & Chemicals ($million/year)	Working Capital ($million)
Ethylene	177	31	3	0.50	27
E. Glycol	75	40	10	0.50	25
LDPE	100	45	4	3.50	15
HDPE	108	45	4	6.10	16
VCM	56	25	5	1.00	28
Chlorine	63	20	5	0.75	10
Total	579	206	31	12.35	121

TABLE X-E-3

TOTAL MANPOWER REQUIREMENTS FOR COMPLEX

Area	Total number of personnel required	
Process units:		
Ethylene	34	
E.glycol	50	
LDPE	49	
HDPE	49	
VCM	30	
Chlorine	25	
Sub total	237	
Utility, storage, loading	120	
Sub total		357
Administration and Services:		
Main office staffing	90	
Plant maintenance/workshops	90	
Stores/warehousing	40	
Laboratory	12	
Drivers	20	
Security	60	
Fire	24	
First aid	12	
Canteen	60	
Camp maintenance	80	
Sub total		488
TOTAL COMPLEX		845

Of this total manpower requirement, approaching a thousand personnel, a large proportion will require technical and/or administrative skills of a high order.

All process operating labour will require a good technical or mechanical background plus training on similar facilities prior to plant start-up. The operating supervision will in particular require extensive previous experience of similar plants.

The main office staffing will include general and area managers, engineering personnel and accounts staff, all of whom will require high-grade experience in this field. The remainder of the main office staffing will consist of clerical, secretarial, personnel and other administrative staff, of whom the training and experience requirements will be less high.

A percentage of the total maintenance, workshop laboratory and other service personnel will need a high level of training and ability plus good previous relevant experience. The remainder of the personnel requirement can be largely filled by semi-skilled labour.

3. Offsites Estimates

Throughout this study, offsites have been estimated for the Arab plants at 55 percent of the battery limits capital cost for each plant. This value was originally derived from the offsites estimate presented below as Table X-E-4, which gives an offsites cost equivalent to approximately 55 percent of the BLCC of this complex.

This 55 percent figure was then applied, as a generalisation, to all the Arab plants.

It is important to note that only "infrastructure" immediately local to the complex itself is included in these estimates. Thus local roads, power supply, desalinisation and marine loading facilities are included: costs of major harbour facilities, roads away from the site area, housing and amenities for operating personnel, airfield, etc. are excluded.

The costs of such general infrastructure can be very large in a completely remote area, and the loading of all such costs onto any one project can easily make the project totally uneconomic, thus hindering industrial development. We consider that such general infrastructure development must be to the account of central and local government, since such infrastructure is clearly of long term and general benefit to the national economy.

TABLE X-E-4

OFFSITES COST SUMMARY FOR COMPLEX

	$million
Power generation (gas turbine/ alternators)	50
Power distribution	35
Cooling water supply (sea water)	15
C.W. distribution	10
Steam generation (packaged boilers)	10
Desalination unit	25
Miscellaneous utilities	15
Buildings (inc. polyethylene storage)	25
Storage (ethylene, glycol, VCM, etc.)	25
Piping (yard piping, lines to jetty etc.)	25
Site preparation (inc. local roads & construction camp)	15
Marine jetty and loading facilities (excluding harbour itself)	15
	265
Contingency (20 percent)	53
TOTAL	318
Battery limits capital cost (BLCC)	579
Offsites as percentage of BLCC	55%

4.. Construction and Expenditure Schedules

The pattern of capital expenditure on a major project of this type will follow the normal curve, with slow build-up, rapid expenditure during the main construction phase, and gradual tail-off after mechanical completion of the main units. Figure X-E-1 shows the estimated pattern of expenditure: it is assumed that the working capital will be provided by the partners during the final year of the project schedule, to finance product inventory build-up etc.

The time schedule assumed for the project is as follows:

Contract award - mid 1976
Mechanical completion - mid 1979
  - ethylene - mid 1979
  - glycol - 3rd qtr 1979
  - chlorine - 3rd qtr 1979
  - LDPE, HDPE and VCM - 4th qtr 1979

The choice of this time schedule is purely arbitrary, and is used only as a reference basis to correspond with the mid-1980 start-up date assumed throughout this study.

c) Conclusions

Thus p-xylene production appears an attractive proposition for an Arab aromatics complex, particularly if integrated with o-xylene production. As discussed in Section X.B.4, o-xylene production itself looks economically attractive, and market potential exists to the developed countries. Assuming therefore that an integrated ortho/para-xylenes complex can be considered, it should be possible to arrange long-term export contracts of at least a portion of the p-xylene production, since prices could be set below world market rates. Either a Joint Venture partner integrated in the aromatics business, or an established merchant/trader in aromatics, could be a suitable sales outlet for the Arab material.

9. Dimethyl Terephthalate/Terephthalic Acid (DMT/TPA)

a) Markets

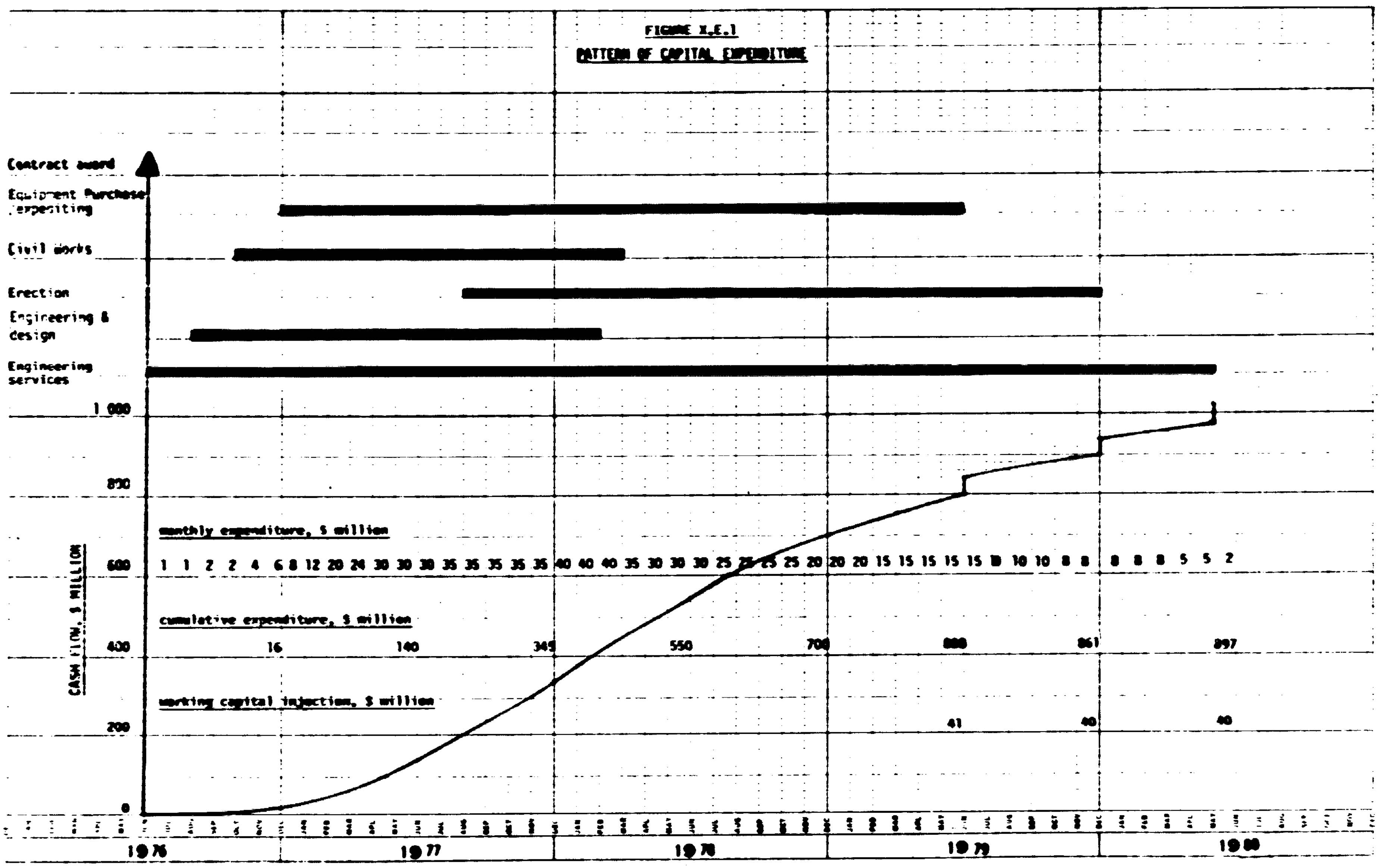
As discussed in Section VIII.G, worldwide overcapacity plus the entrenched market positions of Hercules and Amoco in US/European merchant markets make large-scale Arab penetration of world markets unlikely. The main justification for an Arab project would therefore only come from an operation integrated locally into polyester fibre production. Since the economics of a polyester fibre industry are outside the scope of this report, detailed evaluations of DMT/TPA production for local consumption are not possible here. Some basic cost data is presented below as input to any future evaluation of a polyester fibre project.

b) Prices and Costs

Table X.B.9. presents calculated local Arab prices for DMT and TPA assuming that these prices are set by imports

FIGURE X.E.1

PATTERN OF CAPITAL EXPENDITURE



5. Further Sensitivity Analyses

The discounted cash flow analyses of the previous section showed that the internal rate of return on the basic Arabian Gulf Complex "a" is 26.4 percent, reducing to 22.8 percent if capital costs are in fact 50 percent above W. European levels rather than 25 percent. If ethane feed is charged in at $35/tonne production cost rather than the $70/tonne "alternate value" price level, returns are increased from the basic 26.4 percent to 28.0 percent. The effects of changes in other project parameters are summarised in Table X.E.5 below.

TABLE X.E.5

SENSIVITY ANALYSES ON SELECTED COMPLEX

Case	Internal Rate of Return (percent)
Base (1)	26.4
High capital costs (1)	22.8
Cheap ethane (1)	28.0
Reduced netback prices (2)	23.2
Corporate taxation applied at 25% (3)	23.1
Return on equity if 50% of cost is based upon loan finance (4)	32.4

Notes

(1) as calculated in the previous section, and as discussed above

(2) all netback prices 15% lower throughout project life

(3) after all capital costs allowed against tax

(4) loan repayable over 10 years at 10% p.a., with 3 year moratorium during construction period.

Thus it is shown that a 15 percent reduction in average netback prices, or corporate taxation at a rate of 25 percent, reduce available returns by just over 3 percentage points, which is rather less than impact of higher capital costs. It appears that the project could bear any one of these adverse factors, but not a combination of more than one of them. Thus great care should be exercised by the relevant Arab government in deciding upon what level of taxation, if any, to levy upon projects of this type, because the combination of even modest (25 percent) corporate tax, together with any normal adverse commercial situation (over-run on capital costs, depressed market prices, etc.), will reduce the returns on invested capital to below the level of 22-23 percent generally acceptable to foreign equity partners. Insistence upon such tax levies could therefore preclude foreign investment or involvement if the potential foreign partner takes a pessimistic view of likely market prices or probable actual capital costs.

If the project is to be wholly state-owned, then lower returns on capital are probably acceptable, and higher taxation could be levied. Since this is merely transferring revenue from one source of government revenue to another, however, there is little to be gained even in this situation by high project taxation.

APPENDIX I : PRELIMINARY PRODUCT SCREENING

Contents **Page No.**

APPENDIX I : PRELIMINARY PRODUCT SCREENING

APPENDIX I

PRELIMINARY SCREENING TO SELECT 12 PRODUCTS FOR IN-DEPTH MARKET AND TECHNICAL EVALUATION

A. INTRODUCTION

The Contract between UNIDO and Chem Systems for this Feasibility Study required that at an early stage of the work Chem Systems should select not more than twelve (12) olefin, aromatic and derivative products as the basis for in-depth study. A comprehensive list of potential large-volume commodity-type products was indicated in the Contract as the basis from which this selection should be made.

To assist in making this selection, Chem Systems drew up a set of guidelines concerning export and local market size, market structure, economics of production, shipping costs and other factors. Each potential product was then subjected to a preliminary analysis based upon these guidelines, and a points system was developed to select the most promising products.

While the imperfections of this method of selection are recognised a careful subjective review of the results of this screening exercise showed the selection to be, in our opinion, reasonable. This list of twelve products was therefore proposed by Chem Systems, and agreed during discussions with IDCAS in Cairo during June.

The basis, justification and results of this screening exercise are presented in the following Sections of this Appendix.

B. BASIS FOR PRODUCT SELECTION

A number of factors are considered to have a bearing upon the suitability of a particular product for inclusion in an Arab petrochemical venture. The most important of these items are given a points weighting, products are assessed with regard to each item and are rated accordingly.

1. Export Market Potential

Base export potential upon predicted developed market growth between 1975 and 1985, and supply/demand balance projections around 1980. Assess this market growth as a ratio to the possible Arab project capacity. The following approximate Arab capacities are assumed:

Product	Tonnes/year
ethylene	450 000 total (100 000 export as liquid ?)
ethylene glycol	100 000
LDPE/HDPE	100 000 each
styrene (P.S.)	200 000
VCM (PVC)	200 000
propylene	150 000 total (possibly all exported as liquid?)
acrylonitrile	60 000
polypropylene	60 000
propylene oxide	60 000
butadiene	15 000 total (possible all exported as liquid)
SBR/BR	20 000 each
benzene/toluene	150 000 each
p-xylene	60 000
o-xylene	80 000
DMT/TPA	120 000

This is of dominant importance and is therefore given a high weighting in the analysis (20 pts.). It may also be considered to have an overall veto, since without export marketing potential the project cannot proceed.

2. Local market potential

Base upon ratio of possible Arab project capacities, above, to projected total Arab domestic markets around 1985. Lower weighting, since this will not swing the overall project decisions, but clearly has considerable 'invisible' benefits to the local economy.

3. Ease of transport

Base upon estimated cost/ton (Arabian Gulf to Rotterdam) as a percentage of transfer price in the developed countries.

4. Olefin/aromatics content

(Since objective is to move olefins/aromatics to market). Base upon weight ratio of olefin/aromatics to product.

5. Energy/capital cost balance

(Since high energy content is an advantage; high capital cost is considered to be a disadvantage due to dilution of energy benefits and increased penalty for capital cost markups of construction in Arab States vs Europe). Base upon ratio of utilities and 'energy' feedstock cost in Europe to total transfer price. This is very important, and will be a dominant factor in the economic attractiveness of the project.

6. Technology availability

Readily available 'zero' cost technology is preferable : limited technology in the hands of one company who might object to Arab competition is the worst case. Must be based upon subjective assessment. Of limited importance, since technology will almost always be available in the final analysis.

of solid material from the developed countries with no import duties. Costs of local production are also indicated in the Table, using various assumptions on capital charges and para-xylene price.

TABLE X.B.9.

DMT/TPA NET-BACK PRICES AND TRANSFER PRICES (1980)

($/tonne)

	North Africa	Arabian Gulf
Net-back prices available		
DMT (to local markets)	894	924
TPA (to local markets)	997	1 027
Transfer prices achievable		
DMT: basic case (1)	862	879
20% ROI (2)	823	836
15% ROI	783	792
10% ROI	744	749
p-xylene @ $460/tonne (3)	788	805
TPA: basic case (1)	1 000	1 030
20% ROI (2)	941	966
15% ROI	881	901
10% ROI	822	837
p-xylene @ $460/tonne (3)	920	951

(1) 25 percent ROI: p-xylene feedstock at $570/tonne in N. Africa, $569/tonne in Arabian Gulf, both fixed by economics of plant producing p-xylene alone (i.e. no ortho-isomer)

7. Project range requirements

This covers two factors : main one is range of grades of product required (commodity product - such as benzene - traded against a specification is best, large range of necessary grades - such as HDPE - each serving small market segment, is worst case). Second factor is by-product production : generation of significant quantities of unsaleable/difficult-to-sell by-products is a drawback. Base upon European market assessment.

8. Captive/merchant market situation

Totally merchant market is preferable. Base upon European market analysis.

9. Market fragmentation

A small number of potential customers is preferable to a highly fragmented market, which would require heavy sales cost. Base upon European market analysis.

10. Service requirements

Low or non-existent technical service requirement is preferable.

NOTE: These last three items (8 - 10) (at least) will not be relevant to a joint venture (JV) approach. They are included, however, (at a low points rating) to allow for the general non-JV approach; they would also be relevant if the Arab partner in a JV had eventual access to certain markets on their own account.

The 'ideal' product would have a maximum points rating, based upon the following assessment of the relative importance of the various factors:

TABLE APP I.B.1

RELATIVE IMPORTANCE OF VARIOUS FACTORS IN SELECTING END-PRODUCTS FOR INCLUSION IN AN ARAB PETROCHEMICAL PROJECT

	Factor	Max. Points rating	'Ideal' product
a)	Export market potential	20	Large, growing market
b)	Local market potential	10	Large, growing market
c)	Ease of transport	10	Simple and cheap to ship
d)	Olefin/aromatics content	10	High olefin/aromatics content
e)	Energy/capital cost balance	20	High energy/low capital
f)	Technology availability	5	Widely available
g)	Product range	10	Limited grades/no by-products
h)	Captive/merchant market	5	Totally merchant market
j)	Market fragmentation	5	Few large customers
k)	Service requirements	5	No technical service required
		100	

C. RATING OF POTENTIAL END-PRODUCTS

Table App I.C.1 summarises the results of our assessments of each potential product.

Based upon the points ranking of Table App I.C.1, the selection is as follows:

Liquid Ethylene
LDPE
HDPE
Ethylene glycol
Styrene
Polystyrene
VCM & PVC (as 1 market product, with emphasis on possibility of VCM monomer sales)
Polypropylene
p-xylene
o-xylene
Benzene
DMT/TPA (as 1 market)

TOTAL: 12 products

The following sub-sections summarise the backup justification for the points ratings awarded in Table App I.C.1. (The letter headings (a,b etc) refer to the factors previously listed in Table App I.B.1.)

1. Ethylene (as liquid)

a. Large export market potential - access through pipeline grids to numerous customers (Provided new terminals are

TABLE APP I.C.1

RATING OF POTENTIAL END-PRODUCTS FOR ARAB PROJECTS

	Product	Export Markets	Local Market	Ease of transport	Olefin/ aromatic content	Capital/ vs. energy	Technology available	Product Range	Captive/ merchant	Market Structure	Service require-ments.	TOTA
	Possible rating	20	10	10	10	20	5	10	5	5	5	100
A	Liquid ethylene	12	0	9	10	12	5	10	2	4	5	69
B.	LDPE	16	6	6	10	4	4	6	4	2	4	59
C.	HDPE	15	5	6	10	3	3	4	4	1	0	51
D.	Ethylene glycol	10	2	8	8	12	4	10	4	2	5	65
E.	Styrene	16	1	7	10	16	4	9	3	3	5	74
F.	Polystyrene	16	4	6	9	15	4	6	4	2	1	67
G.	VCM (as end-product)	12	4	2	4	15	4	6	2	3	5	57
H.	PVC(integrated VCM/PVC)	16	8	6	4	14	4	5	4	2	1	64
J.	Liquid propylene	2	0	2	10	12	5	6	2	4	5	48
K.	Acrylonitrile	10	1	7	5	4	4	6	1	3	5	46
L.	Polypropylene	15	3	6	10	5	2	4	4	2	0	51
M.	Propylene oxide	10	1	2	9	3	2	7	3	3	4	44
N.	Oxo alcohols	8	2	6	7	10	3	4	1	4	4	49
P.	Liquid butadiene	1	0	2	10	10	5	8	4	4	5	49
Q.	SBR (integrated with BN)	2	5	6	8	10	5	4	4	3	3	50
R.	BR	2	1	6	9	11	1	4	4	3	0	41
S.	para xylene	16	3	8	10	8	5	9	4	4	5	72
T.	o-xylene	12	1	8	10	8	5	9	4	4	5	67
U.	Toluene	1	0	8	10	4	5	10	3	2	5	48
V.	Benzene	16	2	8	10	11	5	10	4	3	5	74
W.	DMT/TPA	15	3	6	7	5	5	8	3	2	4	56

included). Considerable consumer reservations re. dependance upon imports for a large percentage of the fundamental building block

b. No local markets for liquid ethylene

c. Transport expensive - high proportion of transfer price

d. High olefin content

e. Fairly high dependence upon energy-related costs (mainly feedstock)

f. Technology freely available.

g. Single product grade required. Sold against standard specification. By-products various.

h. Largely captive market, but merchant market on pipeline grids still very large.

j. Few customers, all large.

k. No service requirements.

2. LDPE

a. Very large export market, good growth. Film grades alone are a large market.

b. Relatively large local market.

c. Transport relatively easy.

d. High olefin content

e. Low energy dependence, high capital

f. Technology fairly readily available

g. Fairly limited range of film grades should be acceptable

h. Mainly merchant market

j. Large number of customers. Several film-grade customers are large. No by-products.

k. Service requirements important.

3. HDPE

a. Large export market, good growth.

b. Moderately large local market

c. Transport relatively easy

d. High olefin content

e. Low energy dependence, high capital

f. Technology fairly readily available

g. Wide range of grades required. No by-products

h. Mainly merchant market

j. Large number of customers

k. Service requirements very important

4. Ethylene glycol

a. Moderate export market, moderate/low growth

b. Little local demand

c. Transport easy

d. Fairly high ethylene weight content

e. Fairly energy intensive

f. Technology readily available

g. Single product grade required. No byproducts

h. Mainly merchant market

j. Fragmented market

k. No technical service required

5. <u>Styrene (including Ethyl benzene stage)</u>

a. Large export market, strong growth

b. Some local potential for polystyrene

c. Transport relatively easy

d. High total olefin + aromatic content : (0.32 + 0.84 : 1). Benzene is the key factor

e. Very energy intensive

f. Technology available

g. Single product grade required. Only significant by-product is toluene - no problem (recycle to HDA)

h. Largely captive in Europe, merchant in US & Japan

j. Moderately diffuse market (approx 30 customers per region)

k. No technical service required.

6. Polystyrene

a. Large market, good growth

b. Local potential moderate

c. Transport relatively easy

d. High styrene (and therefore olefin + aromatic) content

e. Fairly low capital costs. Energy input to polymer step also modest : mainly feedstock costs.

f. Technology available

g. Various grades. General purpose is itself a large market (30 percent of total); High impact grades require polybutadiene copolymer

h. Largely merchant market

j. Fragmented market (few large captive processors)

k. Service requirements important.

7. VCM (including EDC Stage)

a. Very large market, good growth

b. Relatively large local market potential

c. Transport moderately expensive (LPG carriers)

d. Moderate ethylene content (0.47); (rest is chlorine)

e. High utilities content (+ chlorine is mostly energy related)

f. Technology readily available

g. Sold on a standard specification. By-product caustic from chlorine production is a major potential drawback

h. Largely captive market in Europe : only 50 percent in US.

j. Modest number of customers

k. No service requirements

8. PVC

a. Very large market, good growth

b. Relatively large local markets

c. Transport relatively easy

d. Moderate ethylene content (rest is chlorine)

e. Low energy input from monomer to polymer

f. Technology available

g. Many grades, but limited number of general purpose grades would alone represent adequate market

h. Largely merchant market

j. Fragmented market

k. Service requirements important

9. Propylene (as liquid)

a. Very large market, good growth, but adequate by-product supply in Europe. Limited terminal capacity.

b. No local market as such

c. Transport relatively easy, but costs high relative to product value

d. 100 percent olefin

e. Fairly high energy content, mainly feedstock element

f. Technology available

g. Can sell as a singly polymer grade. Other by-products (C_4, gasoline) may be attributed to propylene

(2) p-xylene price kept constant
(3) With 25 percent ROI on DMT/TPA plants

c) Conclusions

It is clear therefore that local production of either DMT or TPA can be economic when compared to imported material on the basis of the assumptions made earlier concerning plant sizes, etc. DMT is attractive even under the basic assumptions regarding finance terms and p-xylene price, whereas a TPA project would require some minor concessions on either finance or feedstock price.

However, the major uncertainty concerning the desirability of DMT or TPA manufacture in the Arab states is not competitiveness with imported material, but the economics and market potential of the downstream polyester fibre industry itself. This is outside the scope of this present study, but it seems unlikely that an initial Arab polyester fibre capacity of around 100 000 tonnes/year would be

Capacities of this order would be required to absorb the output from the proposed DMT/TPA project. If significantly smaller plants are considered, then the highly capital intensive nature of the processes will weigh heavily against the Arab venture as economies of scale are lost.

10. Low Density Polyethylene (LDPE)

a) Markets

There is ample market potential for Arab penetration of

h. Mainly captive, but with significant merchant market

j. A few large customers

k. No service requirements

10. Acrylonitrile

a. Moderate market, medium growth

b. Very limited local market for some time

c. Transport easy

d. High propylene content, but ammonia is also required

e. Modest/low energy consumption

f. Technology probably available (SOHIO)

g. Single product grade

h. Largely captive

j. Main users (acrylics) are few and large

k. No service requirements

11. Polypropylene

a. Moderate to large market, strong growth

b. Small local market (mainly woven bags)

c. Transport relatively simple

d. 100 percent olefin

e. Modest energy cost (apart from feedstock costs) : high capital

f. Technology tightly held

g. Range of grades required

h. Merchant

j. Fragmented

k. Service important

12. Propylene Oxide/Glycol

a. Large market, good growth

b. No local markets for many years

c. Transport requires special precautions (35° C B.Pt.) if shipped as oxide

d. High olefin/aromatics content (1.02 propylene, .66 ethylene, 2.[illegible] benzene via Oxirane EB route)

e. Low energy content (all feedstock costs)

f. Doubts re Oxirane technology availability

g. Limited range of products required. Large styrene by-product rate (2.3 x PO rate)

h. Oxide market mainly captive (except Oxirane). Glycol market merchant

j. Medium range fragmentation

k. No service required for oxide and glycol. Service required for polyols

13. Oxo Alcohols (2-EH)

a. Moderate market, good growth

b. Limited and fragmented local markets

c. No transport problem

d. High olefin content

e. Moderate energy content

f. Technology probably available

g. Could be one product only (2-EH) or a range

h. Highly captive

j. Few large customers

k. Little technical service required.

14. Butadiene (as liquid

a. Moderate export market, slow growth, overcapacity in Europe

b. No local markets

c. Refrigerated transport required

d. 100 percent di-olefin

e. Fairly high energy content, feedstock oriented

f. Technology available

g. Sold against standard specification, but some other by-products (other C_4's) may be attributed to butadiene production

h. Mainly merchant

j. Few large customers

k. No technical service

15. SBR

a. Moderate - to-large market, very slow growth

b. Limited local markets at present

c. Transport relatively easy

d. High total olefin + aromatic content

e. Very modest energy input in the polymerisation stage

f. Technology available

g. Various grades required

h. Mainly merchant

j. Medium fragmentation of market

k. Some technical service required

16. BR

a. Moderate to small market, very slow growth

b. Limited local market potential

c. Transport relatively easy

d. High total diolefin content

e. Negative energy input in polymerisation stage, but uses up iso-butylene

f. Technology tightly held

g. Various grades required

h. Merchant

j. Medium fragmentation

k. Technical service required

17. <u>p-xylene</u>

a. Moderate market, strong growth

b. Local potential for DMT/TPA use

c. Transport easy

d. 100 percent aromatics

e. Little energy input (all feedstock costs)

f. Technology readily available

g. Single product required (using recycle complex)

h. Largely merchant

j. Centralised market

k. No technical service required

18. <u>o-xylene</u>

a. Moderate market, good growth

b. Modest local potential markets for phthalic to phthalate plasticers (longterm)

c. Transport easy

d. 100 percent aromatics

e. Little energy input (all feedstock costs)

f. Technology available

g. Single grade

h. Very largely merchant

j. Fairly centralised market (approx 20 consumers in Europe)

k. No technical service required

19. <u>Toluene</u>

a. Moderately large market, but large excess of toluene exists : blended into gasoline or HDA to benzene. Little chance of exports

b. No local market

c. Transport easy

d. 100 percent aromatics

e. Little energy input (all feedstock)

f. Technology available

g. Single grade

h. Two thirds merchant

j. Fragmented market (distributors inportant - solvents etc.)

k. No technical service required

20. Benzene

a. Very large market, strong growth

b. Little local potential at present

c. Transport easy

d. 100 percent aromatic

e. Low energy input for separated product : fairly high for HDA

f. Technology available

g. Single grade

h. Fairly merchant - oriented market

j. Somewhat fragmented market, but mostly large customers

k. No technical service required

21. DMT/TPA

a. Moderately large market, strong growth, shortages likely

b. Fair longterm local potential

c. No particular problem in transport (TPA bagged; DMT bagged or molten/solvent)

d. Moderate aromatic content

e. Modest energy content (in upgrading from pxylene)

f. Technology available

g. Single product grade

h. Largely captive, but with some merchant producers

j. Rather fragmented market

k. Little technical service required

LDPE markets in several market regions during the early 1980's. Massive new investment will be required for LDPE to meet the rapidly growing demand forecast in both developed and developing countries during the early 1980's, and a substantial portion of this investment could be made in the Arab states.

All developed regions are potential target markets during the mid-80's, but the US will be the first to experience supply problems.

Latin America and the Asia/Pacific region both appear good export prospects during the mid-80's.

Local Arab demand for LDPE is substantial, but since most Arab petrochemical projects currently under consideration include LDPE facilities, rapid overcapacity is likely to develop, and the local sales of any given plant are likely to be quite modest.

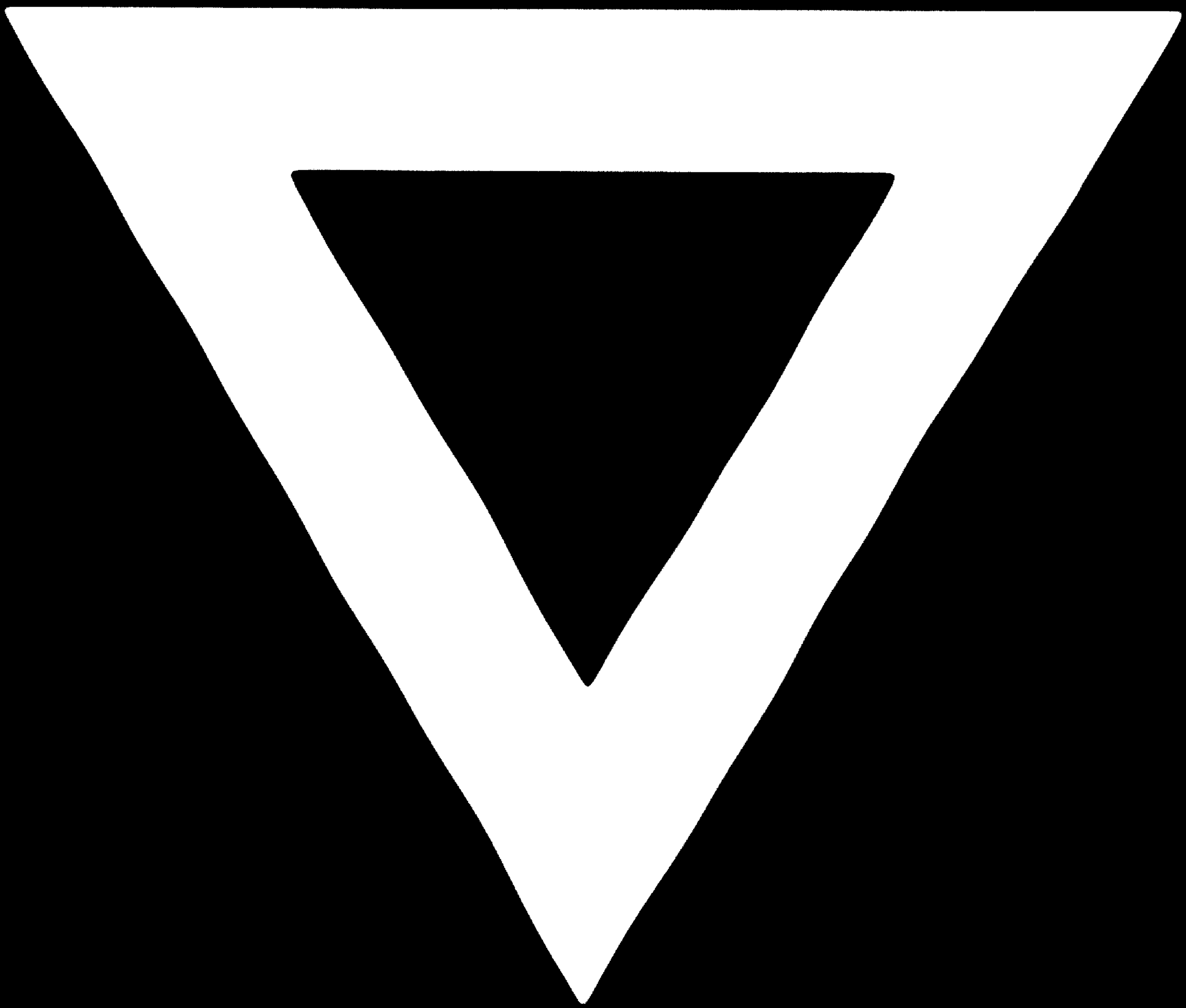
Target sales distribution assumed for LDPE is thus as follows:

Developed markets	60 000 tpa
Developing (non Arab) markets	26 000 tpa
Local Arab markets	10 000 tpa
Total	96 000 tpa

b) Prices and Costs

Table X.B.10. presents calculated net-back LDPE prices to the Arab plants. Also included are simple sensitivity analyses showing transfer prices achievable from the Arab plants using various assumptions on capital charge (ROI) and ethylene price:

1 - 898



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