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UTILIZATION OF NATURAL GAS FOR VINYL CHLORIDE AND PVC PRODUCTION

SI/BGD/75/833

BANGLADESH

Terminal report

Prepared for the Government of Bangladesh
by the United Nations Industrial Development Organization,
executing agency for the United Nations Development Programme

Based on the work of N. B. Dimitrijevic, chemical engineer

United Nations Industrial Development Organization
Vienna

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Explanatory notes

The monetary unit of Bangladesh is the taka. During the period covered by this report, the value of the taka in relation to the United States dollar was $US 1 = taka 15.5.

References to "dollars" ($) are to United States dollars.

The use of a hyphen between dates (e.g. 1985-1990) indicates the full period involved, including the beginning and end years.

A slash (/) between dates (e.g. 1977/78) indicates a financial year.

References to "tons" are to metric tons.

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

In tables, a dash (-) signifies "nil or negligible".

"Tons/day" and "tons/year" signify, respectively, "tons per day" and "tons per year".

1 cubic foot (ft^3) = 0.028 cubic metres (m^3); 1 million ft^3 = 28,000 m^3.

The following abbreviations of organizations are used in this publication:

BCIC	Bangladesh Chemical Industries Corporation
CHEMCON	Chemical Consultants Ltd (Dacca)
EPIDC	East Pakistan Industrial Development Organization
ERL	Eastern Refinery Ltd

The following technical abbreviations are used in this publication:

ACN	Acrylonitrile
DOP	Dioctyl phthalate
h.d.	high density
kWh	kilowatt-hours
l.d.	low density
LNG	liquefied natural gas
LPG	liquefied petroleum gas
PE	polyethylene
PVA	polyvinyl alcohol
PVC	polyvinyl chloride
VCM	vinyl chloride monomer

ABSTRACT

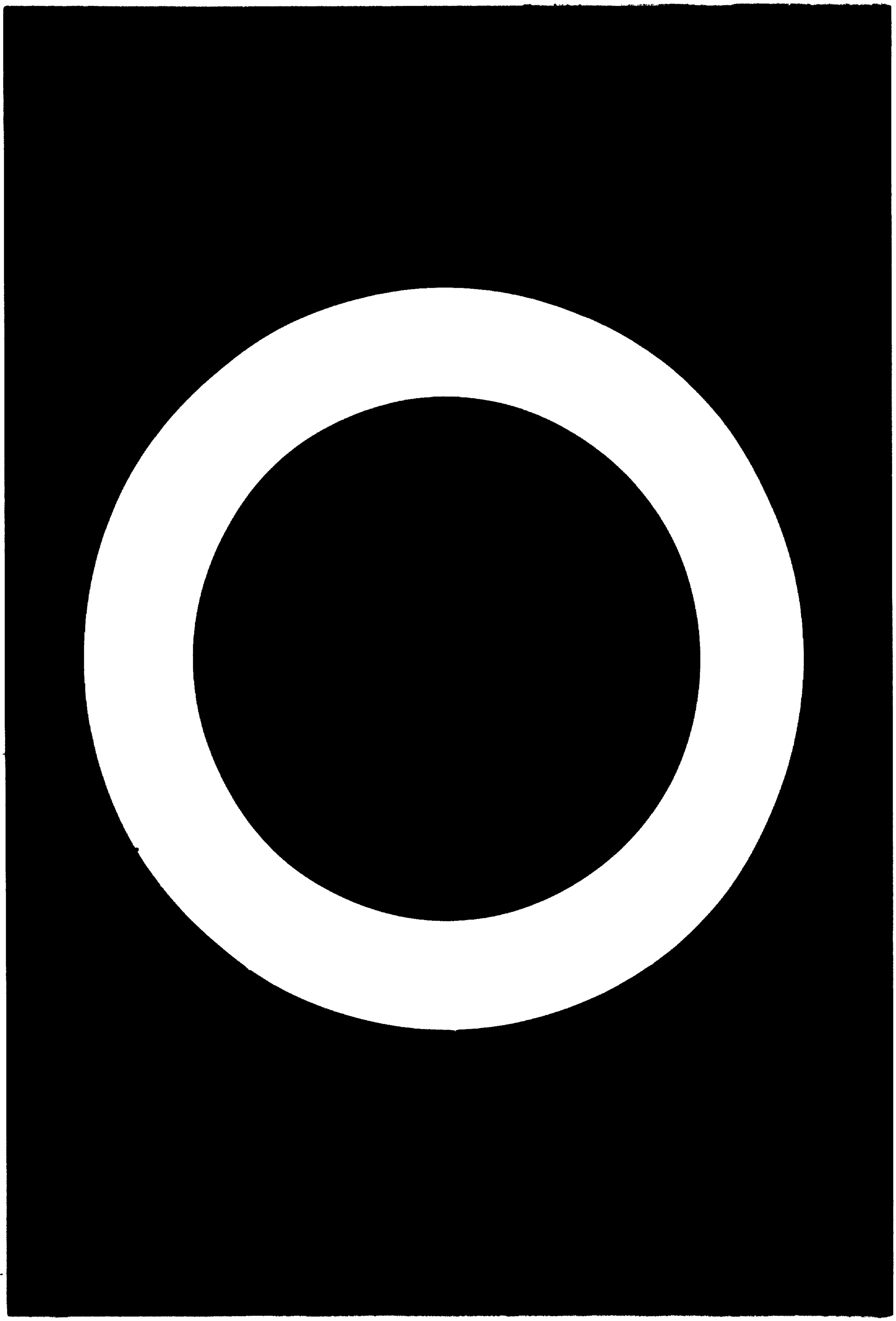
A petrochemical complex based on natural gas has been proposed for Bangladesh with a view to producing polymers including polyvinyl chloride (PVC) and acrylic fibre. This development is expected to stimulate a rapid growth of the plastics-processing industry, which is a major consumer of petrochemical end-products. Several reports and studies in this area have been made as long as 15 years ago, but they no longer have any real value. Many of these studies were made without adequate market surveys, and some technical solutions, which had seemed good 15 years ago and acceptable even 10 years ago, have since been abandoned. An important example is the production of acetylene by the Sachsse technology, which has been given up for both technological and economic reasons.

Instead of growing, as had been foreseen, the market for plastics in Bangladesh has been decreasing, owing to restrictions on imports of raw materials and the lack of domestic sources of some basic chemicals.

The mission reported here (SI/BGD/75/833) originated with a request from the Government of Bangladesh in July 1975. It became operational on 14 November 1977 and continued until 13 January 1978. The co-operating agency was the Bangladesh Chemical Industries Corporation (BCIC) in Dacca. The mission was financed by a UNDP contribution of $8,500. It consisted in the sending of a chemical engineer to assist the Government in carrying out a study of the production of vinyl chloride monomer (VCM) and PVC based on natural gas.

A short review of products that could be derived from ethane and propane in the natural gas is considered. Although the ethane content is rather low for economical recovery, this would be feasible under the specified conditions, for example, in conjunction with a proposed LNG plant. As a short-term measure, the import of ethane and propane as feedstock could be considered. A feasibility study on ethane recovery should be performed.

The form of the projected petrochemical complex is given, based on estimated investment and production costs, and considering the development of the market over the next seven to 10 years. Factors are considered that could be important in the selection of the site for the petrochemical complex, and proposals for the training of the staff, and especially of senior technical staff, are made.



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INTRODUCTION

For some considerable time, the creation of a petrochemical complex based on natural gas in what is now Bangladesh has been planned with a view to producing polyvinyl chloride (PVC) and acrylic fibre. Such an installation would be expected to stimulate the rapid growth of the plastics-processing industry, provided that the prices and quality of the products are competitive. Expert advice had been solicited concerning the selection of appropriate technology for the production of PVC, based on direct conversion from natural gas. Experts from the United Nations Development Programme (UNDP) had been engaged in East Pakistan on four different occasions, starting in 1964. No UNIDO experts in this field had been assigned to Bangladesh since 1971.

The mission reported here (SI/BGD/75/833) originated with a letter to UNIDO from M. Mohiuddin, Chief, TAP, dated 3 July 1975. The project became operational on 14 November 1977, when an expert in polyvinyl chloride (PVC) was sent to Bangladesh to assist the Government in carrying out a study of natural gas based vinyl chloride, including polymerization. The mission continued to 13 January 1978. The co-operating agency was the Bangladesh Chemical Industries Corporation (BCIC) in Dacca. The mission financed by a UNDP contribution of $8,500.

I. FINDINGS

Previous reports and general comments

The first studies related to projects for the erection of a petrochemical complex in what is now Bangladesh were performed 15 years ago. According to information cited in the papers of Chemical Consultants Ltd (CHEMCON), Dacca, a study of possible chemical production based on liquid and gaseous hydrocarbons (C_2H_4/C_3H_6) was performed by Imhausen International Co. in the Federal Republic of Germany, in 1963/64. The study involved both East and West Pakistan. However, it was prepared without an analysis of the market, so the basis of the entire undertaking would appear unsound.

EBS Management Consultants Inc, in New York, prepared a report in 1963 on methyl methacrylate plastics in East Pakistan, but again without practical results, according to the CHEMCON reports.

In 1964, the Japan Consulting Institute prepared a report on the processing of natural gas, especially for the production of PVC compounded granulates, Vinylon fibre and dioctyl phthalate (DOP) plasticizers, as well as for acrylonitrile (ACN), synthetic rubber and the like. However, this study was also not based on market research. In general, it found that, for a small-capacity installation, the relative investment costs would be very high. The findings, as regards ACN and synthetic rubber, were completely negative.

W.L. Badger Associates prepared a report on the manufacture of man-made fibres (1964/65) based on a market survey by an organization named Chechi and Co. The principal product considered was polyvinyl alcohol (PVA) by the acetylene route, that is, from natural gas. However, the conclusions were negative.

In 1964-1966, E. Nagelstein, a UNDP expert, reported that only a naphtha-based petrochemical project should be established, and that such a plant with a capacity of 30,000 tons/year of polymers could be put on stream by 1970. However, this suggestion was not followed up.

In 1966, a group of Japanese companies (Sumitomo Chemical Engineering Co., Mitshubishi Heavy Industries, Kurashiki Rayon Co. and the Shimuzu Construction Co.) prepared a report on the manufacture of PVC resins and PVA fibres using only natural gas, by the acetylene route. This survey was conducted at the request of the East Pakistan Industrial Development Corporation (EPIDC). According to a statement by CHEMCON, this Japanese group had made its project appear to be acceptable by setting unrealizably high prices for the end-products and by underestimating the cost of some utilities, such as steam.

During 1965-1967, EBS Management Consultants Inc., New York, made a study of possible petrochemical production in what was then East Pakistan. Its first volume considered suitable forms of chemical production; the second deals with the economics of the production of PVC and PVA fibres and soda ash through the acetylene route. CHEMCON evaluated this study negatively. Furthermore, this solution was proposed at a time when acetylene technology was declining in favour; the chemical journals were reporting litigation stemming from production problems.

In 1968, a UNIDO expert (V. Tsetkov) produced a report entitled General survey of the existing situation and a proposal for the plastic production and processing industries in Pakistan to 1985. It is noteworthy that this market projection corresponds generally with those of CHEMCON.

In 1968/69 the UNDP expert L. Kotchetkov made a long-term forecast of the production of plastics and synthetic fibres that was also in line with the market forecasted by CHEMCON.

In 1969 the Batelle Institute in Frankfurt studied the market for plastics in East Pakistan. The UNIDO expert T.V. Janakievsky used these findings for his report Proposal of a feasibility pattern for the petrochemical complex industry in Pakistan.

During 1969 CHEMCON and EPIDC prepared a detailed study entitled The manufacture of petrochemicals in East Pakistan. This study is based on the reports cited above and on very thorough market research. Despite the fact that nearly ten years have elapsed since its completion, it can still be used as a basis for the evaluation of the development of petrochemical markets in Bangladesh.

In this CHEMCON-EPIDC study, the acetylene and ethylene routes are compared, and the foreseen capacities for both are compared. However, the capacity for ethylene was only one tenth that of a standard steam-cracking plant for naphtha. Furthermore, because it was almost a pilot plant for ethylene production, its cost was extremely high. The high price of ethylene has some relation to - and influence on - the prices of naphtha and natural gas; for the same caloric value the ratio was 4:1.

The position taken by the authors that the raw material (in this case liquefied petroleum gas (LPG) or naphtha) must not be imported led them to the conclusion that the only available raw material was natural gas, which meant methane at that time. Thus, this predetermined raw material could be processed to thermoplastic production (of PVC) exclusively through the acetylene route.

In the late 1960s Austrian Chemical Consultants Ltd has performed the study East Pakistan petrocomplex, based on the use of natural gas. The firm was aware of the findings of the previous studies. It accepted the thesis that natural gas was the only available raw material and that only the acetylene route was feasible. Their justification of this position is spelt out in item 5, page 9 of their report:

"It is always better to produce an item on a basis of efficiency as against self-sufficiency, protected by unnatural barriers, which are bound to create many complications. In general it is always possible to select raw materials, processes and capacities for a profitable sale of a product at competitive world prices. If production under such conditions cannot be expected to come up to this level, it is better to give up and take any other suitable item to increase production and the utilization of resources". This sentence shows that the Austrian firm was aware that acetylene technology was in decline and that the existing plants that were using Sachsse technology to produce acetylene from methane faced both technical and economic problems. However, it could not have known that, during the following years, not only would no more such plants be erected but also that most existing plants would be shut down.

In the absence of foreign institutions to provide the required financing, the high investment cost and the changes in the country that culminated in the independence of Bangladesh, these projects were not implemented.

The most recent request of the Government of Bangladesh to UNIDO for the revision of existing projects by their experts point up their increased interest in the realization of a petrochemical complex. The studies referred to above and other written material totalling more than 2,000 pages were made available to the expert.

Market survey

In the CHEMCON-EPIDC report of 1969 and in a report of the Planning Commission - Industries Division in 1973, different sources with different figures for the consumption of plastics are given. For example, in the CHEMCON-EPIDC study (vol.3, pages 15 and 16) the following tonnage figures are given:

	1972/73	1974/75	1980
PVC	9 000	15 000	30 000
PE	6 500	10 000	20 000

But in the papers of the Planning Commission and in a lecture by A. Haque in a lecture at a London symposium [1/], the estimates were as follows: were as follows:

Tons/year	1972/73	1974/75	1980	1984
PVC	12 500	-	41 000	80 200
PE	-	15 800	26 600	38 200

During his first weeks in Dacca, the expert was given still other statements of the consumption of PVC and PE, again with considerable differences. For example, the Trade Section, Statistics Division, Ministry of Planning has recorded the import of about 2,000 tons/year of PVC, but the importers estimate that the amount could be as much as 12,000 tons/year. Comparison of these figures might reveal the relation between actual consumption and the potential consumption that could have been attained had imports not been restricted so strongly and if the prices corresponded more closely to those of other products used for the same or similar purposes. On the basis of such a relation, the trends of consumption in, for example, 1990, could be estimated.

As of 1976, based on the July-December figures, consumption was about 1,000 tons/month of PVC, with a value of taka 14.6 million and about 300 tons/month of PE. Importation probably occurs irregularly, so this estimate may not be very important, but it still indicates that consumption was small. Importers and plastics-processing technicians estimate present consumption of PVC somewhere between 6,000 and 10,000 tons/year; it would appear reasonable to place it at about 8,000 tons/year.

This rate of consumption, which is less than that prevailing in 1972/73, results from tight restriction of imports and high taxes, although the need for such goods is increasing with the rise in living standards. Indeed, it is said that the taxes on plastics are several times higher than those of the metals and cement with which they compete. Such policies have decreased consumption and invalidated all previous forecasts. However, there can be no doubt that consumption would rise at the predicted rate if plastic materials were offered on the market in sufficient volume and at prices that corresponded to those of

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1/ UNIDO Seminar on the applications of plastics, 18-27 June 1973.

the materials with which they compete. Both PVC and PE are used primarily by persons with limited incomes.

Based on the statement of CHEMCON and the reports of the Planning Commission, the future development of the consumption (tons/year) of PVC and PE would be as follows:

	1977/78	1980	1985	1990
PVC	8 000	15 000	35 000	75 000
PE	3 000	7 000	17 000	40 000

These figures should be considered as the normal evolution of consumption of PE, but it might well be more rapid, as it has been elsewhere in the world market. Still, when consumption has grown to the levels shown for 1990, it will be time to decide on the start-up of the erection of a new petrochemical complex. For such growth to be possible, however, it will be necessary to stimulate imports temporarily, decrease taxes and support the erection of large plastics processing plants.

Bearing in mind that investment studies must be performed for the selected location, that feasibility studies must be made, that financial resources must be found, that final project proposals must be prepared, and that three or four years will be needed for plant erection before production can begin, and that normal full production could not be attained before 1985, the capacities of these plants would have to be adjusted for the period 1985-1990 if the growth of production is to be as shown in the tabulation above.

Export markets will become ever more limited, since in the next five to ten years the world market will have changed fundamentally. According to some British authorities, about $75 thousand million will be invested in petroleum refineries and petrochemical plants in the countries of the Middle East and North Africa (Algeria, Iran, Iraq, Libyan Arab Jamahiriya, Saudi Arabia and so on). This would be 2.5 times more than the investment in similar installations in Western Europe and North America during this period. This trend will alter the direction of movement of raw materials and petrochemical end-products, and it would appear certain that these developments will not facilitate the entry of smaller new producers into the world market. However, if a small country such as Bangladesh could absorb about 80% of its possible output in its domestic market, the remaining 20% would be available for export. The export price would certainly be below the world market average, but the difference could be recovered from domestic prices. In any case, a petrochemical complex will have to be built to satisfy domestic requirements and markets.

Availability of raw materials

Natural gas

Considerable quantities of natural gas have been found in north-eastern Bangladesh. Among the most important gas wells are those at Titas, Habiganj and Rashidpur, with methane contents of more than 97% and even 98%. Furthermore, the most recent explorations have resulted in the discovery of large reserves, in three layers, at Bakhrabad. Further development of the chemical industry and power generation as well as the export of liquefied natural gas (LNG) are being planned, according to the Special Project Manager of Petrobangla, the composition (per cent by volume) of this gas is as follows:

Methane (CH_4)	94.3
Ethane (C_2H_6)	3.4
Propane (C_3H_8)	0.8
Butane (C_4H_{10})	0.6
Nitrogen (N)	0.4
Carbon dioxide (CO_2)	0.5

The gas field is not yet being exploited, but the gas will be brought to Chittagong when the pipeline connections have been completed. A consumption of 150 million ft^3/day (4.2 million m^3/day) there by a new nitrogen fertilizer plant and a power plant there after 1990 is foreseen. If other arrangements are realized, including the export of LNG, the consumption of natural gas would be increased to 660 million ft^3/day (about 18.5 million m^3/day).

To recover 100,000 tons of ethane, which is the most suitable raw material for the production of ethylene, from Bakhrabad natural gas, it would be necessary to run about 7.5 million m^3 (270 million ft^3) through the separation plant daily. This would mean a yield of more than 300 tons/day of ethane, 100 tons/day of propane and 100 tons/day of butane, leaving about 7 million m^3 (rather less than 250 million ft^3) of methane which would be piped back and for which a use would have to be found.

With the coming on stream of new fertilizer and power plants and the development of small industries to supply the domestic market, even without the export of LNG, a methane consumption of about 250 million ft^3/day (7 million m^3/day) with an ethane or ethane/propane mixture consumption of 300 tons/day. In addition to the Bakhrabad natural gas, some more gas of similar composition from off-shore wells could be used. The possible discovery of new gas wells with higher ethane content cannot be excluded.

Naphtha

In the United States of America, ethane and LPG are mostly used for the production of ethylene, but in Europe naphtha is the usual raw material.

Eastern Refinery Ltd (ERL) in Chittagong has a surplus of light naphtha, while the sale of petrol, in ratio to the middle distillates, is very low. The economic difficulties experienced by ERL result not only from the export of naphtha priced lower than crude oil, but from a surplus of heavy oil, which is being increasingly replaced as fuel by natural gas. Considering these difficulties, no extension of the refinery in the next few years is probable. If financial resources permitted it, the erection of a hydrocracking unit that could produce the needed middle distillates and small quantities of propane and butane from heavy oil might be expected. The small demand for petrol excludes the erection of a catalytic cracking unit, and it will be impossible to obtain either ethylene or propylene from the off-gases of the refinery.

About 20,000 tons/year of LPG is now available. The yield of propane and butane from the new hydrocracking unit will probably cover future consumption of LPG. Consequently, these 20,000 tons/year of LPG would still be available for industrial use.

For the time being, the raw material available for the petrochemical industry is natural gas from Bakhrabad, which contains substantial amounts of ethane and propane, and about 20,000 tons/year of LPG and 30,000 to 50,000 tons/year of light naphtha from ERL. The possibility of importing ethane or an ethane-propane mixture could also be considered.

Products and possible chemical routes

At present, large quantities of methane are available for the production of petrochemicals, and under certain conditions definite quantities of ethane and higher hydrocarbons could also be available.

Products from methane

Natural gas with a high methane content could be used in the chemical industry for the production of synthesis gas, which is the basic material for ammonia and methanol and, in smaller ratio, for oxysynthesis, acetylene, formic acid and the like.

Ammonia and urea

These products have already been introduced into Bangladesh, and new plants to produce them are under construction. Since this country is primarily agricultural, ammonia was its first petrochemical product, there being an adequate market for it. Urea will continue to be the most easily storable and transportable nitrogen fertilizer and thus the most suitable one for export. It is also the most advantageous dry product of natural gas, which means that it could be treated as an indirect natural gas export. However, its production entails quite high investment as well as the experienced staff that Bangladesh does not yet have.

Methanol

This material is also made from synthesis gas and thus can also constitute an indirect export of natural gas. Many studies have dealt with the possible sale of methanol in both domestic and foreign markets. The former is very limited, compared with the standard capacities of methanol plants.

Most methanol is used in the production of formaldehyde. However, the use of formaldehyde resins is still small in Bangladesh; only about 3,000 tons/year of methanol are used for this purpose. Since the standard capacity of a modern methanol plant is about 1,000 tons/day, it is evident that more than 90% of this production would have to be exported, which would be a very risky venture. Paraformaldehyde, being a dry substance, might be more suitable for export. Its production might therefore be more rational and the plant capacity more economic. The production and export of methanol or methyl liquid (a mixture of metyanol and higher alcohols) for use as fuel as an alternative to the export of LNG is being seriously considered by energy experts.

Much methanol could be used for the production of protein. It has been noted in some chemical journals and in informal advertising that ICI Ltd, in the United Kingdom, has succeeded in producing single-cell proteins by the fermentation of methanol in a manner similar to that of the British Petroleum (BP) procedure with hydrocarbons. Such synthetic proteins are destined primarily for cattle feed. As of 1977, ICI was unwilling to sell or licence the technology, but it is expected that it will be prepared to begin negotiations in the latter part of 1978. While the production of synthetic protein from natural gas is of obvious interest to Bangladesh, this would not necessarily involve the preparation of methanol as an intermediate. Methanol is also used, but to a much lesser extent, for the production of certain methyl esters, methyl amine, methyl chloride and the like.

Increased domestic consumption of formaldehyde, the possible export of paraformaldehyde and the possible production of protein from methanol could justify the erection of a small methanol unit. Such an installation might be set up in a duty-free zone so as to avoid import taxes on the equipment and subsequently on the needed chemicals and catalysts. At present, the most suitable process for methanol production would be the ICI low-pressure process or a similar one.

Acetylene

There was a notable expansion of the production of acetylene from hydrocarbons during the 1950s. The production from methane by modification of the Sachsse process, which is based on the partial oxidation of methane, aroused the most interest at that time. Many industrial procedures, among them those of BASF (Federal Republic of Germany), SBA and Montecatini (Italy), have been elaborated from Sachsse inventions. The cited processes are basically similar, differing in operating pressure, the construction of their burners, the mode of quench, the recovery of acetylene and the like. The BASF procedure is the most widely used of the three named.

By the mid 1960s, however, the production of acetylene by Sachsse processes had peaked and begun to decline. It appears that no plant based on Sachsse processes has been erected during the last decade, during which time all existing ones have shut down, the last one being in Japan.

The main reason for the discarding of the Sachsse technology is unsolved technical problems, among them corrosion, soot, and the risk of explosions. There have been important lawsuits, such as that of Tenneco Chemical Corp. (USA) against SBA and Diamond Alkali, and of by the Government of Poland against Montecatini. However, the search for improved technical solutions was abandoned for economic reasons.

Very much more energy is required to form the acetylene triple bond than the ethylene double bond. This difference in energy input has prevented the use of acetylene for products such as acetic acid, vinyl acetate and VCM that can be made from ethylene, which is usually very much cheaper. The situation is similar as regards the use of propylene to produce ACN. The use of acetylene to produce VCM is now considered wasteful of energy. Nevertheless, acetylene will continue to be used as raw material in the chemical industry where it cannot be replaced by olefines. For some special synthetic rubbers (neoprene and some elastomers) and some plastics, as well as for organic and metallo-organic synthesis, acetylene is still used in considerable quantities. The sources of acetylene are calcium carbide, liquid hydrocarbons (thermocracking to acetylene and ethylene) and, from methane by means of an electric arc, or by partial combustion with the use of oxygen.

Great interest in the production of acetylene based on methane was shown in Dacca. It is for this reason that the Huels electric arc process is discussed some length later in this report. A copy of the manual Information for economic evaluation for a plant for the manufacture of acetylene from methane, prepared by the Chemische Werke Huels in the Federal Republic of Germany in 1974, has been given to the Industries Division of the Planning Commission.

It was more than a century ago that M. Berthelot reported that acetylene could be produced by passing a stream of hydrocarbons through an electric arc; however, this process was not used comercially for more than 60 years. The first such plant, that of the Chemische Werke Huels, went on stream in Germany between the two World Wars. Since that time the process has been improved and refined, and Huels is willing to licence its modern technology.

In addition to the Huels plant in the Federal Republic of Germany, a similar plant has been erected in Montague, Michigan, United States, for I.E. du Pont de Nemours and Co., with a capacity of 25,000 tons/year of acetylene. Another factory in Borzesti, Romania, is operating a small plant on these lines, but no details on it are available.

The Huels electric arc process is thoroughly described in the publication referred to above. In order to make useful comparisons, it was necessary to reduce the Huels acetylene capacity to 33,000 tons/year, with a possible expansion to 45,000 tons/year. It was proposed to begin with six equipment groups, two oil scrubbers and two water scrubbers with controllable venturis. The present investment cost for such a plant, including engineering fees, are estimated at $45 million.

For comparison with the above technology it must be added that, for each 100 kg of acetylene produced from calcium carbide, about 1,100 kWh of electrical energy are required, while 1,370 kWh, which is 25% more, would be needed for the same amount produced by the electric-arc process. The investment cost for the production of calcium carbide from lime and coke, using electrical energy, is considerably lower than that for the production of acetylene from methane. The consumption of electrical energy will be high both for the arc process and for the carbide route.

Products from ethane and higher hydrocarbons

Ethane

Ethane is the most suitable material for the production of ethylene. In the United States of America more ethylene (40%) is produced by this route than by any other; the other principal raw materials are LPG and refinery off-gases. The ethane is recovered primarily from natural gas and in part from oil refineries.

Ethane was formerly extracted from natural gas by the oil-absorption process, which usually recovered up to 25% of the ethane present. Now, however, plants being built that use cryogenic processing, and up to 90% of the ethane is being recovered economically. Successful ethane recovery depends on several factors, among them the composition, pressure and price of the natural gas, the prices of electrical energy and steam, and transport costs. It is usually considered that ethane recovery from natural gas should be attractive when it contains 7% ethane and 3% or more of methane. With Bakhrabad gas, which contains only one half of the desirable proportion of ethane, the relatively high investment cost could raise the price of the ethane significantly. The recovery cost of the ethane should not exceed $80/ton, compared with the present price of $16/ton for natural gas and about $110/ton for light naphtha, to permit a price for the ethylene that would correspond to the costs of further chemical treatment and remain competitive.

To pass through about 8 million m^3/day of lean gas of the Bakhrabad type would require a rather large separation plant; the investment cost could, perhaps, be $55 million. First, however, a feasibility study on ethane recovery would have to be made both to check out this source of raw material, as well as reflecting the most economic type of compressor and drive (steam, electric or gas turbine with turboexpander for tail gas in all cases. If the price of the ethane is to be competitive, plant depreciation must be over 15 years or less and the financing cost must be low. If the fixed production costs are no higher than 10% of the investment cost, ethane and propane could be used for the production of ethylene at an acceptable price.

The contract for the construction of the plant could be let to any established engineering organization such as Pullman-Kellog, Fluor, Pritchard, Davy Powergas, KTI or Technip, or to more specialized firms such as C.E. Natco, Randal Corp. or Sutton County.

If plans for the production of LNG could be realized, the costs of extraction of ethane and propane could be reduced. The cost of ethane recovery is almost negligible compared with the cost of the equipment for a liquefaction unit. The erection of an LNG plant with a capacity of 500 million ft^3/day (14 million m^3/day) is under active consideration. This plant would be located on the island of Kutubdia, about 30 miles (48 km) south of Chittagong, where the water is deep enough for barges.

Until a reliable domestic source of ethane has been secured and a market for products made from it have been established, it would be advisable to consider the importation of LNG. Ethane technology is indubitably the most economic for the production of ethylene and PVC, and the price of ethane is just one tenth of that of PVC powder. It may well be economic to check out the import of ethane from Algeria, Kuwait, the Libyan Arab Jamahiriya or Saudi Arabia where LNG liquefaction plants are either already on stream or in preparation. Such an arrangement would not be new; Norway already imports an ethane/propane (8:2) mixture for the production of ethylene. Indeed, the experience of Norway could be very useful.

Indeed, the importation of raw materials for petrochemical industries is by no means unusual. With the sole exception of the Union of Soviet Socialist Republics, all industrialized countries import crude oil, its derivatives or both. (The new fields in the North Sea could change this situation somewhat.) The growth of petrochemical production in the industrialized countries has been constant, probably because the price of its products is from five to 20 times that of its raw material.

Ethylene

In addition to ethane, LNG and some heavier hydrocarbons are used in the production of ethylene. However, the investment cost rises with the molecular weight of the raw material. Also, while the yield of ethylene is smaller, considerable quantities of propylene, butadiene, BTX (benzene, toluene and xylene) aromatics and fuel gas and oil are also produced. The relation of the raw materials to the investment cost are shown in table 1.

The relative investment costs of various processes and raw materials are shown in table 1, in which the steam cracking of full-range naphtha is 100.

The differences could be even greater, depending on factors such as the composition of the raw materials, the type of furnace, cracking conditions or the effectiveness of separation.

A modern steam cracker for a light, straight-run naphtha has a standard capacity of about 400,000 tons/year of ethylene. There are crackers with smaller capacities in some small countries and some with even higher capacities for countries with very large markets. However, ethylene plants of capacities less than 200,000 tons/year are not built, since the specific investment cost of such erected capacity is 50% higher than for the optimal capacity.
If the raw material is propane, which has a better yield of ethylene and a lower investment cost, the capacity could be less than 200,000 tons/year.

Table 1. Relative investment costs with various processes and feedstocks

Process	Feedstocks			
	Ethane	Propane	Full-range naphtha	Gas oil
Desulphurization	-	-	-	3
Steam cracking	76	85	100	115
Gasoline hydrogenation	-	2	4	5
C_4 and aromatics	-	5	17	19
Totals	76	92	121	142

The yields of various products obtained by steam-cracking various feedstocks are shown in table 2.

Table 2. Products obtained by steam-cracking various feedstocks

Feedstocks	Products obtained (per cent ranges)						
	Ethylene	Propylene	Butadiene	Other C_4	BTX or	Gasoline	Fuel gas and oil
Ethane	80-82	1.4- 1.8	1.9-2.1	0.9-1	0.9-1	(1- 1.1)	11-13
Propane	42-45	15.0-17	2.6-3	1.4-2	3.5-4	(4- 7)	28-32
Butane	35-43	16.0-19	3.0-3.2	6.5-9	4.0-7	(8-12)	28-32
Light naphtha	31-36	16.0-17	3.0-4.3	3.0-4.2	6.0-9	(9-14)	25-30
Full-range naphtha	29-33	12.0-13	4.0-4.8	4.0-4.5	12.0-14	(22-25)	25-29
Gas oil	25-26	12.0-13	4.0-4.8	4.0-4.5	9.0-12	(9-14)	28-33

The use of ethane is more economic than that of light naphtha. It has been calculated that a steam cracker with a capacity of 100,000 tons/year of ethylene, based on ethane, would have the same economy as one for 200,000 tons/year starting from naphtha.

The limited market for ethylene in Bangladesh and the possible difficulties in exporting it, owing to geographical considerations, has lead to the selection of the smallest unit for the production of ethylene - one with a capacity of 80,000 to 100,000 tons/year. At the outset, the capacity of the furnace will be 80,000 tons/year, and that of the purification section 100,000 tons/year. The raw material will be ethane from Bakhrabad gas plus, and eventually, some imports. This proposal for the production of ethylene should be verified thoroughly from the economic standpoint, but technically it is the only feasible approach to the domestic production of plastics from petrochemicals. The decision could be made after the preparation of a feasibility study of ethane recovery, with or without the production of LNG, as well as another study on the use of imported ethane.

An ethylene plant with a capacity of 80,000 to 100,000 tons/year, based on ethane as raw material, would cost about $55 million at this time, with all necessary objects. Possible contractors for such a plant might be Stone and Webster, Lummus, Kellog, KTI, Technip, IFP, Lurgi Linde, Montedison or Mitsubishi.

Salt electrolysis

Two types of cells, the diaphragm type and the mercury type, are used to produce chlorine. With the former, the caustic soda solution is leaner and the salt (NaCl) content higher, but the investment costs are lower than in the latter. On the other hand, while mercury cells are more costly, the alkaline solution is much cleaner and is suitable for the production of dry caustic soda which can easily be transported.

In recent years graphite anodes have been replaced by metallic alloy ones. While there are some positive technical improvements associated with the new metal anode cells, their eventual acceptance may depend upon the possibility of regenerating them.

An electrolysis plant is foreseen with a capacity of 50,000 tons/year of chlorine and an input of 84,000 tons/year of NaCl. The present cost of such electrolytic unit would be about $40 million. The equipment could be acquired in the Federal Republic of Germany, Italy, the United States or elsewhere.

Vinyl chloride (VCM)

VCM was originally produced from acetylene through the addition of gaseous hydrochloric acid. The first patent was granted in 1930, and soon afterwards polyvinyl chloride (PVC) polymer appeared. After the Second World War, a new technology based on ethylene or a mixture of ethylene and acetylene was introduced. Ethylene was much cheaper than acetylene, but the process was rather complicated. It was necessary, first, to produce ethylene dichloride and then to subtract hydrochloric acid from it and to find a suitable use for this by-product. This process led to combined processes (acetylene-ethylene) and to the development of acetylene-ethylene production (Wulff process), introducing the naphtha-cracker plant for ethylene to produce VCM and polyethylene (PE).

A few years ago the producers of vinyl acetate were among the largest consumers of acetylene. Since then, many plants have been converted to ethylene technology. In some existing depreciated plants, vinyl acetate could still be produced, based on acetylene as the last remnant of the old technology, but there appear to be few commercial vinyl chloride plants that use only acetylene.

Unfortunately, investment figures for the comparison of the acetylene and ethylene routes for the production of VCM were not available; the main sources of data for all other plants were records taken from published literature. Since it is simpler than ethylene technology, acetylene technology the investment cost for an acetylene-VCM plant should be less; it is estimated that such a plant with a capacity of 77,000 to 100,000 tons/year would be about $40 million. The capacity of the reactors would have to be 77,000 tons/year, and that of the rectification unit 100,000 tons/year.

The ethylene-oxychlorination process has replaced all others for the production of VCM. There are three steps to this process: first, the chlorination of ethylene to ethylene dichloride, then the thermal decomposition of ethylene dichloride to VCM and HCl and their separation, and finally, oxychlorination. This is chlorination with chlorine created simultaneously with HCl and oxygen. The reaction could be represented by the equation

$$C_2H_4 + HCl + \frac{1}{2}O_2 = CH_2CHCl + H_2O$$

The prooess is exothermic, and the recovered heat is used to produoe steam. The usual catalyst is cuprous chloride. Some processes use air for oxidation, others use oxygen. The yield of VCM on ethylene is 96% and on chlorine over 92%. These routes are diagrammed in figure I.

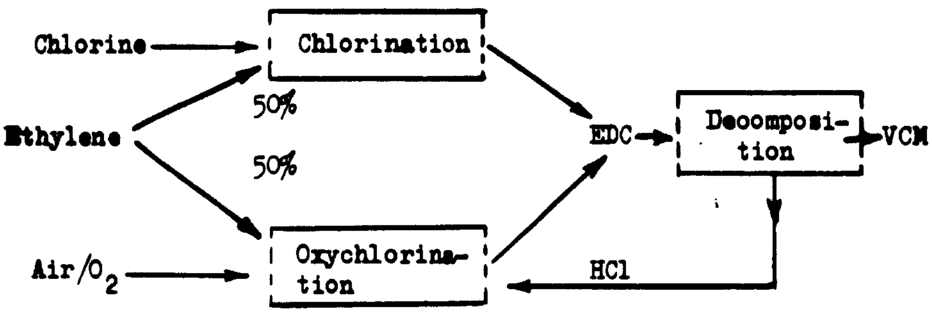


Figure I. Diagram of the ethylene-oxychlorination process

There is residue of chlorinated hydrocarbons (a few kilograms per ton of VCM), the elimination of which could present a problem. The treatment of this waste material constitutes a problem that must be solved before plant start-up. The erection of an oxychlorination unit with a capacity of 77,000 to 100,000 tons/year could amount to $55 million.

Polyvinyl chloride (PVC)

The commercial production of PVC began in the 1930s and is still increasing, despite the introduction of newer plastic materials. The polymerization process is typically additive. At first, polymers were made in emulsion, but a bit later the suspension procedure was discovered. The first process is suitable for paste-forming grades of polymer, the other turns out a product that is purer and that has a better dieletric constant.

A new block-polymerization process has been invented by Pechiney, in France. The medium for this reaction is vinyl chloride, which is polymerized. This discovery quickly aroused great interest, especially since the product was very pure. Nevertheless, most newly erected plants use the suspension process. It appears probable that vinyl chloride is carcinogenic; there is thus an obligation to remove all traces of VCM from PVC, probably by steam treatment. All firms that license VCM processes also have polymerization processes. Some other sources of licences are Dinamit Nobel, Huels, Hoechst, Uhde, Solvay, Rhône and Progil. Some Japanese companies also have good PVC processes.

The erection of four polymerization units, each with a capacity of 56 tons/day, for a total of about 74,000 tons/year, is foreseen. The cost of such an installation would be about $50 million.

Polyethylene (PE)

After PVC, the most widely used plastic material is polyethylene (PE). These common plastics are usually primary products used in most countries. There are enormous markets for these polymers, both of which have the same raw material, namely ethylene. Market surveys indicate, roughly, a possible future consumption of 40,000 tons/year of PE in Bangladesh. The world market for low-density PE is larger than that for high-density PE, although for use in hot climates the high-density material has several advantages. A careful market survey is needed before a final choice of PE type and process is made, but the first plant would probably use the high-pressure process. The technology can be purchased in the Federal Republic of Germany, Japan, the United Kingdom or the United States. The investment cost for such a plant could be about $35 million.

Products from propane

The use of propane as the raw material for ethylene production would entail a higher investment cost. Propane might be used because of an insufficient consumption of methane for fertilizers and energy, resulting in a smaller flow through the separation unit, which would entail a smaller yield of ethane. (Another reason might be a surplus of propane.) Propane might also be substituted for some imported ethane. Bearing in mind all of such possibilities, the steam cracker should have furnace and rectification facilities for propane. The ethane-propane ratio could be set at various levels, but the plant should be designed for ethane and propane in a 2:3 ratio.

The calculated ratio of 80:35 is based on propane from natural gas and, partially, from refinery off-gasses. From 6 million m^3/day of natural gas (i.e. about 210 million ft^3/day) about 80,000 tons of ethane and 26,700 tons of propane could be recovered. When the propane from the refinery is added, there would be a total of 35,000 tons. Based on the figures in table 2, the yield of ethylene would be about 80,000 tons and from 6,500 to 7,000 tons of propylene. With capacity expanded to 100,000 tons of ethylene, the cracking of the ethane-propane mixture would yield about 8,500 tons/year of propylene.

An acrylonitrile plant based on the American Sohio process for economic production would require a larger amount of propylene. The propylene produced could be used for the oxysynthesis process to produce oxoalcohols. The principal product would be 2-ethylhexanol, a constituent of DOP. The standard units for this kind of synthesis are usually many times larger, but it is probable that an economic balance could be reached more easily with oxoalcohols than with ACN. Such oxo-units could produce higher oxoalcohols and, eventually, propionic acid and its derivatives. The entire amount of 2-ethyl-hexanol produced could be used to produce DOP, which is a plasticizer for PVC; all of it would be needed for PVC processing.

II. CONCLUSIONS AND RECOMMENDATIONS

Estimated capital costs and product costs

Investment costs

The probable investment costs of the various plants have been considered in the previous chapter. These estimates are based on reports in various chemical publications, with corrections for the required capacities and adjustments for price escalations. It should be borne in mind that these figures would probably have to be increased owing to import taxes imposed by Bangladesh, high transport costs and the like. They have therefore been presented only as rough indications.

Production costs

In Bangladesh, assuming an exchange rate of $1 = taka 15.5, the domestic price for natural gas for the basic chemical industry is $0.0112/m^3$, for use as industrial fuel it is $0.02/m^3$, and the price of electrical energy is $0.0484/kWh. These figures have been used to calculate the cost of cooling water, demineralized water and steam. The adjusted price of $37/ton is used for NaCl. The price of chlorine is adjusted by the sale of caustic soda for other industrial uses.

The price of ethane, one of the basic raw material, has only been estimated, since it is not a normal trade item. The accepted price is $80/ton, which lies between the domestic price of light naphtha ($108/ton) and of natural gas, which has been calculated to be $16/ton.

The fixed costs have been calculated on the basis of the following percentages of the investment cost:

Depreciation	10
Interest	4.5
Maintenance and repair	3
Management, rent, insurance etc.	1.5
Total	19

The labour cost has been calculated at $1,000/year per skilled worker. The profit must be added to the final product price. The results obtained with these figures are annexed to the present report. As noted, these findings must be accepted as indications only, since they are derived from information from various sources. Nevertheless, the ratio between the product costs and prices is very nearly correct, and the general picture presented by these calculations is realistic.

As anticipated, the price for VCM by the acetylene route is $608/ton, as compared with $350/ton by the ethylene route. This cost differential is the main reason that acetylene is no longer used to produce VCM.

In setting up the petrochemical complex, about 20% to 30% of the investment costs and more than 80% of the operating costs could be paid for in local currency. Based on the figures presented in the annex, the production costs for the final items would be as follows:

Product	Volume/year (1,000 tons)	Price ($/ton)	Total value ($1,000)
PVC	74	542	40 108
PE (l.d.)	40	619	24 760
NaOH	54	284	15 478
Cl_2	2	103	206
		Total	80 552

When local prices for single deliveries in Europe and the United States are compared with the present prices in Bangladesh, the following selling prices would appear to be acceptable:

Product	Volume/year (1,000 tons)	Price ($/ton)	Total value (1,000)
PVC	74	705	52 170
PE	40	725	29 000
NaOH	54	345	18 802
Cl_2	2	155	310
		Total	100 282

The price differential for PVC is higher than for PE because there are four stages of production for the former but only two for the latter. While these prices are relatively high, it is assumed that they would permit the development of a domestic market for plastics.

Form of the petrochemical complex

Based on the findings and conclusions presented in the previous section, the Bangladeeh chemical complex would probably take the following form shown in figure II.

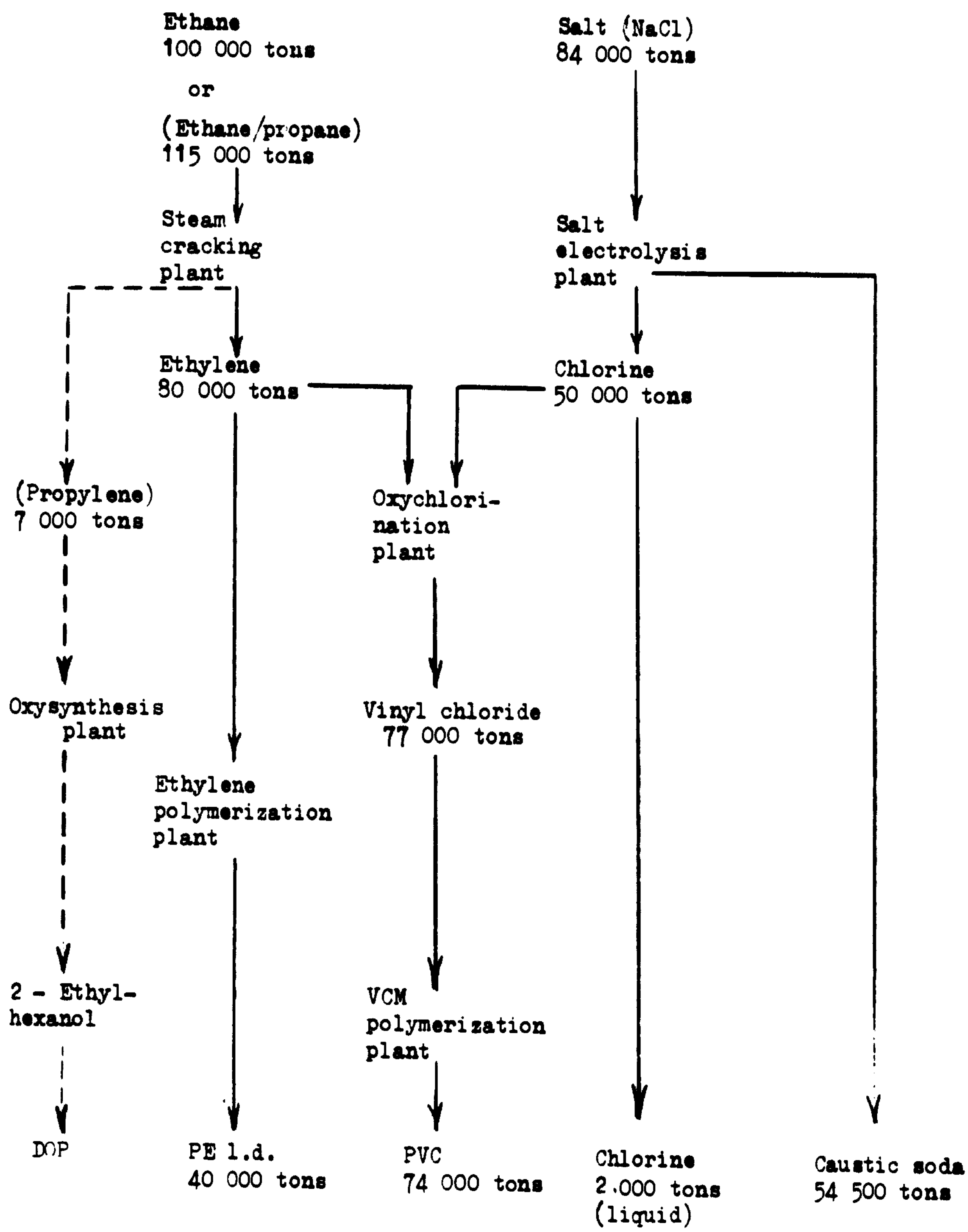


Figure II. Flow chart of the proposed petrochemical complex

The most advantageous method for the recovery of ethane and propane is by the liquefaction of natural gas. To be economically acceptable, however, there must be favourable credit conditions for the extraction plant. The complementary raw material to ethane is propane, obtainable from natural gas or from the oil refinery. If need be, ethane could be imported, temporarily, which would still improve the foreign currency balance. The programme for producing PVC and ACN from acetylene should be dropped.

The present domestic market for plastics is rather restricted, but in from seven to ten years it could be brought up to 75,000 tons/year of PVC and 40,000 tons/year of low-density PE. While such a level of consumption would still be modest, it would justify the erection of a petrochemical plant.

If a feasibility study finds that ethane is economically recoverable, a petrochemical complex could be erected over six or seven years; the capacities of the individual plants could be adjusted to fit projected market demand projected above. The primary product would be ethylene; the raw material would be either ethane or an ethane-propane mixture. Ethylene production would be 80,000 tons/year at the outset, possibly rising to 100,000 tons/year.

An output of 50,000 tons/year of chlorine, with a corresponding amount of caustic soda is foreseen from the electrolysis of NaCl. VCM will be produced by the oxychlorination of ethylene in a plant with a capacity of 77,000 tons/year, possibly increasing to 100,000 tons/year. The polymerization plant for PVC production by the suspension process would have a capacity of 74,000 tons/year.

Location of the petrochemical complex

The location of the projected installation can influence production costs and future development significantly. Factors that must be considered in site selection include, for example, transportation costs of raw materials, liquid or gaseous fuels, water and end-products. Also important is the availability of a supply of skilled labour and technicians, the proximity of metalworking, electrical and electronic shops for repairs and maintenance. All factors that are important in any building operation must also be considered.

The complex should be located on the Bakhrabad natural gas pipeline. A cryogenic separation plant for ethane recovery should be a part of the complex, but it must not be adjacent to the natural gas liquefaction plant on Kutubdia Island. It is somewhat easier to transport ethane (5 kg/sec) than water, workers, electrical power and so on. The cost of a few kilometres of pipeline would not be great, as compared with the cost of the complex. The complex should be located on the riverside but not too far from the LNG plant. It is important that there be good connections with railroads, roads and, if possible, river ports.

Technical training of the staff

As soon as it has been decided to erect the petrochemical complex, in addition to the appointment of the General Manager and his administrative and commercial staff, it will be essential to form a technical cadre. The engineers, whose backgrounds will be primarily in chemistry and energetics, would have to become familiar with similar plants before they can be of real use during the preparations of the contracts with the engineering company that will perform the construction or regarding the purchase of equipment and, most importantly, the start-up of the plants. The most suitable people to form this cadre would be engineers with experience in nitrogen factories or the ERL refinery; there is no real alternative. As the project progresses, they will have to learn to cope with the day-to-day production problems of the operating plants. Thus, each member of this cadre should work in some of the following units: cryogenic extraction of ethane, steam cracking of LPG or naphtha, chlorine electrolysis, ethylene oxychlorination and the polymerization of VCM and ethylene. It would be advisable for each cadre member to spend a few weeks in each plant. All of these processes could be observed in Yugoslavia. While the oxychlorination plant there has not yet gone on stream, it is expected to do so in late 1978 or early 1979.

The technicians, supervisors and skilled workers required for production and maintenance should be recruited entirely from existing nitrogen fertilizer plants.

Comment

It must be recognized that the market survey reports on this projected petrochemical complex, which were prepared ten years ago, are no longer adequate, considering the changes that have occurred in the use of plastics. Nevertheless, the general outlines are the same.

In Bangladesh, the fact that imports of plastic resins are strictly limited has resulted in decreased consumption of plastics; it has been estimated that present consumption of PE and PVC is somewhat smaller than it was in 1972/73. Considering the projected increases in living standards and purchasing power, the domestic market for plastics powders and granulates will, in the next ten years, reach 71,000 to 100,000 tons/year of PVC and about 40,000 tons/year of PE if the import of plastics powders and granulates is facilitated. Consumption on such a scale would justify the erection of the petrochemical complex.

To an extent even greater than the market survey, the ten-year-old techno-economic reports have lost their value. When they were prepared, and even for some while afterwards, the Sachsse technology for acetylene production seemed adequate. There are still two or three plants that produce acetylene from methane. Furthermore, the acetylene route is only economically feasible for VCM in special circumstances.

Most modern vinyl chloride plants use the ethylene route. Ethylene could be produced in Bangladesh either from ethane or from an ethane-propane mixture. Both of these gases could be extracted from Bakhrabad gas, although its ethane content is only about one half the optimal concentration. The economics of such a plant should be established by a feasibility study.

Based on the available raw materials, and with plants whose capacities are still within the economics of scale, even though on the lowest level, to supply the domestic market, the projected petrochemical complex would take more or less the following shape:

An ethane or ethane-propane steam cracker with a capacity of 80,000 to 100,000 tons/year of ethylene

A salt (NaCl) electrolysis plant with a capacity of 50,000 tons/year of chlorine

A vinyl chloride plant with an installed capacity of 77,000 to 100,000 tons/year

A PVC polymerization plant with an installed capacity of 74,000 tons/year

A low-density polyethylene plant with an installed capacity of 40,000 tons/year

Rough calculations for all of these plants have been presented in the annex. The same calculation has been made for a Huels acetylene with a capacity of 33,000 to 45,000 tons/year (six units) and for corresponding downstream capacities for VCM and PVC, the production costs would be unacceptable.

Were an ethane-propane mixture, rather than ethane alone, to be used, a steam cracker would be from 10% to 15% more expensive, but there would be 6,500 to 8,500 tons/year of propylene as a by-product. This material could be converted by oxysynthesis to 2-ethyl hexanol by oxysynthesis for DOP.

Recommendations

Based on the conclusions listed above, the following recommendations are made. If the project is to succeed, the growth of consumption of plastics must be stimulated so that they can support the erections of new facilities for the processing of plastics.

BCIC and Petrobangla should determine the optimal solution for the recovery of ethane from Bakhrabad gas and determine the time at which the petrochemical complex would have ethane and LPG to use as raw material.

With due regard for the growth of the domestic market for plastics and for the requirements for the eventual delivery of ethane, all other preparatory work for the erection of the petrochemical complex should be completed.

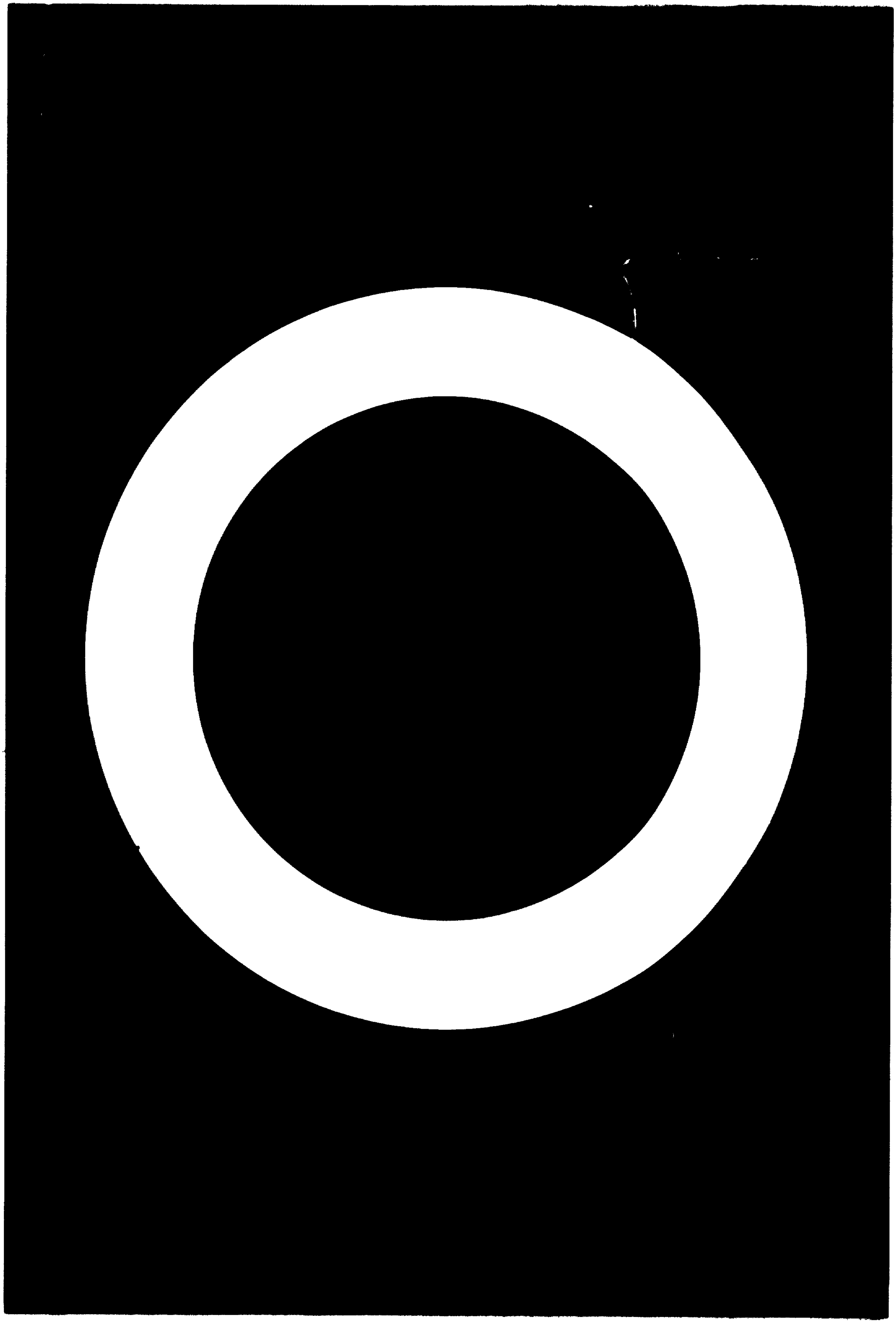
The possible importation of ethane or of an ethane-propane mixture for use as raw material should be examined. As noted in the section Products from ethane and higher hydrocarbons this is being done successfully in Norway; the experience of that country might be of value to Bangladesh.

The preparation of a feasibility report that could be used to attract financial support for the project would have to be done by an engineering organization with broad experience and a good reputation in this field.

The most acceptable form of the projected petrochemical complex, based on all of the prevailing conditions, have been presented above.

The optimal location of the complex, which would be determined by the proximity of the ethane recovery facilities and the accessibility of other raw materials and sources of energy, must be decided.

Some of the leading engineers of the technical staff should receive training in similar complexes in other countries.



Annex

ESTIMATED COSTS OF THE PLANTS [a]

Acetylene[b]

Capacity (tons/year)	33 300 to 45 000
Investment cost ($1000)	45 000
Production costs ($1000)	
Fixed costs	8 550
Variable operating costs	24 230
Total production costs	32 780
Production cost/ton [b]	$984

Ethylene

Capacity (tons/year)	80 000 to 100 000
Investment cost ($1000)	55 000
Production costs ($1000)	
Fixed costs	10 450
Variable operating costs	10 905
Total production costs	21 355
Production cost/ton [b]	$267

Chlorine and caustic soda

Chlorine capacity (tons/year)	50 000
Caustic soda capacity (tons/year)	54 500
Investment cost ($1000)	40 000
Production costs ($1000)	
Fixed costs	7 600
Variable operating costs	13 178
Total production costs	20 778
Production cost/ton of chlorine	$103
Production cost/ton of caustic soda	$284

Vinyl chloride monomer (VCM)

(acetylene route)

Capacity (tons/year)	77 000 to 100 000
Investment cost ($1000)	40 000
Production costs ($1000)	
Fixed costs	7 600
Variable operating costs	39 211
Total production costs	46 811
Production cost/ton [c]	$608

Polyvinyl chloride (PVC)
(acetylene route)

Capacity (tons/year)	74 000
Investment cost ($1000)	50 000
Production costs ($1000)	
Fixed costs	9 500
Variable operating costs	50 494
Total production costs	59 994
Production cost/ton	$811

Vinyl chloride (VCM)
(ethylene route)

Capacity (tons/year)	77 000 to 100 000
Investment cost ($1000)	55 000
Production costs ($1000)	
Fixed costs	10 450
Variable operating costs	16 487
Total production costs	26 937
Production cost/ton b/	$350

Polyvinyl chloride (PVC)
(ethylene route)

Capacity (tons/year)	74 000
Investment cost ($1000)	50 000
Production costs ($1000)	
Fixed costs	9 500
Variable operating costs	30 638
Total production cost	40 138
Production cost/ton b/	$542

Polyethylene (PE)
(low density)

Capacity (tons/year)	40 000
Investment cost ($1000)	35 000
Production costs ($1000)	
Fixed costs	6 650
Variable operating costs	18 116
Total production costs	24 766
Production cost/ton	$619

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a/ Assuming an exchange rate of $1 = taka 15.5.

b/ Huels arc process.

c/ At the lower end of the capacity range.

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