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STEAM CRACKING PROCESSES[1]

by

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I - Introduction

Vapour phase cracking of hydrocarbons, more commonly known by its English name of steam cracking, has become the principal method of olefin production in France as well as an important source of aromatic hydrocarbons. According to the fifth plan, French steam cracking plants must produce [illegible],000 metric tons of olefins in 1967, perhaps [illegible] of consumption, and 1,150,000 metric tons in 1970, about 73 per cent of consumption. Thus steam cracking has become an essential utility for production of petrochemicals.

It is interesting to examine the progress made in this relatively recent technique, to deduce from it the possible extent of development and to determine the production cost of olefins which may be achieved by this process in order to predict future changes in their selling price.

The principal product, ethylene, has shown an extraordinary development throughout the world. World production capacities for ethylene and propylene in 1967/1968 are shown in Table I:

Table I

World production capacities for ethylene and propylene 1967/1968

1,000 metric tons per year

	USA	Outside USA	Total
ethylene	7,256	9,206	16,460
propylene*	1,680	5,760	7,440

*) Not including the important quantities of propylene produced in oil refineries.

The total annual ethylene production capacity for Great Britain and the Common Market countries is [illegible] mm te/a and if all the units under construction or planned are added in this figure becomes about 6.8 mm te/a in 1970 and could double again by 1980. In France, according to the 5th plan, the development shown in Table II can be expected:

Table II

5th Plan, Ethylene and propylene production in France

1,000 metric tons per year

	1967		1970	
	Production	Consumption	Production	Consumption
ethylene	590	500	1,025	860
propylene	328	330	478	400

Although steam cracking of liquid hydrocarbons has become the principal source of ethylene in Western Europe, the same is not true of the USA, where the main source of ethylene is ethane recovered from natural or refinery gas followed by LPG (liquified petroleum gas), mainly propane. This situation is brought about by the low price of light naphthas in Europe (10-11 centimes per kg against 15 centimes in USA) and because ethane and propane are more freely available in the USA than in Europe.

This situation could, however, change. Quotas for the import of crude oil at a low price have been granted to manufacturers setting up installations in the Caribbean which allows them to obtain naphtha at the European price. At the same time, the price of ethane and propane is tending to rise in the USA and to fall in Europe. Table III shows the expected changes in basic raw materials for ethylene production in the USA. It can be seen that the liquid feedstock share will largely increase by 1975.

In any case, the steam cracking process can use hydrocarbons ranging from ethane to heavy fuel oil. It seems certain therefore, to provide the lions share of ethylene production in the USA as in Europe.

Table III

Primary materials for ethylene production in the USA

Ethylene (in barrels per calendar day) coming from	1966	1970	1975
ethane	145,000	158,000	217,000
propane	132,000	157,000	184,000
C_5+ (liquids)	74,000	150,000	307,000

II - Description of the vapour phase cracking process

II.1. Raw materials

As already shown, the following raw materials may be used:

Ethane

	Sp. Gr.
LPG	
condensates and light gasoline	0.65 - 0.69
light naphtha	0.69 - 0.73
heavy naphtha	0.74 - 0.78
kerosine	0.78 - 0.83
gas oil	0.84 - 0.86
heavy fuel oil	0.85 - 0.87

The English term, virgin naphtha, currently used to designate the raw material for steam cracking covers the whole range of crude liquid fractions boiling between 20°C and 200°C. The ethylene yields from steam cracking are proportionally higher as the starting material gets lighter. Moreover, great progress has been made in the past 10 years in raising these yields as can be seen from Table IV. This has been achieved by increasing the severity of cracking by increasing the cracking temperature and by recycling ethane and LPG through special furnaces which crack them to olefins.

Table IV

Steam cracking - ethylene yields

Feedstock	% yield of ethylene	
	1957	1967
ethane	81	86
propane	40 - 45	45 - 48
naphtha	16 - 20	24 - 35
gas oil	12 - 16	18 - 25

II.2. Pyrolysis furnaces

Two principal designs are in competition:

1. The Selas furnace with lateral burners and two banks of horizontal tubes.

2. The Foster Wheeler furnace with burners at the bottom of the furnace and one range of vertical tubes. Both types have their advantages and disadvantages. Both provide for temperature regulation according to the desired profile and for the cracking of a range of hydrocarbons from ethane to liquid fractions. The Foster Wheeler furnace can also be used to crack gas oil and heavy fuel oil.

A minimum of 5 furnaces is used so that a furnace may be shut down, for removal of coke or for other reasons, without interrupting production. The capacity of furnaces has increased, it varies between 25,000 and 45,000 metric tons/year of ethylene.

The gas or the vapourized naphtha, preheated and diluted with steam, enters the tubular section of the furnace where cracking takes place. The steam acts as an inert diluent, minimizes the formation of coke, decreases reaction temperature and controls the transfer of heat from the tube wall to the reaction medium. The optimum amount of steam used varies with the process, the cracking severity and the type of hydrocarbon. With light naphtha the optimum is around 1 kg of steam for 2 kg of hydrocarbons. With gas oil it would be much lower.

The cracking reaction takes place at near atmospheric pressure in a very short time (0.2 - 1.3 seconds) which depends on the nature of the feedstock.

The cracking temperatures vary between 675°C and 950°C. Typical furnace outlet temperatures for the vapours are 860°C when feeding ethane or propane and 760°C to 900°C when feeding naphtha. This leads to temperatures on the outside of the tube walls of 1050°C or higher. The tubes are a very important component in the steam cracking process and they must be of very high quality.

The volume increase during cracking is 1.95 times for ethane, three to four times for naphtha and eight to nine times for gas oil. This leads to vapour velocities at the furnace outlet in excess of 330 m/sec.

II.3. Flow sheet

A schematic flow sheet is shown in Fig. 1. The vaporized naphtha and steam enter the pyrolysis furnace 1 where cracking takes place. The cracked products are partially cooled in the waste heat boiler 2 before their final cooling in the column 3 from which the residual fuel oil is recovered. The overhead from column 3, the gasoline and lighter components are compressed in compressor 4, from which the gasoline is recovered, and the remainder passes through the caustic soda wash column 5 and the drier 6 before entering the depropanizer 7. In column 7 the C_3 and lighter gases are separated from the C_4 and heavier products.

The depropanized bottoms are sent to a debutanizer 8 from which the C_4's emerge at the top and stabilized gasoline at the bottom.

The C_4's go to the extractive distillation column 9 which separates the butanes and butenes as top products. The column bottoms pass through the stripper 10, the topping column 11 and the tailing column 12 from which butadiene is taken as overhead product.

The overhead products from the depropanizer are contacted with hydrogen rich gas in the acetylene removal column 13, where acetylene is hydrogenated to ethylene, and are then compressed in 14, cooled in 15 and passed into the demethanizer 16 which separates methane and hydrogen as an overhead product by low temperature fractionation. The demethanizer bottoms go to the deethanizer which separates the C_2 and C_3 hydrocarbons.

The C_2's pass to the low temperature fractionating column 18 which gives ethylene as overhead and ethane as a bottom product. The latter may be recycled through a special steam cracking furnace to increase the overall yield of ethylene or it may be passed into the fuel gas stream. The refrigeration necessary is provided by an external propylene/ethylene cascade system 20/19 and by the expansion of gases.

It should be noted that the butanes and butenes coming from column 9 as well as the propane can equally well be recycled through a cracking furnace which will have the effect of still further increasing the production of ethylene as well as that of butadiene.

Finally, if there is no market for the propylene it can be:

- used by an oil refinery either by polymerization or by alkylation with iso-butene for production of a high quality alkylate for raising the octane number of gasolines.

- transformed to ethylene and n-butenes by the entirely new "Triolefin" process of the Phillips Petroleum Co. (molecular disproportionation). The n-butenes in their turn, can be recycled through a cracking furnace to increase the yield of butadiene. They may also be dehydrogenated, which gives a better yield of butadiene but is much more costly, or may be returned to a refinery for the alkylate pool for octane improvement of gasoline.

As for the pyrolysis gasoline, which has a high octane number, it may be returned to a refinery for treatment or retained for recovery of the contained benzene, toluene and xylenes for which the chemical demand is also high. In any case, whether it is done in the refinery or the steam cracking plant, the gasoline must be hydrogenated. A technique which is often used is two stage catalytic hydrogenation in which the diolefins are saturated in the first stage and the remaining olefins in the second (not shown on the schematic diagram of Fig. 1).

The hydrogenated product is cooled, passed through a separator to remove combustible gases and then to a stripper column which removes any remaining hydrogen and methane. The liquid bottoms then go to a tower for separation of any heavy products. A second hydrogenation treatment of this gasoline is usually necessary if aromatics are to be extracted from it.

II.4. Triolefin process

As stated above the Phillips Petroleum Co. has brought out a process of "molecular disproportionation" which can, in particular, convert propylene into ethylene and n-butenes according to the following catalytically promoted reaction

$$2\ C_3H_6 \rightarrow C_4H_8 + C_2H_4$$

The reaction pressure varies from 0 to 35 kg/cm^2 and the yields are close to the theoretical which, for 100 t propylene are 33.4t ethylene and 66.6 t of n-butenes. The most interesting way of utilising this process is to include it in a steam cracking plant to convert all or part of the propylene and to crack the n-butenes to butadiene in a special furnace as shown in Figure 2.

The naphtha enters the cracking furnace 1; after cracking and cooling, the gases enter 2 where they are compressed and separated from the liquid C_5+ fraction. Methane and hydrogen go as fuel gas and the remainder passes into the low temperature fractionation section 3 from which come the ethylene, propylene and C_4.

The dried propylene goes to the conversion section 4 (shown dotted in the flow diagram) where it is converted to ethylene and n-butenes.

The C_4 fraction from section 3 goes to unit 5 for extraction of isobutylene and then to unit 6 for recovery of butadiene. The n-butenes from unit 6 are added to those from unit 4 and passed to unit 7 (dotted on the flow diagram) where they are converted to butadiene. The gases coming from unit 7 are recycled with those from the cracking furnace 1 to the compression section 2.

A plant cracking 400,000 t/a of condensate at low severity can give the performance shown in Table V and VI where the effects of adding the units 4 and 7 shown by dotted lines on the flow diagram, are also indicated.

The cracking has been carried out at medium severity to maximize the yield of butadiene, the most valuable product. Addition of the triolefin process raises the production of ethylene by 35,000 te/a and of n-butenes by 56,000 te/a. The total of n-butenes, say 70,000 te/a is cracked to 24,800 te/a of butadiene raising its production from 18,800 to 43,600 te/a.

The steam cracking unit would cost about 106 million francs. To this sum the following investments for the triolefin process would have to be added:

	10^6 Francs
disproportionation of propylene and auxiliary equipment	13.500
cracking of n-butenes to butadiene and auxiliary equipment	8.750
total investments for the process	22.250

The total investment is thus 128 x 10^6 francs (+ value added tax and working capital). Costs of operation of the process are 9.5 x 10^6 francs/a.

Allowing 15 years for amortization of the plant, 50% of the profit for taxes and valueing 94% propylene at 0.18 francs/kg, the process gives a pay out time of less than 4½ years.

Table V

Conventional steam cracking using naphtha

	Yields % by weight in naphtha		
	Low severity	medium severity	high severity
CH_4 and lighter	13.6	17.1	20.8
ethylene	26.0	33.1	36.4
propylene	17.5	14.7	12.6
propane	1.2	1.1	1.0
isobutylene	4.0	3.2	2.3
butenes	3.5	2.9	2.1
butadiene	4.7	3.8	3.4
butanes	0.4	0.3	0.3
C_5+	29.1	23.8	21.1
	Naphtha cracking and triolefin		
CH_4 and lighter	16.3	19.4	22.7
ethylene	34.9	40.3	42.7
propylene	-	-	-
propane	1.2	1.1	1.0
isobutylene	4.0	3.2	2.3
butenes	-	-	-
butadiene	10.9	9.0	7.7
butanes	0.4	0.3	0.3
C_5+	32.3	26.5	23.3

Table VI

Steam cracking of 400,000 t/a of light condensate at low severity

Production 10^3 t/a	without the triolefin process	with the triolefin process
CH_4 and lighter	54.4	65.2
ethylene	104.0	139.6
propylene	70.0	0
n-butene	14.0	0
butadiene	18.8	43.6
isobutylene	16.0	16.0
C_5+	116.4	129.2

II.5. Ethylene yields

In the USA, where the feedstock is mainly gas, the yields of ethylene are very high but the quantities of by-products are low (see Table I). In Europe, for the reasons already given, liquid feedstocks are cracked but still the maximum yield of ethylene is aimed at.

For these reasons a light liquid feedstock (light naphtha or natural gas condensate) is chosen and is cracked at high temperature. Also it is usual to recycle all the ethane through the cracking furnaces and, sometimes, the available propane and butane as well which further increases the yield of ethylene.

In conformity with these ideas Table V shows how far it is possible to go with a light naphtha in cracking at low (760°C) medium and high severity (860°C). It confirms that the ethylene yield rises from 26 to 36.4% but propylene yields fall from 17.5 to 12.6% and those for butadiene from 4.7 to 3.4%. At the same time, the quantity of liquids produced (gasoline, fuel) falls from 29% to 21%.

Research has been carried out, especially in Japan, to try to increase the yield of ethylene still further. Thus, if the steam in the cracking furnace is replaced either by hydrogen or by cracker gas rich in hydrogen, the ethylene yield may be improved by 20%, but the propylene decreases a little.

The motives for all this are threefold:

1. Low price for light naphtha in Europe (of the order of 10 centimes/kg)
2. Large outlets for ethylene
3. Small outlets for propylene.

For some time now however, the situation has been changing. Light naphtha is becoming much sought after, particularly for the giant ammonia plants, which are currently being built in Europe. At present the prices for this material are sensitive and have, it appears, risen by about 10%. There is no reason to believe that this tendency will not continue in the future. The Americans, especially who have ever greater and greater demands for propylene and butadiene, will themselves use increasing quantities of this material.

As for propylene, the situation has changed radically in the USA and its price is rising. In effect, numerous chemical uses have been developed for this product and Europe is following but with a certain time lag. The price of propylene will become firmer in Europe also, although lower than in the USA.

In these conditions one can either crack at lower severity or crack heavy naphtha, gas oil or even crude heavy fuel oil.

In any case, the ethane should not be recycled. Thus one obtains much more propylene and butadiene but, obviously, less ethylene (see Table VI).

II.5. Realizations

Steam cracking plants of 30,000 t/a ethylene capacity, considered modern in 1960–1961 were completely out of date by 1965 where capacities of 150,000 to 250,000 t/a were being envisaged. Typical of these are the plants of ROW (BASF and SHELL) in Germany, started up in [illegible] 1965. Original capacity 200,000 t/a ethylene now extended to 300,000 t/a, and the very recent plant of the Société Rhône - Alpes at Feyzin, France with high severity cracking of a million t/a of light naphtha and producing 250,000 t/a of ethylene. Here the gasolines are hydrotreated. At the time of its construction (1966) this plant was considered to be the largest but it has already been outranked by several units in course of construction throughout the world in 1967. Finally, it is worth mentioning the ESSO steam cracking plant in France at Port-Jérôme with a capacity of 200,000 t/a of ethylene starting from fuel oil.

III - Investments

The investments for a steam cracking plant should include:

- everything within battery limits with engineering, catalyst charges and licence if one is needed
- utilities
- spare parts
- auxiliary services comprising:
  - the site and its preparation
  - the laboratory
  - the receipt and dispatch services
  - the offices
  - the maintenance workshops
  - the maintenance materials
  - the general services

Steam cracking plants are usually sited alongside a refinery and the investments should include the cost of all the pipelines which tie the two units together, whether for the transfer of feed-stocks or for the products returned to the refinery: fuel, gasoline, fuel gas and gas for alkylates.

Excluded from the above are any sums necessary for delivery of products by pipeline at distances greater than 15 km as sometimes happens (200 km gas line for ethylene for example) nor for special storage reservoirs (underground cavern for ethylene, large refrigerated tanks for butadiene etc.).

By the French Petroleum Law, 192[illegible], a chemical company desiring to set up a steam cracking plant would not have the right to market the gasoline, fuel or gas by-products directly. There are three possibilities open to it:

1. To combine with a petroleum company which does have a licence permitting it to import and to sell these products on the French market.
2. To export all its products.
3. Arrange the manufacturing processes so that all petroleum fractions are turned into chemical products.

The case is the same for a petroleum company which has not obtained, by decree, a share of the French market for petroleum products.

Solution 3 is not impossible theoretically and it has given rise to feasibility studies in France. Such a company would be permitted to import the steam cracking plant feedstock free of customs duties and taxes. All the products from this unit would have to be sold as chemical base materials or burnt in the cracking furnaces.

Careful calculations have proved that the production costs obtained would be less attractive than for a normal steam cracking unit, even if this bought a somewhat dearer feedstock from a nearby refinery.

Solution 2 is equally possible theoretically, supposing the steam cracking plant is near a frontier (like that of La Société SAR-LOR). It is considered more normal however, to place a steam cracking plant in the area where its products can be sold. That is why in all cases at present, it is solution 1 which is adopted with three variants:

- it is the oil company itself which has outlets for olefins and constructs its own steam cracking plant as a part of its refinery (ESSO at Port Jerôme, SHELL at Berre);
- or the oil company builds a steam cracker and signs a long-term supply contract for ethylene with a chemical company (for example CALTEX which delivers ethylene under contract to HOECHST-Germany);
- or the petroleum and chemical companies get together to build and operate a steam cracker by the side of the refinery which will supply it with raw material; Examples:

  in France: NAPHTHACHIMIE (Rhône-Poulenc* + British Petroleum),
  Rhône Alpes (UGP + Solvay + Ugine + SNPA + Progil);
  in Germany: ROW (BASF + SHELL);
  in Belgium: PETROCHIM (PETROFINA + PHILLIPS, etc).

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*) Rhône Poulenc now holds the Péchiney share in NAPHTHACHIMIE since the take over of Péchiney St. Gobain.

In all cases, a steam cracker must be regarded as an important unit requiring a site, utilities and services.

III.1. Steam cracking for 50,000 tons/a of ethylene

In the example considered let us suppose it is to be a simplified plant to crack 200,000 tons/a of dilute ethylene at a concentration of 52.1% (see Table VII) without ethane recycle. The plant within battery limits including catalyst charge but excluding engineering will cost, under actual French conditions 18,330,000 FFR and includes a compressor of 3,850 C.V. as well as the back pressure turbine to drive it.

Table VII

High severity steam cracking of virgin naphtha

Products	% by weight	Metric tons/a
hydrogen	1.9	1,800
methane	32.8	31,300
ethylene	52.1	50,000
ethane	13.2	12,500
Total ethylene stream		95,600
C_3 fraction 94% propylene		37,200
C_4 fraction		19,200
pyrolysis gasoline		39,000
fuel oil		9,000
		200,000

The supplement for ethylene recovery at 99.8% purity with a 4,300 C.V. compressor and turbine is 7,123,000 FFR.

The supplement for raising propylene purity to 98.5% is 675,000 FFR. Table VIII shows the requirements for utilities and personnel.

Table VIII

Steam cracking for 50,000 tons/a of ethylene

Steam cracking	Cracker gas production	Additive for Ethylene extraction	Additive for Propylene concentration	Additive for Butadiene extraction
Compressors requiring	3,850 CV	6,300 CV	0	0
Electrical energy	485 kw	0	33 kw	30 kw
Fuel	32×10^3 th/hr say $256 \cdot 10^6$ thermies/a	0	0	0
Cooling water	1,000 m^3/hr	850 m^3/hr	250 m^3/hr	224 m^3/hr
Demineralised water	24 m^3/hr	0	0	0
Steam balance				
Steam production (LP)	12.3 tons/hr	0	0	0
Steam consumption(LP)			9 tons/hr	7.7 tons/hr
Catalysts and chemicals	300,000 Fr/a	0	0	0
Hydrogen at 98 %				2.7 m^3/t of butadiene
Staff and supervision	2 engineers 1 foreman/shift 4 workmen/shift	1 man/shift	1 man/shift	1 man/shift
Maintenance as % of investments/a	4 %	4 %	4 %	4 %
Battery limits investments without engineering	12.330×10^6 Fr	7.123×10^6 Fr	0.375×10^6 Fr	3.780×10^6 Fr
Licence (estimated)				0.9×10^6 Fr
C_4 production tons/	19,200	19,200	19,200	19,200 of which 6,85[illegible] tons/a butadiene

A - Utilities

The utilities are a very important factor. According to the assumptions made the investments required can vary within wide limits.

A.1. Steam balance

The steam cracker under consideration produces steam at high and low pressure and consumes steam at high, medium and low pressures. In Table I. [illegible] constructed a steam balance for the [illegible] steam cracker [illegible] high pressure [illegible] low pressure [illegible] [illegible] will [illegible] for [illegible] chosen [illegible] will [illegible] high pressure [illegible] the [illegible] will [illegible] a special [illegible] to [illegible] [illegible]/m² [illegible].

[illegible]

- [illegible] 3,[illegible] [illegible] = [illegible] tons/hr [illegible]

4,3[illegible] [illegible] need [illegible] = 31. [illegible] tons/hr high pressure steam

Thus the total [illegible] for [illegible] is [illegible] tons/hr high pressure steam. In practice [illegible] boil[illegible] [illegible] to produce 60 tons/hr of high pressure steam which will [illegible] [illegible] tons/hr low pressure steam. This [illegible] that there will be [illegible] for [illegible] tons/hr of low pressure steam. This is generally [illegible] and it is [illegible] [illegible] other petrochemical units [illegible] steam cracking [illegible] ethylene, propylene etc. which need low pressure steam.

If this [illegible] it will be necessary:

- either [illegible] steam [illegible] condensation turbine (an expensive [illegible])
- or to drive the compressors by electric motors and arrange a special contract with the electricity supply company.

The last solution has the advantage of appreciably reducing the investments in the utilities and auxiliary services. Furthermore the turbines can be replaced by much less costly electric motors.

Generally high pressure turbines are preferred, above all for the large steam crackers. It is one of the reasons for raising the cracking temperature and producing the maximum of high pressure steam at 100 kg/cm^2 and 560°C. Here a substantial quantity is available for expansion through the turbines and the auxiliary boiler to be provided is smaller.

On the other hand, in low severity steam crackers treating crude fuel oils with a relatively small quantity of steam, the auxiliary boiler must be larger and must provide not only the steam for the turbines but also steam for cracking.

Table [illegible]

Steam cracker [illegible],000 tons/yr ethylene at 52.1 %

Steam balance

Balance in tons/hr		Conversion coefficient HP —— LP	LP steam equivalent
Consumption			
HP steam	13 tons/hr	1.1	14.3
LP steam	5.7 tons/hr	1	5.7
			20.0
Production			
HP steam	23.7 tons/hr	1.25	28.8
LP steam	3.5 tons/hr	1	3.5
			32.3
LP steam available			12.3 tons/hr

A.2. Thermal balance

In the example being considered the classic method of high pressure turbines and an auxiliary boiler for the required high pressure steam has been chosen. Table VIII shows that 256 x 10^6 thermies/a are needed for the cracking furnaces. Besides this the auxiliary boiler will need 815 x 58.6 = 47,700 thermies/hr say 382 x 10^6 thermies/a. Total requirements therefore are 382 + 256 = 638 x 10^6 thermies/a.

The steam cracker produces: fuel (Table VII):

9,000 tons/a x 9,700 thermies = 87 x 10^6 thermies/a

fuel gas (hydrogen, methane, ethane) Table VII and X (gas type I): 521 x 10^6 thermies/a.

Table X

Combustible gases

Composition of combustible gases	Production 10^3 t ms/a	Heating value thermies/kg	Value centimes per kg	Turnover 10^3 [illegible]/a
(I)			1 thermie = 1 centime	
Gas type I				
H_2	1.8	32.5	32.5	585
CH_4	31.3	10.7	10.7	3,350
C_2H_6	12.5	10.2	10.2	1,275
Total	45.6	10^6 x 521 th/a		5,210
(II)				
Gas type II				
H_2	1.8	32.5	32.5	585
CH_4	31.3	10.7	10.7	3,350
C_2H_6	12.5	10.2	10.2	1,275
C_3H_6	[illegible].7	10.0	10.0	[illegible]
Total	47.[illegible]			[illegible]

Table X continued

Combustible gases

Composition of combustible gases	Production 10^3 tons/a	Heating value thermies/kg	Value centimes per kg	Turnover 10^3 Fr/a
(3)				
Gas type [illegible]				
H_2	1.8	32.5	32.5	585
CH_4	31.3	10.7	10.7	3,350
C_2H_6	12.5	10.2	10.2	1,275
C_3H_8	1.7	10.0	10.0	170
C_4 cut	12.35	9.8	9.8	1,210
Total	59.65			6,590

Table XI

Steam cracker 50,000 tons/a ethylene. Investments for utilities

Utilities	Steam cracker only	Supplement for extraction of			Steam cracker complete
		ethylene	propylene	butadiene	
Production and distribution of electrical energy	For 485 kw 765×10^3 Fr	0	For 33 kw 52×10^3 Fr	For 30 kw 47×10^3 Fr	864×10^3 Fr
Cooling water	$1,000 \times 10^3$ Fr	850×10^3 Fr	250×10^3 Fr	324×10^3 Fr	$2,424 \times 10^3$ Fr
Demineralized water	216×10^3 Fr	0	0	0	216×10^3 Fr
Production of steam	For [illegible] tons/hr $2,800 \times 10^3$ Fr	For 32 tons/hr $3,200 \times 10^3$ Fr			$6,000 \times 10^3$ Fr
Total 10^3 [illegible]	4,781	4,050	302	371	9,504

In total the steam cracker produces 608 x 10^6 thermies/a, that is to say practically all the heat needed for the auxiliary high pressure boiler. This can explain the preference for turbine drives rather than for buying electricity. If this second alternative were used it would be necessary to find a use for a substantial amount of fuel gas corresponding to 521 x 10^6 thermies/a. There is no reason to believe that the neighbouring refinery would need this heat. Even if it did the refiner would only offer 0.5 centime/thermine which would penalize the steam cracker. It would certainly be possible to use this fuel gas to raise low pressure steam for the adjacent petrochemical plant. It would then be necessary to build a boiler almost as large as the auxiliary boiler already considered and virtually takes us back to the previous case.

It is interesting to note that of 638 x 10^6 thermies/a required 521 x 10^6 thermies are provided by the fuel gas, free of tax, whereas until now liquid fuels pay a non recoverable 10 % value added tax (although this may possibly be abolished).

A.3. Investments for utilities

These are shown for French conditions, engineering included, in Table XI. They amount to 9.5 x 10^6 Fr for a steam cracker costing within battery limits 29 x 10^6 Fr. Steam raising alone accounts for 6 x 10^6 Fr (for security the boiler capacity has been increased by 50% by adding an auxiliary boiler).

B - Total investments

These are set out in Table XII where it can be noted that the battery limits total of 29 x 106 Frs. becomes 75.5 x 106 Frs. for the complete steam cracker. This shows to what extent battery limits prices, especially without engineering and licence fees are illusory and how wrong it is to base calculations of production cost on them, as one sees done all too often in the literature.

Attention must also be drawn to the supplementary cost which increase the total investment by 20 %:

- 1st establishment costs: all the costs of studies, setting up the company etc. made before construction starts.
- interest-payments during the two years or so required for construction.

The money is available and interest-payments begin to fall due but they cannot be integrated into any operating account as there are no sales.

Table XII

Steam cracker for 50,000 tons/a ethylene

Total investments

Investments 10^6 FFR	Steam cracker only	Supplement for extraction of ethylene	Supplement for extraction of butadiene	Steam cracker complete	Supplement for propylene concentration
Battery limits without engineering	18,330	7,123	3,780	29,233	0,675
Engineering (estimated) 33%	6,110	2,370	1,260	9,740	0,225
Utilities (with engineering)	4,781	4,050	0,371	9,202	0,302
Spare parts	0,692	0,335	0,125	1,152	0,029
Auxiliary services with engineering	7,630	3,680	1,370	12,680	0,322
Licence fee (estim.)			0,900	0,900	
Part total	37,543	17,558	7,806	62,907	1,553
Supplementary costs: 20 % +1st establishment 5 % -interim interest 5 % - unforeseen delays 10 %	7,500	3,515	1,560	12,575	0,311
Total investment 10^6 FFR	45,043	21,073	9,366	75,482	1,864

- cost of delay and contingency: 5 % of investment for each of these two items appears to be in line with reality but for extrapolation from a pilot plant it would be necessary to double this figure. It should be remembered that 25 % (recoverable) for value added tax and 10 % of the turnover for working capital also has to be provided. These two last items do not come into amortisation or calculations of production cost and have been ignored.

In Table XIII the supplementary costs have been redistributed under the three headings: battery limits, utilities and auxiliary services. From it one can deduce that:

- battery limits costs account for 63.5 %
- utilities account for 14.6 %
- auxiliary services account for 21.9 %

in the total investments

Table XIII

Investments as a function of the capacity for 99.8 % ethylene

Production of ethylene tons/a	Investments in millions of francs			
	Battery limits and licence	Utilities	Auxiliary services and spare parts	Total
50,000	47.90 (63.5%)	11.05 (14.6%)	16.53 (21.9%)	75.48 (100%)
100,000	67.0	15.3	23.0	105.3
200,000	99.7	22.9	34.0	157
300,000	129.6	29.8	[illegible]	[illegible]
400,000	153	35.2	52.8	241

III.2 Variation of investments as a function of capacity

Figure 3 shows how investments vary as a function of ethylene production capacity for the chosen example. The curve in this figure closely follows the law of extrapolation

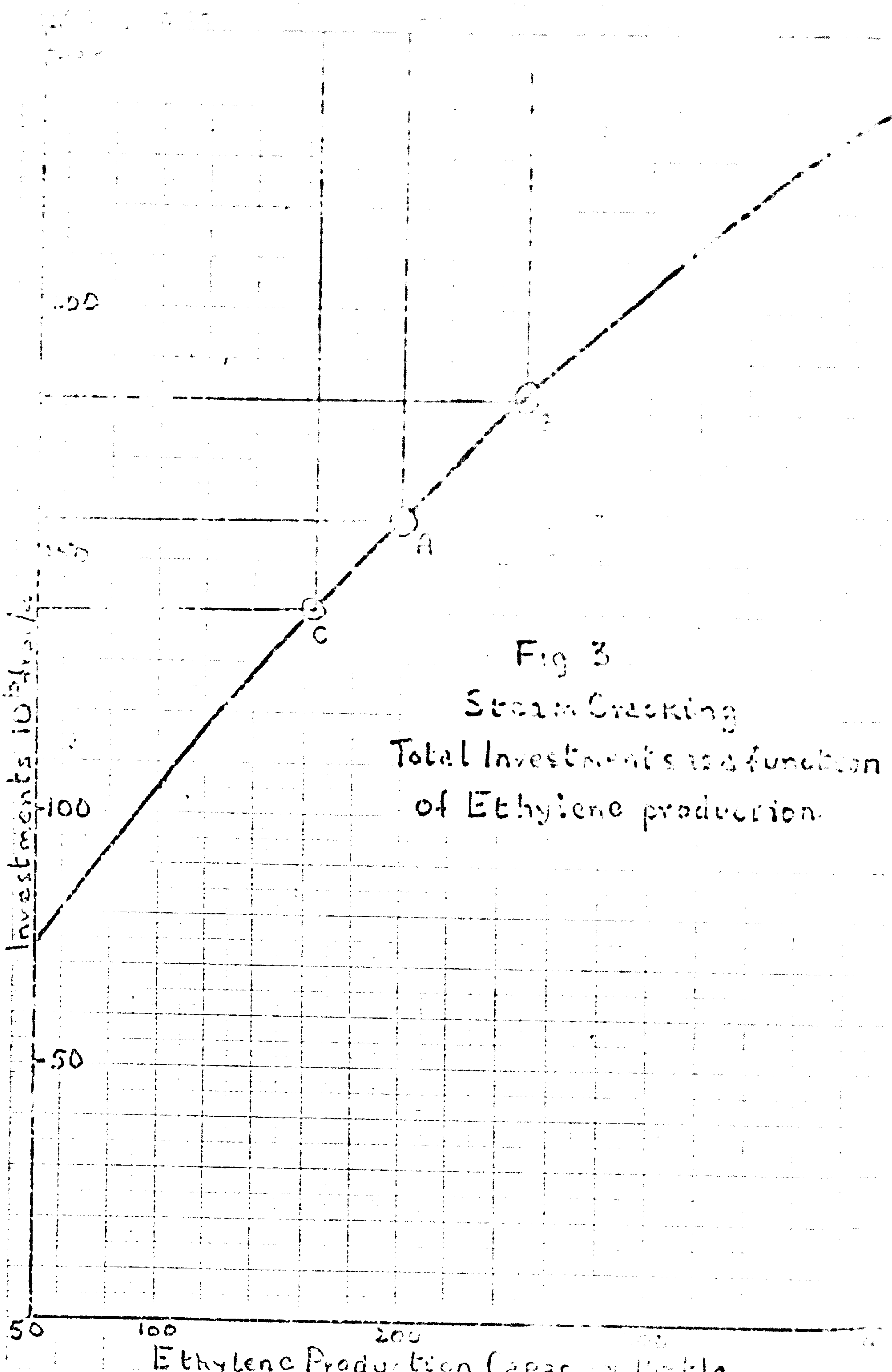


Fig 3
Steam Cracking
Total Investments as a function of Ethylene production.

$$\frac{I}{I_o} = \left(\frac{C}{C_o}\right)^{0.6} \quad \text{where}$$

I_o = the known investment

C_o = the corresponding capacity

I = investment to be calculated

C = the corresponding capacity

Care must be taken not to apply this curve except for the chosen method of cracking. Table XIV shows that for the production of the same 100 tons of ethylene the quantity of feedstock can vary from 135 to 384 tons according to its nature. This variation becomes even more important if the cracking temperature is varied.

Figure 3 may however be used to calculate the investments as a function of the tonnage of naphtha consumed.

Table XIV

Effect of feedstock on the production of ethylene and other olefins

	Ethane	Propane	Naphtha	Gas oil
Feedstock, tons	135	248	302	384
Olefin production, tons				
Ethylene	100	100	100	100
Propylene	3	37	44	58
Butylenes	0.5	4	18	20
Butadiene	3	5	12	14

III. 3 Steam cracker for 200,000 tons/y ethylene

The data from Figure 3 have been reported in Table XIII and distributed in the same proportions between battery limits costs, utilities and auxiliary services. They give the investments to be expected for very large steam crackers treating the same feedstock according to the same process scheme as in the chosen example, in particular:

- no ethane recycle through a cracking furnace
- no hydrogenation of gasoline
- no recovery of hydrogen from the fuel gas. Thus a steam cracker four times as large would produce:

  200,000 tons/a ethylene 99.8 %
  148,000 tons/a propylene 94 %
  27,400 tons/a butadiene 98 %

It would consume [illegible]0,000 tons/a of virgin nephtha and would cost 157 millions of francs.

If it were required to concentrate one quarter of the propylene produced to [illegible] an increased investment of 1.8 millions of francs can be expected. This steam cracker, then, has a capacity Co=800.000 tons/a and costs Io = 157 x 10^6 francs (point A, Figure 3).

A steam cracker producing 200,000 tons/a of ethylene by cracking a crude fuel oil at moderate severity would do no more than attain a 20 % yield of ethylene, especially if ethane were not recycled. Thus it would consume 1,0[illegible] tons/a of feedstock (point B, Figure3) and would cost [illegible] millions of francs. But it would produce more propylene and very much more butadiene and gasoline.

In the [illegible], in considering high severity cracking of light naphtha with ethane recycle, an ethylene yield of 30 % can readily be obtained. 200,000 tons/a of ethylene then correspond to a feedstock consumption of [illegible] tons/a (point C, Figure 3). It will only cost 140 x [illegible] francs but will produce much less propylene, butadiene and gasoline.

These [illegible] figures for investment which we know to be [illegible] the method of calculation shown is valuable. It is, however, for the method of cracking we have chosen that use of the curve in Figure 3 gives the most accurate results.

III. 4. Steam cracker for 400,000 ts/a of ethylene

In the same way, a steam cracker double the capacity of the preceding one would consume 1,600,000 ts/a of virgin naphtha to produce 400,000 ts/a of ethylene at 99.8 %. It would call for a total investment of 24 x 10^6 francs (fig. 3 and table XII) broken down as follows:

Battery limits costs and engineering and licence	153 x 10^6 francs
Utilities	35.2 x 10^6 francs
Auxiliary services	52.8 x 10^6 francs
	241.0 x 10^6 francs

IV - Manufacturing costs

It is now intended to calculate with some accuracy and with realistic assumptions the production costs of ethylene, propylene and butadiene for the chosen example at three levels of capacity - 50,000; 200,000 and 400,000 ts/a of ethylene.

IV.1. Steam cracker for 50,000 ts/a of ethylene

A difficulty arises from the fact that a steam cracker produces several products and changing the cost of one means changing the cost of all the others. The method of calculation proposed is simple; the production cost of dilute ethylene produced by the steam cracker alone is determined: the C_3's and C_4's have the values which would be found on the market less a profit of X %. The supplementary expenses (fixed and operating costs) of recovering 99.8 % ethylene are added and this gives its production cost. The same thing is done for 98.5 % propylene and 98 % butadiene and their production costs are deduced in the same way.

A - Expenditure

Table XV, which also takes in the element of table VIII sets out the expenses. Five cases are considered:

Columns 2 and 3: steam cracking alone producing 96,500 ts/a of mixed gases containing 52.1 % ethylene;

Columns 4 and 5: supplement for ethylene concentration to 99.8 % (producing 50,000 ts/a ethylene)

Columns 6 and 7: supplement for propylene concentration to 98.5 %
(producing 35,500 t/a propylene)

Columns 8 and 9: supplement for extraction of 98 % butadiene
(producing [illegible] t/a butadiene)

Columns 10 and 11: complete steam cracker producing
50,000 t/a ethylene 99.8 %
35,500 t/a propylene 98.5 %
6,850 t/a butadiene [illegible]

<u>Steam cracker for 50,000 t/a ethylene - Expenditure</u>

A - 1. <u>Feedstock</u>

This has been put at [illegible].11 FF/kg which should be the price at which a chemical manufacturer associated with a petroleum refiner might hope to buy virgin naphtha from him.

A - 2. <u>Catalysts and chemicals</u>

An annual cost of [illegible]00,000 FF is to be expected.

A - 3. <u>Electricity</u>

Taking account of the investments made and included in the utilities, 1 kWh distributed in the factory should not cost more than 2.[illegible] centimes.

A - 4. <u>Water</u>

Costs 0.9 centimes/m^3 and rises to 68 centimes/m^3 for purified water.

A - 5. <u>Fuel</u>

As a general rule, fuel has been priced at 1 centime per thermie which is normal for supply of large quantities. In any case, since the steam cracker produces less than the total amount required, valuation should be at the same price as the extra fuel consumed. 1 centime per thermie does not present any problem.

A - 6. <u>Steam</u>

This costs [illegible].65 FF/t, taking account of the cost of the boiler, included in the investments for the steam cracker utilities.

A - 7. <u>Hydrogen</u>

necessary for extraction of butadiene comes from a separate installation, not included in the investments. It has been

Table XV Steam cracker for 50,000 t/a ethylene - expenditure.

Production in 8000 hrs/a	Steam cracker olefins: concentration %	Steam cracker olefins: production 10^3 t/a	Supplements for extraction of ethylene: concentration %	ethylene: production 10^3 t/a	propylene: concentration %	propylene: production 10^3 t/a	Butadiene: concentration %	Butadiene: production 10^3 t/a	steam cracker complete: concentration %	steam cracker complete: production 10^3 t/a
C_2: ethylene	52.[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]	
C_3: propylene	94.[illegible]	[illegible]	94.[illegible]	[illegible]	[illegible]	15.[illegible]	94	[illegible]	[illegible]	
C_4: butadiene		19.2		19.2		19.2	[illegible]	6.46	[illegible]	[illegible]
others							others	12.35	others	[illegible]
gasoline		39.0		39.0		39.0		39.0		39.[illegible]
fuel oil		9.0		9.0		9.0		9.0		9.[illegible]
fuel gas				45.6		[illegible].7				4[illegible]
investments complete 10^3 FFR		45,043		21,073		1,864		9,366		77,346
Feedstocks		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a
virgin naphtha 200,000 t/a at 0.11 FFR/kg		22,000								22,000
catalysts and chemicals		300						negligible		300
total materials		22,300		0		0		0		22,300
Utilities										
electricity kwh at 2.85 c		$3.88.10^6 \times 2.85.10^{-2}$ = [illegible]				$264.10^3 \times 2.85.10^{-2}$ = 7.5		$240.10^3 \times 2.85.10^{-2}$ = 6.9		
fuel at [illegible] thermie		256.10^6 th/a $\times 10^{-2}$ = 2,560								
cooling water at [illegible] c/m³		8.10^6 m³/a $\times$ [illegible] = 2,262		[illegible] 10^6 m³/a: 61		2.10^6 m³/a: 18		$2.6.10^6$ m³/a: [illegible]		
purified water at 68 c/m³		192.10^3 m³/a: 131								
steam production HP at 8.85 FFR/t		[illegible]								
steam consumption HP						72.10^3 t/a: 636		$61.6.10^3$ t/a: 545		
hydrogen at [illegible]% at 12 c/m³								$19.2.10^3$ m³/a: 2		
total utilities		2,503		67		662		577		3,303
Labour + supervision		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a		10^3 FFR/a
engineers at 60.10³ FFR/a	2	120								
foremen at 40.10³ FFR/a	4	160								
workmen at 20.10³ FFR/a	16	320	4	80	4	80	4	80		
total labour		610		80		80		80		850
Maintenance 4% of investments		$\frac{45,043 \times 4}{100}$ = 1,815		$\frac{21,073 \times 4}{100}$ = 870		$\frac{1,864 \times 4}{100}$ = 75		$\frac{9,366 \times 4}{100}$ = 375		3,135
General factory charges 0,6 (labour + maintenance)		1,455		570		93		27[illegible]		2,391
General commercial charges (estimated)		1,000								1,000
Fixed charges: amortisation 10%, interest 6%, taxes, insurance etc 1% — 17%		$\frac{45,043 \times 17}{100}$ = 7,700		$\frac{21,073 \times 17}{100}$ = 3,69[illegible]		$\frac{1,864 \times 17}{100}$ = 317		$\frac{9,366 \times 17}{100}$ = 1,590		13,302
Total expenditure 10^3 FFR/a		36,983		5,274		1,287		2,895		46,281

passed to the steam cracker at its cost of production, i.e. 12 centimes/m^3.

4 - 8. Labour.

[illegible] and workmen 4 crews are provided (3 for day and one for [illegible] holidays). Maintenance labour is not provided since it is included in the maintenance charge (4 [illegible] of investments per annum).

The [illegible] include the social insurance charges and [illegible] which must be applicable to this item (assistance [illegible] etc).

4 - 9. [illegible]

[illegible] original cost per annum

[illegible] per annum of investments

[illegible] investments

Thus the [illegible] annual expenditure is arrived at:

[illegible]	[illegible],0[illegible]3,000 francs
Supplement for [illegible] extraction	5,2[illegible],000 francs
Supplement for [illegible] concentration	1,227,000 francs
Supplement for [illegible] extraction	[illegible],000 francs
Total expenditure	4[illegible],[illegible]1,000 francs

5 - Results [illegible] I)

[illegible] considered:

[illegible] 95,000 ts/a of a C_1C_2 cut containing [illegible] cost of C_2 francs/kg of which ethylene [illegible]

[illegible] cut at 94 % propylene

19,[illegible] C_4 cut

[illegible] pyrolysis gasoline

6,00[illegible] fuel oil

Table XVI: Steam cracking for 50,000 t/a ethylene - Receipts

Production in 8,000 hrs./a	Steam cracker alone			Steam cracker with ethylene, concentrated			ethylene + propylene [illegible]			ethylene + propylene [illegible]		
	concentration %	production 10^3 t/a	turnover 10^6 FFR/a	concentration	production	turnover	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_1-C_2 cut at C_2 FFR/kg of which ethylene	52.1 (C.FFR/kg)	[illegible]	95.6[illegible]	[illegible] kg	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_3 cut at 0.153 FFR/kg. of which propylene	94.0	37.2	5.[illegible]	[illegible]	37.[illegible]	5.[illegible]	[illegible] FFR/kg	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C_4 cut at 0.153 FFR/kg butadiene FFrs/kg others 0.153 FFR/kg		19.2	2.94		19.2	2.94		19.2	[illegible]	[illegible]	6.55 [illegible]	
gasoline at 0.13 FFR/kg		31.6	5.30		32.[illegible]	[illegible]		32.[illegible]	[illegible]		[illegible]	
fuel oil at 0.[illegible] FFR/kg		2.2	0.[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		9.[illegible]	
fuel gas at [illegible] centime/thermie				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		47.[illegible]	
total production 10^3 t/a		200.0			[illegible]			[illegible]				
turnover without taxes 10^6 FFR/a			9[illegible].[illegible] +11.[illegible]			[illegible]			[illegible]			[illegible]

Tab. XIII (?)

If there were chemical outlets for propylene, it would be sold for between [illegible] and [illegible] centimes/kg. If not (the assumption made here) the C_3 cut can be:

- sold to the neighbouring refiner for 18 centimes/kg (price used in the refinery for alkylates for gasoline)
- passed to the triolefin process for reconversion to ethylene and butadiene
- sold at [illegible] centimes/kg as LPG.

Thus one can be practically certain of getting a price of 18 centimes per kg for this cut. If a profit of 15% is allowed, the production cost of the C_3 must be 15.3 centimes/kg.

In the same way the C_4's can be sold to the refiner at 18 centimes/kg (as LPG or for alkylates) which leads to the same production cost of 15.3 centimes/kg.

As for the gasoline, it has not been hydrogenated. This treatment is necessary to remove the diolefins, which are likely to cause gum in car engines; this job is left to the refiner. However, this gasoline has a high octane number; once hydrotreated, it would be worth 0.18 frs/kg. It can be considered that hydrotreating, including amortization of investments costs 0.02 francs/kg. This gasoline ought therefore to be sold to the refiner at 0.16 francs/kg. A profit margin of 15 % gives a production cost of 0.136 francs/kg.

It is worth noting that the hydrogenation of the gasoline could have been carried out on the steam cracker site before extracting the aromatics from it. One could also envisage the conversion of benzene to cyclohexane. These conversions, not envisaged in this study, would undoubtedly permit a higher valuation for the gasoline.

Finally, the fuel oil is used, as shown, for the normal needs of the steam cracker. There is no point in taking a profit on it. Costing 1 thermie at 1 centime, the fuel is worth 9.7 centimes/kg.

C - Production costs

Two assumptions have been made:

- one normal with C_3 and C_4 at 15.3 centimes/kg
- one pessimistic with C_3 and C_4 treated as fuel

C.1. First assumption

The steam cracker gives a turnover, without profits of (95.6 C_2+14.81) x 10^6 francs/a (see Table XVI) for expenditure of 36.88 x 10^6 francs (see Table XV). By equating expenses and receipts one gets the following equation:

$$36.88 = 95.6\ C_2 + 14.81 \text{ or } 95.6\ C_2 = 22.07 \text{ and } C_2 = 0.231 \text{ francs/kg}$$

Now C_2 is for a mixed gas containing 50,000 tons of ethylene at E_1 francs/kg diluted with 45,600 tons of gas type I of which the composition is shown in Table X (1). The LCV (lower calorific value) of this gas shows a total of 521 x 10^6 thermies/a. At a valuation of 1 centime/thermie within the confines of the steam cracker gives 5.21 x 10^6 francs/a. By equating the cost of the ethylene and the cost of the gas = the cost of the mixed gases one obtains the equation:

$$50 \times 10^6 E_1 + 5.21 \times 10^6 = 95.6 \times 10^6\ C_2 = 22.07 \times 10^6$$

from which the cost of the dilute ethylene E_1 = 0.337 francs/kg. In keeping the same 15% profit margin for the selling price, the dilute ethylene could be sold for 39.6 centimes/kg.

The steam cracker with concentration of ethylene gives expenditure (Table XV) of (36.88 + 5.28) x 10^6 francs/a and receipts (Table XVI).

50,000 tons/a ethylene 99.8% at E_2 francs/kg i.e. 50 E_2 x 10^6 francs/a
37,200 tons/a propylene 94 % at 0.153 francs/kg i.e. 5.70 x 10^6 francs/a
19,200 tons/a C_4 at 0.153 francs/kg i.e. 2.94 x 10^6 francs/a
39,000 tons/a gasoline at 0.136 francs/kg i.e. 5.30 x 10^6 francs/a
9,000 tons/a fuel at 0.097 francs/kg i.e. 0.87 x 10^6 francs/a
45,600 tons/a of fuel gas i.e. 5.21 x 10^6 francs/a

The fuel gas originates as already seen, from the ethyleno gas mixt (Table X (1) gas type I). In equating expenditure and receipts (without fits) we have:

$$36.88 + 5.28 = 50\ E_1 + 20.02$$

from which the cost of ethylene 99.8 % E_2 = 0.443 francs/kg. With a marg of 15 % this ethylene could be sold at 52.2 centimes/kg.

The concentration will have cost 44.3 - 33.7 = 10.6 centimes/kg.

Thus the selling price of a mixture of 1 kg ethylene 99.8% and 1 kg propylene [illegible] = 70 francs/2 kg.

This summarises the information which we possess on the possible selling [illegible] mono-olefins from a steam cracker of this size.

For the steam cracker with concentration of both ethylene and propy lene expenses are (Table XV)

$$(36.88 + 5.28 + 1.23) \times 10^6 = 43.39 \times 10^6 \text{ francs/a},$$

receipts are (Table XVI)

50,000 ts/a ethylene 99.8% at E_2 francs/kg i.e. $50 \times 10^6 E_2$ francs/a
35,500 ts/a propylene at [illegible].5% at P francs/kg i.e. 35.5 [illegible]
19,200 ts/a C_4 cut at 0.153 francs/kg i.e. 2.94×10^6 francs/a
39,000 ts/a [illegible]line at 0.136 francs/kg i.e. 5.304×10^6 francs/a
9,000 ts/a fuel oil at 0.097 francs/kg i.e. 0.87×10^6 francs/a
47,[illegible] ts/a fuel gas [Table X(2)], i.e. 5.38×10^6 francs/a

The fuel gas arises from the ethylene gas mixture and the C_3 cut (propane set free in the concentration of the propylene). Its compositio is given in Table X(2), gas type II. Valuation at 1 centime/thermie giv 5.38×10^6 francs/a.

Equating expenses and receipts we have

$$43.39 = [illegible]\ E_2 + 35.5\ P + 14.49$$

We have seen that E_2 = 22.14; from this the price of propylene 98.5% [illegible] fixed

35.5 P = 6.76 and P = 0.190 francs/kg

Concentration of the propylene has cost

19 - 15.3 = 3.7 centimes/kg

With the margin of 15% propylene 98.5% can be sold at 22.40 centimes/kg.

Steam cracking for ethylene, propylene and butadiene.

Expenses (Table XV)

(3[illegible] + 5.[illegible] + 1.23 + 2.99) x 10^6 = 46.[illegible] francs/a

Receipts (Table XVI)

50,[illegible] t/a ethylene 99.5% at E_2 francs/kg i.e. 50 E_2 x 10^6 francs/a

33.5 t/a propylene 98.5% at P francs/kg i.e. 33.5 P x 10^6 francs/a

6.[illegible] t/a butadiene at B francs/kg i.e. [illegible] 10^6 [illegible]

[illegible] francs/a

[illegible] 0.19 francs/kg [illegible] x 10^6 francs/a

[illegible] + fuel at [illegible] francs/kg i.e. [illegible] x 10^6 francs/a

[illegible] x 10^6 francs/a

[illegible]

[illegible] E_2 [illegible] B + [illegible] + 13.[illegible]

[illegible] cost of butadiene [illegible] B = 3.94 and B = 0.57[illegible] francs/kg

[illegible] margin of [illegible], the butadiene can be sold at 67.7 centimes [illegible] price [illegible] 1 franc/kg.

[illegible] butadiene has cost 57.[illegible] - 15.3 = 42.2 centimes/kg.

[illegible] price of 1 franc/kg [illegible] could be [illegible] this product which would lead to a pro[illegible] francs/kg. Under these conditions the ethylene price [illegible] the previous equation one has

[illegible] E_2 + [illegible].8[illegible] B + 20.20

[illegible] finds 50 E_2 = 20.26 and E_2 = 0.405 francs/kg.

[illegible] margin of 15% gives a selling price for ethylene of 47.7 centimes/kg.

C_2 second assumption

Now suppose that no use can be found for the C_3 and C_4 cuts and that it would be necessary to use them as fuel. Propylene 94% would be worth 0.10 francs/kg and the C_4 0.098 francs/kg [see Table X(3) gas type III].

The profit margin of 15 % can now only be taken on ethylene, butadiene and gasoline.

Expenditure remains the same (Table XV)

Receipts are detailed in Table XVII.

Equating receipts and expenditure we have for steam cracking alone

$36.88 = 95.6\ C_2 + 11.77$ or $95.6\ C_2 = 25.11$

Thus $C_2 = 0.262$ francs/kg.

The cost E_1 of dilute ethylene in the mixed gases is this:

$50 \times 10^6\ E_1 + 5.21 \times 10^6 = 95.6\ C_2 \times 10^6 = 25.11 \times 10^6$

and the production cost of ethylene is 0.398 francs/kg; giving a selling price of 46.3 centimes/kg (15% margin). For the steam cracker with ethylene concentration Table XV and Table XVII give in the same way

$36.88 + 5.28 = 50\ E_2 + 16.98$ so that $E_2 = 0.504$ francs/kg

and the selling price of concentrated ethylene becomes 59.2 centimes/kg (15% margin).

Concentration of ethylene and propylene

$36.88 + 5.28 + 1.23 = 50\ E_2 + 35.5\ P + 13.43$

$43.39 = 25.18 + 35.5\ P + 13.43$

$4.78 = 35.5\ P$ and $P = 0.135$ francs/kg

Concentration of the propylene will have cost 13.5 - 10 = 3.5 centimes/kg and it would be sold for 15.9 centimes/kg.

Concentration of ethylene and propylene and extraction of butadiene in the same way

$36.88 + 5.28 + 1.23 + 2.90 = 46.28$

$= 50\ E_2 + 35.5\ P + 6.85\ B + 12.76$

$46.28 = 25.18 + 4.78 + 6.85\ B + 12.76$

and $B = \dfrac{3.56}{6.85} = 0.520$ francs/kg giving a possible selling price of 61.3 centimes/kg for butadiene.

[illegible] XVII

[illegible] for 50,000 tons/a of ethylene

[illegible]

[illegible] in [illegible] frs/a	Steam cracking: Production %	tons/a	10^6 frs/a	Ethylene concentration: Concentration %	tons/a	10^6 frs/a	[illegible]	[illegible]	[illegible] frs/a	[illegible]	[illegible] tons/a	10^6 frs/a
[illegible] out at C_2 frs/kg [illegible] which ethylene	52.1 (F frs/kg)	95.6	33.6 [illegible]	99.8 [illegible] frs/kg	[illegible]	[illegible]	99.8	[illegible]	[illegible]	[illegible]	50	50 E
[illegible] at [illegible] frs/kg [illegible] which propylene	94.5	37.2	[illegible]	94.0	[illegible]	3.72	93.5 [illegible] frs [illegible]	35.5	[illegible]	[illegible]	35.5	35.5P
[illegible] at 0.[illegible] frs/kg [illegible] which butadiene (Btrs/kg)		14.[illegible]	1.68		14.[illegible]	1.68		[illegible]	[illegible]	[illegible]	[illegible]	[illegible] B
[illegible] at [illegible] frs/[illegible]		33.0	3.30		33.0	5.30		33.[illegible]	[illegible]		[illegible]	[illegible]
[illegible] at 0.[illegible] frs/kg		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]
[illegible] at [illegible] centime/thermie				[illegible] III [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]			[illegible]			[illegible]				
[illegible] with [illegible] taxes [illegible] frs/a			[illegible]			[illegible]			[illegible]			[illegible]

If it is agreed that the production cost of butadiene can be 0.85 francs/kg and that [illegible] propylene 0.19 francs/kg the previous equation [illegible] production cost K_2 for ethylene of:

[illegible] = 12.[illegible] that

K_2 = [illegible] francs/kg and the selling price of ethylene becomes 49.3 centimes/[illegible]

It is thus interesting to note that, even if C_3 and C_4 are valued at their [illegible] value, [illegible] possible conditions, this steam cracker allows selling prices of [illegible] centimes/kg for ethylene 99.8%, 19 centimes/kg for propylene [illegible] and 1 franc/kg for butadiene 98%.

[illegible]. 2 [illegible] tons/a ethylene capacity

For [illegible] it has been thought that steam crackers for 50,000 tons [illegible] their production cost is too high. [illegible] Naphtha [illegible], also at Port Jérôme, Petrochim [illegible] to steam crackers of 200,000 [illegible]. Starting from the same type of cracker as before [illegible] four times the size and to investigate the [illegible], still maintaining a margin of 15% on ethylene, propylene, butadiene and gasoline (1st hypothesis of the preceding study).

[illegible] investments for ethylene capacities of [illegible] with the supplements in the same [illegible] tons/a ethylene. The investment for the complete steam cracker ([illegible] propylene at 94%) are taken from Figure 3.

Table XVII

Investments for [illegible]

Investments 10^3 fr.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Table XIX

Steam cracker for 200,000 tons/a ethylene

	Steam cracker plant	Solvent for extraction of	
		[illegible]	butadiene
Utilities compressor necessary:	[illegible] cv	[illegible],200 cv	0
Electricity	[illegible] kw	0	120 kw
Fuel	108x10^3 thermies/hr 1.[illegible] [illegible] m/hr	0	0
Cooling water	4,[illegible] m^3/hr	[illegible],400 m^3/hr	1,296 m^3/hr
Demineralized water	[illegible] m^3/hr	0	0
Low pressure steam produced Consumed	[illegible]9.2 tons/hr	0	0 30.8 tons/hr
Catalysts and chemicals	1,200,000 frs/a	0	0
Hydrogen at 98%			2.7 m^3/ton butadiene
Labour and supervision	5 engineers 10 foremen 40 workmen	10 workmen	10 workmen
Licence (estimated)			19 x 10^6 frs

[illegible] cracker for 200,000 tons/a ethylene

Production in [illegible] hrs/a	Expenditures: Steam cracker alone: Concentration %	Steam cracker alone: Production 10^3 tons / a	Supplement for [illegible]: ethylene: Concentration %	Supplement: ethylene: Production 10^3 tons / a	Supplement: butadiene: Concentration %	Supplement: butadiene: Production 10^3 tons / a	Steam cracker complete: Concentration %	Steam cracker complete: Production 10^3 ts/a
[illegible] : ethylene	52.1	382.4	99.[illegible]	[illegible]	52.1	[illegible]	99.8	200.0
[illegible] : propylene	94.0	143.8	94.0	143.8	94.0	[illegible]	94.[illegible]	143.8
[illegible] : butadiene }		} 76.8		} 76.8	98.0	27.4	98.0	27.4
others }						4[illegible].4		49.4
[illegible]		156.0		156.0		[illegible]		156.0
[illegible] oil		36.0		35.0		35.0		36.0
[illegible]				182.4				182.4
[illegible] production 10^3 tons/a		800.0		800.0		[illegible]		800.0
[illegible] investment 10^6 frs	94.0		43.6		19.4		157	
[illegible]	10^3 frs/a		10^3 frs/a		10^3 frs/a		10^3 frs/a	
[illegible]	89,200		0		0		89,200	
[illegible]	8,012		244		2,300		10,564	
[illegible] and supervision								
[illegible] at [illegible]x10^3 frs/a	5 :	325						
[illegible] at [illegible]x10^3 frs/a	10 :	400						
[illegible] at [illegible]x10^3 frs/a	40 :	[illegible]	10 :	200		200		
[illegible] labour and supervision		1,[illegible]		200		200		1,225
[illegible]	[illegible] x 40 :	[illegible]	43.6 x 40 :	1,745	19.4 x [illegible] :	777		[illegible]
[illegible] fact [illegible] costs: [illegible]		[illegible]		1,1[illegible]		[illegible]		4,925
[illegible] supervision and maintenance)								1,[illegible]
[illegible] general costs		[illegible]						
[illegible] interests [illegible]	[illegible]		[illegible] x [illegible]		[illegible] x [illegible]		[illegible] x [illegible]	

Table XXI

Steam cracker for 200,000 tons/a ethylene

Receipts

Production in 8,000 hrs/a	Steam cracker [illegible]			Steam cracker with					
				ethylene concentration			[illegible] butadiene		
	Concentration	Production 10^3 tons/a	Turnover 10^6 frs/a	Concentration	Production 10^3 tons/a	Turnover 10^6 frs/a	[illegible]	[illegible]	Turnover 10^6 frs/a
C_1–C_2 cut at C_2 frs/kg of which ethylene	[illegible].1 ([illegible] frs/kg)	[illegible]	[illegible].4 C_2	93.8	200.0	200 E_2	[illegible].8	200	200 E_2
C_3 cut at [illegible].153 frs/kg of which propylene	94.0	148.3	22.75	94.0	148.3	22.75	94.0	148.8	22.75
C_4 cut at [illegible] frs/kg of which butadiene at 8 frs/kg [illegible] at [illegible].153 frs/kg		75.3	11.75		76.3	11.75	38.0	[illegible] [illegible].4	27.4 B 7.56
Gasoline at [illegible] frs/kg		156.0	22.21		156.0	22.21		[illegible].0	22.21
Fuel oil at [illegible] centimes/k		[illegible]	3.50		36.0	3.50		[illegible]	3.50
Fuel [illegible] at [illegible] centimes/thermie					182.4	[illegible]		[illegible]	[illegible].80
Total production 10^3 tons/a		800.0			800.0			[illegible]	
Turnover 10^6 frs/a			382.4 C_2 + 60.21			200 E_2 + 81.01			200 E_2 + 27.4 B + 76.82

In equating as before, the receipts and expenses the following equations are obtained.

A. Steam cracker alone

$122.95 = 382.[illegible]\ C_2 + 60.1$ from which

$382.40\ C_2 = 62.[illegible]$ and $C_2 = 0.164$ FFR/kg

Now C_2 is a mixture containing 200,000 t/a ethylene diluted with 1[illegible],[illegible] t/a of a gas for which valuation as fuel would give 20.8×10^{6} [illegible]/a. Thus:

$382.40\ C_2 \times 10^{[illegible]} = 20[illegible]\ E_1 \times 10^{[illegible]} + 20.80 \times 10^{6}$

i.e. $[illegible]2.[illegible] = 200\ E_1 + 20.[illegible]$ from which the production cost of dilute ethylene is.

$E_1 = \frac{41.9[illegible]}{200} = 0.210$ FFR/kg.

Thus dilute ethylene can be sold for $\frac{21}{0.85} = 24.7$ centimes/kg.

B. Steam cracker with Ethylene concentrated

We have: $122.[illegible] + [illegible].7[illegible] = 200\ E_2 + [illegible]1.01$ from which the production cost of 99.8 % ethylene is

$E_2 = \frac{[illegible]}{2[illegible]} = 0.2[illegible]4$ FFR/kg.

Ethylene concentration has cost

$2[illegible].4 - 21.[illegible] = [illegible]$ centimes/kg and the selling price of 99.8 % ethylene can be

$\frac{26.4}{0.85} = 31.1$ centimes/kg.

C. Steam cracker with Ethylene at 99.8 % and Butadiene at 98 %

We have $1[illegible].[illegible] = 2[illegible]\ E_2 + 27.4[illegible]\ B + 76,82$

$1[illegible] = [illegible].7[illegible] + 27.4[illegible]\ B + 76.8[illegible]$

from which $[illegible]\ B = 11.35$ or $B = 0.415$ FFR/kg.

Extraction of butadiene has cost $41.5 - 15.3 = 26.2$ centimes/kg and its selling price can be

$\frac{41.5}{0.85} = 4[illegible].[illegible]$ centimes/kg.

As the market price of butadiene is much higher than this a production cost of B = 0.750 FFR/kg (corresponding to selling price of 88 centimes/kg) can be accepted.

In these conditions the preceding equation can be written:

$140.88 = 200\ E_2 + 27.4 \times 0.75 + 76.82$ from which a possible production cost for concentrated ethylene

$E_2 = \frac{43.51}{200} = 0.218$ FFR/kg and a selling price of

$\frac{21.8}{0.85} = 25.60$ centimes/kg can be derived.

Finally if it were desirable to concentrate one quarter of the propylene to 98.5 % we know that an additional investment of 1.864 x 10^6 FFR would be required. The cost of concentration would be 3.7 centimes/kg. Concentrated propylene could be sold at 22.40 centimes/kg with the [illegible] materials being sold at 18 centimes/kg, always maintaining the 15 % profit margin.

IV. 3. Steam cracker of 200,000 t/a Ethylene Capacity

It is thus clear from reference to the first steam cracking study (50,000 t/a ethylene) that the second one of 200,000 t/a gives substantial savings in production costs. In particular the production cost of 99.8 % ethylene decreases from 44.3 to 26.4 centimes/kg - an improvement of 17.9 centimes/kg.

In an attempt to do even better, giant units are now being constructed.

In the U.S.A.

Dow at Freeport (Texas) 320,000 t/a ethylene

Dupont at Orange (Texas) 340,000 t/a ethylene, rising to 500,000 t/a in 1969

Union Carbide at Texas City 550,000 t/a with 2 lines.

In Great Britain

I.C.I. [illegible] in 450,000 t/a

In Western Germany

ROW at Wesseling is increasing from 200,000 t/a to 320,000 t/a

In France

Rhône-Alpes at Feyzin 300,000 t/a

In Japan the Minister of Commerce and Industry in January 1967 set the minimum capacity of new steam crackers at 200,000 t/a ethylene. Six months later the minimum capacity was raised to 300,000 t/a so that the country could maintain competitive production costs.

It seems essential therefore to investigate the production costs one might-hope to obtain with such a giant unit of 400,000 t/a ethylene capacity. The steam cracker to be studied will thus be twice the size of the proceding one. It will consume 1,600,000 t/a of virgin naphtha and will produce (see table XXIII).

Products	% by weight	t/a
Hydrogen	1.9	14,400
Methane	32.8	250,400
Ethylene	52.1	400,000
Ethane	13.2	100,000
Total ethylene stream (ethylene 52.1 %)	100	764,800
C_3 with 94 % of propylene		297,600
C_4 (of which 54,800 is butadiene)		153,600
Pyrolysis gasoline		312,000
Fuel oil		72,000
		1,600,000

It will cost 241×10^6 FFR of which 35.2×10^6 FFR are for the utilities and 52.8×10^6 FFR for the auxiliary services (see table XIII). It will require an auxiliary boiler of 450 t/hr steam capacity to feed the back pressure turbines driving the compressors of 28,800 CV and 34,400 CV (see table XXII). It can thus be seen that it will be a very big unit indeed.

In equ[illegible], as before, the expenses and receipts (tables XXIII and XXIV) column by column we get the following equations:

Table XXII: High severity steam-cracker for 400,000 t/a ethylene

Steam-cracker	Steam-cracker alone	Supplement for ethylene concentration	Supplement for butadiene extraction
Investments 10^6 FFR	144.2	67.0	29.8
Utilities			
compressors for:	28,800 C.V.	34,400 C.V.	0
electric power	3,880 Kw	0	240 Kw
fuel	256×10^3 thermies/h $2,048.10^6$ th/a	0	0
cooling water	8,000 m^3/h	6,800 m^3/h	2,592 m^3/h
[illegible] treated water	[illegible] m^3/h	0	0
steam L.P. production	[illegible]8.4 t/h	0	0
consumption			61.6 t/h
catalysts + chemicals	2.4×10^6 FFR/a	0	0
hydrogen 9[illegible]%			2.7 m^3/t of butadiene
Labour + supervision			
Engineers	7		
Foremen	15		
Workmen	60	15	15
Licence - estimated			28.5×10^6 FFR

Table XXIII

Steam Cracker per 400,000 t/a ethylene Expenditure

Production in 1,000 t/a	Steam cracking alone: Concentration %	Steam cracking alone: Production 10^3 t/a	Supplement for extraction of Ethylene: concent. %	Ethylene: product. 10^3 t/a	Butadiene: concen. %	Butadiene: product. 10^3 t/a	Complete: concent. %	Complete: product.
Ethylene	52,1	764,8	99,6	400,0	52,1	764,8	[illegible]	[illegible]
Propylene	94,0	297,6	94,0	297,6	94,0	297,6	[illegible]	[illegible]
Butadiene		153,6		153,6	98,0	54,8 / 98,8	[illegible]	[illegible]
Gasoline		312,0		312,0		312,0		[illegible]
Fuel oil		72,0		72,0		72,0		72,0
Fuel gas				364,8				[illegible]
Total production 10^3 t/a		1,600,0		1,600,0		1,600,0		1600,0

	Steam cracking alone	Supplement Ethylene	Supplement Butadiene	Complete
Total investments 10^6 FFR	144,2	67,0	29,8	241,[illegible]
	10^3 FFR/a	10^3 FFR/a	10^3 FFR/a	10^3 FFR/a
Feedstock	178,400	0	0	178,400
Utilities	16,024	488	4,616	21,128
Labour and Supervisor				
Engineers at 65×10^3 FFR/a	7: 455			
Foremen at 40×10^3 FFR/a	15: 600			
Workmen at 20×10^3 FFR/a	60: 1200	15: 300	15: 300	
Total L + S	2255	300	300	2,655
Maintenance: 4% of investments/a	144,2 x 40: 5768	67,0 x 40: 2680	29,8 x 40: 1192	241 x 40: 9,640
General factory charges 0.6 (L+S maintanance)	4820	1790	890	7,500
General and Commercial costs (estimated)	1500			1,500
Fixed costs: Depreciation 10%, Interest 6%, Tax + Insurance 1% = 17%	144,2 x 170: 24550	67,0 x 170: 11400	29,8 x 170: 5,050	241 x 170: 41,000
Total expenditure 10^3 FFR/a	233,317	16,658	12,048	262,023

[Tab]le XXIV

[Steam] Cracker for 400,000 t/a Ethylene - Receipts

[Produ]ction in [10³ F]FR/a	Steam cracking alone: concentration %	production 10^3 t/a	Turnover 10^6 FFR/a	Supple[ment] for Ethylene concentration: Ethylene concent. %	product. 10^3 t/a	Turnover 10^6 FFR/a	Ethylene [Butadiene] concentration: Ethylene concent. %	Product 10^3 t/a	Turnover 10^6 FFR/A
[C]$_2$ cut at C_2 FFR/kg [of] which ethylene	52,1 (E_2 FFR/kg)	764,8	764,8 C_2	99,8 (E_2 FFR/kg)	400,0	400 E_2	99,8	400,0	400 E_2
[C]$_3$ [cut] at 0,153 FFR/kg [of] which propylene	94,0	297,6	45,50	94,0	297,6	45,50	94,0	297,6	45,50
[C$_4$ cut] at 0,153 FFR/kg [of] which butadiene Bfrs/kg others 0,153 FFR/kg		153,6	23,50		153,6	23,50	98,0	54,8 98,8	54,80 B 15,12
[Gaso]line at 0,13[6] FFR/kg		312,0	44,42		312,0	44,42		312,0	44,42
[Fuel] oil at 0,097 FFR/kg		72,0	7,00		72,0	7,00		72,0	7,00
Fuel gas at 1 centime/thermie					364,8	41,60		364,8	41,60
Total production 10^3 FFR/a		1,600,0			1,600,0			1,600,0	
Turnover 10^6 FFR/a			764,8 C_2 + 120,42			400 E_2 + 162,02			400 E_2 + 54,8 B + 153,64

A. Steam cracker alone

$233.32 = 764.80\ C_2 - 120.42$ from which

$764.80\ C_2 = 112.90$ and the production cost of the ethylene mixture C_2 = 0.148 FFR/kg. This is approaching its value on a thermal basis of 0.11 FFR/kg. It is a mixture of 400,000 t of ethylene at E_1 FFR/kg with 364,800 t of a gas with a value on a thermal basis of 41.6×10^6 FFR. From this the production cost of ethylene can be calculated by the equation:

$400\ E_1 + 41.6 = 764.8\ C_2 = 112.90$ from which

$400\ E_1 = 71.30$ and $E_1 = 0.178$ FFR/kg.

With a margin of [illegible] % the dilute ethylene can be sold at 21 centimes/kg.

B. Steam cracker with Concentration of Ethylene

In the same way (tables XXIII and XXIV):

$233.32 + 16.66 = 400\ E_2 + 162.02$ from which $400\ E_2 = 87.96$ and the production cost of 99.8 % ethylene $E_2 = 0.220$ FFR/kg.

The concentration of the ethylene has cost 22 - 17.8 = 4.2 centimes/kg and the selling price could be 26 centimes/kg.

C. Steam cracker with Ethylene Concentration and Butadiene Extraction

We have:

$262.02 = 400\ E_2 + 54.80\ B + 153.64$

$262.02 = 87.96 + 54.80\ B + 153.64$

$54.80\ B = 20.42$ and the production cost of 98 % butadiene B = 0.374 FFR/kg. The butadiene extraction has cost 37.4 - 15.3 = 22.1 centimes/kg and the selling price of butadiene could be 44 centimes/kg.

Taking a higher selling price for butadiene (for example 80 centimes/kg equivalent to a production cost of 68 centimes/kg) the preceding equation becomes

$262.02 = 400\ E_2 + 54.80 + 0.68 \div 153.64$

giving a production cost for 99.8 % ethylene $E_2 = 0.178$ FFR/kg and a possible selling price of 21 centimes/kg.

[illegible]

[illegible] the production costs according to the initial [illegible]. The results of the preceding calculations have been plotted on [illegible]:

F_1 [illegible] of dilute ethylene

F_2 Production cost of concentrated ethylene

[illegible] Production [illegible] of butadiene

The [illegible] clear the advantages of large steam crackers of 200,000 to [illegible],000 t/a ethylene capacity. Above 300,000 t/a the further gain [illegible] small. They can, moreover, be largely influenced by the need to distribute [illegible] part of the products by pipeline to a distance of 200 [illegible]. [illegible], the [illegible] of transporting ethylene by pipeline for [illegible] 12 centimes/kg. Thus steam crackers of 400,000 t/a ethylene [illegible] justified in comparison with 300,000 t/a units if [illegible] the whole of the products can be distributed in the neighbourhood of the plant.

Table [illegible] and figure 5 show the variations in production cost of ethylene [illegible] function of the capacity and according to different assumptions.

1st assumption (curve F_2) that of the study, namely:

- [illegible] price of propylene constant at 18 centimes/kg.
- price of C_4 [illegible] constant 18 centimes/kg.
- price of gasoline 1[illegible] centimes/kg.
- profit margin [illegible] 1[illegible]% on the three products - that is to say their production costs are 15.3 , 15.3 and 13.6 centimes/kg respectively.

The assumption for propylene is not optimistic as the chemical industry can pay a good price for it and it appears to be justified.

Assumption No. 2 (Curve F_3)

The price of 94 % propylene alone has been varied by assuming that a production of 37,000 t/a can be entirely sold to the chemical industry [illegible]/kg (equivalent to a production cost of 25.50 centimes/kg). Even for the chemical industry very great quantities of propylene cannot be sold at high prices. For intermediate capacities we have made intermediate assumptions in the price of propylene (see Table XXV).

This assumption is probably the nearest to reality. It gives gains in ethylene production cost - with reference to a plant of 100,000 to/a capacity identical with the figures published by the Japanese (Ref. Japan Chemical Week 16 July 1967) (see also Table XXV and Figure 6). It imposes a smaller penalty on small steam crackers.

Assumption No. [illegible] (Table XXV and Figure 12, Curve [illegible]$_4$)

It has been assumed that the cracker will only make profits on ethylene and butadiene. In these conditions the production cost of the other products is equal to their selling prices - i.e. C_3+C_4 18 centimes per kg, gasoline 16 centimes/kg.

This method of reasoning naturally lowers the production cost of ethylene and penalizes the steam crackers.

Financial Aspects

In Table XXVI an attempt has been made to set out the profitabilities of steam crackers, making the following assumptions on selling prices:

Steam cracker of 50,000 to/a

Possible ethylene selling price 52 centimes/kg, leaving a margin of [illegible]

Propylene selling price 18 centimes/kg, leaving a margin of 15 %

Butadiene 1 [illegible]/kg.

C_4 selling price 18 centimes/kg, leaving a margin of 15 %

Gasoline selling price 16 centimes/kg, leaving a margin of 15 %.

The assumptions made for steam crackers of 200,000 and 400,000 to/a are detailed in Table XXVI. It has been assumed that the larger the quantity of ethylene for sale the lower the price - 31 centimes/kg and then 26 centimes/kg. The prices of propylene and butadiene, already very low, have not been modified. The same applies to the C_4's (usable as LPG or alkylates) and the gasolines.

It is clear that, in these conditions, the financial aspects of the 3 steam crackers studied are very favourable. In particular:

Fig. 4

Steam Cracking

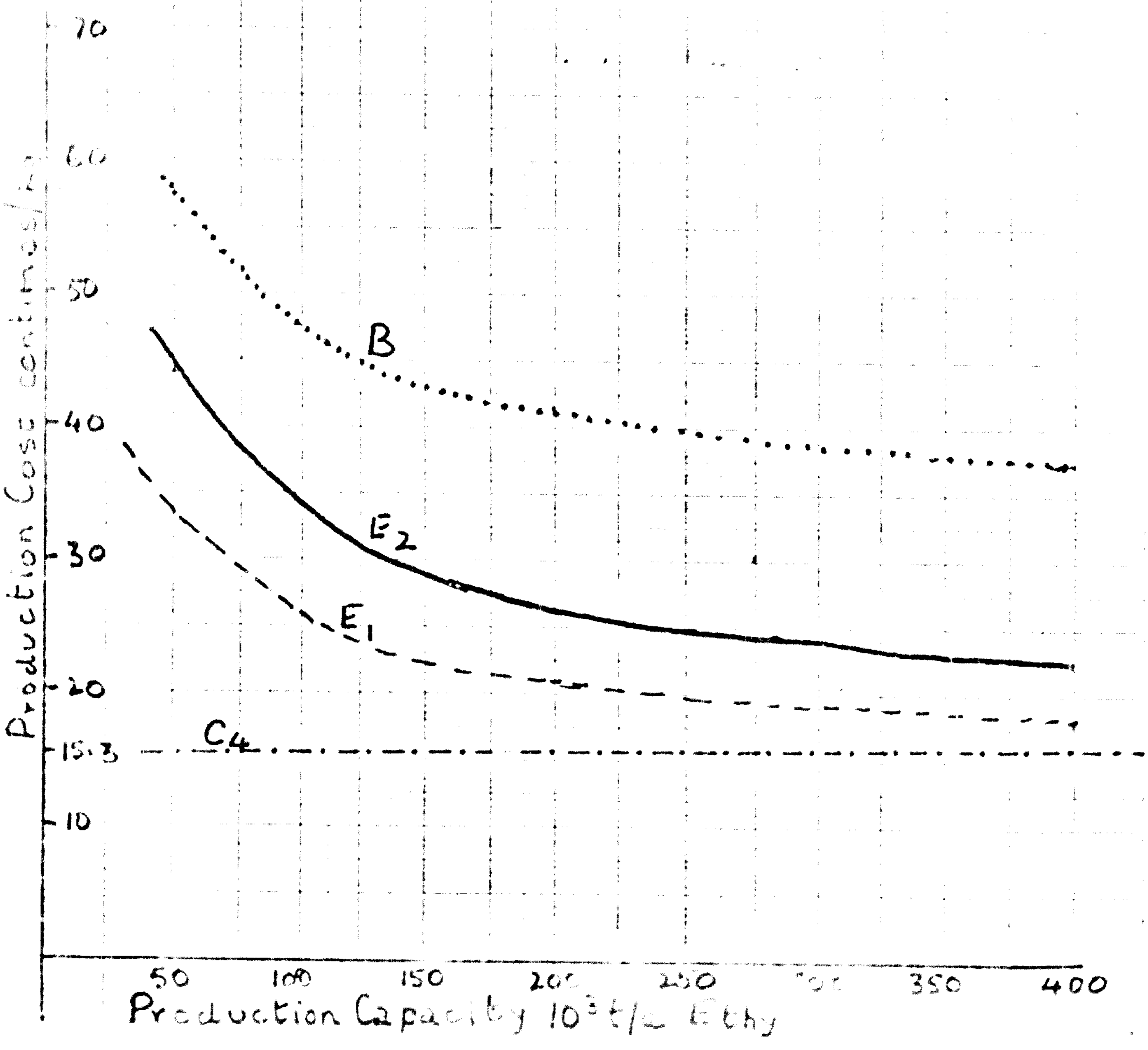
Variation in Production Cos[illegible] Function of Capacity in t/a Ethylene.

E1 Production Cost [illegible] Ethylene

E2 Production Cost of concentrated Ethylene

B Production Cost of Butadiene.

C4 [illegible]



- Profits before tax 18 to 24 % of turnover.
- Cash flow (profits after tax and depreciation allowances) very favourable
- Pay out times, i.e. ratio of investments to cash flow, from 6 to 4 years. Naturally if the ethylene had had to be sold at 31 centimes/kg the small steam cracker would see its 9×10^6 FFR/a profits turned into a 1.52×10^6 FFR/a loss while for the larger steam crackers, the situation would remain very favourable as shown in the table.

VI. Conclusion

This study shows the importance attaching to steam crackers of 300,000 t/a ethylene capacity and above. It also shows the advantage of using heavier hydrocarbons at lower temperatures in order to produce more butadiene - a product with a big profit margin. These units make possible the following selling prices with an excellent profit margin.

- dilute ethylene at 21 centimes/kg
- concentrated ethylene at 25 centimes/kg
- 94 % propylene at 18 centimes/kg
- 98 % butadiene at 45 centimes/kg

This explains the Japanese decision to impose a minimum capacity of 300,000 to/a ethylene for new units as well as the establishment at Feyzin in France of a comparable unit.

Further, when the butadiene price is above 60 centimes/kg this product is the most important contributer to the profits from steam crackers. It is thus advantageous to produce as much as possible, even at the expense of propylene.

This also throws light on the advantages of the triolefin process for steam crackers of 200,000 - 300,000 t/a ethylene capacity, treating around 1 million t/a naphtha. These units could, in effect, produce 100,000 t/a of butadiene.

In any case with the selling prices for olefins which these large steam crackers make possible many new markets should be open to petrochemicals which can be expected to take a new and impressive leap forwards.

Fig 5

Steam Cracking

Variation in Production Cost of Ethylene as a Function of Capacity on different Assumptions

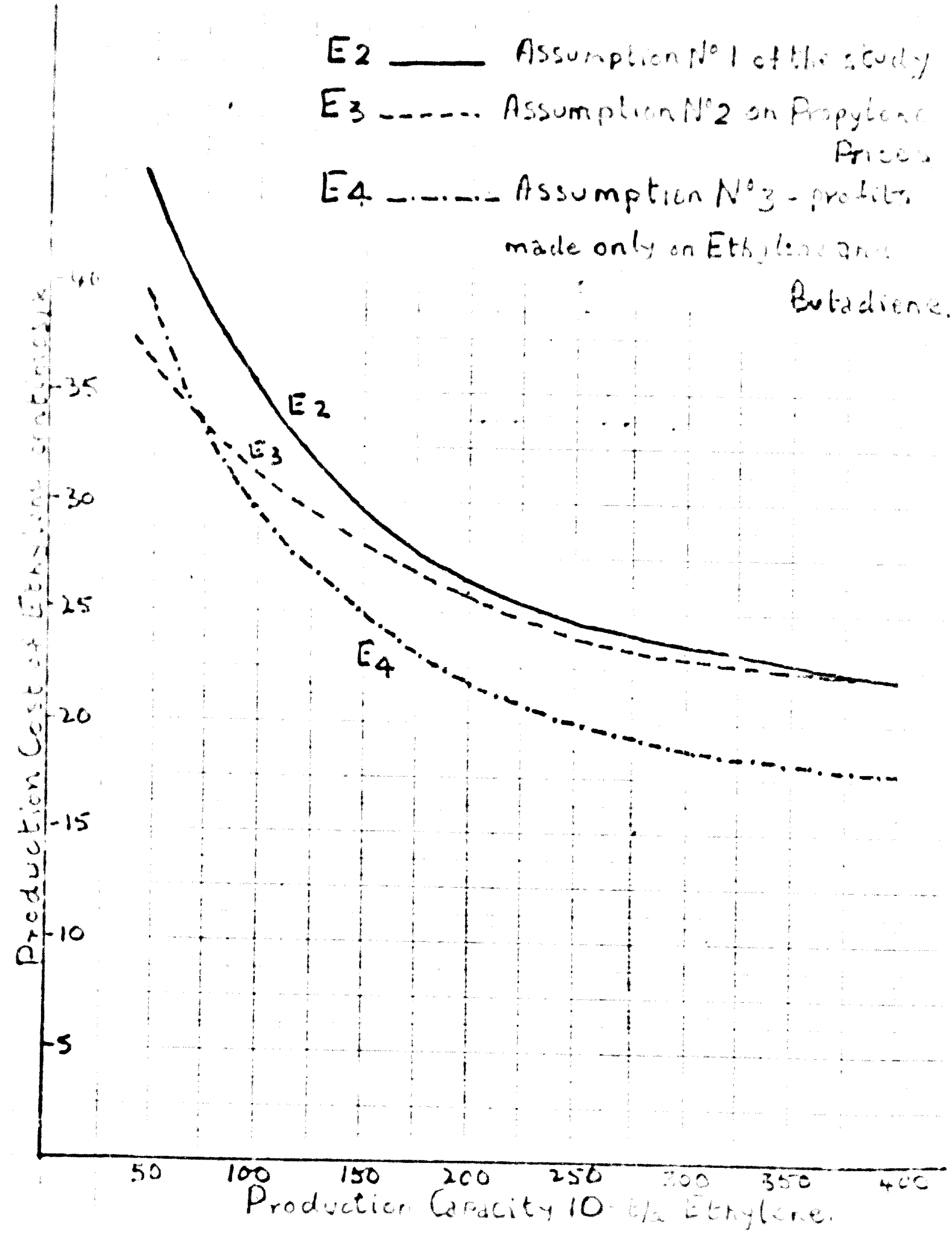
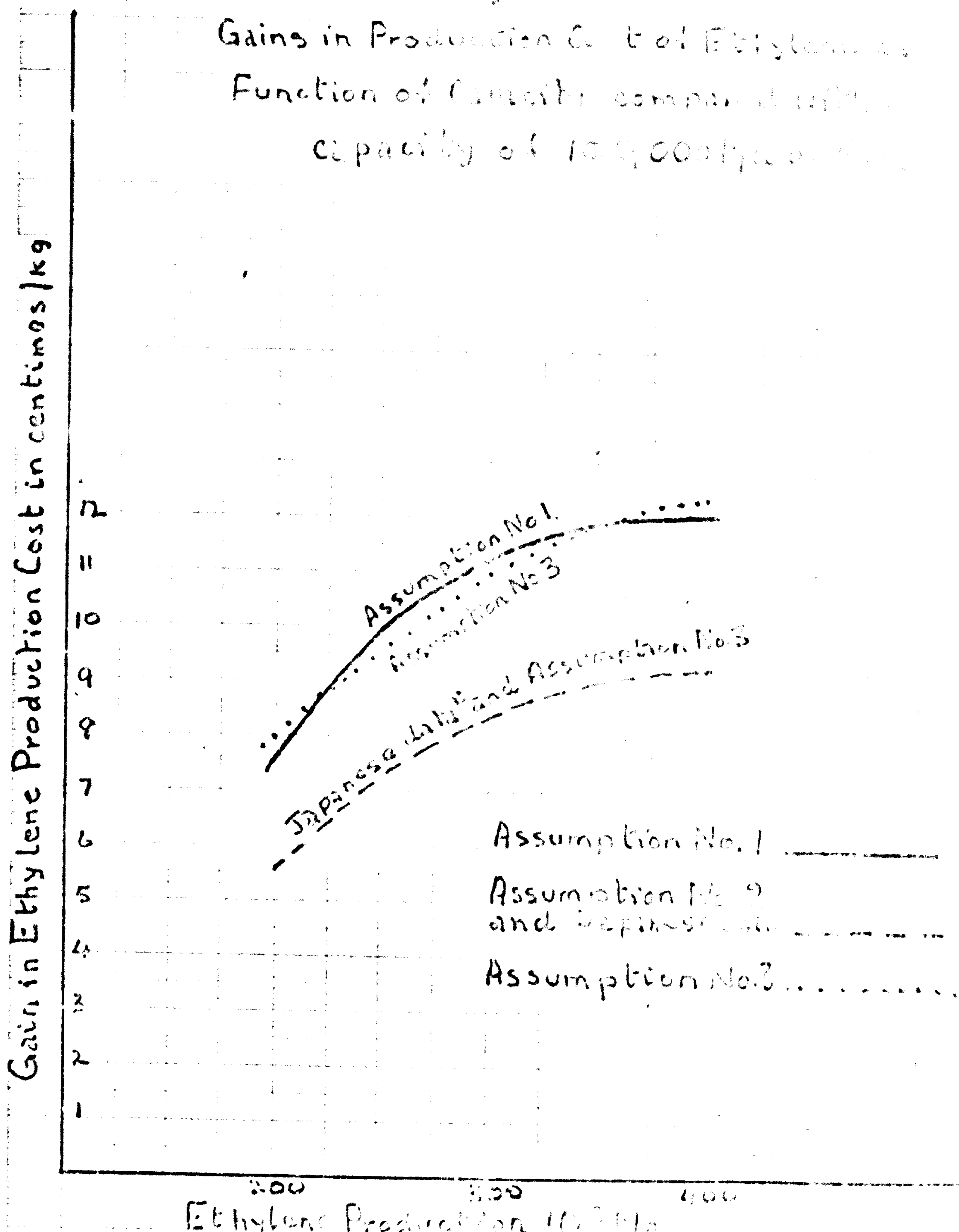


Fig 6



* Ref Japan Chemical Week

Table XXV

[illegible] cost of ethylene as a function of cracking capacity with various consumptions

[illegible] ethylene [illegible] propylene	50 37.2	100 74.4	200 148.8	300 223.2	400 297.61
[illegible] production [illegible] ethylene [illegible] (Fig. 4 & 9)	44.30	34.00	26.40	22.20	22.00
[illegible] (production (cost of (propylene 94% (ethylene E_3 (centimes/kg	25.50 36.68	20.00 31.25	16.30 25.65	15.80 22.8[illegible]	15.30 22
[illegible] consumption E_4 centimes [illegible] /kg.	39.38	29.90	21.90	18.30	17.55
[illegible] from the production [illegible] capacity of 100,000 [illegible] ethylene Δ [illegible] centimes/kg		0	7.6	11.2	12
Δ [illegible] centimes/kg		0	5.6	8.4	9.25
Δ [illegible]$_4$ centimes/kg		0	8.0	11.0	12.35
[illegible] figures centimes/kg		0	5.6	8.4	9.25

Table XVII: Financial aspects of steam cracking

[illegible] plant	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible] before tax	[illegible]	[illegible]	68.53
[illegible] tax	[illegible]	[illegible]	[illegible]
[illegible]	1.[illegible]	1.[illegible]	[illegible]
[illegible]	13.[illegible]	[illegible]	[illegible]
[illegible] after tax [illegible]	[illegible]	17.1[illegible]	[illegible]
[illegible]	[illegible]	15.[illegible]	[illegible]
[illegible]	[illegible]	32.[illegible]	[illegible]
[illegible]	[illegible] years	4.[illegible] years	4.13 years

..... [illegible]
..... [illegible]