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STUDIES IN THE DEVELOPMENT OF PLASTICS INDUSTRIES

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CONTENTS

INTRODUCTION

Many theoretical approaches have been suggested for analysing the economic progress of developing countries. The developing countries have a variety of difficulties: the formation of capital, small domestic markets, low rate of growth in exporting primary goods and low productivity. It is easy to understand why chemical industries, which require extensive technology and high capital investment, are extremely difficult to establish in developing countries.

The pattern of industrial development and the selection of initial key industries differ from country to country. The selection and decisions are left in the hands of private entrepreneurs in such areas as the territory of Hong Kong and Malaysia, where the consumer goods industries occupy an important place in the economy. In other countries, e.g. India and Pakistan, the governments plan industrial development, and heavy industries, particularly iron, steel and machinery, are encouraged. In either case, an industry with a minimal economic size of production usually requires a small capital investment. The technology required is simple, it is not difficult to begin domestic production, and such an industry can easily become a domestic producer. Chemical industries generally do not meet such conditions and are therefore, with the exception of fertilizers, still in the early stages of development in most less advanced countries.

The fertilizer industry is different from the others because Governments strongly support the use of fertilizers to help agriculture. A domestic supply of fertilizers is particularly encouraged. At present, most ECAFE (Economic Commission for Asia and the Far East) countries import food even though they are agricultural. At the same time, they realize the need to increase food production within their countries without spending too much foreign currency by importing either food or fertilizers. These circumstances increase the importance of the fertilizer industry among the chemical industries in the region. The development of the fertilizer industry promotes related industries, such as the production of sulphuric acid, methanol, formaldehyde, urea-formaldehyde resin, melamine, acrylonitrile, and encourages the introduction of the natural gas and petrochemical industries.

Before the Second World War chemical industries in the developed countries were based on coal, coke and electricity. At that time aromatic compounds were produced from coke-oven gas, but ammonia, soda and carbide were produced by electrolysis and electric furnaces. After the war, the source of energy was changed from coal or hydro-power to petroleum, and the coal chemical industry was gradually replaced by the petrochemical industry. The polymer industry based on petrochemicals has shown remarkable progress, and has greatly developed its output of various kinds of synthetic resins, fibres and rubbers.

Most of the chemical industries in developing countries were started after the Second World War. Even the fast-growing fertilizer industry has based its raw material on petroleum. In other words, the establishment of chemical industries in developing countries is not following the old route of the chemical industries of more advanced countries. Instead, the developing countries are starting with the modern technology of petrochemicals without first organizing a coal chemical industry.

The development of the petrochemical and polymer industry, and the wider use of automatic systems have strongly emphasized the characteristics of the chemical industries and have made a high technical standard necessary. The advantages of large plants have become greater and more decisive. The lack of abundant capital, large markets and high technical standards are obstacles to the establishment of chemical industries in developing countries.

The plastics fabricating industry is basically a consumer goods industry and is not so vital to life in developing countries as the fertilizer industry. As it requires relatively small capital and simple techniques, the plastics industry has been developing in Hong Kong and in Thailand and many other countries in the ECAFE region in recent years. The synthetic resins industry, which requires huge investments and large plants, has not yet been completely developed.

In order to establish a unified plastics industry, the following industries should be developed simultaneously: a petrochemical industry to supply raw materials for synthetic resins and additives; a synthetic resins and a plastics processing industry; an industry for plastics machinery, parts and services; and an industry to supply plasticizers and additives.

ESTABLISHING PLASTICS INDUSTRIES IN DEVELOPING COUNTRIES

1.1 Structure of the plastics industry

Research in polymer chemistry began with a study of possible substitutes for wood, ceramics, leather, natural fibres, natural rubber and metal. As a result, phenolic resin was created in 1904, urea resin in 1922, and polystyrene, polyvinyl chloride, methyl methacrylate, melamine and polyamide resins between 1930 and 1940. Before the Second World War, thermosetting resins, phenolic resin in particular, were used mainly as dielectrical insulating materials. After the war, the popularity of thermoplastics increased and the three major resins became polyethylene, polystyrene and polyvinyl chloride (PVC). Because of their light weight, easy processability and low price, these plastics have been used for many products, such as packaging materials, containers, building materials, mechanical parts, wire and cable. It is expected that the consumption of plastics in the year 2000 will be 50 times as large as present consumption, whereas metal consumption will increase only 25 times. Table 1 gives additional information on the estimated consumption of basic materials.

TABLE 1. ESTIMATED WORLD CONSUMPTION OF BASIC MATERIALS
(kilograms *per capita*)

	1966	*1970*	*1980*	*1985*	*1990*	*2000*
Estimated world population (millions)	3,400	3,700	4,600	5,000	5,600	7,000
Metals	14.5	158.0	206.0	241.0	270.0	362.0
Plastics	5.0	7.0	23.0	48.0	75.0	243.0
Synthetic rubber	1.1	1.5	2.5	3.2	4.1	6.4
Chemical fibres	1.6	1.9	2.8	3.4	4.3	6.6
Natural rubber	0.6	0.7	0.6	0.5	0.5	0.4
Natural fibres	5.5	5.8	6.6	7.0	7.4	8.6

Source: Kunststoffe (Munich), August 1966.

The plastics industry is still young and many new resins will undoubtedly be created in the future. At the same time, the production costs of established resins will be reduced as new processes are developed. New resins and the improvement of processes are two reasons for the rapid growth in the consumption of plastics; one may assume that this constant improvement is inherent in the plastics industry.

The structure of the plastics industry will now be reviewed with respect to synthetic resins, plastics processing, the structure of demand and patents.

Production structure of the synthetic resins industry

Technical developments in the synthetic resins industry are resulting in new resins and a reduction of costs through new processes. These developments, in turn, are creating additional demand for the products. Acetylene from calcium carbide has been used as a raw material for polyvinyl chloride resin, but the recently developed oxychlorination process now employs ethylene as the raw material in place of acetylene. The production of melamine is presently undergoing a change from the dicyandiamide process to the urea process.

Figure 1 shows the flow of production from raw materials to finished plastics products in plastics-related industries.

Thermoplastic resins are available primarily in pellet or powder form, while thermosetting resins are supplied chiefly in the form of paste or liquid. The thermosetting moulding powder is produced by drying the liquid resin and they are essentially the same. This difference between thermosetting and thermoplastic resins is characteristic of the two resins. The thermoplastic resin is a high polymer which has been controlled by polymerization. In addition, reversible thermal characteristics have been utilized in its processing. But three-dimensional molecules are formed during the processing of thermosetting resins and they are often manufactured in part during processing. The thermoplastic resin is often more convenient to transport and store than the thermosetting resin.

There are two ways of making thermosetting resins. One method is to make a single product continuously by mass production, and the other is to make, at the processor's request, batches of resins of different composition or different degrees of polycondensation. As an example of the first method, urea-formaldehyde resin adhesives are produced for plywood plants. Installing a larger reactor can save production costs; however, even in this case, the size of the reactor must be limited in order to maintain uniform reactions and good-quality products. In the second method, semi-reacted resins are produced in the resin plants, and the remaining reaction takes place in the moulds of compression-moulding machines. Requirements for such a resin are so diversified that the resin producers are compelled to manufacture small batches of different types. This does not help reduce production costs.

Since the thermosetting resin is cross-linked in the processing, the requirements from the processor are varied and special orders are not rare; therefore plant size is not a problem. Starting production in a developing country is easier with thermosetting resins than with thermoplastics.

With thermoplastic resins, there is no chemical reaction in the processing stage and there is therefore only a limited variety of resins produced. Different properties can be obtained however by a polymer-blending procedure or by an after-treatment such as radiation. In this process, the raw materials for thermoplastic resins are supplied through pipes in the gas-liquid phase to the polymerization reactor. The size

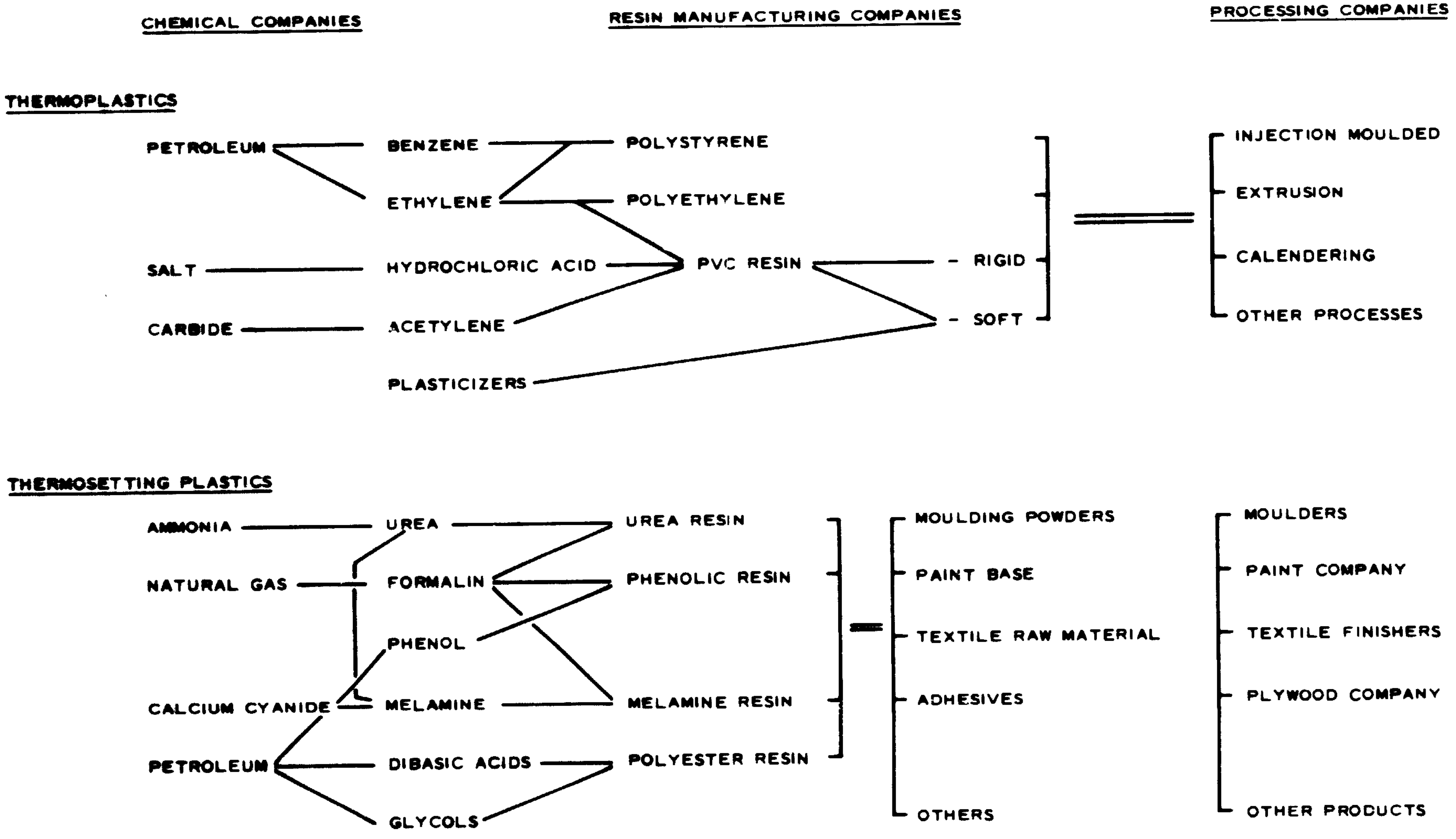

Figure 1. *Flow of production in plastics-related industries*

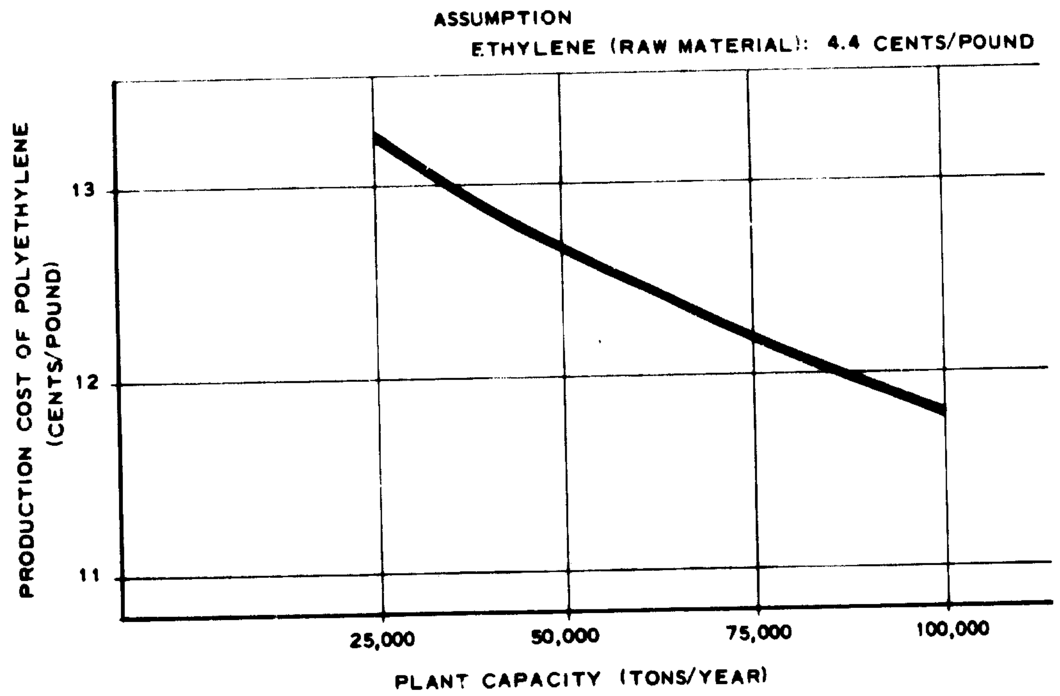

Figure 2. *Interrelationship of production cost and plant capacity in a polyethylene plant*

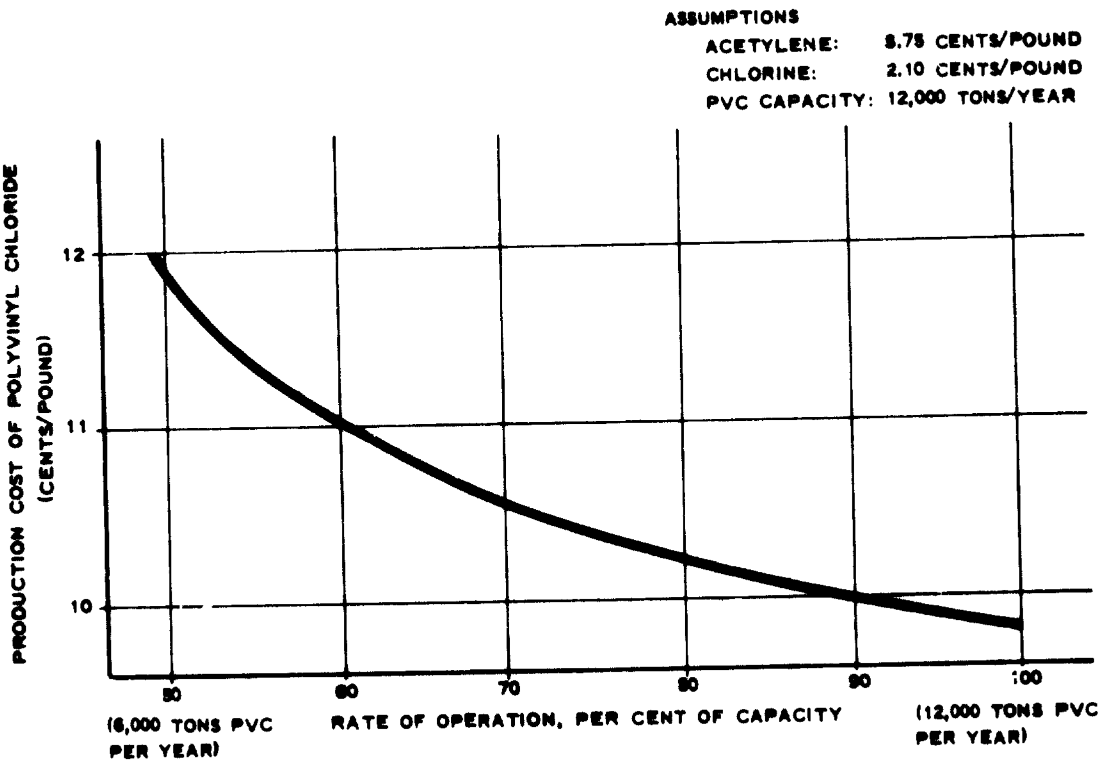

Figure 3. *Interrelationship of rate of operation and production cost in a polyvinyl chloride plant*

of the polymerization reactor is determined by what is usual in the apparatus industry. Large production capacity will not be an advantage when the size is obtained from many small units. Economy will be more easily achieved with a few large reactors. Figure 2 shows the production cost of polyethylene in relation to plant capacity.

The nature of the apparatus industry also determines the rate of operation in a thermoplastic resin plant, and plant size is closely related to the production cost. Figure 3 shows the interrelationship of production cost and rate of operation in a polyvinyl chloride plant.

The major raw materials for thermoplastic resins are petrochemicals. The size of the petrochemicals plant therefore has an overwhelming effect on the cost of raw materials for thermoplastic resins. Ethylene is the raw material for polyethylene, polystyrene and vinyl resins; thus, the size of the ethylene plant is particularly important. Figure 4 gives the production cost of ethylene for various plant capacities.

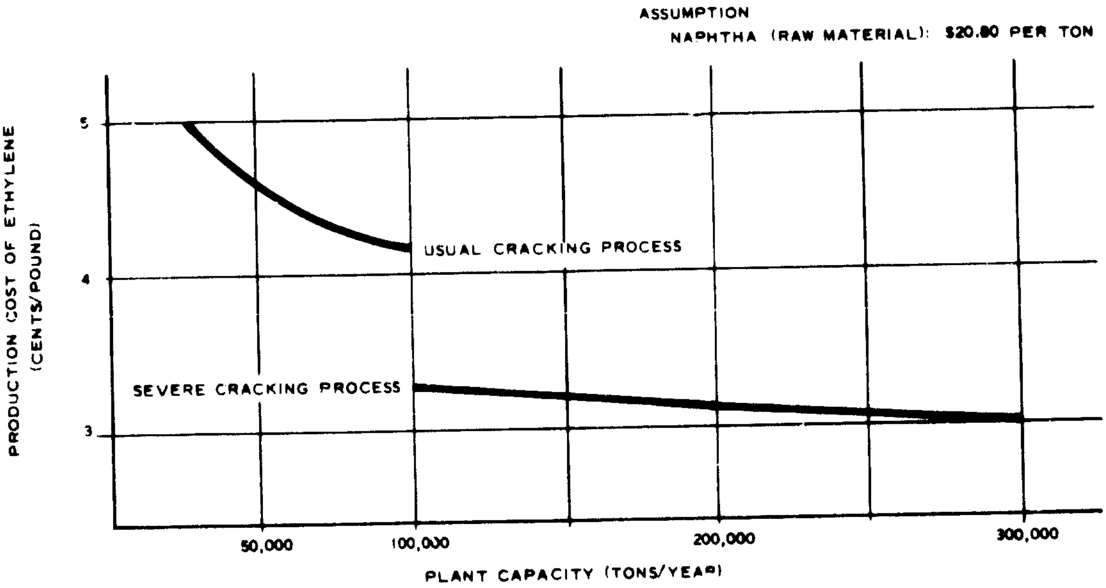

Figure 4. Interrelationship of production cost and plant capacity in an ethylene plant

There is a trend towards larger ethylene plants; the newest ones have a capacity of more than 300,000 tons per year. An ethylene plant with a capacity of 50,000 tons per year in a developing country can hardly compete with finished products from the 300,000-tons-per-year plants existing elsewhere, unless political or tariff barriers are established to protect it against imports and outside competition.

Another important point in judging the economy and competitiveness of an ethylene plant is its effective use of by-products, such as propylene and butadiene. A demand for these by-products should be created and should balance the required output of ethylene. If the by-products cannot be used, the main product (ethylene) must bear the full cost of all expenses in the plant and this naturally raises its cost. There are differences among countries with respect to the consumption pattern of various petroleum products; this also implies a difference in the source of ethylene.

The United States of America has a great need for automotive fuel and has built large refineries to meet this need. Gasoline is the major product of such refineries, and the production system is organized to obtain as much gasoline as possible. Naphtha is reformed in the refineries to produce the reformed gasoline and therefore is not a major raw material in the petrochemical industry. On the other hand, European and Japanese refineries produce less gasoline and more heavy distillates for fuel consumption. Naphtha is seldom reformed to produce gasoline; it is used instead in the petrochemical industry.

It is not expected that gasoline consumption will be very great in developing countries. Naphtha is therefore available as a chemical raw material. In countries where natural gases are abundant, for example Iran, naphtha need not be used as a raw material. The price of naphtha is closely related to its pattern of consumption in refineries.

As mentioned above, the cost of thermoplastic resins is dependent on the rate of operation, the size of the polymer plant, the operation of the ethylene plant, the degree to which by-products are utilized, and the price of the ethylene feedstock, either gas or naphtha. These are all relevant to the production capacity. A high consumption of resin is essential if prices are to be reduced.

Structure of the plastics processing industry

In the earliest stage of the plastics processing industry, the compression-moulding tradesmen produced household goods and electrical appliance parts with thermosetting resins. The main thermosetting resin at that time was phenolic moulding powder. The moulding enterprises were small but usually sucessful for several reasons: compression moulding machines were relatively cheap; business could be started with a small investment; the moulding process was not suitable for mass production, small shops could therefore compete well with larger ones; and it was possible to vary products and quantities to suit specific orders. Many moulders subcontracted for electric companies. The subcontractors were usually low in labour cost, productivity and efficiency.

The present stage of the plastics processing industry came in with the new thermoplastic resins. Low-density polyethylene is easy to process and the processing machine required is relatively cheap. The moulders are therefore able to maintain their "cottage industry" characteristics.

The processing of polyvinyl chloride resins, on the other hand, is difficult. Many types of processing methods have been developed and large enterprises have entered the plastics processing industry. Mass production has been employed to make film, sheet, plate, pipe and other products by calendering, extrusion or injection moulding. Markets such as those for natural rubber, leather, metal pipe and celluloid were invaded by plastic products, and even processors of natural raw materials changed to plastics processing. Processors of PVC resins were required to have relatively large amounts of capital and high technical standards. The calendering, extruding or compounding of PVC require more than the plain extrusion of polyethylene. The distribution of the processing methods in some European countries is shown in table 2.

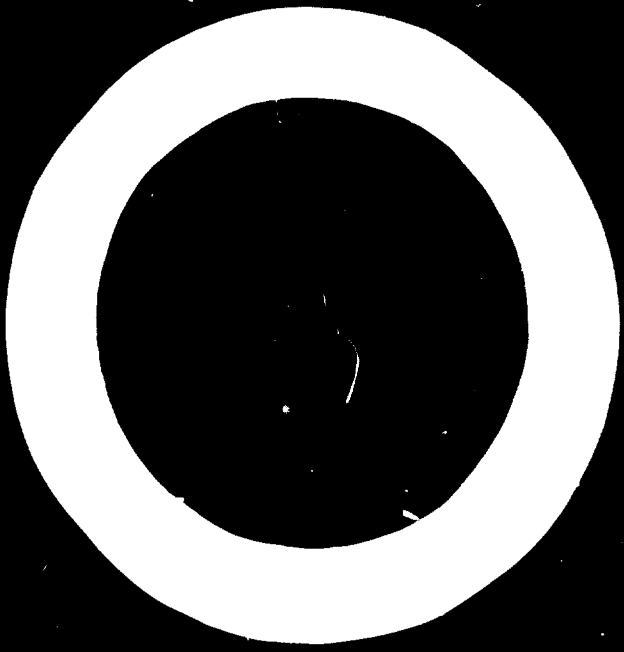

TABLE 2. POSSIBLE CHANGES IN PLASTICS PROCESSING BETWEEN 1964 AND 1970 IN SELECTED EUROPEAN COUNTRIES

	FRANCE			*GERMANY, FED. REP.*			*ITALY*			*BENELUX COUNTRIES*			*UNITED KINGDOM*		
	1964 (thousands of tons)	*1970 (est.) (thousands of tons)*	*Growth[a] %*	*1964 (thousands of tons)*	*1970 (est.) (thousands of tons)*	*Growth[a] %*	*1964 (thousands of tons)*	*1970 (est.) (thousands of tons)*	*Growth[a] %*	*1964 (thousands of tons)*	*1970 (est.) (thousands of tons)*	*Growth[a] %*	*1964 (thousands of tons)*	*1970 (est.) (thousands of tons)*	*Growth[a] %*
Compression moulding	30.5	42.5	5.7	66.5	103.0	7.6	38.3	41.5	1.2	9.2	16.0	9.7	65.5	54.0	3.2
Injection moulding	107.0	205.0	11.4	196.0	335.0	9.4	89.0	175.0	12.1	35.0	75.0	12.8	103.0	210.0	12.4
Blow moulding	17.5	58.0	21.6	31.6	126.0	26.6	7.5	40.0	32.2	9.1	34.0	24.6	24.3	82.0	22.5
Extrusion	128.0	307.0	15.8	322.0	683.0	13.3	188.0	404.0	13.6	84.0	191.0	14.9	188.0	445.0	15.4
Calendering	46.0	87.0	11.2	95.5	160.0	9.1	38.0	58.0	7.3	15.0	29.0	11.6	70.5	131.0	10.9
Coating	28.0	52.0	11.1	38.5	75.0	12.0	17.0	33.0	11.7	7.5	18.0	15.2	14.0	32.0	15.2
Reinforced plastics	15.0	29.5	12.3	12.0	29.5	16.5	12.0	23.5	11.5	7.5	15.5	13.0	14.5	23.5	11.9
Foams	24.6	83.0	22.5	54.6	140.0	17.1	20.6	71.0	22.9	14.6	39.0	17.9	33.6	107.0	21.1
Emulsions	160.0	285.0	10.2	390.0	660.0	9.0	170.0	305.0	10.5	90.0	150.0	9.4	170.0	300.0	10.2
Miscellaneous	39.4	97.0		51.3	102.0		19.6	43.0		12.1	24.5		28.6	68.5	
TOTAL	596.0	1,246.0	13.1[b]	1,258.0	2,413.5	11.5[b]	600.0	1,194.0	12.2[b]	284.0	592.0	13.0[b]	712.0	1,453.0	12.7[b]

Source: *European Plastics Report*, Plastics Society of Japan.

[a] Percentage of growth per year between 1964 and 1970.

[b] Average growth of all processes.

In general, most of the plastics processing industries in developed countries are still small-scale enterprises with the characteristics of a labour-intensive industry. The total number of processing plants in the United States in 1966 was approximately 8,700, of which 52 per cent had less than ten moulding machines. In the Federal Republic of Germany there were 2,037 processing plants with more than ten workers in August 1966. In the United Kingdom there were only 800 such plants and the average number of workers was 50. Italian plants with more than ten workers totalled 2,750 in 1965, of which 1,350 consumed less than ten tons of resin per year, 800 consumed 10 to 100 tons, and only 600 companies used more than 100 tons. In Japan at the time of writing (October 1967), the total number of processing plants was approximately 15,000, of which 1,500 had more than 30 workers. In Hong Kong in 1963, the total number of plants was 1,700 and the average number of workers among the 1,277 larger processors was approximately 36. Thailand has 170 processing companies, ten of which have more than 30 workers. Indonesia, Pakistan and the Philippines have about 300 processing companies each. The Republic of China and India have about 120 each, and Malaysia and Singapore each have approximately 50 companies (table 3).

TABLE 3. ESTIMATED NUMBER OF PLASTICS PROCESSING PLANTS IN SELECTED COUNTRIES

Country	*No*
Japan	15,000
Unites States	8,700
Italy	2,750
Germany, Fed. Rep.	2,037[a]
Hong Kong	1,700
Argentina	840
United Kingdom	800[a]
Mexico	500
Indonesia	300
Philippines	300
Pakistan	290
Chile	240
Thailand	170
China (Taiwan)	120
India	120[a]
Malaysia	50
Singapore	50

[a] Not including companies with less than ten workers.

TABLE 4. TYPES OF PROCESS IN USE IN PLASTICS INDUSTRIES IN JAPAN AND DISTRIBUTION OF PLANTS BY SIZE AND SALES, 1963

Type of moulding process	*Estimated number of companies*	*Size (per cent)*		*Sales (per cent)*	
		Large plants	*Medium to small plants*	*Large plants*	*Medium to small plants*
Compression moulding	3,800	2	98	25	75
Injection moulding	3,300	5	95	30	70
Extrusion moulding	1,300	10	90	50	50
Inflation	260	5	95	10	90
Blow moulding	470	5	95	20	80
Calendering	350	80	20	90	10
Vacuum forming	360	5	95	20	80
Lamination	200	80	20	90	10
Others	3,000	1	99	5	95
TOTAL	13,040				

Source: *Japan Plastics*, September 1964.

Table 4 indicates that calendering and lamination processes have been employed by the large processing companies as a result of extremely high investment requirements.

As observed above, many small plastics processing companies tend to specialize. They are often individually owned, but are, at the same time, relatively weak financially and technically owing to a shortage of capital. This type of business bases its expansion on individual ability and sales power. Some specialized companies in Japan and the United States have grown to be large enterprises and have been able to start their own resin production; these cases are, however, exceptional.

Many manufacturers of industrial parts are subcontractors to electrical, communication or automotive industries and progress together with their parent companies. Manufacturers of housewares depend primarily on their ability to develop something unique and sellable, but also on their sales power. Other processing companies are subsidiaries of resin manufacturers, rubber processors, metal pipe manufacturers, electronic companies and distributors of plastic products. These subsidiaries often reach medium or large capacity and usually employ mass production. If the resin manufacturers have enough subsidiary processors, they can mass produce resins because of their high captive consumption.

The distributors of plastics ware accept and distribute all completed products, justifying large-scale operations in the processing industry. Electrical or machinery companies prefer to have common parts supplied by the subsidiaries while they produce the delicate parts themselves. Rubber fabricators and metal products companies want to maintain their own markets and expect that their own plastics production will compensate for any decrease in sales of the existing line of products. Some large companies often employ subcontractors for the purpose of maintaining their business volume. In this case, the large company often passes off any loss to the subcontractors where it is covered by a low cost of production.

Parent companies, or large companies, assist subcontractors by providing equipment, financing and credit, renting equipment or an entire plant, offering long-term contracts or advance payment for products, and giving technical assistance. In Japan about 90 per cent of all small processing plants with less than twenty workers obtain their business by subcontracting.

Most plastics processing companies are located in and around cities, which indicates that the majority of plastics end-uses are consumer goods. The moulded products are usually too bulky and costly to transport far.

As figure 5 shows, the average sales of an extrusion-moulding company are much higher than for other moulding companies, because extrusion-moulding machines have high productivity since the extruder die can be changed easily. The other moulding specialists, particularly in compression or injection moulding, have less control of the quality and type of their products because die changing costs much more in time and money. The moulds are difficult to make quickly and there are long delays in delivery. These difficulties seem to be the causes of the low rate of growth in compression and injection moulding.

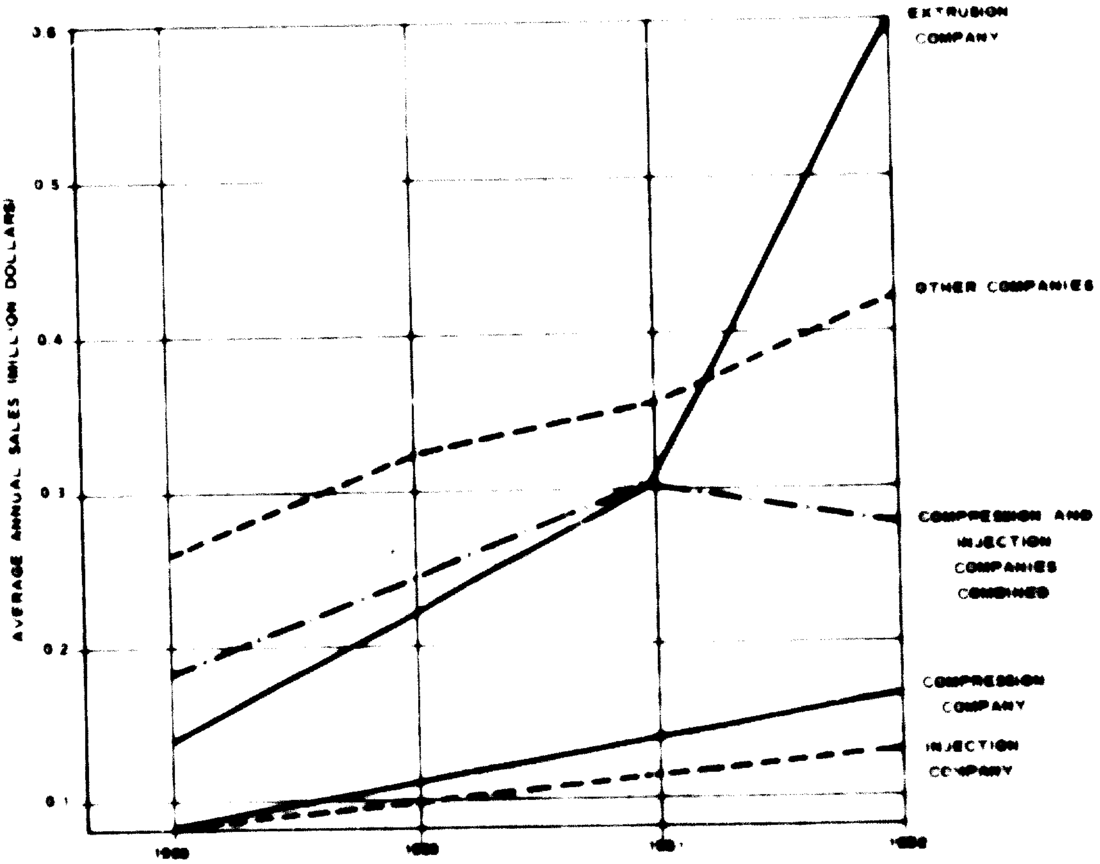

Figure 5   Average annual sales in plastics processing companies in Japan, 1959-1962

Since the initial stages of plastics processing, the mould industry has been closely connected with the plastics industry, including compression and injection moulding. The problems of the mould industry are primarily technical a shortage of capacity and weak management. The technique of making moulds is based on experience, and often theory is of no help. The flow of the molten resin in the mould and the shrinkage of the resin must be considered in mould designing.

The worker in a mould-manufacturing plant needs more training than one in a plastics processing company. In an average mould-making company in Japan, the proportion of workers with more than three years' training is 48 per cent, compared with 36 per cent in an average processing company.

As requirements for the quality of plastic products grow in the future, so requirements for moulds will become correspondingly extensive, detailed and complicated. It is therefore necessary for the mould industry to prepare high-precision machines for making moulds. In order to develop the plastics industry in a country, the mould industry must be developed and expanded at the same time. It is also important that the qualitative and quantitative goals for the mould industry are set higher than the present standards of the industry in that country.

The development of plastics machinery is important to the growth of the plastics processing industry. There are many examples of co-operation between synthetic resin manufacturers and plastics-machine manufacturers in the developed countries. However, in the developing countries, it is necessary in the first stage to import the processing machines with the hope of later supplying them domestically, with or without foreign technical aid. Shortage of spare parts causes delays and trouble with the machines. The availability of good, inexpensive machines and equipment increases the number of processors, resulting in an increased consumption of resins.

Structure of demand for plastic products

The structure of demand for plastic products is formed by four factors: method of processing, physical properties of plastics, prices and social circumstances.

The processing method is the first factor in forming the structure of demand indicated in figure 6. The shape of the products and their applications are limited by the processing method. Injection moulding is suitable for making inexpensive household goods and industrial parts. The extruded products are suitable for film and pipe, and calendering is used for making artificial leather and sheets. In the total consumption of plastics products in seven countries of the European Economic Community (EEC) and the United Kingdom in 1964, the extruded products occupied 26.4 per cent, injection-moulded products 15.4 per cent, calendered products 7.7 per cent, compression-moulded products 6.1 per cent, and other processes 44.6 per cent. Polyethylene, PVC and urea resins occupied 77 per cent of the consumer goods market in Japan in 1962. The building industry, on the other hand, uses plastics because of their light weight and ease of fabrication. Unfortunately, they lack strength and fire resistance, putting them at a disadvantage for building uses. In industry, plastics are used for electrical and mechanical parts, particularly in electronics, and they are becoming more important in engineering as new resins with improved properties are introduced.

In the United States in 1966, extruded products consisted of 57.6 per cent PVC, 31.5 per cent polyethylene and 6.9 per cent polystyrene products. The injection of polyethylene products occupied 35.3 per cent, polystyrene 38.5 per cent and polypropylene 9.9 per cent. Approximately 42 per cent of the total low-density

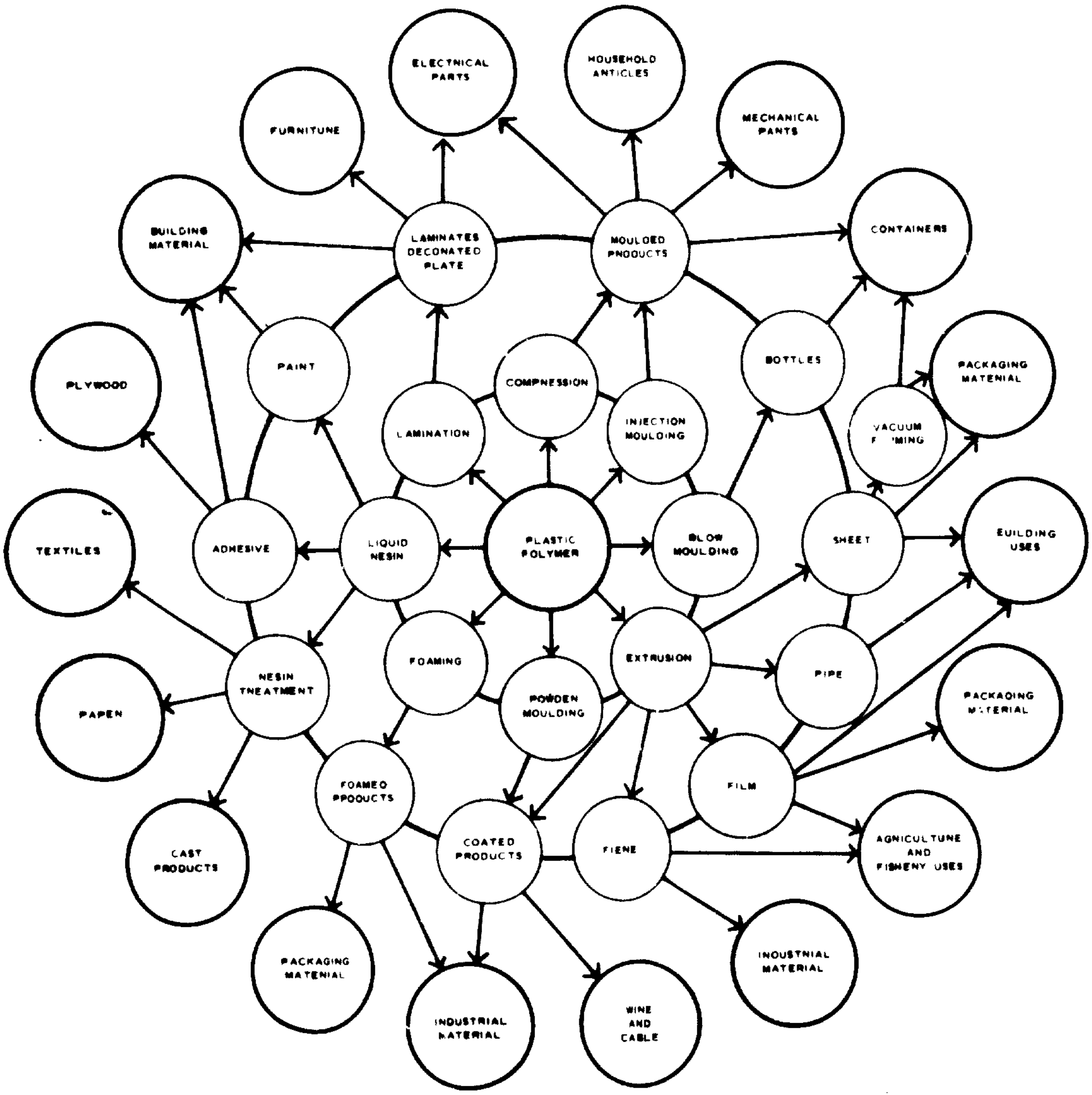

Figure 6. Interrelationship among methods of plastics processing, end-products and applications

polyethylene consumption was used for making packaging film. About 35 per cent of PVC resin was used for sheet and floor coverings, and 53 per cent of polystyrene resin was used for moulded products such as containers, housewares, toys and so forth. The consumption figures of low- and high-density polyethylene and PVC classified by manufacturing methods are shown in tables 5, 6 and 7. Table 8 shows the plastics production in several countries.

The second factor in the structure of demand for plastics is their physical properties. They generally have good chemical resistance, light weight, corrosion resistance, ease of colouring and processing, beauty of appearance, and are insulators of heat and electricity. Plastics have some disadvantages: low resistance to heat, scratchable surfaces, some aging, and vulnerability to organic solvents. There are many kinds of synthetic resins and each has its own features in addition to those mentioned above. The choice of the correct resin depends on its particular application.

TABLE 5. CONSUMPTION OF LOW-DENSITY POLYETHYLENE CLASSIFIED BY MANUFACTURING METHOD IN JAPAN, THE UNITED KINGDOM AND THE UNITED STATES, 1966

	JAPAN		*UNITED KINGDOM*		*UNITED STATES*	
	(thousands of tons)	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*
Film and sheet	192.4	63.5	76.7	45.8	500.0	49.3
Injection moulding	29.1	9.6	29.2	17.4	175.0	17.3
Extrusion coating	44.8	14.8	17.9	10.6	120.5	11.9
Wire and cable	21.0	6.9	15.8	9.4	120.5	11.9
Blow moulding	9.2	3.0	17.4	10.4	22.7	2.2
Pipe and conduit	2.0	0.7	5.5	3.2	29.5	2.9
Miscellaneous	4.7	1.5	5.5	3.2	45.5	4.5
TOTAL	303.2	100.0	168.0	100.0	1,013.7	100.0

TABLE 6. CONSUMPTION OF HIGH-DENSITY POLYETHYLENE CLASSIFIED BY MANUFACTURING METHOD IN JAPAN, THE UNITED KINGDOM AND THE UNITED STATES, 1966

	JAPAN		*UNITED KINGDOM*		*UNITED STATES*	
	(thousands of tons)	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*
Blow moulding	20.1	20.8	16.8	48.0	181.8	50.0
Injection moulding	30.7	31.7	10.4	29.5	88.6	24.4
Fibre	22.9	23.7	3.1	9.0	2.3	0.6
Film and sheet	19.2	20.0	1.7	5.0	20.4	5.6
Wire and cable	0.1	0.1	1.0	3.0	13.6	3.8
Pipe and conduit	1.6	1.6	0.9	2.5	22.7	6.3
Extrusion coating	0.5	0.5			4.6	1.2
Miscellaneous	1.7	1.6	1.1	3.0	29.6	8.1
TOTAL	96.8	100.0	35.0	100.0	363.6	100.0

TABLE 7. CONSUMPTION OF PVC RESIN BY TYPE AND MANUFACTURING METHOD IN JAPAN, THE UNITED KINGDOM AND THE UNITED STATES, 1966

Type of PVC resin and product	*JAPAN*		*UNITED KINGDOM*		*UNITED STATES*	
	(thousands of tons)	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*
Flexibles						
Calendering						
Sheet and film	113.1	23.0	34.6	17.2	175.0	18.0
Flooring	15.5	3.1	28.1	14.0	131.8	13.5
Extrusion						
Wire and cable	43.9	8.9	36.7	18.3	114.0	11.7
Flexible profiles	6.4	1.5			38.6	4.0
Sheet and film	41.9	8.5	18.4	9.2	13.6	1.4
All other extruded products					27.2	2.8
Coating	6.5	1.1	13.0	6.5	131.9	13.5
Moulding						
Footwear	–	–	4.3	2.1	36.5	3.7
Slush and rotational moulding	–	–	8.6	4.3	20.5	2.1
Miscellaneous	–	–	–	–	8.2	0.8
Flexibles sub-total	227.3	46.1	143.7	71.6	697.3	71.5

Rigid						
Extruded						
Pipe and conduit	112.6	22.9	30.2	15.0	56.8	5.8
Other extrusion	27.1	5.5			19.6	2.0
Moulding						
Phonograph records	4.2	0.8	8.6	4.3	45.5	4.7
Blow moulding	–	–	1.1	0.5	4.1	0.4
Other mouldings	15.7	3.2	–	–	7.3	0.8
Calender or extruded sheet	90.7	18.4	6.5	3.2	22.3	2.3
Rigid sub-total	250.3	50.8	46.4	23.0	155.6	16.0
Miscellaneous	15.1	3.1	10.8	5.4	122.2	12.5
GRAND TOTAL	492.7	100.0	200.9	100.0	975.1	100.0

TABLE 8. PRODUCTION OF PLASTICS IN SEVEN COUNTRIES, 1963-1966

Plastics distribution by country	*1963*		*1964*		*1965*		*1966*	
	(thousands of tons)	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*	*(thousands of tons)*	*(per cent of total)*
FEDERAL REPUBLIC OF GERMANY								
Phenolic resin	72.9	5.1	89.9	5.2	103.0	5.4		
Urea-melamine	219.0	15.4	268.2	15.3	272.0	14.2		
PVC resin	273.2	19.2	341.2	19.6	370.0	19.3	no breakdown of sub-total available	
Polyethylene	165.3	11.6	225.8	12.9	275.0	14.3		
Polypropylene	16.6	1.2	15.9	0.9	19.5	1.2		
Polystyrene	193.8	13.5	230.3	13.3	250.0	13.0		
Others	484.8	34.0	573.7	32.8	631.4	32.6		
Sub-total	1,425.6	100.0	1,745.0	100.0	1,920.9	100.0	2,200.0	
FRANCE								
Phenolic resin	28.4	5.6	32.0	5.2	32.1	4.7		
Urea-melamine	31.4	6.3	40.9	6.6	43.0	6.4		
PVC resin	172.5	33.7	207.3	33.7	213.4	31.6	no breakdown of sub-total available	
Polyethylene Polypropylene } Polyolefins	64.9	12.8	79.3	12.9	111.4	16.3		
Polystyrene	53.6	10.6	63.9	10.9	71.3	10.6		
Others	157.2	31.0	187.6	30.7	205.8	30.4		
Sub-total	508.0	100.0	611.0	100.0	677.0	100.0	780.0	

ERRATA
ID/SER. J/4
8 June 1970

STUDIES IN THE DEVELOPMENT OF PLASTICS INDUSTRIES

Page 59, Table 31

	1970 (estimated)	
	Consumption	*Balance*
Change first line to read	3,121	1,941
Change last line (total) to read	27,346	

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ITALY								
Phenolic resin	42.5	6.8	45.0	6.2	47.0	5.6		
Urea-melamine	67.0	10.7	76.0	10.4	78.0	9.2		
PVC resin	250.0	40.0	290.0	39.6	330.0	39.2	no breakdown of sub-total available	
Polyethylene Polypropylene } Polyolefins	104.0	16.7	125.0	17.2	189.0	21.9		
Polystyrene	67.0	10.7	80.0	10.9	90.0	10.7		
Others	94.5	15.1	116.0	15.7	114.0	13.4		
Sub-total	625.0	100.0	732.0	100.0	848.0	100.0	930.0	
JAPAN								
Phenolic resin	65.0	6.1	77.8	5.6	76.4	4.8	98.3	5.0
Urea-melamine	237.2	22.3	276.4	20.1	293.2	18.4	350.0	17.6
PVC resin	348.8	32.8	473.8	34.5	483.0	30.2	485.4	24.4
Polyethylene	223.4	21.6	289.4	21.0	396.3	24.8	553.3	27.8
Polypropylene	21.2	2.0	39.5	2.9	57.5	3.6	99.7	5.0
Polystyrene	70.9	6.7	100.4	7.3	125.5	7.8	200.9	9.9
Others	95.6	8.5	119.2	8.6	169.3	10.4	203.2	10.3
Sub-total	1,062.1	100.0	1,376.5	100.0	1,601.2	100.0	1,990.8	100.0

Table 8 *(continued)*

Plastics distribution by country	*1963* (thousands of tons)	*1963* (per cent of total)	*1964* (thousands of tons)	*1964* (per cent of total)	*1965* (thousands of tons)	*1965* (per cent of total)	*1966* (thousands of tons)	*1966* (per cent of total)
UNION OF SOVIET SOCIALIST REPUBLICS								
Phenolic resin	130.0	22.1	138.0	19.2	157.0	19.2	no breakdown of sub-total available	
Urea-melamine	135.0	22.9	152.0	21.1	173.0	21.2		
PVC resin	88.0	14.9	140.0	19.4	160.0	19.4		
Polyethylene **Polypropylene** } Polyolefins	40.0	6.8	60.0	8.3	68.0	8.2		
Polystyrene	29.0	4.9	40.0	5.5	46.0	5.6		
Others	167.0	28.4	190.0	26.5	217.0	26.4		
Sub-total	589.0	100.0	720.0	100.0	821.0	100.0	940.0	
UNITED KINGDOM								
Phenolic resin	57.7	7.8	63.8	7.3	66.5	7.1	70.0	6.8
Urea-melamine	95.8	12.9	111.8	12.8	116.0	12.3	122.5	12.0
PVC resin	151.5	20.2	178.0	20.2	190.5	20.1	202.5	18.8
Polyethylene	197.9	26.5	n.a.[a]	n.a.	232.5	24.7	258.0	25.3
Polypropylene	n.a.	n.a.	240.0	27.4	19.0	2.0	27.0	2.6
Polystyrene	78.9	10.6	92.0	10.5	99.2	10.5	116.5	11.4
Others	164.2	22.0	192.4	21.8	218.8	23.3	235.5	23.1
Sub-total	746.0	100.0	878.0	100.0	942.5	100.0	1,032.0	100.0

UNITED STATES								
Phenolic resin	333.2	8.2	364.5	8.0	402.8	8.0	441.8	7.4
Urea-melamine	232.5	5.7	238.5	5.1	252.5	5.0	297.2	4.9
PVC resin	623.6	15.5	715.5	15.6	819.0	16.0	1,000.0	16.6
Polyethylene	1,021.5	25.3	1,215.0	26.6	1,341.0	26.2	1,554.5	25.9
Polypropylene	88.6	2.0	117.0	2.5	166.5	3.2	231.8	3.8
Polystyrene	692.4	17.0	789.5	17.3	881.6	17.3	1,050.0	17.4
Other	1,059.9	26.3	1,134.0	24.8	1,259.4	24.3	1,447.7	24.0
Sub-total	4,051.7	100.0	4,574.0	100.0	5,122.8	100.0	6,023.0	100.0
Total								
Phenolic resin	729.7	8.1	811.0	7.6	884.8	7.4		
Urea-melamine	1,017.9	11.3	1,163.8	11.0	1,227.7	10.3		
PVC resin	1,907.6	21.2	2,345.8	22.0	2,565.9	21.5	no breakdown of total figure available	
Polyethylene Polypropylene } Polyolefins	1,943.4	21.6	2,406.9	22.6	2,871.7	24.1		
Polystyrene	1,165.6	13.0	1,394.1	13.1	1,563.6	13.1		
Others	2,223.2	24.8	2,512.9	23.7	2,815.7	23.6		
GRAND TOTAL	8,987.4	100.0	10,634.5	100.0	11,929.4	100.0	13,883.8	
Total production in the world	10,415.6		12,337.6		13,810.3		16,309.0	
Share of the above seven countries in total world production		86.4%		86.2%		86.4%		85.1%

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[a] n.a. = not available in October 1967, the date on which the present report was written.

The third factor is the price of plastics. Synthetic resins, particularly the thermoplastic resins, become cheaper as the petrochemical industry develops. The petrochemical raw materials for plastics resins are plentiful at the time of writing (October 1967), and large-scale production is becoming more economical every year. This tendency should continue.

The fourth factor is the social circumstances in various countries. Each country's population has its own pattern of living and this makes the demand structure of plastics variable according to area. As tables 5, 6, 7 and 8 show, the pattern of consumption is different in each country. In the United States, soft PVC products are in much greater demand than rigid ones. The same situation is found in the United Kingdom. Japan, on the other hand, has a large share of rigid products. The consumption *per capita* of PVC resin in soft products in 1963 was 6.8 pounds in the United States, 5.9 pounds in the Federal Republic of Germany, 5.8 pounds in France, 5.7 pounds in the United Kingdom, 3.8 pounds in Japan, and 3.2 pounds in Italy. The consumption of PVC resin for rigid use ranges from 3.8 pounds in Japan and 3.6 pounds in the Federal Republic of Germany, to 2.2 pounds in Italy, 1.2 pounds in France, 0.8 pounds in the United Kingdom and 0.4 pounds in the United States. The consumption of rigid PVC resin products is rising quickly in Europe where the EEC nations with the United Kingdom produced 34 per cent rigid and 66 per cent soft PVC in 1964; these proportions are expected to change by 1970 to 44 per cent rigid and 56 per cent soft PVC.

There are various types of PVC resin and the resin preferences sometimes differ from country to country. In Japan in 1960, 92 per cent of the PVC resin was homopolymer, 6 per cent copolymer and 2 per cent paste resin, while in the United States, 66 per cent was homopolymer, 33 per cent copolymer and 1 per cent paste resin. In 1966 the United Kingdom and the United States used 42 per cent of their polyethylene in manufacturing packaging film. The figure was 60 per cent for Japan and about 80 per cent for China (Taiwan). The figure could be much higher in the developing countries; it might be safe to assume that almost all the polyethylene would be used as packaging film.

Plastics products can be classified into five main markets: consumer goods, industrial materials, building materials, adhesives and paints. In 1964 the EEC and the United Kingdom reached a consumption total of 40.1 per cent in consumer goods, 18.2 per cent in industrial materials, 13.6 per cent in building materials, 12.9 per cent in adhesives and 11.5 per cent in the paint industry. Of the 40.1 per cent in consumer goods, 45 per cent was used in packaging materials. Consumer goods industries usually start with cheaper raw materials since the products are directly consumed or given away.

There are two major considerations in the plastics processing industry. One is the dual structure of the industry. The resin manufacturing industry is an industry with large equipment, but the plastics processing industry is mainly a "cottage industry". Because of the big difference in capital investment and technology between the two, the processors should develop their own specialized applications and methods.

Second, through constant contact with the resin producers, the processors and machine producers should be able to find the most suitable processing method for the resin. They should also be able to select good-quality processing machines and improve the design and quality of moulded products, thereby increasing the demand for their products.

Patents and other industrial property

As figure 7 below shows, the structure of the manufacture of plastics is composed of monomer production, polymerization, processing and the interrelationship of the three. The methods have been developed by enterprises and research institutes in the developed countries, and many patents have been granted. Particularly for thermoplastics, most of the monomer production processes are based on petrochemical techniques developed, for the most part, by several United States companies. Polymers such as polyethylene, polypropylene and epoxy resins have been developed also by European companies. Therefore, developing countries interested in establishing such plants, using either their own or foreign methods, must introduce patent rights and/or know-how. The establishment of a joint company with patents and know-how supplied by participating companies or countries is often the best choice.

It is apparent that an effort by a developing country to create its own processes without infringing existing rights would be very time-consuming. It is highly desirable to establish an industry at an early date. These two factors indicate that the introduction of foreign processes complete with know-how is the best solution for the time being. But in order to encourage the interest and participation of foreign corporations, the governments of developing countries should create favourable domestic conditions.

A good environment for investment includes political stability, steady development of the economy and good protection for foreign investments, including free repatriation of capital and free remittance of earnings. The most important aspect is the protection of industrial rights. Most of the above conditions apply when the introduction of patents and know-how is considered with emphasis on guaranteeing safety and profitability for foreigners. It is also reported that there is a lack of good engineers and educated operators in developing countries, which tends to discourage foreign investment. Some steps must therefore be taken to provide qualified personnel who take an interest in their work.

Many developing countries have not completed a system of patent laws. Enterprises in developed countries are apt to be hesitant about selling technology to or investing in projects in these countries. Full ownership of a company in such countries might guarantee a certain amount of security for such enterprises; however, most developing countries prefer not to start their plastics industry in this way. Among the ECAFE countries, Ceylon, Indonesia, Iran, Laos and the Philippines are members of the Union of the Convention of Paris for the Protection of Industrial Property. China (Taiwan), India, Pakistan, and the Republic of Korea have their own patent laws, but they have not joined the Union. Afghanistan, Bhutan, Nepal and Thailand have no patent system. It is hoped that a common international patent system may be established to include most of the patent laws of different countries. The activity of BIRPI *(Bureaux Internationaux Reunis pour la Protection de la Propriété Intellectuelle)* in Geneva could be helpful in establishing such a system.

The authors believe that it is very important for developing countries to establish patent laws and to join the Union of the Convention of Paris. This may encourage more foreign enterprises to offer technical assistance and to invest their patents and know-how in new companies and industries.

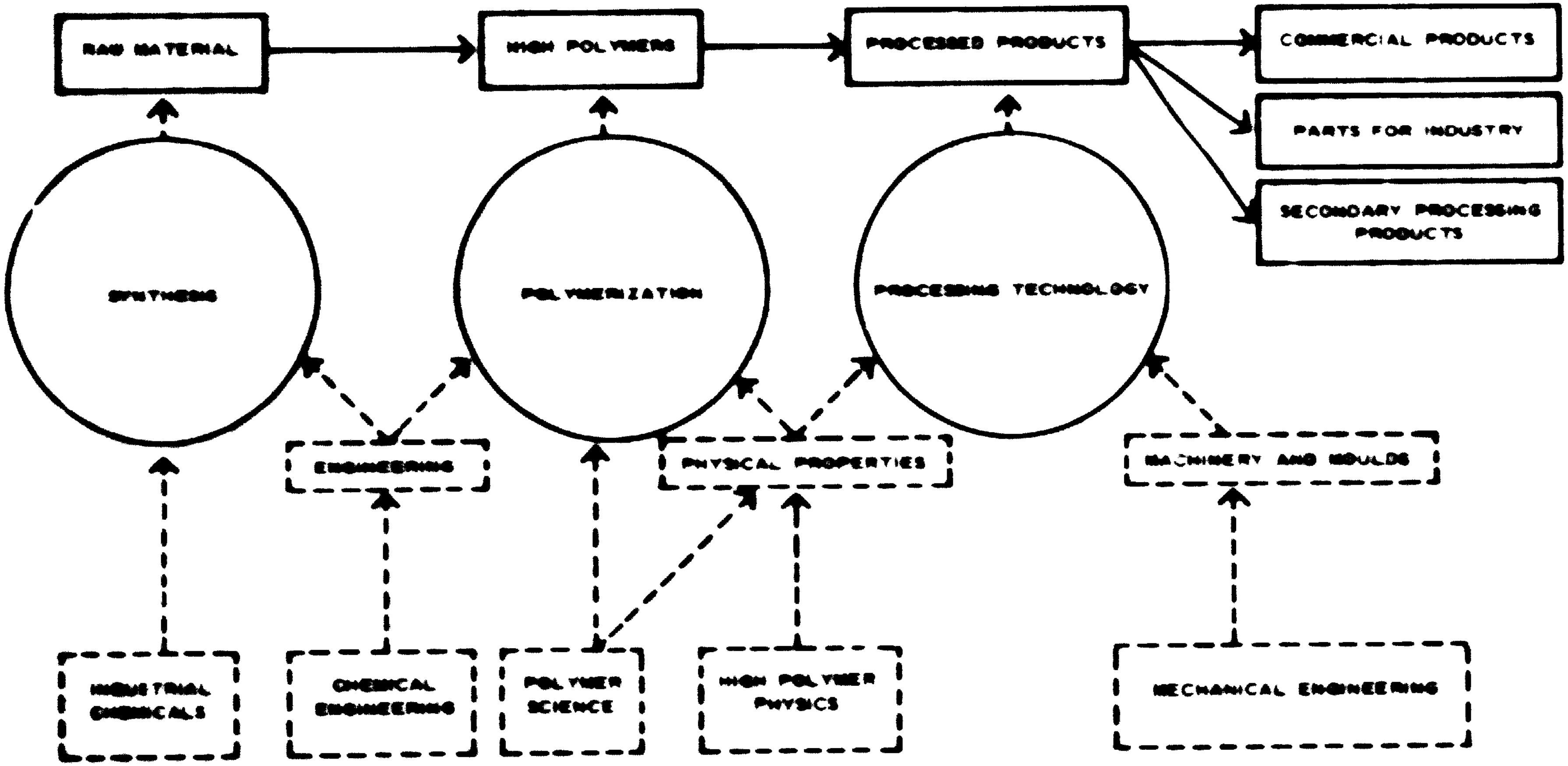

Figure 7. Interrelationship of pure and applied sciences with methods of making plastics products

1.2 Present situation of the plastics industry in the developing countries of the ECAFE region

The distribution of world plastics production between 1963 and 1966 is presented in table 8. The total output figure for plastics rose from 10,415,600 tons in 1963 to 16,309,000 tons in 1966. The annual rate of growth was 16 per cent. The Federal Republic of Germany, France, Italy, Japan, the Union of Soviet Socialist Republics, the United Kingdom and the United States shared 86 per cent of the total. Japan controls approximately 90 per cent of total production in the ECAFE region. The consumption *per capita* in this region is very small. Table 9 below shows the world production and consumption of plastics. The Federal Republic of Germany has the highest consumption of plastics *per capita*, and the United States, the United Kingdom, France and Japan follow.

Polyethylene

In India the production of polyethylene began in 1959 and by 1965 had reached a yearly output of 13,198 tons (table 10). In August 1959 Alkali and Chemical Corporation of India, a subsidiary of ICI (Imperial Chemical Industries), began production of polyethylene at Rishra, West Bengal. Union Carbide of India, a subsidiary of UCC (Union Carbide Corporation), began its operations at Trombay in 1961. Both plants manufactured ethylene from alcohol, however, Union Carbide has already switched from alcohol as the raw material to naphtha supplied by Esso from their Trombay refinery.

A plan to construct a plant with an annual capacity of 40,000 tons is now being developed in the petrochemical complex at Koyali, Gujarat in India. Another 29,000-ton-per-year capacity plant is being constructed in the Barauni (Bihar) petrochemical complex. A plant with an annual capacity of 13,500 tons of high-density polyethylene is now under construction by the Polyolefines Industries Ltd with financial and technical aid from Hoechst of the Federal Republic of Germany. The goal for production of polyethylene by the end of the Fourth Five-Year Plan (1970/1971) is 125,000 tons.

In China (Taiwan) polyethylene was not produced until recently. The Taiwan Polymer Corporation is now building a low-density polyethylene plant with an annual capacity of 18,000 tons at Kaoshiung with financial and technical aid from the National Distillers and Chemical Corporation of the United States. It was expected to begin work early in 1968. Ethylene will be supplied from the naphtha cracker of the Chinese Petroleum Corporation.

In Pakistan, Valika Chemical Industries began production of low-density polyethylene at Karachi in 1966. The present raw material for the 5,000-ton-annual-capacity plant is alcohol, but a switch to ethylene from the naphtha-cracker centre of the Ethylene Corporation is anticipated when another polyethylene plant (10,000-ton annual capacity) begins operations.

In Iran a joint venture of National Petrochemical Company and Allied Chemical Company of the United States has resulted in a low-density polyethylene plant with an annual capacity of 60,000 tons. As Iran is one of the large oil-producing countries, its abundant supply of natural gas is used as the raw material for polyethylene.

As mentioned above, the annual production capacity of polyethylene in the ECAFE countries will reach 180,000 tons of low-density polyethylene and 24,000 tons of high-density polyethylene in the very near future (table 11).

TABLE 9. WORLD PRODUCTION AND CONSUMPTION OF PLASTICS, 1966

Country	*Total production*	*Export*	*Import*	*Trade balance*	*Domestic consumption*	*Population (millions)*	*Consumption* per capita *(kg)*
Germany, Fed. Rep.	1,920.9	574.0	297.7	276.3	1,644.6	55.1	29.8
France	677.0	188.3	196.0	–7.7	684.7	47.6	14.4
Italy	844.0	390.4	97.9	292.5	551.5	56.1	9.8
Japan	1,601.2	253.9	23.2	230.7	1,370.5	98.3	13.9
USSR	821.0	–	–	–	821.0	225.0	3.6
United Kingdom	942.5	324.0	188.0	136.0	806.5	51.4	15.7
United States	5,122.8	470.0	32.0	438.0	4,684.8	190.0	24.7
Others	1,880.9	–	–	– 1,365.8	3,246.7	243.7	1.3
TOTAL	13,810.3				13,810.3	Average	4.4

TABLE 10. PRODUCTION OF SYNTHETIC RESINS IN SELECTED ECAFE COUNTRIES, 1960-1966

(tons)

Distribution of resin by country	*1960*	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*
Polyethylene							
India	4,147	5,796	8,064	7,923	9,156	13,198	14,130
PVC[a]							
China (Taiwan)	3,418	7,055	10,924	16,751	25,198	25,305	44,175
India	–	917	2,664	3,907	9,216	12,441	10,790
Philippines	–	–	–	–	–	n.a.[b]	6,000 (approx.)
Polystyrene							
China (Taiwan)	–	–	–	–	–	195	1,456
India	3,676	3,485	3,887	5,515	5,114	5,690	5,790
Phenolic resin							
China (Taiwan)	–	–	–	–	334	619	914
India	2,135	2,111	2,423	2,886	3,226	3,384	n.a.
Rep. of Korea	–	–	–	–	–	11	n.a.
Urea							
China (Taiwan)	n.a.	n.a.	10,000	11,400	11,806	13,194	17,202
India	365	433	3,232	4,373	1,167	n.a.	n.a.

[a] The Republic of Korea is also a producer of PVC resin, but figures are not available.

[b] n.a. = not available at time of writing, October 1967.

TABLE 11. PRODUCERS AND PLANT CAPACITY OF POLYETHYLENE IN SELECTED ECAFE COUNTRIES

Distribution of polyethylene by country	*Producer*	*Plant capacity (tons/year)*			
		Present	*Under construction*	*Projected.*	*Total*
Low-density polyethylene					
India	**Alkali and Chemical**	4,500	–	4,000	8,500
	Union Carbide India	9,000	–	–	9,000
	Gujarat petrochemical complex	–	–	40,000	40,000
	Baruni petrochemical complex	–	–	29,000	29,000
	Sub-total	13,500	–	73,000	86,500
China (Taiwan)	**Taiwan Polymer Corp.**	–	18,000	–	18,000
Iran	**National Petrochemical Allied Chemical J-V**	–	60,000	–	60,000
Pakistan	**Valika Chemical Industry**	5,000	10,000	–	15,000
Total low-density polyethylene		18,500	88,000	73,000	179,500
High-density polyethylene					
India	**Polyolefines Industries**	8,400	–	15,600	24,00
Total polyethylene		26,900	88,000	88,600	203,500

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TABLE 12. EXPORT OF PLASTICS FROM JAPAN TO THE ECAFE REGION, 1966

(tons)

	Polyvinyl chloride			*Polyethylene*		*Polystyrene*	
Country	*Resin*	*Rigid products*	*Soft products*	*Resin*	*Products*	*Resin*	*Products*
China (Taiwan)	4,193	175	110	8,745	16	1,280	41
Hong Kong	4,300	1,139	8,278	36,548	208	4,569	22
Malaysia	239	164	1,095	1,207	5	60	6
Pakistan	511	29	1,810	3,006	6	155	3
Philippines	1,167	118	2,727	5,998	3	625	30
Republic of Korea	1,104	316	184	2,206	34	11	22
Singapore	591	159	1,889	4,348	9	31	–
Thailand	2,255	549	4,511	15,599	159	1,179	4
Others	2,358	500	4,291	4,520	477	249	7
Total	16,718	3,149	24,895	82,177	917	8,159	135
GRAND TOTAL (as resin)	36,467		(16,600)[a]	83,094		8,294	

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[a] Estimated quantity of PVC resin after subtracting plasticizer content.

The largest consumer of polyethylene in this region is Hong Kong, which imported approximately 43,000 tons in 1965 and 49,000 tons in 1966. Table 12 shows the export of polyethylene resin totalling 100,000 tons from Japan to the ECAFE region in 1966. The *per capita* consumption in Hong Kong is, at 13.3 kilograms, the highest in the region. Singapore follows with 2.3 kilograms, China (Taiwan) with 0.7 kilograms, and Thailand with 0.5 kilograms. All other ECAFE countries consume less than 0.5 kilograms of polyethylene *per capita*, as shown in table 13. If all ECAFE countries, with the exception of the territory of Hong Kong, Singapore and China (Taiwan), were to consume 0.5 kilograms of polyethylene *per capita*, the total consumption would be approximately 500,000 tons. Detailed figures are given in table 14. If this were possible, Iran would become the only country with a surplus production of polyethylene.

TABLE 13 *PER CAPITA* CONSUMPTION OF POLYETHYLENE IN THE ECAFE REGION, 1966

Country	*Population (thousands)*	*Consumption (tons)*	Per capita *consumption (kg)*
China (Taiwan)	12,257	12,000	1.0
Hong Kong	3,692	49,000	13.3
Malaysia	9,135	1,195	0.1
Philippines	32,073	5,998	0.2
Republic of Korea	28,024	2,205	0.1
Thailand	29,700	15,599	0.5

Low-density polyethylene is easier to process than other synthetic resins, and even the smallest plants in the world have been producing this resin. This should act as an incentive for the developing countries to start processing polyethylene. Large amounts of capital and advanced techniques are not required. The processing of high-density polyethylene is gradually increasing in the ECAFE countries, but it is more difficult than with low-density polyethylene. Another disadvantage of high-density polyethylene is its lack of a large market such as one for packaging film. Therefore, medium-sized or large plants for manufacturing moulded products and pipes would be needed.

TABLE 14. POTENTIAL TOTAL CONSUMPTION OF POLYETHYLENE IN THE ECAFE REGION

Country	*Population (thousands)*	*Potential total consumption*[a] *(tons)*
Afghanistan	14,900	7,450
Bhutan	700	350
Brunei	93	47
Burma	23,735	11,868
Cambodia	5,900	2,950
Ceylon	10,625	5,312
China (Taiwan)	12,257	20,000[b]
Hong Kong	3,692	50,000[b]
India	475,305	237,652
Indonesia	100,800	50,400
Iran	22,523	11,262
Laos	1,925	962
Malaysia	9,135	4,568
Nepal	9,700	4,850
Pakistan	100,762	50,381
Philippines	32,073	16,036
Republic of Korea	28,024	14,012
Republic of Viet-Nam	15,715	7,858
Singapore	1,900	5,000[b]
Thailand	29,700	31,200[b]
	TOTAL	532,158

[a] Number of inhabitants X 0.5 kg *per capita*.
[b] Based on present consumption plus future estimates.

Polyvinyl chloride

The ECAFE countries that are presently producing PVC resins are China (Taiwan), India, Iran, Pakistan, the Philippines and the Republic of Korea (table 15 below). The first plant in the area, the Formosa Plastics Corporation, was established in China (Taiwan) and started operations in June 1957. China Plastics, Yee Fong Plastics and Casey Plastics have operated plants since 1966. Total capacity in August 1966 was 84,000 tons per year and an increase to 100,000 tons is expected in the near future.

TABLE 15. PRODUCERS OF POLYVINYL CHLORIDE RESIN AND PLANT CAPACITY IN SELECTED ECAFE COUNTRIES

Country	*Plant*	*Plant capacity (tons/year)*				*Technology introduced by*
		Present	*Under construction*	*Projected*	*Total*	
China (Taiwan)	Formosa Plastics	48,000	–	12,000	60,000	Japan
	China Plastics	12,000	–	–	12,000	Japan
	Yee Fong Plastics	12,000	–	–	12,000	Japan
	Casey Plastics	12,000	–	12,000	24,000	Japan
	Sub-total	84,000	–	24,000	108,000	
India	Calico Mills Chemical Division	7,200	–	–	7,200	Germany, Fed. Rep.
	Rajasthan Vinyl and Chemicals	10,000	–	10,000	20,000	Japan
	Chemicals and Plastics	6,000	–	–	6,000	United States
	Plastics resins and chemical plant	–	–	12,000	12,000	–

	National organic chemical plant	–	–	20,000	20,000	—
	Gujarat petrochemical complex	–	–	20,000	20,000	—
	Sub-total	23,200	–	62,000	85,200	
Rep. of Korea	**Daihan Plastics**	6,000	–	–	6,000	Japan
	Kong Young Chemical	6,000	–	–	6,000	Japan
	Korea Ind. Chemical	–	15,000	–	15,000	Japan
	Yupoong Chemical	–	10,000	–	10,000	Japan
	Sub-total	12,000	25,000	–	37,000	Japan
Iran	**National Petrochemical and B.F. Goodrich J-V**	–	20,000	–	20,000	United States
Pakistan	Arokey Chemical	5,400	–	–	5,400	Japan
Philippines	**Mabuhai Rubber**	6,000	–	–	6,000	Japan
GRAND TOTAL		130,600	45,000	86,000	261,600	

In India the Calico Mills, Chemical Division, began operations in September 1961. Rajasthan Vinyl and Chemicals, a subsidiary of Delhi Cloth and General Mills, started its plant in Kotah in 1964. Chemicals and Plastics Ltd began operating in 1967. The present total annual capacity of the plants is 23,200 tons. With the addition of a national organic chemical plant in Thana, a Gujarat petrochemical complex in Koyali, and a plastics resins and chemical plant in Tuticorin, the total annual capacity is expected to reach 85,200 tons in the near future.

In the Republic of Korea, Daihan Plastics started a plant in 1966 with 6,000 tons annual capacity, and Kong Young Chemical Industry began operations in its 6,000 tons annual capacity plant in September 1967. Korea Industrial Chemical Corporation proposes a plant with an annual capacity of 15,000 tons and the 10,000 tons annual capacity plant of Yupoong Chemical is scheduled at the time of writing (autumn 1967) for completion in 1968.

In the Philippines, Mabuhai Rubber Company, which is now in full operation, has operated its plant of 6,000-tons annual capacity since August 1965.

In Iran a joint venture of National Petrochemical Company (Iran, 74 per cent) and B. F. Goodrich Chemical Company (United States, 26 per cent) was established and a 20,000-ton-capacity plant is under construction at the time of writing.

After these plants are completed, the annual production of PVC resins in the ECAFE countries is expected to total 70,000 tons. Japan exported 16,715 tons to this area during 1966, or about 50 per cent of imports to these countries. The amount of PVC resins produced in China (Taiwan), India and the Philippines, plus the amount imported, constitutes the total consumption of PVC. Table 12 indicates that the present annual demand for PVC resin in these countries is approximately 90,000 tons, including the import of some PVC products which are partially plasticized. The figures in table 12 have been adjusted to allow for this difference.

The production of PVC in China (Taiwan) has reached 7,000 tons per month, an amount which exceeds domestic requirements. Approximately 70 per cent of the output is processed by subsidiary companies of the resin producers and only 10 per cent is processed by independent processors. Nan Ya Plastics Fabrication Company, a subsidiary of Formosa Plastics Corporation, is now increasing its number of calenders from 14 to 16 or 18. Its processing capacity is 3,000 tons per month, which ranks it as one of the largest producers of PVC in the world. About 20 per cent of the resin is exported to the territory of Hong Kong, the Republic of Korea, the Republic of Viet-Nam and other countries. Approximately 2,500 tons per month of PVC products such as sheet, film and raincoats have been exported to Australia, Canada, South-East Asia and the United States. The 2,500 tons of exported goods are worth $7.55 million per year.

In Hong Kong the import of PVC resin (table 41) was 5,355 tons in 1962, 8,749 tons in 1963, 12,038 tons in 1964, 8,727 tons in 1965, 8,316 tons in 1966, and was expected to increase to about 12,000 tons in 1967. The resin consumption is detailed in table 16 below. The decrease in the consumption of PVC resin in recent years was a result of the lower import of PVC products by Indonesia and the establishment of sandal and shoe plants in the Near East and Africa. There are about ten companies that produce sandals and other products, e.g. Nylex Plastics Ltd, Wofou Enterprise, Thian's Plastics Industry Company and Kwong Yue Plastics Company, and each consumes more than 100 tons of PVC resin per month.

There are many plastics processors in East Pakistan where the main business activity is manufacturing shoes. Approximately 600 tons of resins are consumed

TABLE 16 CONSUMPTION OF PVC RESIN BY TYPE AND PRODUCT IN HONG KONG, 1964-1966

(tons)

Type of PVC resin	*Product*	*1964*	*1965*	*1966*
Soft	Film and sheet	1,500	1,550	1,600
	Leather	300	320	380
	Injection moulded items	6,500	4,000	3,500
	Flooring material	150	80	20
	Wire and cable insulations	70	80	20
	Compound for export	1,800	1,000	500
	Slush moulding	1,300	750	700
Rigid	Phonograph records			5
	Plates	30	120	500
	Pipe and conduit	120	150	160
Others		80	100	400
TOTAL		11,850	8,150	7,785

annually for this purpose, and Bella Artifitex Industries has consumed more than 300 tons of PVC a year for coating leather and for extruding sheet and film. In West Pakistan there are about 30 PVC processing plants that manufacture primarily soft products such as garden hose and sandals. Only two companies, SRS Industry Company and Basco Industries, were producing calendered sheet and rigid PVC products in 1966 based on Japanese techniques. These companies suffered from a shortage of PVC resin and for a long period of time their plants could not work to full capacity. This was partly a result of import market fluctuation which sometimes prevented them from importing PVC resin. Arokey Chemical has started domestic production, and two other companies are each planning to construct a 5,000-ton-capacity PVC resin plant.

In Iran the main products made of PVC are shoes, leather, sheet and garden hose. Each of four companies, Plastico Kar, Wien Shoes, Bella Shoes and Zardoshty, consumes more than 100 tons of PVC per month. There are other small-scale manufacturers of soft, plasticized PVC products and several small processors of rigid products who follow the example of Polyca Factory, the first rigid-PVC-pipe plant owned by the Government.

The largest single use of PVC resin in India is for calendered products such as leather-cloth, sheet and film. Two companies, Bhor Industries Ltd and Caprihans (India) Ltd, have been operating since 1964. Another important field is wire and cable coating in which six companies, Delton Cable Company, India Cable Company, National Conductors, Radio and Electricals Manufacturing Company, Reliable

Electric and Cable Company and Plastic Moulders Ltd have been operating The estimated total demand for PVC resin was approximately 30,000 tons in 1967 Domestic production was not sufficient to cover this figure thus some resin had to be imported

In Thailand the demand for PVC compound is between 170 and 210 tons per month and most of it is used in the five wire and cable companies This industry is growing at a rate of 10 to 12 per cent per year Major demands include garden hose and rigid pipe which account for approximately [illegible] tons per month in compound Almost all the PVC film, sheet and leather have been imported Most of the PVC processors are very small

In Malaysia the demand for PVC compound ranges from 150 to 200 tons per month Most of the processors are small producers of garden hose with the exception of Malayan Cable which consumes almost 100 tons of compound per month

In Singapore the monthly demand for PVC compound is between 200 and 250 tons. Approximately twenty processors including Camel Industry Corporation a subsidiary of China Plastics, Signa Cables and Yamatai Plastics, have produced sheet leather, garden hose, tile wire and cable rigid pipe and others

In the Republic of Korea, PVC resin has been produced solely by Daihan Plastics. The number of processing plants is very limited and the PVC resin producers are planning to proceed with the construction of their own processing plants When this takes place, it is expected that the consumption of PVC will increase rapidly

In the Philippines there are many plastics processors such as REHCO Plastics Incorporated of Quezon City and Philippine Fabrikoid Incorporated The PVC products of these major producers include wire and cable vinyl tile sheet and other products. The Mabuhai Rubber PVC plant is in full operation and the resin demand is balanced with the resin supply by Mabuhai

It has already been indicated that among ECAFE countries the production of PVC in China (Taiwan) has already exceeded the domestic demand This will also be the case in Iran and the Republic of Korea when the proposed plants in those countries go on stream. It is more difficult to build many processing plants in the other ECAFE countries, therefore, the above-mentioned and future PVC resin manufacturers must find an outlet for their increased production Processing industries set up under the ownership and control of resin manufacturers facilitate the export of PVC products instead of the resin itself

In general, PVC is a more difficult resin to process than polyethylene or polystyrene. It is necessary to add plasticizers and stabilizers in PVC processing to make flexible and soft products The processing of PVC in various forms also requires more complex techniques, especially to produce the rigid type of PVC, PVC processors therefore require more assistance from resin manufacturers in order to ensure good processing. It is, in this case, good practice for a resin manufacturer to own part or all of the PVC processing plant

Polystyrene

India and China (Taiwan) are the only two ECAFE countries manufacturing polystyrene Production in India was begun by Polychem Ltd in July 1957, at which time styrene monomer was imported. Later the monomer was domestically supplied by manufacturing ethylene from alcohol. Hindustan Polymer started making monomer and polymer by obtaining ethylene from the Caltex refinery in 1963. Nandlal Koppers and Synthetics and Chemical are also producing styrene monomer for different uses but they are not making polystyrene.

In China (Taiwan) Ta-Ta began production of polystyrene with imported styrene monomer in 1964. The new polystyrene plant of Lin Chui Yuan Company is now under construction. The Chinese Petroleum Corporation will begin operations in its naphtha cracker and styrene-monomer plant in 1968. This will enable the companies mentioned above to obtain their monomer supply domestically.

As table 12 shows, Japan exported 8,159 tons of polystyrene to the ECAFE countries in 1966, an estimated 20 per cent of the total imports of these countries. The total consumption of polystyrene will be approximately 48,000 tons in these countries when the production capacity is increased as planned in China (Taiwan) and India. Hong Kong controls the largest share, 46 per cent, of this total consumption estimate. Hong Kong imported about 22,000 tons of polystyrene in 1965 from Canada (6,700 tons or 31 per cent), the United States (5,000 tons or 23 per cent), Japan (3,100 tons or 14 per cent) and Australia (2,300 tons or 10 per cent). The main uses of polystyrene are for electrical parts, containers and household ware. In Hong Kong and Thailand, the consumption of polystyrene is the second largest of all plastics. Consumption of the resin is increasing in India and Pakistan. The use of polystyrene as foam in the packaging industry of developing countries would increase consumption of the resin.

Phenolic resin

In the ECAFE region, China (Taiwan) and India are the two phenolic-resin-producing countries. The moulding business in India, based on imported phenolic formaldehyde moulding powder, started in the early 1930s. The production of phenolic moulding powder in India was started in 1946 and was based on imported phenol and formaldehyde. The production of phenolic resin did not reach 1,000 tons per year until 1957. Since 1961 five companies, Indian Plastics, the Industrial Plastics Corporation, Rawji Awarji, Saurashtra Electrical and Metal Industries, and Hyderabad Laminated Products, have operated plants with capacities totalling approximately 4,500 tons per year. In addition to moulding powder, phenolic laminates have been produced by two companies, Hyderabad Laminated Products and Coprihans (India) Ltd. Thirteen smaller companies produce electrical accessories.

The main applications for phenolic resin are electrical parts, electric insulating material and mechanical parts such as gear wheels, paint and adhesives. The rate of consumption is lower than that of thermoplastics and increases more slowly.

Urea resin

Urea resin is produced in China (Taiwan), India and the Republic of Korea, and is used mainly in adhesives for making plywood.

About 90 per cent of all the thermosetting resins used in China (Taiwan) go into the plywood and lumber industry. At the same time, about 90 per cent of the urea-formaldehyde resin is used in plywood production. The raw material for plywood is the timber that Taiwan imports from the Philippines. The industry was started in order to satisfy domestic consumption in China (Taiwan), but it has grown rapidly to its present size and is now earning valuable foreign exchange by exporting a large share of the products.

In India the consumption of urea-formaldehyde adhesives increased steadily during the first two Five-Year Plans, leading to their commercial production in 1961. The producers (Allied Resins and Chemicals and Indian Plywood Manufacturing Company) controlled 70 per cent of the total urea-resin output. Approximately 30 per cent of this figure is represented by moulding powder, the production of which was started in 1956 by four companies (Allied Resins and Chemicals, Simpson and Company, Atul Products and Rattanchnd Harjasrei Plastics), with a total capacity of 4,600 tons per year.

In Singapore a new plant (Singapore Adhesives and Chemicals) started work in the summer of 1967 making adhesives for plywood.

The outlook for plywood manufacture in the ECAFE countries is very hopeful and the use of urea resin is expected to increase correspondingly.

Other synthetic resins

There are many other resins that have not been mentioned in the above paragraphs, such as polypropylene, epoxy resins, acrylic resins and so on. Polypropylene is consumed in China (Taiwan), Hong Kong, Pakistan, Thailand and other countries. Polyester resins have been used in China (Taiwan), Hong Kong and elsewhere. Alkyd resins have been produced in India and the Republic of Korea.

Plastics machines and equipment

The basic processes for synthetic resins are compression moulding, injection moulding, extrusion and calendering. Other processes, such as slush moulding, blow moulding, vacuum forming, rotational moulding, transfer moulding, fluidized bed coating and injection blow moulding, are not as basic as the above, but are nevertheless employed in various ways.

The machines that predominate in developing countries are extruders, injection machines, inflation machines (a type of extruder) and presses for compression moulding. As table 17 below shows, extrusion and injection moulding are very popular for producing low-density polyethylene. Injection machines are used mainly for polystyrene. Soft PVC products are produced by extrusion and calendering. Calendering is particularly suitable for processing high-grade sheet and leather products. Extrusion and injection moulding are popular methods for producing rigid PVC products. Compression moulding has been used for processing thermosetting resins. The use of injection-moulding machines for thermosetting resins is a recent application with a bright future.

The machine used in the calendering process is the most expensive and requires the most experience to operate. This is one reason why only a minimum of calender equipment has been installed in developing countries. Companies with calender machines in 1967 were Nan Ya Plastics Fabrication Company in China (Taiwan), Yamatai Plastics in Singapore, Philippine Fabrikoid in the Philippines, SRS Industry Company and Basco Industries in Pakistan, Zardoshty in Iran, and Bhor Industries Ltd and Caprihans (India) Ltd in India. The Nan Ya Plastics Fabrication Company, with fourteen calenders, was the largest plant. Other companies had one or two units each.

Extruders and inflation machines are suitable for mass production and are most popular for the production of packaging film, sheet, tube, pipe, rattan and garden hose in the ECAFE countries. Soft products, such as polyethylene film or soft PVC

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ERRATA
ID/SER.J/4
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Page 3 1st paragraph, line 13: *Change* 25 to *2.5.*

Page [illegible] Table 1, line 2 (metals), 1966 column: *Change* 14.5 to *145.0.*

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TABLE 17. CONSUMPTION OF SELECTED PLASTICS BY PROCESS IN THE UNITED STATES, 1966

(millions of pounds)

Process	*High density polyethylene*	*Low density polyethylene*	*PVC resin*	*Polystyrene*
Injection moulding	195	385	210	1,270
Blow moulding	400	50		
Pipe and conduit	50	65	180	
Film and sheeting	45	1,100	465	
Wire and cable	30	265	251	
Other extrusions			145	354
Coating	10	325	210	170
Roto moulding	5	15	45	
Floor covering			370	
Miscellaneous (foam etc.)	65	85	269	483
Export	100	350	70	123
TOTAL	900	2,640	2,215	2,400

Source: Modern Plastics, January 1967.

garden hose and tubes, are especially popular because complex technology is not required. Theoretically, the design of extruders for polyethylene should be different from that of extruders for soft PVC. If the same machine is used for both processes, the products are not always satisfactory.

The injection-moulding machine is popular for making moulded products, but requires a new mould for each change of pattern. The expenses and complex technology necessary in making a mould have been a burden for the processors. The same injection machine can be used in many cases for different resins, however, the mould must be changed in order to correspond to the different properties of the resins to be moulded. In order to advance this moulding process, a firm should be established specifically to manufacture moulds for processors.

Plastics processing machines, including moulds, are presently being manufactured locally in Hong Kong. Machines such as the fully automated hydraulic injection-moulding machine with a screw pre-plasticizer can also be manufactured. Hong Kong Technical College is reportedly considering offering courses on mould making so as to increase the number of mould technicians.

In India plastics machines and equipment were imported until several years ago. The production of mould and processing machines was included in the Third Five-Year Plan. Windsor India and Pecos of the United Kingdom have established plants in Bombay, and Eagle of Australia has built a plastics-machinery plant in Calcutta.

TABLE 18. COMPARISON OF COSTS OF MAKING ETHYLENE FROM CANE SUGAR AND ETHYL ALCOHOL

(A) Small-scale production of ethylene[a]

Item	*Quantity*	*Estimated annual costs of production*				
		@		*Annual amount (dollars)*	*Accumulated total (dollars)*	*Cost/ton of ethylene (dollars)*
Ethyl alcohol	5,500 tons	$100	=	550,000		
Catalyst etc.				1,000		
Maintenance	$400,000	5%	=	20,000		
Labour	15 men	$4,000	=	60,000		
Utilities						
Water	212,000 m^3			100,000	731,000 (direct cost)	252
Steam 75 psig[b]	7,270 tons					
Electricity	290,000 kWh					
Fuel oil	260,000 kWh					
Refrigeration	378 million kcal					

Depreciation	$400,000	15%	=	60,000		
Interest	$400,000	7½%	=	30,000		
Supervision and control				30,000	851,000 (net cost)	293
Profit	$600,000	15%	=	90,000	941,000 (cost of production)	324 = 14.6 cents/lb

By comparison,

(B) In Japan, a naptha-based medium-scale plant in 1965 produced ethylene at 5 cents/lb

(C) In the United States a 200,000 tons/year plant produced ethylene at 2.5 cents/lb

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[a] Size of plant: 2,900 tons ethylene/year, investment $400,000, raw material Cane sugar ethyl alcohol, cost of production 14.6 cents/lb as shown.

[b] psig = lb/in^2 gauge (above atmospheric pressure).

In the other ECAFE countries plastics machines have been imported from the Federal Republic of Germany Hong Kong Japan the United Kingdom and the United States The quality of plastics machines and moulds contributes to the quality of plastic products and it is therefore very important to raise the level of production techniques

1 3 Raw materials and production costs of important synthetic resins

As was mentioned in chapter 1 2 polyethylene polyvinyl chloride polystyrene and urea formaldehyde resins are the main synthetic resins in the ECAFE countries The raw materials and the production costs for each of the resins based on various plant capacities will now be reviewed

Polyethylene

Since the raw material for polyethylene is ethylene the production of ethylene greatly influences the production of polyethylene The sources for the production of ethylene in the ECAFE countries are alcohol (India and Pakistan) naphtha cracking (China (Taiwan) India and Japan) and natural gas (Iran) Natural gas can only be used as a raw material in countries like Iran where abundant natural gas is available at reasonable cost It is reported that India and Pakistan have good supplies of natural gas in some areas of their countries where this process could be employed The first raw material alcohol was used by Alkali and Chemical Corporation of India a subsidiary of ICI in 1959 and by Union Carbide India in 1961 These plants however suffered from the unstable supply and high price of fermentation alcohol and concluded that a switch from alcohol to naphtha was necessary Union Carbide India has already replaced alcohol by naphtha from the Esso refinery in Trombay Synthetics and Chemicals has been producing ethylene from alcohol for making styrene monomer since 1963 Chemicals and Plastics in 1967 began to produce ethylene from alcohol for making PVC It is interesting to note that the raw material for ethylene is different for each ethylene plant in India This is a result of the availability and cost of the various raw materials near the plant In Pakistan, Valika Chemical Industries has used alcohol as a raw material for making 5,000 tons of polyethylene per year, but it will use ethylene from the naphtha cracker after production is expanded

The disadvantage of alcohol as a petrochemical raw material is its unstable supply The production of alcohol is dependent on the supply of molasses and some other carbohydrates, however, because the other carbohydrates are necessary as food molasses is almost the only raw material available The full utilization of molasses and the maintenance of adequate supplies for every distillery are difficult to co-ordinate with such seasonal production The storage and transport of molasses cause additional problems because molasses is a heavy, viscous liquid which must be maintained at a high temperature and kept free of humid conditions Molasses is expensive on the world market, and it is widely in demand, therefore, the production costs of alcohol are increasing year by year In developed countries, so as to reduce costs, alcohol is now synthesized from ethylene and the fermentation method is going out of use

Alcohol-based fermentation is not competitive even in developing countries unless the finished products are marketable at three times or more the price of a

TABLE 19 COST OF PRODUCTION OF LOW-DENSITY POLYETHYLENE BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)	25 000	50 000	75 000	100 000
Cost of plant (millions of dollars)	11.7	20.0	27.8	35.6
Cost of ethylene (cents/lb)	*Cost of low density polyethylene (cents/lb)*			
3.1	14.91	13.43	12.69	12.35
3.75	15.57	14.09	13.36	13.01
4.375	16.23	14.76	14.02	13.67
5.0	16.89	15.42	14.68	14.33
5.625	17.56	16.09	15.34	15.00

TABLE 20 COST OF PRODUCTION OF HIGH-DENSITY POLYETHYLENE BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)	10 000	20 000	40 000	60 000
Cost of plant (millions of dollars)	6.1	10.0	17.78	25.0
Cost of ethylene (cents/lb)	*Cost of high density polyethylene (cents/lb)*			
3.1	14.91	13.43	12.69	12.35
3.75	15.57	14.09	13.36	13.01
4.375	16.23	14.76	14.02	13.67
5.0	16.89	15.42	14.68	14.33
5.625	17.56	16.08	15.34	15.00

possible medium-sized petrochemically originated product. The fermentation process is not suitable for mass production and the labour cost is gradually increasing. Table 18 shows the costs of alcohol-based ethylene compared with naphtha-based ethylene.

Ethylene from naphtha cracking is considered to be the best choice when new polyethylene production is planned in an area where no natural gas supply exists. Table 19 shows the effect of plant size and cost of ethylene on the production cost of low-density polyethylene. Table 20 shows the same relationship for high-density polyethylene. The details of synthesis will not be explained here.[2]

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[2] For additional information, please refer to *Manufacture of Plastics*, edited by May and Smith, Reinhold Publishing Corporation, New York; *Reinhold Plastics Application Series*, Reinhold Publishing Corporation, New York; and *Kirk-Othmer Encyclopedia of Chemical Technology*, 2nd edition (1957) Interscience Publishing Company, New York.

Polyvinyl chloride

The raw material used for PVC resin is acetylene or ethylene. Acetylene may be manufactured from calcium carbide derived from limestone and coal or by cracking natural gas or naphtha.

Calcium carbide derived from limestone and coal has been used to produce acetylene in China (Taiwan), India, Japan, the Philippines and the Republic of Korea.

The second process, acetylene from cracking natural gas, was developed by Montecatini of Italy and was licensed to Diamond Alkali of the United States and Shinetsu Chemical of Japan. There are many flaws in this process and these plants are not operating very well.

Only one plant has been proposed based on the third process, acetylene from naphtha cracking, developed by BASF (Badische Anilin- und Soda-Fabrik). A recent tendency is to select ethylene instead of acetylene as the raw material because of the high cost of acetylene. In addition, the production of acetylene requires a large amount of power in order to produce calcium carbide in electric furnaces. Thus, the cost of production is apt to increase as power costs increase. There is very little chance of reducing the cost of producing acetylene from calcium carbide, but the cost of ethylene is expected to decrease as larger naphtha-cracking furnaces are established.

In general, the consumption of power in a country tends to increase in accordance with industrialization and improvements in the standard of living. The power supply cannot meet the demand because of high investment costs and the time required to install additional equipment for power supply. In China (Taiwan) the increase in the consumption of power in industry and in the home has brought about restrictions every year during the dry season. The price of power for making calcium carbide is 0.72 cents per kilowatt-hour for an installation of 10,000 or more kW, a figure which is very low compared with that for other industries. During the dry season, December to March, the power supply for carbide production is the first to be cut, resulting in an increase in the price of carbide. PVC manufacturers are therefore thinking of changing from acetylene as a raw material to ethylene as soon as the naphtha-cracking plant of the Chinese Petroleum Corporation is completed, which at the time of writing (October 1967) was predicted for 1968. In India the operation of the calcium carbide and chlorine plants is often disturbed by the shortage of power. In Malaysia the feasibility study for making PVC resin from calcium carbide did not materialize owing to the high cost of power (2.5 cents per kilowatt-hour).

The countries producing calcium carbide in the ECAFE region are China (Taiwan), India, Japan, the Philippines and the Republic of Korea. Power costs in these countries are much less than in the other ECAFE countries. Most of the PVC producers in Japan have, however, been changing from acetylene as a raw material to ethylene, a change which is also being considered by producers in China (Taiwan) and India. This is why it is difficult to use the calcium carbide process in those ECAFE countries where power costs are high.

The relationship between power costs and the costs of calcium carbide and acetylene is shown in table 21 below.

TABLE 21. PRODUCTION COSTS OF CALCIUM CARBIDE AND ACETYLENE, BASED ON COST OF POWER

Cost of power (cents/kWh)	0.28	0.42	0.56	0.69	0.8[illegible]	0.97	1.25	1.53	1.81
Cost of calcium carbide (dollars/ton)	48.81	52.98	57.14	61.31	65.48	69.64	77.98	86.31	94.64
Cost of acetylene (cents/lb)	7.43	8.02	8.60	9.18	9.76	10.34	11.50	12.69	13.83

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7.8.73

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, VIENNA

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FOREWORD

This publication is the fourth of a series of monographs in the Petrochemical Industry Series to be published by the United Nations Industrial Development Organization. The titles of other studies in this series will be found on the back cover of this publication.

The world petrochemical industry has shown a high rate of growth during the last ten years. The industry supplies intermediate products for a number of othe industries and provides substitutes for traditional materials such as steel, lumber, packaging materials, natural fibres, natural rubber and soap. It is considered to be one of the most strategic sectors of industrial development because most of its products go on to other producing sectors.

This series of monographs is designed to assist the developing countries in dealing with technical and economic problems related to the establishment and development of facilities for the manufacture of petrochemicals and consumer products. The present series is concerned with basic and intermediate petrochemicals and end products, such as plastics, synthetic rubbers and synthetic fibres. Nitrogenous fertilizers[1] and textile production based on synthetic fibres are excluded from the series.

The present report was prepared in October 1967 by Mr. Masashi Honda and Mr. Mitsuru Kakimi serving as consultants to UNIDO. The views and opinions are those of the consultants and do not necessarily reflect the views of the secretariat of UNIDO.

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[1] See the Fertilizer Industry Series published by the United Nations Industrial Development Organization (ID/SER. F, Nos. 1, 2, 3, 4 and 5).

Explanatory notes

Reference to tons is to metric tons unless otherwise stated.

Reference to dollars ($) is to United States dollars unless otherwise indicated.

Reference to gallons is to US gallons (3.785 litres).

A one-year period that is not a calendar year is indicated as follows: 1965/1966.

A period of two years or more is indicated as follows: 1965-1966, 1965-1968 etc.

2 OF 3

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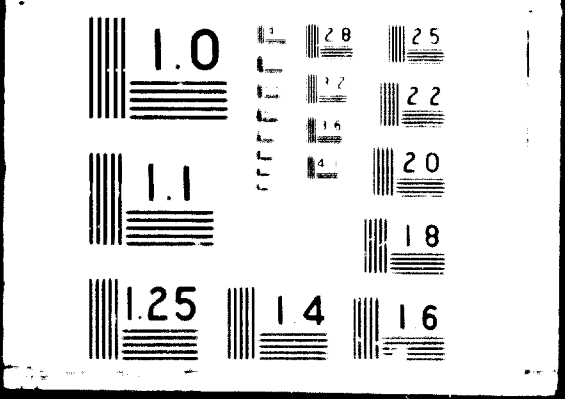

The processes for producing vinyl chloride monomer from ethylene include the following:[3]

(a) Ethylene dichloride (EDC), which is made with ethylene and chloride, is cracked to make vinyl chloride monomer and hydrogen chloride. Hydrogen chloride is sold in that form or is reacted with acetylene from carbide to produce additional vinyl chloride monomer;

(b) Hydrogen chloride in the above *(a)* process is used to recover chlorine which is re-cycled to react with ethylene;

(c) Ethylene dichloride is produced from ethylene, hydrogen chloride and oxygen, and is cracked to make vinyl chloride monomer and hydrogen chloride which is re-cycled (oxychlorination process);

(d) The diluted mixed ethylene and acetylene gas derived from naphtha cracking is reacted with re-cycled hydrogen chloride, producing vinyl chloride. The remaining gas, mainly ethylene, is reacted with chlorine to produce EDC, which is then cracked to vinyl chloride monomer and hydrogen chloride to be re-cycled. No hydrogen chloride remains as a residual (balanced process).

A recent tendency in the developed countries is to emphasize the use of the oxychlorination process, while reserving the balanced process for those areas where naphtha is plentiful and inexpensive and ethylene is not available. In developing countries, if the PVC plant is constructed in a petrochemical complex, the

TABLE 22. PRODUCTION COST OF VINYL CHLORIDE MONOMER USING ACETYLENE PROCESS, BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)		12,000	24,000	48,000	96,000
Cost of plant (millions of dollars)		1.11	1.67	2.50	3.75
Cost of acetylene (cents/lb)	*Cost of hydrogen chloride (cents/lb)*	*Cost of vinyl chloride monomer (cents/lb)*			
8.75	1.25	6.12	5.78	5.55	5.38
8.75	1.875	6.50	6.16	5.93	5.76
8.75	2.50	6.87	6.54	6.30	6.13
11.25	1.25	7.20	6.86	6.63	6.46
11.25	1.875	7.57	7.23	7.00	6.83
11.25	2.50	7.95	7.61	7.38	7.21

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[3] For additional information see the following periodicals: *European Chemical News*, London, September 11, 1964, p. 31; August 28, 1964, p. 26; May 6, 1966, p. 32; August 21, 1964, p. 27; *Chemical Week*, New York, August 22, 1964, p. 93; September 24, 1966, p. 71; *Hydrocarbon Processing*, Houston, 43(11),165; *Chemical Engineering* New York, November 21, 1966, p. 102.

Interest rates

Table 30 compares the prime rates of interest in countries in the ECAFE region, Europe and North, Central and South America. The comparison demonstrates that the ECAFE, Central and South American countries have much higher interest rates than do European countries. Developing countries generally have high rates in comparison to developed countries. Of course, it is true that the prime rates of interest do not always correspond with the actual borrowing rates in a certain country. Sometimes the prime rates are maintained because of various regulations controlling the volume and flow of currency; the prime rates that have remained unchanged since 1959 are examples of this. Nevertheless, the prime rates give a fair indication of the actual rates of interest.

High rates of interest are often the result of policies designed to control inflationary tendencies in developing countries. Such a situation makes it particularly difficult for the resin-producing industry to get started since it needs high investment which must be tied down for one year before sales can begin. The amount of capital must be considered carefully so that the resin producers are able to obtain some low-interest capital from public sources along with high-interest private capital. The processors do not have serious problems of this nature. The borrowing of machines from a governmental financial organization under a hire-purchase arrangement must be considered by the resin producers.

Import duties

Some developing countries charge high tariffs on plastic resins and products. The following are examples of current rates of duty in the ECAFE countries as of 1967.

Australia	PVC resin	60% of CIF (cost, insurance, freight) value, or fair value in exporting country, whichever is higher, plus 90% of the difference between CIF value and support value of \$510 per ton when CIF value is lower
	Polyethylene resin	60% of CIF or fair export value, plus 90% of the difference between CIF and support value of \$540
China (Taiwan)	PVC resin, polyethylene and any manufactured article produced primarily from these materials	
	Duty rate	$45\% \times \frac{\text{wholesale (dutiable) value}}{1 + 0.45 + 0.14}$
	Harbour dues	3% of dutiable value
	Defence surtax	20% of duty
	Internal tax	$17\% \times \frac{\text{average wholesale value}}{1 + 0.17 + 0.10}$
India	PVC resin	25% *ad valorem* of CIF value, plus 24% excise tax on CIF and duty amount
	Polyethylene	25% *ad valorem* of CIF value, plus 24% excise tax on CIF value and duty amount

Japan	PVC resin Polyethylene	20% *ad valorem* of CIF value 20% *ad valorem* of CIF value
Pakistan	PVC resin Polyethylene	25% *ad valorem* of CIF value 24% *ad valorem* of CIF value
Philippines	PVC resin Polyethylene	20% *ad valorem* of CIF value 20% *ad valorem* of CIF value

These figures indicate that some countries charge high rates of duty, while others charge 20% of the CIF value. The latter method generally produces the lower figure.

It has been the practice in most countries to charge high rates of duty for the protection of the domestic industry in the growing stages, because a newly established industry could easily be hurt by a more developed one. This consideration is particularly important in chemical and plastics industries. It is however not always necessary to levy high duties on every item. Different policies must be followed in certain circumstances.

In general, the chemical industry requires large investments. The competition between a new plant with all initial expenses and depreciations and an old plant with these costs already taken care of is not fair. Certain factors must be adjusted before the two plants can compete.

Another consideration is economy of scale. The plastics industries in developing countries are usually smaller than those in more advanced countries. The economy of scale works in favour of the country already in operation. The late-comer has one advantage: his chance to obtain the newest method for his plant. Technical innovation in a developing country can always give it a decisive edge over developed countries. The newest process should be employed wherever possible despite the fact that it is not always the easiest way to get started.

The following suggestions on rates of duty will help to develop good economic conditions for an integrated plastics industry.

(a) Import duties on resins, additives, plasticizers and processing machines should be kept down so as to stimulate domestic consumption,

(b) Establishing "free zone" or "duty draw-back" systems is helpful in encouraging export of processed articles, increasing domestic processing capacity and preparing for future domestic resin production,

(c) The rate of duty should be adjusted whenever a resin or machine or some other item is produced domestically. A reasonable amount of competition should be maintained in such a protective duty schedule. An over-protected industry cannot always be motivated to constantly improve its own production system,

(d) It is advocated that monomers should be produced jointly among several countries in order to enjoy the advantages of a large plant. In this case, special allowances have to be made for items imported from this plant. The production of a monomer in a jointly-owned centre should be regarded as production within one's own country, and duty should not be levied for these imported items,

(e) The revenue aspect of import duties should be eliminated as much as possible. Growing industries always have a shortage of low-interest cash. When duty is paid in cash before anything starts, high interest rates can burden the finances of the industry.

1.5 The plastics market in developing countries

General outlook for the market

The total world consumption of plastics is now about 15 million tons per year. This figure includes thermoplastic and thermosetting resins, including some cellulose modified plastics. The total figure is expected to increase by 1975 to 50 million tons per year (see table 31).

The expansion of the plastics industry is much greater in some countries than in others. It is believed that expansion in the ECAFE countries will bring about a larger than average increase in the consumption of plastics; therefore, the market for the plastics industry in ECAFE developing countries is itself ready for development.

Tables 32 through 39 below show that a fair amount of plastics has been imported into the ECAFE countries. This flow of imports should be maintained in order to meet increased domestic requirements. Plants being built in these countries should be able to compete successfully with the imports that are often shipped from large, economical plants. Domestic production should be reasonably competitive in price and should be able to accommodate the local requirements of quality grades, technical services and management services. On this basis, domestic products will have definite advantages over imported goods and will enjoy their own domestic market.

The market for plastics is divided basically into the following categories: consumer goods, industrial and electrical parts, agricultural pipes and sewers and other civil applications.

It is difficult to forecast requirements for consumer goods. The industrial and agricultural uses are co-ordinated with the plans for industrial and agricultural expansion, and the size of the market can be planned. Plastics first replace existing materials. Metal is replaced by PVC resin, some polyethylene, polypropylene, polycarbonate, phenolic resin and nylon. Appliance parts and conduit tubes made of plastic are already accepted. Irrigation pipes and water systems are the important end-uses for plastic pipes of PVC and polyethylene. Cellulose, natural fibre, leather and rubber are also replaced by PVC, polyethylene, polypropylene and some polystyrene. Wood and lumber can partially be replaced, and building materials in general can be made of plastics. Polystyrene-polyethylene modified materials are expected to replace paper in some applications.

It has been found that the creation of new uses for plastics in existing markets is usually accompanied by an expansion of production capacity and a price reduction. Plastics have become indispensable in many areas. One of the major end-uses is packaging because plastics offer sanitary and attractive packaging at a very low cost. This situation has advanced the already extensive use of films. Fertilizer and agricultural products will soon be packed in heavy gauge (or woven) plastic bags. Some plastics have been used for disposable items in the household article market. New adhesives and coatings made of plastics are more useful than those made of other materials. The consumption of plastics is increasing, like that of other materials.

TABLE 31. WORLD PRODUCTION AND CONSUMPTION

(thousands

Country	*Production*	*1960–1962* *Consumption*	*Balance*	*Production*	*1963–1965* *Consumption*	*Balance*
Africa, Asia (except Japan) and Latin America	180	557	– 377	360	1,080	– 720
Canada	153	176	– 23	226	266	– 40
France	380	380	0	590	600	– 10
Germany, Fed. Rep.	1,080	830	+ 250	1,700	1,290	+ 410
Italy	400	340	+ 60	740	540	+ 200
Japan	700	690	+ 10	1,350	1,240	+ 110
United Kingdom	625	500	+ 125	880	730	+ 150
United States	3,200	2,850	+ 350	4,650	4,150	+ 500
USSR	400	430	– 30	750	800	– 50
EEC countries not named	145	220	– 75	290	370	– 80
Remaining Western European countries	220	440	– 220	390	770	– 380
Remaining Eastern European countries	320	390	– 70	550	640	– 90
TOTAL	7,803	7,803		12,476	12,476	

OF PLASTICS, DISTRIBUTED BY COUNTRY

of tons)

	1970 (estimated)			*1975 (estimated)*		*Growth between 1963–1965 and 1975*	
Production	*Consumption*	*Balance*	*Production*	*Consumption*	*Balance*	*Production (per cent)*	*Consumption (per cent)*
1,180	2,121	– 941	2,100	3,745	– 1,645	583	347
446	555	– 109	755	970	– 215	334	365
1,310	1,340	– 30	2,260	2,320	– 60	383	386
3,290	2,450	+ 840	4,400	3,800	+ 600	258	294
1,850	1,300	+ 550	3,360	2,350	+ 1,010	454	435
3,260	2,300	+ 960	5,500	4,500	+ 1,000	407	363
1,580	1,400	+ 180	2,400	2,250	+ 150	272	308
8,900	8,200	+ 700	13,800	13,300	+ 500	296	320
2,260	2,560	– 300	6,150	6,500	– 350	820	813
750	800	– 50	1,380	1,370	+ 10	476	370
870	1,770	– 900	1,700	3,000	– 1,300	436	390
1,650	1,550	+ 100	3,640	3,340	+ 300	662	522
27,346	26,346		47,445	47,445		380	380

TABLE 32. AUSTRALIA: PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954 1956	*1957 1959*	*1960 1962*	*1963 1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	14	29	59	100	242	440	440
Imports	10	21	49	57	130	110	193
Consumption	24	50	108	157	372	550	350
Points of reference							
Population (millions)	9.2	9.8	10.5	11.1	12.3	13.3	119
GNP[b] (1,000 million $)	13.1	14.7	16.5	19.0	25.0	31.0	163
GNP *per capita*[b] ($)	1,427	1,489	1,569	1,709	2,035	2,380	
Consumption *per capita* (kg)	2.6	5.0	9.5	14.0	26.3	40.5	

[a] Rate of growth between 1963–1965 and 1975.
[b] 1964 value is used for GNP.

TABLE 33. CHINA (TAIWAN): PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954– 1956	*1957– 1959*	*1960– 1962*	*1963– 1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	1.8	3.2	13.6	36.5	107	230	630
Imports	–	--	–	8.0	21	25	312
Exports	--	–	0.3	–	--	–	
Consumption	1.8	3.2	13.3	44.5	128	255	572
Points of reference							
Population (millions)	8.9	9.9	11.0	12.1	13.9	15.7	
GNP[b] (1,000 million $)	1.3	1.6	2.0	2.5	3.9	5.5	
GNP *per capita*[b] ($)	150	162	182	210	183	352	
Consumption *per capita* (kg)	0.1	0.3	12.0	3.7	9.0	17.0	

[a] Rate of growth between 1963–1965 and 1975.
[b] 1964 value is used for GNP.

TABLE 34. INDIA: PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954–1956	*1957–1959*	*1960–1962*	*1963–1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	0.9	3.7	19.5	37	135	400	1,080
Imports	6.9	14.3	13.0	20	45	100	500
Consumption	7.8	18.0	32.5	57	180	500	877
Points of reference							
Population (millions)	387	411	439	472	543	611	
GNP[b] (1,000 million $)	29.5	32.0	36.5	40.7	49.5	61.7	
GNP *per capita*[b] ($)	76	78	83	86	91	101	
Consumption *per capita* (kg)	-	–	0.1	0.2	0.3	1.0	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

TABLE 35. JAPAN: PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954–1956	*1957–1959*	*1960–1962*	*1963–1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	116	298	700	1,350	3,270	5,550	412
Imports	6	7	–	–		–	770
Exports	–	–	10	130	520	1,000	
Consumption	122	305	690	1,220	2,750	4,550	373
Points of reference							
Population (millions)	89	92	94	97	102	105	
GNP[b] (1,000 million $)	30	37	53	69	103	137	
GNP *per capita*[b] ($)	334	405	566	720	1,007	1,286	
Consumption *per capita* (kg)	4.1	8.2	13.0	17.5	27.0	43.0	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

TABLE 36. UNION OF SOVIET SOCIALIST REPUBLICS: PRODUCTION AND CONSUMPTION OF PLASTICS

(thousands of tons)

	1954–1956	*1957–1959*	*1960–1962*	*1963–1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	177	258	400	750	2,250	6,150	820
Imports	3	12	30	50	300	300	600
Consumption	180	270	430	800	2,550	6,450	806
Points of reference							
Population (millions)	196.2	206.8	218.0	227.7	245.7	260.8	
GNP[b] (1,000 million $)	122.9	161.8	202.1	241.7	343.3	448.5	
GNP *per capita*[b] ($)	626	782	927	1,061	1,397	1,720	
Consumption *per capita* (kg)	0.9	1.3	2.0	3.5	10.5	25	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

TABLE 37. NORTH AMERICA: PRODUCTION AND CONSUMPTION OF PLASTICS

(thousands of tons)

	1954–1956	*1957–1959*	*1960–1962*	*1963–1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	1,730	2,380	3,360	4,860	9,300	14,700	303
Exports	100	250	360	460	900	500	109
Consumption	1,630	2,130	3,000	4,400	8,400	14,200	323
Points of reference							
Population (millions)	181.7	192	202	211	228	244	
GNP[b] (1,000 million $)	500	534	588	677	884	1,077	
GNP *per capita*[b] ($)	2,752	2,781	2,908	3,208	3,875	4,408	
Consumption *per capita* (kg)	8.8	11.1	14.7	21.0	38.4	57.8	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

TABLE 38. EASTERN EUROPE: PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954-1956	*1957-1959*	*1960-1962*	*1963-1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	247	430	725	1,290	3,800	9,850	762
Imports	54	55	95	140	300		
Consumption	301	485	820	1,430	4,100	9,850	688
Points of reference							
Population (millions)	306.6	320.1	334.0	346.5	370.5	391.6	
GNP[b] (1,000 million $)	178.8	232.4	287.6	339.6	478.7	623.8	
GNP *per capita*[b] ($)	583	726	861	980	1,291	1,593	
Consumption *per capita* (kg)	1.0	1.5	2.4	4.1	11.0	25.0	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

TABLE 39. WESTERN EUROPE: PRODUCTION AND CONSUMPTION OF PLASTICS
(thousands of tons)

	1954-1956	*1957-1959*	*1960-1962*	*1963-1965*	*1970 (est.)*	*1975 (est.)*	*Growth[a] (per cent)*
Production	975	1,660	2,850	4,550	9,600	15,820	347
Exports	65	70	150	250	500	820	328
Consumption	910	1,590	2,700	4,300	9,100	15,000	349
Points of reference							
Population (millions)	284	291	299	308	322	333	
GNP[b] (1,000 million $)	294	330	389	448	477	708	
GNP *per capita*[b] ($)	1,034	1,134	1,304	1,455	1,792	2,126	
Consumption *per capita* (kg)	3.2	5.5	9.0	14.0	28.0	45.0	

[a] Rate of growth between 1963–1965 and 1975.

[b] 1964 value is used for GNP.

A reduction in the cost of resins and processing is the key to obtaining a larger market, thus justifying larger plants. Processing techniques should be improved in order to cope with the improvements in resins and machinery. A plastics machinery industry should be established and technicians should be trained, so as to keep up to date. Machines for special applications and highly automated units could be imported. The industry should concentrate on producing the most popular machines domestically. Also important is the creation of applications and markets for the new resins. The people within the industry are the ones who should find new uses for plastics, even if this necessitates a testing programme. If rewards are built into the economic structure, people will overcome all barriers in order to attain them.

Experience shows that as the national economy advances, the consumption of plastics correspondingly increases. The GNP indicates the economic growth of a country and is used as a point of reference in tables 32 through 39.

Requirements for expansion of the plastics market

The first requirement for the expansion of the plastics market is a favourable economic climate. This implies that the level of private incomes should be raised, both for private consumption and for industrial investments. Investments in water supply, in electricity or in sewerage should increase the consumption of plastics. They are also used in irrigation and in housing. Interregional planning in co-ordination with such economic growth is most desirable for the plastics industry in developing countries.

Sometimes the plastics industry in one country may not be sufficiently advanced to produce all the products it needs. Co-operation with other countries is needed for the supply of resins, introduction of technicians, new machines for fabrication, patents and know-how. This could be arranged between two or more developing countries, or between a developing country and a developed one.

A fair amount of plastics is consumed in the form of household items, and the consumer appeal of such items is therefore important for their increased consumption. Attractive design is a key to this. Colouring, packaging and display must be well planned by the suppliers, and the processing companies should be aided, either by the government or by another organization obtaining helpful information for a reasonable service charge. A close investigation into the customs and practices in a country might create some unique applications for plastics.

The export market is another area where plastics, resins or products could be sold. As was explained in earlier chapters, export to developed countries would be limited to processed products. In manufacturing elaborate articles, developing countries can compete with developed countries even at their low resin prices. For instance, China (Taiwan) and Hong Kong are exporting a remarkable amount of goods to the United States. But countries such as Iran, where natural gas is abundant, might well be competitive suppliers of resin in the world market because of the low cost of the raw material. This applies particularly to polyethylene, polypropylene and PVC resins. Special resins are limited in quantity and are often custom-made to satisfy a certain customer or order. These resins are not classified as export items.

Monomers and resins can be exported from one developing country to another because the processing industry must be supported in one's own country in order to obtain a future independent plastics industry. Some arrangement among developing countries for the exchange of different resins would be helpful, making possible the construction of larger equipment than would be possible if each country built small oxychlorination process is the best choice. If the plant is established in an area far from a petrochemical centre and the market permits expanding the plant to a large enough size, the balanced process is preferable.

The production cost for vinyl chloride monomer obtained by means of the acetylene process is given in table 22 above; and that using the balanced process in table 23. The data for the oxychlorination process are shown in table 24. The cost of manufacturing PVC resin is given in table 25.

TABLE 23. PRODUCTION COST OF VINYL CHLORIDE MONOMER USING BALANCED PROCESS, BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)		24,000	48,000	96,000
Cost of plant (millions of dollars)		5.56	8.33	12.50
Cost of naphtha (cents/lb)	*Cost of chlorine (cents/lb)*	*Cost of vinyl chloride monomer (cents/lb)*		
1.0	1.5	6.38	5.60	5.04
	2.25	6.85	6.07	5.51
1.125	1.5	6.50	5.71	5.16
	2.25	6.97	6.19	5.62
1.25	1.5	6.61	5.83	5.27
	2.25	7.09	6.30	5.74

TABLE 24. PRODUCTION COST OF VINYL CHLORIDE MONOMER MADE BY OXYCHLORINATION, WITH PLANTS OF DIFFERENT CAPACITIES AND VARYING COST OF ETHYLENE, AND HYDROGEN CHLORIDE AT 1.5 CENTS/POUND

Plant capacity (tons/year)	24,000	48,000	96,000
Cost of plant (millions of dollars)	2.33	3.61	5.56
Cost of ethylene (cents/lb)	*Cost of vinyl chloride monomer (cents/lb)*		
3.125	4.81	4.50	4.28
3.75	5.12	4.81	4.58
4.375	5.43	5.11	4.89
5.0	5.73	7.42	5.20
5.625	6.04	5.73	5.50

units for its own consumption. International organizations such as the United Nations could be helpful in organizing exchanges and in planning the industrialization time-tables of various developing countries. Prices to be applied in such exchanges should not be based on market prices but on the cost of production. Special duty arrangements should also be made for these import exchanges.

Expansion of the processing industry

The consumption of plastics is wholly dependent on the growth of the processing industry. Each country must develop its processors in order to produce resin domestically on a large scale. Iran would be an exception to this rule. The following sectors should be encouraged for the expansion of processors and eventually for the whole plastics industry:

(a) Building and repair of processing machines;

(b) Die and mould making, design and improvement;

(c) Designing of plastics products;

(d) Reasonable supply of plasticizers and stabilizers, and other additives such as pigments or dyes;

(e) Education of technicians in various areas of the industry.

In addition to the above, men with initiative are needed for that part of the industry which seeks applications for new materials and a wider use of plastics in different fields. This type of person is not easily found, but training, research and development, and sales efforts can be combined to create such a personality. Seminars sponsored by international organizations for processors in the area could provide a good opportunity for orienting the management of the processing industry.

1.6 Methods of setting up an integrated plastics industry in developing countries

The main plastics consumed in the ECAFE countries are polyethylene, polyvinyl chloride and polystyrene. The manufacturing processes for these products consist of three stages, namely monomer production, polymerization and processing. The first stage, monomer production, economically favours larger plants. The second stage, polymerizing monomers, requires smaller plants for the greatest economic benefits. The third stage, processing, requires very small plants. Therefore, one monomer plant, a few polymer plants and many processing plants make up one unit of plastics production. But to establish a real demand for a polymer, it is necessary to have many large plastics processors, and their technical standards must be raised in order to increase exports.

It might be helpful to show the difference between the plastics industries in China (Taiwan) and Hong Kong. In Hong Kong, all polymers and pigments are imported and most of the finished products are exported to Australia, Canada, the United Kingdom, the United States and other countries. In 1960 the import of resins cost $24 million, while export of their products brought in $45 million. Net income therefore was $21 million. In 1966 imports cost $38 million while exports brought in $120 million, with a net gain of $82 million. The major items for export were toys and dolls, leading with 54 per cent in 1966, plastic flowers, foliage and fruits with 36 per cent; and other items with only 10 per cent. The major destinations of export were the United States (55 per cent), the United Kingdom (13 per cent) and Canada (4 per cent), with the remainder divided among Australia, the Federal Republic of Germany and Japan. The import figures for resins are given in tables 40 and 41.

TABLE 40. RESINS IMPORTED INTO HONG KONG, 1964–1966

(tons)

	1964	*1965*	*1966*
Polyethylene	65,650	43,175	48,940
Polystyrene	22,900	22,927	21,896
Polyvinyl chloride	12,038	8,727	8,316
TOTAL	100,588	74,829	79,152

TABLE 41. IMPORT OF RESINS AND EXPORTS OF PLASTICS PRODUCTS, HONG KONG, 1960–1967

(millions of US dollars)[a]

	1960	*1961*	*1962*	*1963*	*1964*	*1965*	*1966*	*1967*
Import of resins	23.6	27.4	27.2	27.8	43.0	36.5	37.5	44.2
Export of products	44.9	51.4	61.1	70.6	100.0	110.0	119.5	147.2
Balance	21.3	24.0	33.9	42.8	57.0	73.5	82.0	103.0

[a] Converted from Hong Kong dollars at 6.06 HK$ per US$.

The quantity of imports is large enough to justify the production of resins in Hong Kong; however, there is no plan at present to begin such a project. It is still cheaper to import the resins than to produce them domestically. Large producers of resins in the world are offering their products at low prices, and manufacturers in Hong Kong feel that their present situation is satisfactory. The characteristics of the plastics industry in Hong Kong can be explained as follows:

(a) Heavy consumption of various kinds of resin processed by many small units,

(b) Export of most of the plastics products to developed countries, through which the plastics industry obtains profit for itself and foreign currency for Hong Kong.

China (Taiwan) has started and accelerated the domestic production of resins. The production capacity of PVC resin had reached 7,000 tons per month at the time of writing, October 1967, actual output being 6,000 tons. But there were very few processors, only 700 tons of the total PVC resin were consumed by independent processors and 3 800 tons by subsidiaries of resin making companies. At the time of writing, approximately 1 500 tons had already been exported. Plastics products such as toys, film, sheet, window shades and raincoats are exported to Australia, Canada, the United States and other countries. Exports in 1965 totalled $7.5 million. Seventy five per cent of the exports were resins or compounds. A new plant in Taiwan has started production of polyethylene in a plant of 18 000 tons annual capacity. The demand for polyethylene is approximately 1 000 tons per month, and the supply in 1968 was expected to range between 4 000 and 5 000 tons per year.

In order to encourage the export of processed goods, the Government of China (Taiwan) has established the Kaoshing Export Process Zone. Synthetic resins are imported free of duty for re-export in this zone. This will help the future export of plastic processed products. It is characteristic of the plastics industry in China (Taiwan) that the production of synthetic resins exceeds the domestic requirements, the number of independent processors is small, resin manufacturers have their own large processing plants and surplus resins are exported to the developing countries, while plastic processed products are exported to developed countries.

The examples of Hong Kong and China (Taiwan) present several points for consideration. First, the plastics industry is labour intensive and the relatively low cost of labour in developing countries works in its favour. Processed products can easily be exported to developed countries for this reason. Second, it is necessary to establish larger processing facilities near the resin producers in the area, if the resin plants have been constructed ahead of those for the processing industry.

The demand for plastics products in developing countries is gradually increasing. Expanding electric lighting and telephone systems will require greater amounts of products such as wire and cable. Plastic bags for fertilizers, sugar, foods and household articles are gaining in popularity. The major drawback in such countries as Burma, Indonesia, Malaysia and Thailand is the low technical standard. Technical assistance and financial aid would help sales. International organizations such as the United Nations should help establish in the region a technical guidance centre for processing plastics. This could be accomplished with the co-operation of the Governments. The curriculum should include the working of processing machines, techniques for making moulds, standardization of tests for plastics and for product quality. Financial aid to enable processors to obtain improved machinery to produce higher-quality goods would encourage further export. This help would increase the number of processors in that area, improve the standard of fabrication and create a larger consumption of resin. The production in processing industries could be based on imported resin until domestic production is feasible. In India and Pakistan, the expansion of processing created a shortage of resin and this has stimulated domestic resin production.

It is recommended that the resin manufacturing industry start with imported monomer if possible. For example, styrene monomer was imported when China (Taiwan), India and Japan began making polystyrene. A large monomer production plant should be designed to meet competition from developed countries. Small monomer plants force up prices in the domestic industry, thus killing the competitive spirit in the export of processed products.

It is recommended that several countries co-operate in establishing and financing a large, jointly owned monomer plant to supply the polymer plants in each participating country. For example, one naphtha-cracking petrochemical centre could be built near to and sponsored by Indonesia Malaysia, the Philippines and Thailand. Such a centre could produce styrene monomer, vinyl chloride monomer and ethylene in large quantities. If the demand for resin exceeds the output in one centre, another site in a different country could be selected by the sponsoring countries. The assistance of international organizations in forming a joint unit would be very helpful in advancing the plastics industry. It would also allow member countries to compete with other established suppliers.

An increase in the size of plants making monomer has been noticed. Several polymer producers in the United States plan to enlarge plant capacity to a new level. A Japanese ethylene centre is planning to produce vinyl chloride monomer in large amounts in order to supply the polymer producers in the area. It would not now be economical for any country to build a small monomer plant, and it would harm the economy of the country's plastics industry as a whole. The only way to solve the difficulties would be to construct large, jointly owned plants in various regions.

The procedures necessary to establish a plastics industry in developing countries should be re-emphasized:

(a) The number of processors should be increased at the same time as an effort is made to enlarge each processor, in order to increase the consumption of resins;

(b) In order to bring in foreign currencies through the plastics industry, its technical level must be raised and efforts should be made to encourage the production of quality goods;

(c) For the purpose of improving technology, international or national organizations should establish technical guidance centres for the plastics processing industry;

(d) Plastics processing machines and mould-making techniques should be improved;

(e) Financial help from international or national organizations is desired so that processors can equip themselves to make quality goods. Free trade zones should be established in order to relieve the industry from customs duties on export items;

(f) The plan for resin production should be co-ordinated with the country's consumption of resin;

(g) Large monomer plants should be built in order to provide helpful competition within the co-operating developing countries.

Part 2

RESEARCH AND DEVELOPMENT IN PLASTICS INDUSTRIES

2.1 Research and development in developed countries

Expenditures for research and development in the chemical industry

The success of the chemical industry is based on research and development. It is said that more than 60 per cent of the total sales of Du Pont in 1950 were for products unknown or still in development in 1930. A plastics company in the United States has estimated that 50 per cent of its sales and 60 per cent of its profit come from approximately 500 new products that were not in production ten years previously. A recent survey by the Department of Economics of McGraw-Hill, Incorporated, indicates that chemical companies anticipate that $8,760 million, or 18 per cent of estimated sales in 1969 will be earned for products not produced in 1965. Also predicted by 48 per cent of the chemical manufacturers is a technical or basic research breakthrough; 67 per cent of these optimistic chemical companies expect it to come in the area of new products.

TABLE 42. RELATIONSHIP BETWEEN COST OF RESEARCH AND DEVELOPMENT AND PROFIT INCREASE IN INDUSTRIES IN THE UNITED STATES 1954-1959 and 1957-1960

	Cost of R & D (per cent of sales)	*Number of companies*	*Rate of profit increase (per cent)*
1954–1959	over 7.0	19	148
	4.0–7.0	20	94
	3.5	30	21
	3.0	425	22
1957–1960	over 8.5	10	238
	5.0–8.5	10	147
	3.5	30	–11
	3.0	425	–7

TABLE 43. COST OF RESEARCH AND DEVELOPMENT BASED ON GROSS NATIONAL PRODUCT IN SELECTED COUNTRIES, 1952, 1962 AND 1972

	1952			*1962*			*1972 (estimated)*		
Country	*GNP*	*Cost of R & D (millions of dollars)*	*Rate (per cent of GNP)*	*GNP*	*Cost of R & D (millions of dollars)*	*Rate (per cent of GNP*	*GNP*	*Cost of R & D (millions of dollars)*	*Rate (per cent of GNP*
Australia	8,680	–	–	16,800	101	0.6	33,600	403	1.2
Canada	24,640	123	0.50	36,400	291	0.8	58,800	941	1.6
France	39,760	117	0.30	64,400	700	1.08	106,400	2,341	2.2
Germany, Fed. Rep.	35,000	–	–	84,000	1,260	1.5	201,600	5,040	3.97
Ghana	840	-	–	1,680	4	0.24	3,360	11	0.33
India	25,200	–	–	36,400	76	0.21	53,200	213	0.4
Japan	16,800	81	0.48	53,200	798	1.5	165,200	4,956	3.33
Netherlands	6,160	31	0.50	12,880	193	1.5	25,200	756	3.0
Norway	2,800	–	–	5,040	39	0.7	8,400	134	1.6
Sweden	7,000	–	–	15,680	244	1.56	33,600	1,008	3.0
United Kingdom	44,800	403	0.9	78,400	1,960	2.5	137,200	6,860	5.0
United States	350,000	5,040	1.4	546,000	19,110	3.5	851,200	59,584	7.0

Source: Chemical Age 9 May 1964.

TABLE 44. RATE OF RESEARCH AND DEVELOPMENT BASED ON GROSS NATIONAL PRODUCT IN SELECTED COUNTRIES, 1955-1964

(per cent of GNP)

Country	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964*
France				—	1.10	1.25	1.41	1.95	2.10	
Germany Fed. Rep.		1.29	1.45	1.60	1.77	1.79	1.92	2.13	2.38	
Japan	0.78	0.92	1.09	1.21	1.39	1.42	1.59	1.64	1.63	1.73
United Kingdom	1.95	—	—	2.58			2.87	—	—	2.87
United States	1.87	2.38	2.70	2.97	3.13	3.31	3.41	3.47	3.65	
USSR	—		—	1.92	2.07	2.24	2.42	2.59	2.72	

Sources: National Science Foundation (United States); Organization for Economic Co-operation and Development (France); Advisory Council for Scientific Policy (United Kingdom); Science and Technology Ministry (Germany, Fed. Rep.); Science and Technology Survey (Japan).

The large profits and sales that resulted in the past from new products or processes are a driving force to increase the research effort in any industry, and this has correspondingly brought about huge expenditures for research and development. The total expenditure for research and development (also referred to as "R & D") in the United States will increase from $19,000 million in 1964 to $24,000 million in 1967 and $25,000 million in 1968 (estimated at time of writing, October 1967). Total industrial spending in 1964 was $13,740 million and $1,440 million of this was claimed by the chemical industry. In research and development in the chemical industry, $160 million (11 per cent) was spent on basic research, $530 million (37 per cent) on applied research, and $750 million (52 per cent) on development. In the total expenditure of $1,280 million for applied research and development in the chemical industry, research into high polymers and plastics was the highest expenditure with $294 million (23 per cent). In 1961 the plastics industry in the United States spent 11 cents per $1.00 sales for research and development, about four times the average cost of research and development for the whole of the manufacturing industry. The highest expenditure on research into and development of high polymers has coincided with the highest production growth rate in the high polymer industry. The relationship between research expenditures and the rate of profit increase is shown in table 42.

The cost and rate of research and development in selected countries based on the gross national product (GNP) are indicated in tables 43 and 44. The figures are slightly different in the two tables as a result of different definitions for the cost of research and development.

Although Du Pont had previously been reporting only its pioneering research expenditures, it returned in 1966 to the broader definition of research and development that it had once used. Du Pont listed its outlay for research and development as $96 million in 1960 and it reported only $59 million for pioneering research in 1961. Hercules Chemical, on the other hand, shifted to a narrower definition in 1966. Every company has its own ideas about what should be included in research and development and capital expenditure, and it is, therefore, sometimes meaningless to compare the figures from various plants. The National Science Foundation (NSF) in the United States suggest the following definitions:

(a) "Research and development" includes basic and applied research in the sciences and engineering and the design and development of prototypes and processes. Excluded from this definition are routine product testing, market research, sales promotion, sales service, technical services, research in the social sciences or psychology, or other non-technical activities;

(b) "Basic research" includes original investigations for the advancement of scientific knowledge that do not have specific commercial objectives, although such investigations may be in fields of present or potential interest to the company;

(c) "Applied research" includes investigations directed at the discovery of new scientific knowledge that have specific commercial objectives with respect to products or processes. This definition of applied research differs from the definition of basic research chiefly in terms of the objectives of the company;

(d) "Development" includes technical activities of a non-routine nature concerned with translating research findings or other scientific knowledge into products or processes. Development does not include routine technical services to customers or other activities excluded from the above definition of research and development.

The pilot plant is not mentioned in these definitions but it is usually included in "development". However, moving a project through a pilot plant is often the most expensive stage of research and development. Therefore, some companies do not attempt to include the pilot-plant expenses in their research and development budget. Instead, they get approval for each pilot-plant operation as it is proposed.

In the chemical industry in the United States, the expenditures for basic research, for applied research and for development were respectively 11 per cent, 37 per cent and 52 per cent of the total research programme in 1964, and 12.5 per cent, 41 per cent and 46.5 per cent respectively in 1966. The rates for industry in general were 6.7 per cent for basic research, 24 per cent for applied research and 69.3 per cent for development. Table 45 below shows the distribution of types of research in several countries.

Since it is important to find suitable applications for the many chemical intermediates which are discovered, the chemical industry requires more applied research than any other industry. Its expenditure on basic research also is much higher than that of any other industry (tables 46 and 47).

TABLE 45. DISTRIBUTION OF TYPES OF RESEARCH IN ALL INDUSTRIES IN JAPAN, THE UNITED KINGDOM AND THE UNITED STATES, 1966

(per cent of total research programme)

Country	*Basic research*	*Applied research*	*Development*
Japan	14	40	46
United Kingdom	3	20	77
United States	4	18	78

TABLE 46. PURPOSES OF RESEARCH AND DEVELOPMENT FOR VARIOUS PRODUCTS

(per cent of total research programme)

	New products	*Improvement of products*	*New processes*
Chemicals, allied products	70	20	10
Petroleum, coal products	27	33	40
Rubber products	17	83	0
Stone, clay, glass	41	41	18
Non-ferrous metals	39	44	17
Paper, allied products	37	41	22
All industries	45	41	14

Source: Chemical Week 14 May 1966.

TABLE 47. COST OF RESEARCH AND DEVELOPMENT IN INDUSTRIES IN THE UNITED STATES, 1964-1966 AND 1969 (ESTIMATED)

(millions of dollars)

					1966		
	1964	*1965*	*1966*	*1969 (est.)*	*Basic research*	*Applied research*	*Development*
Chemicals, allied products	1,291	1,562	1,687	2,024	211	693	783
Petroleum, coal products	343	384	415	469	41	162	212
Rubber products	146	178	199	229	10	72	117
Stone, clay, glass products	129	150	162	190	10	73	79
Non-ferrous metals	85	101	111	137	11	57	43
Paper, allied products	77	77	84	101	7	33	44
All industries	13,078	13,636	15,219	18,165	1,091	3,667	10,461

Source: Chemical Week 14 May 1966.

The characteristics of research in various industries are very different. For example, in the chemical industry no less than 70 per cent of the research and development programme is spent on finding new potential products. On the other hand, the rubber industry is mainly interested in improving existing products, while the petrochemical industry most needs to find new processes.

Table 48 shows that many chemical companies spend an amount equal to 4 or 5 per cent of their annual sales on research and development. Dow Chemical spends approximately 5 per cent, of which 4 per cent is for research and 1 per cent is for the pilot-plant works. The high cost of research and development has been a headache for many executives of chemical companies. Despite the fact that the total research and development cost of 26 United States chemical companies in 1964 was approximately 3.5 times the cost in 1950, the net profit increased only 20 per cent. The average term for research and development in the chemical industry is decreasing from seven years to less than five years, but it is still much longer than that of any other industry. Research investment is risky.

TABLE 48. RATE OF RESEARCH AND DEVELOPMENT BASED ON ANNUAL SALES IN THE FEDERAL REPUBLIC OF GERMANY, SWITZERLAND, THE UNITED KINGDOM AND THE UNITED STATES, 1959, 1964 AND 1965

(per cent of annual sales)

		1959	*1964*	*1965*
Germany, Fed. Rep.	Bayer	4.5	4.7	–
	BASF	5.0	5.2	–
	Hoechst	4.5	4.3	–
Switzerland	Ciba Products	7.1	8.6	–
United Kingdom	ICI	4.4	5.3	–
United States	Allied Chemical	2.4		3.2
	American Cyanamid	4.0	–	5.1
	Dow Chemical	–	–	5.4
	Du Pont	4.3	–	4.1
	Hercules	4.1	–	3.5
	Monsanto Chemical	4.4	–	5.2
	UCC	5.2	–	4.3

Source: **Japanese Survey Mission Report.**
Key: ICI: **Imperial Chemical Industries**
BASF: **Badische Anilin- und Soda-Fabrik**
UCC: **Union Carbide Corporation**

TABLE 25. PRODUCTION COST OF PVC RESIN, BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)	12,000	24,000	48,000	96,000
Cost of plant (millions of dollars)	1.11	1.94	3.47	6.25
Cost of vinyl chloride monomer (cents/lb)	*Cost of PVC resin (cents/lb)*			
5.0	7.69	7.47	7.32	7.20
5.625	8.33	8.12	7.98	7.85
6.25	9.00	8.78	8.63	8.51
6.875	9.65	9.45	9.29	9.16
7.5	10.32	10.09	9.95	9.82
8.125	10.96	10.75	10.60	10.48
8.75	11.63	11.41	11.26	11.13

Polystyrene

The raw materials for making polystyrene are benzene and ethylene. The cost of benzene affects the cost of polystyrene, so that a cheap source of benzene has to be found in coke-oven gas or in aromatic petrochemical production. India is the only country in the ECAFE region that has been producing benzene with coke-oven gas. In other countries, benzene can be obtained either by importing it or from a local petroleum refinery or petrochemical plant.

TABLE 26. PRODUCTION COST OF STYRENE MONOMER, BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)		12,000	24,000	48,000	96,000
Cost of plant (millions of dollars)		3.33	5.0	7.78	11.11
Cost of ethylene (cents/lb)	*Cost of benzene (cents/lb)*	*Cost of styrene monomer (cents/lb)*			
3.75	3.125	8.18	7.38	6.79	6.35
3.75	3.75	8.7	7.89	7.31	6.87
3.75	4.375	9.22	8.41	7.83	7.39
5.0	3.125	8.57	7.76	7.18	6.74
5.0	3.75	9.09	8.28	7.82	7.26
5.0	4.375	9.61	8.80	8.22	7.78

Dr. C. A. Thomas of Monsanto Chemical, in a speech before a meeting of the American Chemical Society, warned, "In the last five years, we have reached a point of indigestion in research and development, and I am of the opinion that the productivity of this effort has fallen off. The research and development is now stumbling in a plethora of projects, sinking in a sea of money, and is being built on a quicksand of changing objectives."

Pilot plants for the development of the chemical industry

A pilot plant has been defined as "any small-scale plant used to provide information about a future large-scale plant".[4] The main purpose of the pilot plant is to study and perfect the most economical process from the chemical engineering point of view, and its second purpose is to provide a product for purposes of evaluation. The pilot plant fills the gap between the experimental stage and the commercial plant and reduces the number of errors in the design and operation of the commercial plant.

The pilot plant, however, is a final stage in research and development and is usually expensive to build and more expensive to work. It is very difficult to get an exact figure on the amount spent on piloting, but it probably amounts to 15 per cent of the total research and development cost of chemical companies. Many chemical companies in the United States have spent 20 to 30 per cent of their research and development budget on piloting. Possibly even more important than the money spent is the amount of research and development talent tied up in the work of the pilot plant. A fully integrated pilot plant may occupy 10 to 150 men for periods ranging from six months to several years. The chemical industry operates many such plants. They are a serious, expensive business.

Mr. David Brown, Senior Vice-President of Halcon Internationals, New York, has stated:

> "In the earlier days of chemical process development, a pilot plant was generally installed, since it was used (aside from sample preparation capacity) mainly as a final analog of the commercial plant, and was expected to uncover any problems not predicted by the design engineer. The large pilot plant certainly has its very definite value in the preparation of large samples for product or market development purposes. However, it is becoming increasingly by-passed as a strategy in the development of plant design data because of its following disadvantages.
>
> "*(a)* It is very expensive. Programs involving large pilot plants can easily run into the multi-million dollar range.
>
> "*(b)* It is time-consuming and may hold back the commercialization of the process by more than a year. The time for design and construction of a very large pilot plant is in itself a fairly large fraction of the time it would take to design and construct a commercial plant.
>
> "*(c)* It is not necessarily more reliable than smaller, non-integrated units specifically designed for the desired measurements. One of the arguments propounded in favor of the large integrated pilot plant is that it goes further than the process simulation stage in permitting the study of the effects of impurity buildups. Actually, most pilot plants have extremely large leaks, on a proportional basis, compared to those experienced in the commercial plant. The only way this leakage can be cut down is by an intensive development of procedures for making ultratight pilot plants, which is an exercise often not justified from the economic point of view.

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[4] JOHNSTONE AND THRING (1957) *Pilot Plants, Models, and Scale-up Methods in Chemical Engineering*, McGraw-Hill, New York.

> "*(d)* Changes are difficult to make. If the equipment is large, it is obviously more time-consuming and costly to introduce equipment changes as part of the experimental program.
>
> "*(e)* Data are not necessarily accurate or reliable. It is believed that the best data are obtainable at each portion of the process by specifically designing the scale of the experiment in accordance with the data required. In this fashion one can obtain the maximum quantity of information per dollar invested in experimental work. Note that some of the experimental steps, in fact, may not be data-producing steps at all i.e., separation by distillation which can be calculated on the basis of vapor-liquid equilibrium data obtained in entirely separate experiments."[5]

Mr. Brown pointed out that a distillation now is almost never piloted. However, he did concede that some reactions or operations are tricky to scale up and cited catalytic reactions in particular need of pilot study. He also singled out certain problems handling solids and discussed polymerizations.

It seems easier to side-step large-scale pilot plants in the petroleum field than it is in the chemical industry. Essentially, it is a matter of the higher grade of chemical reaction. It is much easier to understand a reaction in monomer synthesis than in polymerization. Many things affect molecular structure and, unfortunately, once a polymer is formed, it is impossible to correct its structure in the way that a simple chemical compound can be purified.

In such a case, a bigger pilot plant should be constructed, a project which may cost a million dollars. It is said that U.S. Industrial Chemical spent $800,000 ($300,000 for equipment and $500,000 for operating costs) for piloting a $20 million plant, and that California Research spent more than $1 million to pilot the isophthalic process that resulted in a $12 million commercial plant.

In most cases, when piloting is expected to cost more than 30 per cent of the commercial plant, the decision to go ahead should be made with great caution. Some plants cannot afford the costs of a pilot plant. One good way to keep piloting costs down is to pilot on as small a scale as possible. Monsanto Chemical operates an engineering laboratory where it frequently ties together several unit operations in what is essentially a pilot plant made of glass. Another favourite cost-cutting measure is the use of flexible pilot plants. Multipurpose units can considerably help the economics of piloting. California Research put up a flexible unit to pilot-produce alkyd resins and polyester from isophtalic. One of the major problems, however, is that of manufacturing multipurpose equipment.

In spite of its high cost, the pilot plant has many advantages. Besides the engineering information it provides and the products it supplies for evaluation, it helps to train the crews that will manage and operate a large commercial plant, and it can be used to test process improvements when the commercial plant has been built. Therefore, most chemical companies working to establish their own technology in developed countries proceed from experimental work to pilot plants and then to a commercial plant.

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[5] R. LANDAU (1966), *The Chemical Plant from Process Selection to Commercial Operation*, Reinhold Publishing Company, New York, pp.22–23.

2.2 Government activities and research associations

The extent of government activity in the research and development of technology is different in each country. In the United States a total of $17,308 million was spent on research and development in 1963. As table 49 shows, the contribution of the Government was $11,300 million (65.4 per cent of the total), of which 21 per cent was spent by government organizations and 79 per cent was given in trust to universities and industries for research.

TABLE 49. DISTRIBUTION OF COMPANY AND GOVERNMENT FUNDS IN TOTAL RESEARCH AND DEVELOPMENT EXPENDITURES OF INDUSTRIES IN SELECTED COUNTRIES

(per cent of total)

Country	*Year*	*Company*	*Government*	*Other funds*
France	1963	31.7	68.3	0
Germany, Fed. Rep.	1964	35.6	63.2[a]	1.2
Japan	1964	71.0	29.0	0
Netherlands	1962–63	65.0	13.0	22.0
Sweden	1961–62	50.7	49.3	0
United Kingdom	1961–62	33.6	60.7	5.7
United States	1963	32.1	65.4	2.5

[a] Federal government 26.1 per cent, state governments 37.1 per cent.

The in-trust government funds and the government grants for encouraging research are the largest sources of research capital for universities in the United States (approximately three fourths of the total research fund).

As table 49 shows, the Governments of the Federal Republic of Germany, France, the United Kingdom and the United States have contributed 60 to 70 per cent of the total research and development resources, but in Japan and the Netherlands, the Governments have provided less than 30 per cent of the funds. Government expenditures for research and development in the chemical industries are less than 30 per cent in every country, but for the chemical industries the ratio of government funds is higher in Japan (see table 50 below). Usually the government supplies only a small portion of the total cost of research and development in chemical industries. This seems to be the typical pattern of research and development in the chemical industry.

In the United Kingdom in 1916, the Department of Scientific and Industrial Research (DSIR) was established, with its Industrial Grants Committee and its Research Association system. There were 52 research associations in 1963, spending $31.6 million, including $7.28 million of government grants.

TABLE 50. DISTRIBUTION OF COMPANY AND GOVERNMENT FUNDS IN THE RESEARCH AND DEVELOPMENT EXPENDITURES OF CHEMICAL INDUSTRIES IN FRANCE, JAPAN AND THE UNITED STATES

(per cent of total)

Country	*Year*	*Company*	*Government*	*Other funds*
France	1963	89.2	2.8	8.0
Japan	1958	73.4	26.6	0
United States	1956	97.0	2.8	0.2
United States	1961	80.2	19.8	0
United States	1962	78.4	21.6	0
United States	1963	79.0	20.6	0
United States	1964	82.2	17.8	0

Among the DSIR-aided research associations, the Research Association of British Rubber Manufacturers was established in 1919. The plastics companies joined in 1960, and the name was then changed to the Rubber and Plastics Research Association of Great Britain. The main role of this association is basic physical and chemical research, research into processing methods and machines, and the study of testing methods and equipment for the industry. The National Research Development Corporation (NRDC), a special corporation financed by the Government, was formed by the Development of Invention Act in 1948. The role of the corporation is to develop inventions that will be useful to the public. In this respect, it resembles the Canadian Patents and Development Corporation. The NRDC does not manufacture or sell the product and has no laboratory for research and development, but it owns the patent rights and licenses them to manufacturers or users. Two thirds of the inventions transferred to the NRDC come from national institutes, and one third come from the universities. Among the subjects investigated between 1961 and 1964, several were related to the plastics industry, such as the acetylene-manufacturing process.

The French Government's contribution to research and development is about 70 per cent of the country's total, the largest government proportion from any developed country. Ninety per cent of the government fund is for military purposes. Fifty-six research centres have been established for co-operative research and development, based on the laws of 1901, 1943 and 1948. Among these research centres, the well-known Institut Français du Pétrole (IFP) has developed many petrochemical processes. The plastics research centre (Centre d'Etudes des Matières Plastiques) is managed by people selected from universities and the Government as well as from resin manufacturers and plastics processors. The fields of study include molecular structure, physical properties of polymers and processing methods of polymers.

In the Federal Republic of Germany the Government at federal as well as state level has controlled the policy of research and development in science and industry. The state governments in 1964 provided 57.1 per cent and the Federal Government only 26.1 per cent of the total cost of research and development. The Federal Government sponsors many federal research institutes in every field and at the same time helps the Deutsche Forschungsgemeinschaft (DFG, the German Research Institute), Max Planck Gesellschaft and other institutes. The funds for DFG are provided 85 per cent by the Federal Government and 10 per cent by the state governments.

Besides federal and state research institutes there are approximately 100 co-operative research organizations sponsored by the manufacturing industries, and one third of their research expenditures are paid for by federal or state governments. In 1954 the Arbeitsgemeinschaft Industrieller Forschungsvereinigungen (AIF, the Union of Industrial Research Associations) was formed. At present 61 associations are members, of which two are plastics associations. One is Forschungsgesellschaft Kunststoffe e.V. (FGK) and the other is Vereinigung zur Förderung eines Institutes für Kunststoffverarbeitung in Industrie und Handwerk an der Rheinisch-Westfälischen Technischen Hochschule, Aachen e.V.

The Deutsche Kunststoffe Institut (DKI), controlled by FGK, was established in Darmstadt in 1953 and has been investigating basic polymers in such fields as physical chemistry and radiation chemistry. One half of the research funds come from the Government through FGK. The institute at Aachen was established in 1950 and its main role is to study processing technology and machines. In 1960 43 per cent of the funds for this institute came from the state government and 57 per cent from the manufacturers.

In Japan the policy of science and technology has been controlled by the Government and is similar to the system in the Federal Republic of Germany, except that in Germany many donations for university research have been provided by private companies. This is not customary in Japan. There are no co-operative research organizations in Japan as there are in the Federal Republic of Germany and the United Kingdom, but the Research Development Corporation of Japan, an organization similar to the NRDC in the United Kingdom, was formed in 1961. In the United States there is a strong governmental body controlled directly by the President, which sets the policies for science and industry. The Government takes the lead in investing in research and development, but actual research activities are left to private companies. In Japan the Government has its own research institutes in many fields, but its research and development budget is small, only one third of the country's total research and development programme. Since the Second World War, the tax system has become a strong weapon for carrying out government policies and has been used to increase the productivity of manufacturing industries and to strengthen the economy. The tax system has been a powerful encouragement to research and development in many European and North American countries. Special tax benefits for research and development equipment have been put into effect in Canada, Sweden, the United Kingdom, the United States and other countries. Many countries have taken a favourable attitude towards capital expenditure for research and development. In France working expenses for research are wholly exempted from income and fixed assets for research are allowed to depreciate 50 per cent in the first year.

2.3 Introduction of research, development and foreign technology in Japanese chemical industries

The chemical industry in Japan started with a sulphuric acid plant built in 1872, followed by a military explosives plant in 1874, both of which were owned by the Government. Following the development of these plants, the production of caustic soda, soda ash, superphosphate, cement, glass, paper, celluloid, pigment and paint had begun by 1895. Japan was then a developing country and almost all the technology had to be imported from Germany, the United Kingdom and the United States.

While the Government was following its policy of introducing foreign technology in order to develop the chemical industries, educational and research systems were also being established. It was very important to co-ordinate education and research in the natural sciences with engineering for the purpose of implementing foreign technology. In this first stage, many scholars and engineers were invited from abroad to Japan to counsel and train young students. At the same time, young Japanese researchers and engineers were sent overseas to study new sciences and phases of technology. At this stage of development the educational system was not yet connected with industrial production.

Between 1896 and 1914, plants were built to make plate glass, electrolytic caustic soda and chlorine, calcium carbide, coke-oven-gas products, synthetic dye-stuffs, soap, pulp and rubber. During this time there were several domestic inventions, but most of the technology was still being imported.

At the same time the Government set up national universities provided with research facilities, as well as some national research institutes. In the more developed countries, chemical companies have their own research laboratories to help establish their particular chemical techniques. But in Japan the private companies had no laboratories because the national research institutes and universities had done most of the chemical research and development. The Government had promoted chemical research and education, mainly in applied chemistry, in order to understand and implement foreign technology. Most of the chemical equipment and apparatus had been imported in the hope of establishing a chemical plant. It was therefore very difficult for a single manufacturer to build a chemical plant, even if he personally had completed the basic research.

The First World War made it difficult for Japan to import chemicals and medicines. This caused additional problems for industry. A petition signed by many scholars and businessmen was presented to the Government with the request that a chemical research institute be established. The Physical and Chemical Research Institute was therefore founded in 1917. Following the pattern set by this institute, the Nitrogen Research Institute was established by the Government in 1918, the Textile Research Institute in 1919, and the Fuel Research Institute in 1920. Among the many national research institutes, the Physical and Chemical Research Institute played an important role in basic research, while the government-sponsored Chemical Industrial Research Institute, which had been established in Tokyo in 1900, worked to establish chemical technology for the production of chemicals such as methanol, acetic acid, alginic acid and alumina.

The end of the war dealt a severe blow to chemical research and development with the ensuing decrease in the market resulting from the import of foreign chemical products. The enthusiasm for research and development diminished with the introduction of foreign technology. The cost of importing technology was much lower than the cost of domestic research.

Research laboratories in private companies had been very inadequate. This led the Government to promote the organization of a research system among the private companies. The Society of Electrochemistry was organized in 1933 and the Society of Chemical Equipment was formed in 1936. The Japan Synthetic Fibre Research Association was established in 1941 and was reorganized as the Society of High Polymer Science of Japan in 1942.

The events of the Second World War prompted an effort to use domestic materials and to develop home industry, but technical development in the Japanese chemical industries was delayed by shortages of raw materials, too little experience in establishing home industry, and a halt in the introduction of foreign technology.

The national chemical research institutes were mainly concerned with studying chemical reactions, but, at the time of the Second World War, many of the available funds had to be used for pilot plants. However, because research results had to be commercialized quickly, the role of the pilot plant in checking the most economical working conditions and in selecting the materials for equipment was often neglected. The pilot plants were expected only to confirm the experimental results; they were not in operation long enough to obtain chemical engineering data. Many of them had failed in the industrial operations. Although the reaction mechanism had been studied in the laboratory and the manufacturing conditions had been selected in the pilot plant, the technology for manufacturing chemical equipment had not been established.

A piece of chemical equipment is designed to suit a particular reaction, and special materials and designs are generally required. The quality and quantity of metals or non-metallic materials for making domestic chemical equipment are very important. Shortages of chrome, lead, zinc, special steel and non-metallic materials during the Second World War resulted in low-quality chemical equipment and it was often necessary to close down a chemical plant for repairs.

After the Second World War, the Japanese chemical industries recovered very quickly with the help of foreign technology. Between 1946 and 1950, most of the efforts of the Government were aimed at strengthening the economy. Only a small percentage of the budget was spent on research and development. However, after 1952 a variety of foreign techniques were introduced to fill the technological gap and to rapidly develop the chemical industries. The Government also emphasized individual research, and scientists and engineers who had worked in military research institutes during the war became the leaders in research and development in many industries. The laboratories of private companies were strengthened by the contributions of these individuals and new technical methods were developed in many fields. The process of urea production by Toyo Koatsu Company, methanol synthesis from natural gas by Japan Gas Chemical and the development of polyvinyl chloride resins and polyvinyl alcohol are all examples of Japanese technology developed after the war.

The remarkable development of the chemical industry owes a great deal to foreign methods. However, it should not be forgotten that many chemical companies that introduced foreign techniques spent great amounts on research into new applications and improvements of existing processes. They have sometimes even re-exported the improved process to the owner of the original process. Even among chemical companies importing foreign methods, in 1964 the sale of products resulting from the foreign methods was only 44.8 per cent of total sales.

As was mentioned above, the biggest change in research since the war is that most of the research and development has been undertaken by private companies instead of by national research institutes or universities. The number of chemical companies involved in research in 1963 was 1,333, or 58 per cent of all the companies that conducted research, and the number of research personnel totalled 15,336, or 25 per cent of all industrial employees in those companies.

Research and development in chemical technology require a great deal of basic research, many excellent scientists and engineers and much capital. Even where the experimental work is successful in the laboratory, there is no guarantee that the expected results will be realized in the commercial process. Most failures are the result of limited and rushed operations in a pilot plant when immediate commercial production is required.

In Japan most executives of chemical companies have been hesitant about investing large sums of money in research, or hiring scientists and engineers, or spending a long period of time on research and development (see table 51).

TABLE 51. EXPENDITURE ON RESEARCH IN JAPANESE INDUSTRIES, 1959-1963

(millions of dollars)

	1959	*1960*	*1961*	*1962*	*1963*
Chemical industry	64.9	75.1	102.3	116.1	145.5
All industries	238.0	311.2	397.3	448.3	522.6

TABLE 52. TECHNIQUES IMPORTED BY JAPANESE CHEMICAL COMPANIES UP TO 1961

	Number of methods introduced
Sumitomo Chemical	17
Mitsubishi Chemical	14
Mitsui Petrochemical	13
Chisso	11
Asahi Glass Company	7
Toyo Koatsu	7
Showa Denko	7
Asahi Chemical	7
Nissan Chemical	7
Japan Synthetic Rubber	6

Source: Y. HAYASHI (1966), *Chemical Industry in Japan* (in Japanese), Iwanami Publishing Company, Tokyo, p.183.

TABLE 53. EXPORT OF TECHNIQUES FROM JAPANESE CHEMICAL COMPANIES UP TO 1967

	Number of methods exported
Toyo Koatsu	40
Sekisui Chemical	14
Kureha Chemical	9
Asahi Chemical	7
Shinetsu Chemical	6
Sumitomo Chemical	5
Kyowa Fermentation	5
Nissan Chemical	4
Mitsubishi Chemical	4

Although they have enough scientists and engineers in their own companies, most executives do not rely on domestic research and development, but look instead for foreign methods. The expenditure on research in the largest Japanese chemical company has been only 7 per cent of what Du Pont and 10 per cent of what Bayer (Federal Republic of Germany) spend on research. As table 52 indicates, the large companies tend to use more foreign methods than the smaller companies, and medium-sized companies establish their own techniques (table 53).

Even in developed countries, new methods have often been introduced from other countries or exchanged among companies. The technology of polyester fibre was exchanged for the technology of polyamide fibre between ICI and Du Pont. Chemical industry develops through these exchanges of technology and through competition in the development of new chemical methods.

2.4 Development of plastics technology in Japan: Laboratory work, pilot plant and commercial plant

The plastics industry was introduced to Japan in 1915 when Sankyo Company (later Japan Bakelite Company) bought the patent rights in phenolic resin from Dr. Bakeland. At first, phenol was used as a raw material, but it was later replaced by imported cresol.

Research into urea resins was started in 1930 by Dainihon Celluloid Company and Chugoku Paint Company. Matsushita Electric began production after contracting with the Osaka Industrial Research Institute to develop the process. However, the method for manufacturing urea, used until 1937, was one imported from Germany and the United States. The production of alkyd resin was started in 1934 and that of polyvinyl acetate resin in 1936. Acrylic resin was produced in 1938 and polyvinyl chloride resin in 1940. In 1944 phenolic resin constituted 46 per cent, celluloid 28 per cent, and urea resin 13 per cent of the total plastics production.

Since the Second World War, many foreign methods have been introduced while domestic technology has been developed. These developments will be reviewed below.

Polyethylene

Research into low-density polyethylene began during the Second World War. The polyethylene-insulated cable found in the radar systems of American aeroplanes suggested to Japanese professors the type of research that they should start on the production of polyethylene. Professor S. Kodama of Kyoto University experimentally produced 6.3 grams of polyethylene in March 1944. A plant with a capacity of 20 kilograms per day was designed and the equipment was ordered, but the project was not completed until after the war. The experimental work was taken up again in 1948 and a pilot plant with a capacity of 10 kilograms per day was built. Work began in March 1951 and continued until May 1953. During the experimental period from 1948 to 1951, the plunger pump for raising the pressure had not functioned properly. The first pump could operate only for twelve to thirteen hours continuously at 1,500 atmospheres. The pump was redesigned and was a success.

Sumitomo Chemical Industry Company received a subsidy of $2,000 from the Government of Japan in 1951. The grant helped to improve the manufacturing equipment for polyethylene at Kyoto University. Later, in 1952, Sumitomo received a subsidy of $33,300 for the Industrialization Test Fund from the Government to build a polyethylene pilot plant with a capacity of 200 kilograms per day, this plant began producing polyethylene in August 1954.

Sumitomo had to solve several technical problems, e.g. purification of ethylene, a catalyst to be added at a pressure of 2,000 atmospheres, a special compressor lubricant which is not dissolved by liquid ethylene, and quantity control of oxygen. The quantity of oxygen, in particular, had to be precisely controlled. Although Sumitomo Chemical had plans to construct a plant with a capacity of 3,000 tons per year in 1954 after the success of the pilot plant, it still had additional production problems to solve. For example, the supply of ethylene for making the polyethylene was not assured. At the same time Mitsui Chemical signed a contract with Dr Karl Ziegler to produce high-density polyethylene. This was challenging news for the people at Sumitomo. They contacted the mission from ICI in February 1955 and arranged for a licence to manufacture low-density polyethylene with ICI in July 1955. It was decided to build an ethylene plant and a polyethylene plant. Since Sumitomo had had experience in working a pilot plant, there was no difficulty in operating the commercial plant after introducing the technology from ICI.

Mitsui Chemical, affected by a depression in the coal-mining industry, decided to manufacture higher alcohol from low-grade coal by the oxo process. On a trip to Ruhr Chemie in the Federal Republic of Germany in January 1955, the executives of Mitsui Chemical stopped at the Max Planck Institut in Düsseldorf and signed an option contract with Dr. Karl Ziegler to produce high-density polyethylene. However, this process was successful only in the experimental work, and Mitsui personnel had to obtain the know-how of large-scale operations by themselves.

In April 1955, three engineers were sent to the Max Planck Institut to participate in the laboratory work of the Ziegler process. In May, basic research was started in their own central research laboratory and in the laboratory at the Ohmuta plant. Mitsui received patent rights from Dr. Ziegler, but because it was impossible to commercialize production from the laboratory data, suitable techniques had to be established. For example, basic investigations had to be made into the choice of the

Benzene reacts with ethylene in the liquid or gaseous state, producing ethylbenzene. Ethylbenzene is then dehydrogenated to styrene monomer. The production cost of styrene monomer for each plant capacity is shown in table 26. The production costs of general-purpose (GP) and high-impact (HI) grades of styrene polymer are shown in table 27.

TABLE 27. PRODUCTION COST OF POLYSTYRENE, BASED ON PLANT CAPACITY AND COST OF RAW MATERIALS

Plant capacity (tons/year)		10,000	20,000	40,000	80,000
Cost of plant (millions of dollars)		2.78	4.44	7.22	12.5
Cost of monomer (cents/lb)	*Grade of polymer*	*Cost of polystyrene (cents/lb)*			
6.25	GP	10.67	10.01	9.51	9.19
6.25	HI	11.30	10.64	10.13	9.81
7.50	GP	11.98	11.33	10.82	10.50
7.50	HI	12.61	11.95	11.44	11.13
8.75	GP	13.30	12.63	12.13	11.81
8.75	HI	13.92	13.26	12.76	12.44
10.0	GP	14.61	13.95	13.44	13.13
10.0	HI	15.23	14.58	14.07	13.75
11.25	GP	15.92	15.26	14.76	14.44
11.25	HI	16.55	15.89	15.38	15.06
12.5	GP	17.23	16.58	16.07	15.75
12.5	HI	17.86	17.2	16.69	16.38

Urea-formaldehyde resin

The raw materials for urea-formaldehyde resin are urea and formaldehyde. Urea has been produced in large quantities for fertilizers, and formaldehyde is easily produced from methanol. Obtaining the raw materials for urea-formaldehyde resin is therefore no problem in any country. As explained in chapter 1.1, the manufacturing cost of thermosetting resins is hardly affected by the size of the resin plant, a factor which makes it easy for any developing country to start producing this resin.

Additives for synthetic resins

There are many additives for synthetic resins, the two main ones being plasticizers and stabilizers. In some applications, a flame-retardant agent is added to make the resins safe for building materials and automotive and electrical parts. An antioxidant is added primarily to polyolefins, acrylonitrile-butadiene-styrene (ABS) polymers and polystyrene. An antistatic agent is usually added to polyolefins and polystyrene for food packaging and also to vinyl for phonograph records.

solvent and conditions for polymerization, the after-treatment and the physical properties of products. Also necessary for industrialization were studies concerned with the bulk density of powdered polymer, the effect of molecular weight and density on the processability of the polymer, the elimination of ash in the product, and uniformity of operations so as to ensure a standard quality of product.

All these important problems had been studied in the basic research laboratory. A pilot plant (2 tons per month capacity) was then built in June 1955, and approximately 50 engineers and 60 workers operated the plant until autumn 1956. During these months, they collected important engineering data on the effect of scale-up, the most economical operational process, the selection of apparatus and the design for the commercial plant. Their efforts led to the construction of a pilot plant with a capacity of 10 tons per month. The plant was worked from autumn 1956 to spring 1958, during which time the emphasis was placed on market development and operational techniques.

Mitsui Chemical originally wanted to build its own plant but in accordance with the recommendation of the Mitsui Bank, eight Mitsui companies established a joint company called Mitsui Petrochemical Company to which Mitsui Chemical offered a sub-licence and its technical know-how. A high-density polyethylene plant with a capacity of 1,000 tons per month was constructed at Iwakuni by Mitsui Petrochemical Company in August 1958. The manufacturers had had enough experience in the operation of a pilot plant so that no difficulties arose in the operation of the commercial plant.

The plans for making polyethylene by Mitsui Chemical and Sumitomo Chemical had provoked other chemical companies, and in 1956 Furukawa Chemical, Showa Denko and Mitsubishi Petrochemical announced their own plans.

In April 1956, the executives of Furukawa Chemical had visited the Phillips Petroleum Company in the United States. Their talks lasted two months and ended in the drafting of a contract in which Furukawa agreed to pay $1.6 million for the annual production of 7,500 tons of polyethylene based on Phillips technology.

Later, executives of Showa Denko visited Phillips Petroleum and out-bid Furukawa by raising the fee to $2.475 million. Phillips accepted the new offer and a contract was signed, forcing Furukawa to look elsewhere for a polyethylene manufacturer. It finally paid Standard Oil Company of Indiana $1.5 million for a licence to produce 7,500 tons a year.

Mitsubishi Petrochemical, which was established by nine Mitsubishi group companies and the Shell Oil Company in April 1956, signed a contract with Badische Anilin- und Soda-Fabrik (BASF) of the Federal Republic of Germany to produce 10,000 tons of polyethylene per year, paid $0.68 million, and started operations in June 1959. (BASF had bought the patent rights from ICI and had established its own know-how. Its commercial plant had been operated by the Rheinisch Olefin Werke, which is jointly owned by BASF and Shell.)

As mentioned above, many companies had competed for foreign technology. Several of the companies were successful, others were not. The reasons for failure were shortage of markets and technical problems mentioned below.

Sumitomo Chemical and Mitsubishi Petrochemical entered full operations as soon as the first round of production had realized large profits. However, Mitsui Petrochemical operated at less than 50 per cent of capacity for more than a year because of lack of demand for high-density polyethylene and a shortage of applications technology. It considered producing low-density polyethylene and established a joint venture called Mitsui Polychemicals Ltd with Du Pont of the United States in December 1960.

Showa Petrochemical, a subsidiary of Showa Denko, started its polyethylene operations in December 1959. Showa Denko was not experienced in experimental work or in the operation of a pilot plant, but its introduction of polyethylene technology from Phillips was a success because of Phillips' wide experience of laboratory research and commercial plants.

Phillips Petroleum developed a catalyst system (chrome-oxide catalyst on silica-alumina) and announced its process in 1954. After successful bench-scale experiments, it was decided to progress to the pilot plant. The men in charge of the reaction group began to operate a 10-US-gallon (38-litre) batch reactor and to build a 20-US-gallon (76-litre) continuous reactor in 1954. After two months, the 20-gallon reactor was completed and a 24- to 48-hour continuous operation was accomplished. However, it was difficult to operate the reactor for longer than 48 hours because of certain mechanical problems. One problem was a clog in the polymer pipe, owing to scale-up problems with mixing and heat dissipation.

While the polymerization group was attempting to solve these problems, another group in charge of eliminating catalyst residue and recovering polymer was trying to choose the most suitable process and design of apparatus. As soon as the polymerization process was perfected, the polymerized product was separated, filtered, dried, and sent to the laboratory where its physical properties were tested. Within two months, the polymerization group was able to operate the reactor continuously for six days. As a result of a change in solvent, the process was remarkably improved.

Eight months of production resulted in 270 kilograms of polyethylene from this pilot plant which were used for making samples for a market survey. After another four months, the plant design, plant cost and the manufacturing cost in the commercial plant were estimated. The results of the market research were so encouraging, that the executive committee decided to go ahead with plans to build a commercial plant. Designs for the ethylene plant and the polyethylene plant were drawn up. At this stage, the functions of the pilot plant were to collect technical data, to unify the data collected in each section and correlate them to the design schedule, and to produce various kinds of polymer for market research. While the commercial plant was being designed, the pilot plant operated continuously, and the drying extrusion and pelletizing systems were changed from a batch system to a continuous system. In addition, a 60-US-gallon (227-litre) polymerization reactor was added to the system.

It was not necessary to construct a semi-commercial plant before designing the commercial plant, but for the purpose of market development, a semi-commercial plant with a capacity of 500 kilograms per day was built at Bartlesville, Oklahoma. This plant was used to train and drill the operators, study the safety problems and develop the market. The commercial plant began production in March 1957.

These experiences in the Phillips plant served to assist Showa Denko in its operation and Showa thus did not need to build a pilot plant. However, no demand developed for the product of the medium-pressure process, and the low rate of operations continued for a long time.

Furukawa was less successful, since as was mentioned earlier, it had been defeated by Showa's competition for Phillips' technology. Furukawa finally imported an immature technique from Standard Oil Company of Indiana. Standard had undertaken the basic research and had obtained many patents, but it had not enough experience of pilot plants. Production in the Furukawa plant was therefore delayed for one year while attempts were made to solve technical troubles. Even after operations began in June 1960, the plant was plagued by problems. In addition to technical problems, there was very little demand for the injection-moulded products, wire and cable coating. These blows proved fatal and in 1966 Furukawa Petrochemicals was sold to the Nisseki Petrochemical Company.

The large consumption of low-density polyethylene attracted many newcomers to the production of the resin. Nitto Chemical established a joint venture called Nitto Unicar with UCC of the United States in 1962, Asahi Dow Company introduced a technique from Dow Chemical of the United States in 1964, as did Ube Industries from Rexall Chemical in 1965 and Toyo Soda Company from National Distillers and Chemical Corporation in 1966. Japan Petrochemical is now constructing a plant based on the technology of Rexall Chemical. All the companies eliminated the pilot-plant stage and built commercial plants immediately. As they used established techniques, there were no particular troubles in operation. All of them have since established their own applications research laboratories for the purpose of market development. All current polyethylene producers have introduced foreign methods, and no company has established a commercial plant based on its own technique. Toyo Koatsu Company and Mitsubishi Chemical, however, established their own techniques in pilot plants that have been working for several years. Unfortunately they cannot build commercial plants, because it is very difficult to attain reasonable profits and success on the market as a result of keen competition and low prices.

Polyvinyl chloride

PVC resins were imported in 1938 from pre-war Germany under the trade name "Igelit" made by IG Farbenindustrie AG, and from the United States under the name "Vinylite" developed by UCC. These resins became the models for Japanese researchers, and in August 1939, Nippon Chisso Company began the production of a PVC resin called "Nippolit". Total production of the resin reached 126 tons by 1944, but in 1945 most of the plant was bombed and production was stopped in 1946. Chisso has never regained its leading position in the production of PVC resins.

In 1947 the Toshiba Company began production in a small pilot plant which remained the only PVC plant in existence until 1949. Toshiba had no raw materials, but bought liquid chlorine and acetylene in cylinders. The 3-tons-per-month-capacity operation of this pilot plant interested other chemical manufacturers with excess chlorine or acetylene. Several companies, e.g. Tekkosha, Mitsui Chemical, Mitsubishi Chemical and Kanegafuchi Chemical, started research in 1948 and each began to produce 10 tons of PVC per month. The companies had had some experience in polymerization during the war, so it was not difficult for them to begin research again on synthetic resins. But other inexperienced chemical manufacturers, e.g. Kureha Chemical, Denki Kagaku, Japan Light Metal Industry and Showa Denko, requested leadership for their research from the Government Chemical Industrial Research Institute in Tokyo. A member of this organization, Dr. K. Muzutani, gave instructions in the synthesis of vinyl chloride monomer to chemists from the four companies from April 1949 to March 1950.

Kureha Chemical started its own research work in September 1949 and began the construction of a 10-ton-per-month-capacity plant which was completed in July 1950. This plant was later transformed to produce polyvinylidene chloride resin

Kureha Chemical originally dealt in the production of viscose rayon, but its rayon plant was scrapped by military order during the war. The original plan to manufacture PVC resin was replaced by a plan to produce a polyvinylidene chloride fibre using vinyl chloride monomer.

When Kureha started research work in 1949, the research groups were composed of ten people each in monomer and polymer synthesis groups; another ten people in a fibre fabrication research group were added in 1950. After six months of research, they succeeded in spinning the polyvinylidene chloride fibre in the laboratory as a result of experiences in spinning protein fibres during the war. On the other hand, Kanegafuchi Chemical and Toa Gosei Company were not successful in spinning because their researchers had had no previous spinning experience. The laboratory work in Kureha was operated by means of a 10-litre reactor, which was replaced first by a 100-litre reactor, then by a 2,000-litre reactor and finally by an 8,000-litre reactor. In 1952 the capacity of the pilot plant was expanded from 10 tons to 30 tons per month and the engineering and market research continued.

While Kureha was starting research on the polyvinylidene chloride fibre, Asahi Chemical, Kanegafuchi Chemical and Toa Gosei Company were each beginning similar research. Asahi Chemical entered into joint operations with Dow Chemical and in 1953 the Asahi Dow Company was established. The other two companies failed in their attempts to spin the fibre, but in later years made polyvinylidene chloride latex.

Of the companies that started research into PVC resins, Japan Light Metal Company contacted B. F. Goodrich Chemical Company of the United States, and the Furukawa companies and Goodrich established a joint venture called Japan Geon Company in 1951, forming an excellent model for the Japanese PVC manufacturers. Mitsubishi Chemical imported a technique from Monsanto Chemical Company of the United States and together the two companies established Mitsubishi Monsanto Chemical in 1952.

Japan Geon and Mitsubishi Monsanto Chemical are at present the only two joint ventures with foreign companies in the group of fourteen PVC producers. Among the other twelve companies, Mitsui Chemical introduced a technique from the United States in 1950, Toa Gosei bought licences from St Gobain of France in 1957, and Nippon Carbide Company imported the process of continuous polymerization from BASF of the Federal Republic of Germany in 1956. Eight of the fourteen PVC companies began operations between 1949 and 1952, but six others, Kureha Chemical, Denki Kagaku, Shinetsu Chemical, Toa Gosei, Nissin Chemical and Gunmma Chemical (subsidiary of Denki Kagaku), started several years later. Of these late starters, Kureha and Denki Kagaku established their own technology, and the other three companies, Shinetsu Chemical, Nissin Chemical and Toa Gosei, introducted methods from other companies. Shinetsu introduced their PVC technology from Chisso Company and chlorine techniques from Kureha Chemical, and the Nissin Chemical plant was constructed and operated by engineers from Chisso. The technology of PVC resin production has been progressively developed from emulsion polymerization to suspension polymerization and dispersion polymerization, and has been expanded from homopolymer to special kinds of copolymers.

The PVC products have been accepted by many customers and the range of application possibilities extends from rigid water pipe and rigid corrugated sheet for housing to soft film and sheet products. The model for PVC technology has always been Geon products made by Goodrich. In recent years, however, Japanese PVC technology has generally been classified with the best in the world and many plants in developing and developed countries have been built with Japanese technical assistance. For example, Sumitomo Chemical sold its method to France and the United States; Kureha Chemical to the Soviet Union and the United States and Mitsui Chemical to the United States. In addition, Shinetsu built plants in China (Taiwan), India, the Philippines, Portugal, the Republic of Korea and other developing countries.

Polystyrene

The production of polystyrene was started in 1957 with the importation of styrene monomer by Mitsubishi Monsanto Chemical and Asahi Dow Chemical. In 1959 both companies developed a petrochemical complex and produced styrene monomer. The third producer, Kokan Chemical, a subsidiary of Japan Steel Pipe Company, introduced the technology of the Koppers Company of the United States in 1959 and started it in 1961.

Toyo Polystyrene Company, a subsidiary of Mitsui Chemical Company, and Toyo Koatsu Company bought a technique from Cosden Petroleum in the United States and began operations in 1964. Denka Petrochemical, a subsidiary of Denki Kagaku, introduced a technique from the Petrocarbon Company of the United Kingdom and proceeded to operate it in 1965. One year later in 1966, Yawata Chemical, a subsidiary of Yawata Iron and Steel Company, went on stream employing a method from UCC. As previously mentioned, no home technology or pilot-plant work has been used for making polystyrene.

All these companies have a very different share of the market. Asahi Dow Chemical and Mitsubishi Monsanto Chemical hold approximately 80 per cent of the total market because of their early start and the excellent quality of their products. Other companies have been trying to develop a market for their products and to establish the necessary applications research laboratories. Their share of the market is still small.

Japan Steel Pipe gave up control of Kokan Chemical and sold it to Showa Denko, and Mitsui Chemical sold its share of Toyo Polystyrene to Toyo Koatsu Company. Such a situation is a result not only of a later start, but also of the type of technique imported. Dow Chemical's technique is the best. The companies that introduced other foreign methods have not been able to use pilot plants to improve them and have had to be satisfied with a low success rate.

Vinyl chloride monomer

In recent years the synthesis of vinyl chloride monomer has developed remarkably from the conventional acetylene process to the newer oxychlorination process.

The diluted mixed-gas process for making vinyl chloride monomer is a good example of a process that has been perfected through the co-operation of many companies in research and development. Usually it is difficult for chemical companies to co-operate in research. However, it is important to develop home techniques both for companies that cannot afford to import foreign ones and for governments that fear loss of currency and a disturbance to industrial policy by the invasion of foreign methods and capital. The Japanese Government in 1961 passed a Law of Research Associations for Technical Development in Industries and Mines.

The Research Association for Developing Raw Materials for High Polymers was the first association based on the law. The Chiyoda Engineering and Chemical Construction Company was influential in this move.

In May 1958 the prospects for establishing an association for developing acetylene were explained. Delegates from seventeen companies attended a meeting to establish an acetylene-ethylene development association in July 1959, and on 10 July 1959, the association was formally started with seven PVC resin producers, ten other chemical companies, three petroleum refining companies, and three other companies as founder members. Two university professors and one executive from the Petroleum Division of the Resources Research Institute acted as consultants for the association. After the establishment of the association, the design of a pilot plant with a capacity of 0.5 tons of acetylene per day was investigated. The construction of this plant was begun in January 1960.

In 1958 before the association was established, the engineers at Chiyoda Engineering Company had planned to investigate the possibility of making acetylene and ethylene from naphtha. They began preparing the bench-scale research equipment in January 1959. The experimental apparatus treating 5 litres of naphtha per hour was ready in April, but as a result of carbon trouble and erosion of the furnace, reliable data could not be obtained for several months. After August 1958, the experiments proceeded successfully, a concentration and purification system was set up, and a 0.5-ton-per-day acetylene pilot plant was completed on 15 June 1960. Fifty-one operators, sent by the member companies after completion of university engineering courses and four to seven years of experience in their respective chemical plants, started the operational tests in the pilot plant.

The plant was partially operated for a month, during which time the instruments and machines were tested. After replacing the faulty parts, the cracking furnace was started up on 31 July. Twelve runs were completed during the next four months. The yield of acetylene and ethylene reached 57 per cent of capacity, a figure better than those recorded for the bench-scale operations and those in the data supplied by foreign companies. Between January and April 1961, the purification step was accomplished, enabling the purity of acetylene to reach 99.9 per cent. The recovery of acetylene from the cracked-gas operations was 95 per cent, indicating a success for the first plan of the pilot plant.

In the second stage, in 1961, a plant yielding 3 tons per day was planned. However, since eight companies did not go on to the second stage, the remaining fifteen companies were forced to continue the project alone. The acetylene pilot plant (3 tons per day) was completed in December 1961 and was worked by 49 people including twenty engineers from fifteen companies. Seven tests were run before the end of March 1962 and the plant was successful in completing 100 hours of continuous operation. The consumption of utilities was improved 20 to 25 per cent over that in the 0.5-ton-capacity pilot plant.

The third-stage experiment was held from May to August 1962. Twelve companies did not go on to the third stage, leaving Kureha Chemical, Chiyoda Engineering and Mitsubishi Oil Company (the supplier of naphtha for this experiment) to operate the pilot plant (6 tons per day). In the third stage, operational control apparatus was successfully introduced into the operation of the naphtha-cracking furnace.

The cost of development for each stage in this particular operation is shown in table 54.

TABLE 54. DEVELOPMENT COST FOR THE SYNTHESIS OF VINYL CHLORIDE MONOMER IN JAPAN, 1959-1962

	First stage	*Second stage*	*Third stage*
Size of plant (tons/day)	0.5	3.0	6.0
Term of operation	100 days	15 days	200 hours
Cost of development thousands of dollars			
Cost of plant	403.1	289.0	
Remodelling cost	36.3	12.1	18.5
Cost of operation	88.1	83.3	58.3
Administration fee	8.3	10.0	10.0
Design fee	11.7		
Reserve fund	19.5		
Total cost of development	567.0	394.4	86.8

Source: T. SOGAWA, "Research and Development", *High Polymer Industry Plant* (No. 19 of *High Polymer Industry Series*, in Japanese), Chijin Publishing Company, Tokyo, p. 38.

A comparison of working costs from the basic research stage to the third stage pilot plant is shown in table 55. The cost of operation in the third stage is 142 times that of the bench-scale experiment. This indicates the importance of obtaining enough process data from the small pilot plant. The operation of the larger pilot plant should also be considered in finalizing the design for the commercial plant.

The work accomplished by this research association was limited to the production of acetylene and ethylene from naphtha. By the third stage, only Kureha Chemical remained from the seventeen chemical companies that had joined in the

TABLE 55. COMPARISON OF WORKING COSTS FOR VARIOUS STAGES OF RESEARCH AND DEVELOPMENT OF VINYL CHLORIDE MONOMER

	Basic research	*Bench-scale operation*	*Pilot plants*		
			0.5 tons/day	*3.0 tons/day*	*6.0 tons/day*
Cost of operation ($/day)	3.17	32.70	417.0	3,315.00	4,670.00
Cost compared with bench-scale	0.1	1	12.8	103	142

Source: T. SOGAWA, "Research and Development", *High Polymer Industry Plant* (No. 19 of *High Polymer Industry Series*, in Japanese), Chijin Publishing Company, Tokyo, p. 38.

first stage. The engineers of Kureha Chemical planned to use the research work from the cracked gas for the production of vinyl chloride monomer and in 1962 they built a pilot plant to manufacture vinyl chloride monomer from cracked gas. This very successful project led in April 1963 to the construction of a commercial plant for making vinyl chloride monomer from naphtha. The process is now called the Kureha-Chiyoda vinyl chloride monomer process or the dilute mixed gas VC monomer process. This method has been sold to India, Norway, the United Kingdom and the USSR.

The reasons why Kureha Chemical remained through the third stage of the association and succeeded in building a commercial plant have been stated by Dr. Eiji Munekata, chief of the Noguchi Research Institute, president of the Japan Atomic Research Institute and former director of the board of the Asahi Chemical Industry Company. At that time he was in charge of the association's research, and he has explained the success of Kureha Chemical in his book *Research and Development in the Chemical Industry*, 1964. The following extract from his book is translated informally from Japanese:

> "When the association was established, the managers belonging to the large chemical companies hesitated to [illegible] the association, because they had relied on foreign methods. At the same time, it was important for them to avoid any responsibility for the failure of the experiments. Even the companies that joined the association were content to watch the experiment with a conservative attitude; thus, eight companies avoided the risk in the second stage. In the second stage, I attended the technical discussion. There were very few engineers who were anxious to develop the process and the discussion was limited to them. Most of the engineers attending the meeting were only listeners. Dr. Gomi of Kureha Chemical was the most eager person in the association and the engineers from Kureha directed by him became the core of the association's research work. Their eagerness carried them through to the final stage.
>
> "Thus, the observations and forecasts for the development of the process took on a quite different quality among the enthusiastic engineers and spectators. The pioneering spirit of the engineers of Kureha Chemical brought about a welcome success."

On the other hand, Shinetsu Chemical, which had backed out after the first stage, imported an acetylene process from Montecatini of Italy in 1961, which failed at its introduction. Since the acetylene plant built by Montecatini did not work well, payment to Montecatini was finally stopped and Shinetsu was forced to spend a great deal of money on improving the process in the commercial plant, a situation which created a financial crisis for Shinetsu.

Mitsubishi Chemical introduced the acetylene process from BASF in 1962 and planned to manufacture polyvinyl alcohol at Mizushima, but it gave up this plan in order to build a commercial plant. Sumitomo Chemical introduced the SBA process from Belgium in 1960 and worked the plant for three years before it was forced to abandon it because of uneconomical operation. It later introduced the oxychlorination process from Stauffer Chemical of the United States. Toa Gosei and Kanegafuchi Chemical have bought the licence for the Wulff process, but they have not begun to synthesize vinyl chloride monomer commercially.

The experience of the Research Association for Developing Raw Materials for High Polymers can be summarized as follows:

(a) The engineers and planners in the large chemical companies such as Mitsubishi Chemical, Sumitomo Chemical and Mitsui Chemical were hesitant about joining the co-operative research. They preferred to import technology rather than to establish their own, and decided not to join the association.

(b) Most of the companies that joined the association were interested only in being observers. They lacked the pioneering spirit necessary to establish home industry. A co-operative effort in research and development is limited and unsuccessful unless it includes enthusiastic engineers who make an effort to advance the project. It is not difficult to collect funds from several companies for research and development, but it is difficult to find engineers and scientists who have sufficiently creative minds to act positively and eagerly.

(c) The most important requirements in an attempt to establish a new technique are the pioneering spirit of scientists and engineers and the sympathy of the company's executives with this spirit.

Synthetic fibres

Research into synthetic fibres in Japan was started after the sample importation of nylon 6.6 from the United States in 1938 and nylon 6 from Germany in 1939. Toyo Rayon began investigating nylon 6/6 in 1938 and nylon 6 in 1939 and 1940. In 1943 a pilot plant was put into operation. The product was sold under the name of "Amilan". After the Second World War, the process of Toyo Rayon was investigated by engineers at Du Pont and it was found that there were no infringements on patent rights. Toyo Rayon decided in 1947 to buy the trade mark and polymerization process for nylon from Du Pont. The other four manufacturers of nylon all introduced foreign methods after the war.

Polyacrylonitrile fibres had been studied by Professor Kanbara of Tokyo Technological University in 1941 and the fibre was named "Synsen". The death of his co-researcher, Mr G. Mamiya, during the war prevented the commercialization of the fibre. Acrylic fibre was commercialized in 1948 by Du Pont, and Japanese engineers began their own research into the fibre at this time. The commercialization of acrylic fibres was started with the establishment of an acrylonitrile-vinyl chloride copolymer fibre by Kanegafuchi Chemical in 1954. In 1956 Exlan Company, a joint venture of Toyo Spinning and Sumitomo Chemical, imported a technique from the American Cyanamid Company. Mitsubishi Rayon Company introduced a technique from the Chemstrand Corporation in 1958. Asahi Chemical established its own method of making an acrylic fibre called "Kashimilon". This method has since been sold to the USSR.

One unique fibre developed in Japan is the polyvinyl alcohol fibre, investigated independently by Professor I. Sakurada of Kyoto University and Dr S. Yazawa of Kanegafuchi Spinning Company. The fibre produced by Professor Sakurada was called "Gosei Ichigo" (synthetic No 1). A pilot plant, which was later absorbed by Dai Nihon Spinning Company, was operated by Gosei-Ichigo Kousha. The product made by Dr Yazawa was named "Kaneviyan" and a pilot plant to make three tons per month of it was started in 1939 by Kanegafuchi Spinning Company, but the work was later stopped.

Dr Tomonari of Kurashiki Rayon was interested in the polyvinyl alcohol fibre and started to investigate it in 1942. In 1947 he opened a large commercial plant for making "Vinylon" fibre.

In 1952 the Japan Synthetic Fibre Association was organized and provided for an exchange of research results on synthetic fibres. The association was reorganized as the Society of High Polymer Science in Japan and its activity was extended to cover research conferences on all types of high polymers.

Another new method for producing synthetic fibres was a vanilline-ethylene glycol copolymer fibre called "Vanilon" developed by the Kokoku Rayon Company in 1957. This fibre has characteristics similar to "Terylene" or "Dacron" polyester fibre. Vanilline is included in the waste liquid from pulp. The utilization of pulp waste is a possible source of this fibre, but as yet the process has not been commercialized.

Polyurea fibre was developed by the Toyo Koatsu Company in 1955. It was produced by the condensation of urea and diamine of carbon-9 of aliphatic hydrocarbon. Oleic acid from sperm oil or rice bran was used as a raw material. A pilot plant had been in operation for several years, but it was finally closed down when it became too difficult to collect the rice bran.

Two new kinds of fibre are now under development. One is a polyether fibre called "A-tel" manufactured by Nippon Rayon Company, and another is a protein-acrylonitrile [illegible]olymer fibre called "K-6". Both resemble silk.

Caprolactam

The manufacture of caprolactam, a raw material for nylon 6, has changed from the classical phenol process to the direct oxidation or photo-nitrosation of cyclohexane (PNC). The PNC process was developed by the Toyo Rayon Company in 1950. The establishment of this PNC process is a typical result of chemical research and development.

In 1950 Toyo Rayon started the first expansion of nylon 6 (5 tons per day capacity) by the phenol process. The pilot plant (1 ton per day capacity) had become idle. Mr. Aikawa, head of the synthetic lactam section, who had forecast the future of the phenol process, directed a research group investigating a new process for synthesizing caprolactam in ten years' time. At that time, the phenol process was the only commercial one, but it was incomplete and unsatisfactory.

Other processes for caprolactam had been suggested, but their industrial value was completely unknown. The PNC process was one of the processes selected by the scientists at Toyo Rayon for making caprolactam.

Their idea was that if it were possible to nitrosate cyclohexane directly, this process would be more rational and economical than the phenol process for manufacturing cyclohexanone oxime.

The idea of reacting cyclohexane with nitrous acid to produce nitrosocyclohexane was unsuccessful, so nitrosyl chloride was used instead of nitrous acid. This reaction did not work very well, but eventually an oily salt of oxime was obtained through the reaction of cyclohexane and nitrosyl chloride in sunlight. The yield of the reaction was very low and a small quantity of the product was intermixed with many by-products. The process was improved by the addition of hydrogen chloride, but several difficulties, e.g. suitable amounts and wave lengths of light, remained. It was necessary to find a source which supplied large inexpensive amounts of light of suitable wave lengths while eliminating unsuitable wave lengths, such as ultra-violet light. Also necessary before the process could be commercialized were solutions to the problems of corrosion by nitrosyl chloride and the elimination of heat produced from the light source.

At that time, no large-scale photo-chemical reaction had been commercialized, and many people at Toyo Rayon therefore considered the process hopeless. Preliminary experimental results brought about discussions of the wisdom of proceeding with the experiment. It was finally decided for two reasons to continue

Colouring agents are added to all plastics. Inorganic colouring agents such as titanium dioxide are the most popular choices. Carbon black is the most frequent item among the organic colouring agents, and its share of the total organics in the United States was about 80 per cent in 1964. Titanium dioxide occupied 76 per cent of the total inorganics in the same study. The total consumption of additives for plastics was estimated to be about 800,000 tons in the United States in 1964 (table 28).

TABLE 28. CONSUMPTION OF ADDITIVES FOR PLASTICS IN THE UNITED STATES, 1964

Type of additive	*Consumption (tons)*
Plasticizers	432,000
Aromatic: 326,000 tons[a]	
Aliphatic: 106,000 tons	
Heat stabilizers	18,200
Flame retardants	38,000
Inorganic colours	25,000
Organic colours	10,000
Water-soluble colours	1,700
Organic peroxides	3,950
Antioxidants	1,730
Antistatic agents	0.5 - 1.0% of resin
Ultra-violet absorber	365

[a] Includes 272,000 tons of DOP (dioctyl phthalate).

Source: *Kunststoffe*, March 1966.

There are two processes used for making octyl alcohol, the oxo process and the acetaldehyde process. The acetaldehyde process requires hydrogen as a raw material and the oxo process requires a propylene-carbon-monoxide-hydrogen mixture. Although the oxo process requires less expensive raw materials, its plant costs are higher.

The DOP or DBP can be economically produced on a relatively small scale. The size of the plant has little effect on production, and raw materials and end-products can be fairly easily transported. The cost of the raw material, on the other hand, greatly influences the cost of the process. Octyl-alcohol plants using the oxo process should be planned along with any petrochemical complex to be built in the future, in order to obtain cheap octyl alcohol locally. This product could then be transported, if necessary, to any plant making plasticizers.

It is more advantageous to obtain the raw materials for synthetic resins and plasticizers from the petrochemical line than to select natural materials such as research. First, the present process was based on the old one developed in the nineteenth century and although it had been improved, it was thought that a completely new process should be originated by the Japanese researchers in an attempt to simplify the processing of raw materials. Second, research into nylon in Japan had been delayed more than ten years. Thus it was preferable to select a completely new process rather than to trace the research of United States or European companies.

Research was begun again in October 1951 after a half year interval. One research chemist and three assistants studied the main and side reactions of photo-nitrosation and applied for patents. Mr Kobayashi, head of the synthetic fibre research section, reported to the executives that the process had a hopeful future. As a result, the management officially accepted it as a research project. The adviser, the late Mr Karashima, and the late president, Mr Sodeyama, visited the laboratory several times and their words of support and hope encouraged the researchers.

A year later, in October 1952, a bench-scale plant equipped with a 1 kilowatt mercury lamp was completed and a photoreaction was accomplished lasting ten hours. In this stage the yield of cyclohexane to oxime was about 70 per cent, but the yield of oxime was only 50 grams per kilowatt hour. It was found that the costs of power and construction were very high. To make the process economical the research was therefore aimed at developing a suitable lamp, a larger photoreactor, and more efficient utilization of light.

The period of four years between this first stage and the second stage was the most painful in the development of the PNC process. No lamp manufacturer was willing to attempt to manufacture a trouble-free lamp. In 1957 a 5-kilowatt high-pressure mercury lamp was completed and hope was restored for the industrial manufacture of nitrosyl chloride and for caprolactam production by the Beckman reaction with oxime hydrochloride.

In 1958 the first pilot plant equipped with a 5-kilowatt mercury lamp started operations. The yield of oxime was 130 grams per kilowatt hour and long continuous runs were possible. The development of the lamp proceeded with the help of Tokyo Shibaura Electric Company, and a 10-kilowatt high-pressure lamp was perfected. A pilot plant with a capacity of 100 kilograms per day was equipped with a combined set of five lamps and completed in March 1960. To develop this process, engineers replaced scientists on the main research staff, and the total number was raised from 10 to 60. As a result of unexpected corrosion problems and unusual side reactions, it took about six months to reach stable continuous working.

In October 1960 when Snia Viscosa of Italy announced a caprolactam process starting with toluene, several Japanese companies became interested in the new method. When Mr Notarbastolo visited Japan in January 1961, he was shown through the Toyo Rayon pilot plant and a comparison of processes was proposed. In March 1961 several engineers from Toyo Rayon visited Snia Viscosa to see the pilot plant and discuss its economic and technical problems. The comparison showed that the two processes were almost equally economical. The executives of Toyo Rayon decided to maintain their own PNC process, not only because of its bright future, but also to continue their own technical development. This decision, accepted by the scientists and engineers, acted as an incentive for further development.

In August 1961 a plant to increase production from 100 kilograms to 10 tons per day was accepted and a plant with a capacity of 10 tons was completed in March 1962. Unlike the situation in the former plant, many difficulties erupted at each stage. Equipment was redesigned and materials were changed. After five months corrosion was eliminated. Scale-up data and the most economical conditions of operation were studied for setting up the control system. In November 1962 the process was exported to the Firestone Tire and Rubber Company of the United States. This led to the design of a plant with a capacity of 60 tons per day, which began partial operation in March 1963.

The cost of research and development for the PNC process is shown in table 56 and the steps in its development are outlined in table 57. These tables show the length of time and the costs to develop the original process.

The development of the PNC process has shown how important to research staff it can be to have the understanding and encouragement of top management.

TABLE 56. COST OF RESEARCH AND DEVELOPMENT OF CAPROLACTAM BY THE PHOTO-NITROSATION CYCLOHEXANE (PNC) PROCESS IN JAPAN, 1950-1964

(thousands of dollars)

	Variable costs	*Fixed costs*
1950-1958	127.6	12.5
1959	43.9	19.7
1960	58.9	185.8
1961	331.8	331.6
1962	412.0	781.0
1963	552.0	232.0
1964	187.2	124.1
TOTAL	1,713.4	1,686.7

Source: K. HOSHINO and M. ITO (1967) "PNC Process Lactam", *Chemical Economics* (in Japanese), 14(3), 71.

TABLE 57. DEVELOPMENT OF THE PHOTO-NITROSATION CYCLOHEXANE (PNC) PROCESS IN JAPAN, 1962-1967

	Capacity of plant (tons/day)	*Lamp capacity (kW)*	*Oxime yield (gram/kWh)*	*Rate of plant cost (per cent)*
1962 March	10	10	160	100
1963 March	30	20	200	60
1964 December	60	20	240	40
1965 September	76	20	280	35
1966 December	95	20, 40	320	32
1967 April	140	20, 40	320	28

Source: K. HOSHINO and M. ITO (1967) "PNC Process Lactam", *Chemical Economics* (in Japanese), 14(3), 71.

2.5 National and regional pilot plants in the developing countries

Chapter 2.4 mentioned many examples of commercial development of polymers showing that:

(a) If a company has had its own experience of some process from laboratory to pilot plant, it will have no difficulty in understanding and implementing foreign technology in the same process.

(b) If the foreign company has had enough experience of commercial working there should be no problem in local operation. A manufacturer interested in new methods should buy an established technique for the commercial operation. In this case, a pilot plant is not a necessary additional purchase.

(c) If the foreign technique is in an experimental stage, the buyer should trace the results in the laboratory, build a pilot plant, and develop his own technique for scale up.

(d) Even if the technique is introduced from foreign countries, technical applications and improvements should be investigated individually by each buyer. The applications of products often have special characteristics in each country, and a market must be developed for each.

(e) The attempted co-operation of many private companies in research and development is often difficult. First, the subjects open to research are limited to a field of mutual interest. Second, the responsibility for the research is not always clearly defined. Third, the engineers and scientists who join the co-operative research programme often turn out to be observers instead of researchers. Fourth, company executives generally rely on foreign rather than domestic technology.

(f) It takes time and money to develop a home industry, but each country should bring its own technique up to as high a level as possible and should attempt to create new products. The attitude of the executives is very important for building up an individual technique.

In building up an industry, each developing country should follow a procedure appropriate to its stage of development, natural resources and social conditions including education, religion, transport system, standard of living and will to work.

In the development stage of the Japanese chemical industries, several pilot plants were built in the national research institutes, with or without the co-operation of private chemical companies. The Government Chemical Industrial Research Institute in Tokyo played an important role in the establishment of Japanese chemical technology, from the laboratory to the pilot plant and then on to the private companies. It also initiated research in the private chemical companies by offering instruction to employees in various subjects.

Most of the industry in developing countries comes from the more developed countries. This pattern is not expected to change in the near future. Therefore, the activities of a national pilot plant will be confined to a small area.

If there are special local products in the country, a national research laboratory could study the progress of production from basic research to a pilot plant. It is unlikely that high polymers could be developed because the raw material generally depends on petroleum. It is also doubtful that a regional pilot plant could be established. Almost all the new technical processes in polymers and plastics have been developed in the more advanced countries. Production is no problem so long as the developing country buys an established technique from more developed countries. A pilot plant would then not be a prerequisite for making plastics in any developing country. If a country wants to buy a technique in the experimental stage or if it is interested in the patent rights to a process, a pilot plant is necessary. This requires time, money and manpower and is in the long run not very economical.

It is important for a developing country to create good conditions for the introduction of new techniques from developed countries and for improving and adapting them to local conditions.

Creating a new invention does not always promise economic prosperity. Many European ideas have been introduced into and commercialized in the United States. Japan has used many foreign methods and although the effort to develop home industry is lower there than in European countries, economic development in Japan is sometimes greater than in Europe.

It is important for each developing country to know how to adapt advanced techniques for its own economic development instead of spending a great amount of money and time in creating new ones. A national or regional pilot plant is not necessary in order to make use of established technology, but the developing country must have a national or regional laboratory for applications research. Applications research will help to improve the living conditions in a country and will result in special local products.

Table 58 lists various chemical and industrial research laboratories in the Federal Republic of Germany, France, Japan and the United States and indicates the fields of research, number of staff members and laboratory area.

TABLE 58. CHEMICAL AND INDUSTRIAL RESEARCH LABORATORIES

	Staff^a members		*Laboratory area*
Sumitomo Chemical Central Research Laboratory (Japan)			
Basic research	Main	58	5,578 m^2 (basic research)
Organic, inorganic, and physical chemistry, polymerization, materials evaluation, chemical engineering	Sub	58	
	Doc.	4	
	TOTAL	120	
Applications research	Main	41	5,336 m^2 (applications research)
Application of polymers, technical service	Sub	47	
	Adm.	62	
	TOTAL	150	2,812 m^2 (administration and library)
Sumitomo Bakelite Central Research Laboratory (Japan)			
Applications research	Main	77	
Documentation	Sub	35	
	Adm.	55	
	TOTAL	167	

Table 58 *(continued)*

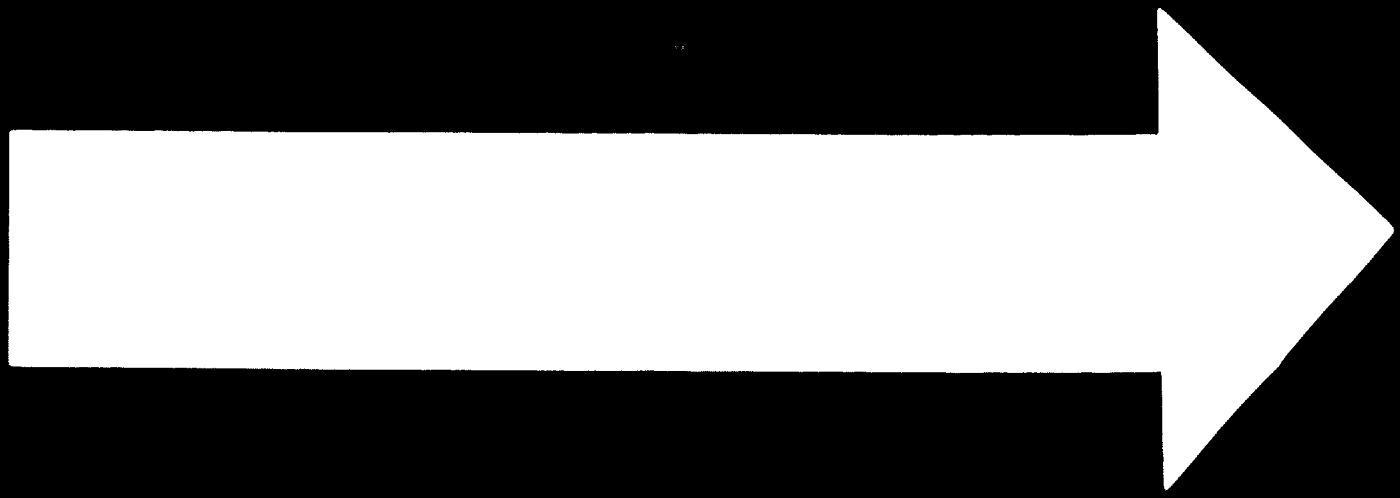
	Staff[a] members		*Laboratory area*
Denki Kagaku Central Research (Japan)			
Basic research	Main	65	4,169 m^2
Organic, inorganic, and physical chemistry, polymerization	Sub	65	
	Adm	24	
	TOTAL	154	
Polymer Research Laboratory (Japan)			
Applications research	Main	10	
Application of polymers, processing methods, technical services, market development	Sub	20	
	Adm	4	
	TOTAL	34	
Asahi Chemical Technological Research Institute (Tokyo)			
Basic research	Main	110	
Organic synthesis, polymerization, biochemistry, physical chemistry	Sub	110	
	Adm	40	
Development	TOTAL	260	
Toyo Rayon Company Basic Research Laboratory (Japan)			
Basic research	Main	78	19,936 m^2
Organic and physical chemistry, biochemistry	Sub	68	(land 380,022 m^2)
	Doc	12	(cost of construction \$10 million)
	Adm	59	
	TOTAL	217	
Physical and Chemical Research Institute (Japan)			
Basic research	Research	333	35,779 m^2
Organic and inorganic chemistry, biochemistry, polymer, agricultural and radiation chemistry, polymer physics, microbiology, ceramics, metallurgy, theoretical physics, mechanical and electrical engineering, electronics	Adm	117	
	TOTAL	450	

Table 58 *(continued)*

	Staff[a] members		Laboratory area
Deutsche Kunststoffe Institut (Germany, Fed. Rep.)			
Basic research	TOTAL	100	
Chemistry, physics, testing			
Documentation			
Centre d'Etude des Matières Plastiques (France)			
Plastics research	TOTAL	45	
Standardization			
Documentation			
National Bureau of Standards, Polymer Division (USA)			
Polymer research	TOTAL	200	
Documentation			
Mellon Institute (USA)			
Sponsored research	Research	355	
Basic research	Adm.	184	
Applications research	TOTAL	539	
Government Chemical Industrial Research Institute, (Tokyo, Japan)			
Analytical chemistry	Research	304	29,943 m^2
Physical chemistry	Adm.	152	
Electrochemistry	TOTAL	456	
Industrial catalysts			
Pigments, dyes			
Polymer chemistry			
Oil and fat chemistry			
Wood chemistry			
Disposal of industrial wastes			
Explosives safety			
High-pressure chemistry			

Table 58 *(continued)*

	Staff[a] *members*	*Laboratory area*
Leather		
Photo-sensitive materials		
Technical consultation		
Government Industrial Research Institute, (Osaka, Japan)		
High-polymer chemistry	TOTAL 312	
Applications research for plastics		
Ceramics		
Industrial wastes		
Fuel cell		
Government Textile Research Institute (Japan)		
Dyeing and finishing	10 research sections	
Synthesis of new polymers	TOTAL 138	
Physical properties of polymers		
Textiles from fibres		
Research into textile products		
Government Industrial Arts Institute (Japan)		
Research into consumer products	TOTAL 215	
Improvement of design		
Packaging		
Applications for plastics		
Metal finishing		
Processing of wood and bamboo		
Government Resources Research Institute (Japan)		
Mining technology	TOTAL 414	
Applications of coal and petroleum		
Raw materials manufacturing processes for polymers		
Combustion technology		
Industrial safety		



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tropical plants and crops for this purpose. In India there is a long history of research in the use of local products for various applications. One local product, developed in the 1930s, is a compression-moulding compound from shellac. However the use of this moulding powder was abandoned as soon as phenolic products became available, because the moulding powder had too long a moulding cycle and various unstable properties. Recently, tannin-formaldehyde glue has been developed and appears to be a promising raw material. Vegetable tannin and cashew nut shell liquid are also being studied as raw materials.

The value of such locally producible resins is not very high unless the resins are produced with the properties and at a cost necessary to compete with the existing important thermoplastic resins, such as polyethylene, PVC resin, and polystyrene. The chances of obtaining such a superb resin locally are very small in view of the development of the present petrochemical resins, and it is considered more advisable to concentrate on them.

The process for producing ethylene from cane sugar or molasses alcohol has already been described. This was acceptable until ethylene could be cheaply made from petrochemicals. The production of important synthetic resins from locally available vegetables or special minerals, instead of from petroleum and natural gas, is not recommended.

1.4 Financial aspects of the plastics industries

Monomer and polymer industry

The plastics industry is usually classified into two very different parts, the resin producers and the processing companies.

Resin production has two stages. The first is the production of monomer, e.g. the production of ethylene in manufacturing polyethylene, vinyl chloride monomer in polyvinyl chloride production, styrene monomer in polystyrene and so forth. The second stage is the polymerization of the monomers to make polymerized resin material. The different steps involved are all part of the so-called apparatus industry, which requires high investments, extensive automation and sufficient plant size. In order to justify production and make it economical, the capacity of the plant and the rate of operation should be as high as possible.

Table 19 shows one example of production costs for low-density polyethylene. The cost of building a plant with a capacity of 25,000 tons per year would be approximately $11.7 million. If the capacity were enlarged to 100,000 tons per year, the cost of the plant would be $35.6 million, or 20 per cent less than the cost of building four 25,000-ton-capacity plants. Considering the fact that the costs of raw material and labour are a small percentage of the total cost, this 20-per-cent figure is very significant in lowering production costs.

This difference could be much greater in the production of other resins. Tables 26 and 27 show the production costs of styrene monomer and polystyrene. In the case of monomer production, a 12,000-ton-capacity plant costs $3.33 million, while a 96,000-ton-capacity plant (eight times larger than the first plant) would cost $11.1 million. This is half the cost of building eight of the former plants. The manufacture of polystyrene from styrene monomer involves similar capital savings on larger-scale production. A polystyrene-polymerizing plant with a capacity of 10,000 tons per year would cost approximately $2.78 million, while the same plant with a capacity of 80,000 tons would cost $12.5 million. This is a capital saving of approximately one third.

A study of the figures in tables 19 through 27 shows that the investment required for monomer production decreases as the capacity of the plant increases. Polymerizing a part of the monomer also offers similar, though smaller savings. A unified large-scale monomer production centre is therefore desirable, but individual polymer production plants could accommodate each local situation by providing smaller plants in more places.

Plastics processing industry

Processing is usually carried on in many small plants. This is partly a result of the smaller investment required to establish a small plant. The size of the plant does not greatly affect the cost of production. Table 29 below shows that in the United States, plants with annual sales of over $2.5 million have an advantage over plants with sales of $250,000 to $500,000. The large processors do not benefit much from their size, nor are the small processors always handicapped by being small. Table 29 also shows that the "profit before depreciation and taxes" averages out to 11 to 12 per cent of sales.

In the United States the processing industries purchase resins at competitive prices. Their selling prices are also competitive. In spite of this, the plastics processing industry is flourishing. A profit of 10 per cent before depreciation and taxes is relatively small compared with the profits of other manufacturing industries. This indicates that the plastics processing industry is very vulnerable and competitive. Capital is accumulated rather slowly through this pattern of internal financing. As explained earlier, the plastics processing industry is the key to establishing an integrated plastics industry. Special consideration must be given to lending money at lower interest rates and special tax rates when commodities are manufactured for export or for a government-supported project.

In order to assist processors to increase their capacity, tax regulations should allow high depreciation rates. Cash equal to the amount of the depreciation should be retained within the company and invested in new machines and buildings within a reasonable number of years, providing a tax relief. A cheap and stable supply of resin is another factor to be considered. Continuous operation at high efficiency is the only means of ensuring fast capital returns and reinvestment possibilities. A shortage of raw materials or a fluctuation in prices discourages reinvestment since it is an indication of a poor risk. For this reason, the supply of resin should be under governmental control.

The design of plastics products often poses problems when the products are exported. Even in the domestic market, a good design encourages further use of the same product. It is rather difficult for small processing companies to maintain a large labour force for the purpose of producing new designs. A "design centre" for plastics processors is a possible solution to the problem. Such a design centre could provide information on patents, regulations, design, assistance in technical problems and so forth. Co-operation between United States designers and design centres in different countries would be helpful.

TABLE 29. OPERATING EXPENSES AND PROFITS OF THE PLASTICS PROCESSING INDUSTRY IN THE UNITED STATES

(per cent of sale price)

	Total industry	*Plants with annual sales of* *$250,000 to $500,000*	*$500,000 to $1,000,000*	*$1,000,000 to $2,500,000*	*over $2,500,000*
Costs of production					
Material	35.2	35.7	35.3	41.0	36.5
Cost of labour	20.6	20.3	21.4	17.9	18.6
Manufacturing expenses (including depreciation)	20.0	19.6	19.5	18.2	23.3
TOTAL	75.8	75.6	76.2	77.1	78.4
Gross profit	24.2	24.4	23.8	22.9	21.6
Selling expenses					
Salaries and commissions	2.7	2.3	2.1	3.3	3.6
Advertising	0.7	0.7	0.4	0.4	1.2
Travel and entertaining	1.0	1.5	0.5	0.5	0.8
Others	0.6	0.3	0.8	1.0	0.4
TOTAL	5.0	4.8	3.8	5.2	6.0
General and administrative expenses					
Executive salaries	8.0	7.4	6.4	3.4	3.3
Debts	0.4	0.3	0.3	0.5	0.3
Others	3.6	4.9	5.2	5.2	4.8
TOTAL	12.0	12.6	11.9	9.1	8.4
Profit before depreciation and taxes	11.1	11.4	12.2	11.3	11.1
Depreciation	3.9	4.4	4.1	2.7	3.9
Taxes	2.8	2.5	2.9	3.4	3.1
Net profit	4.4	4.5	5.2	5.2	4.1

Source: The Plastics Processing Industry 1966, Tarnell Company Incorporated.

TABLE 30. PRIME INTEREST RATES IN SELECTED COUNTRIES

(per cent per year)

Countries	*Rate of interest*	*Since*	
ECAFE COUNTRIES			
Ceylon	4.0	August	1960
India	5.0	September	1964
Indonesia	9.0	August	1963
Japan	5.84	August	1967
Pakistan	4.0	January	1959
Philippines	6.0	January	1962
Republic of Korea	10.5	March	1964
Thailand	5.0	October	1959
EUROPE			
Austria	4.5	June	1963
Denmark	6.5	July	1964
Finland	7.0	April	1962
France	3.5	April	1965
Germany, Fed. Rep.	3.5	April	1967
Greece	5.5	January	1963
Iceland	9.0	January	1961
Ireland	4.89	September	1964
Italy	3.5	June	1958
Netherlands	4.5	March	1967
Norway	3.5	February	1955
Spain	5.0	June	1961
Sweden	5.0	March	1967
United Kingdom	5.5	April	1967
CENTRAL AND SOUTH AMERICA			
Argentina	6.0	December	1957
Brazil	8.0	April	1958
Chile	14.63	July	1964
Colombia	5.0	August	1958
Costa Rica	5.0	April	1954
El Salvador	4.0	August	1964
Mexico	4.5	June	1942
Nicaragua	6.0	April	1954
NORTH AMERICA			
Canada	5.0	May	1967
United States	4.0	April	1967

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Table 58 *(continued)*

	Staff[a] *members*		*Laboratory area*
Government Industrial Development Laboratory (Hokkaido, Japan)			
Waste treatment	TOTAL	113	
Applications of coal			
Recovery of tar acid			
Improvement of tar pitch			
Analysis			
Government Fermentation Research Institute (Chiba, Japan)			
Fermentation of carbohydrates and hydrocarbons	Research	49	(9 sections)
	Adm.	22	(1 section)
Analysis and chemical engineering	TOTAL	71	

[a]Main : main staff or research
Sub. : assistant research
Doc. : documentation
Adm. : administration

RECOMMENDATIONS

What can be done nationally or regionally to promote research and development in developing countries? It is difficult for developing countries to establish their own methods. Most of them lack the manpower, time and money needed to create new processes. Therefore, their economic development should be based on the introduction of methods from advanced countries. For this purpose, it is hoped that developing countries are well prepared to digest the foreign methods and adapt them to their own societies.

The establishment of a national industrial research institute is recommended in each developing country to promote applications research and to collect information on the uses of local products. However, it may also be possible to establish an institute through the co-operation of several developing countries. In this case, UNIDO should work to set up such a regional industrial research institute.

The functions of such an industrial research institute are as follows:

(a) Collection of technical information and samples;

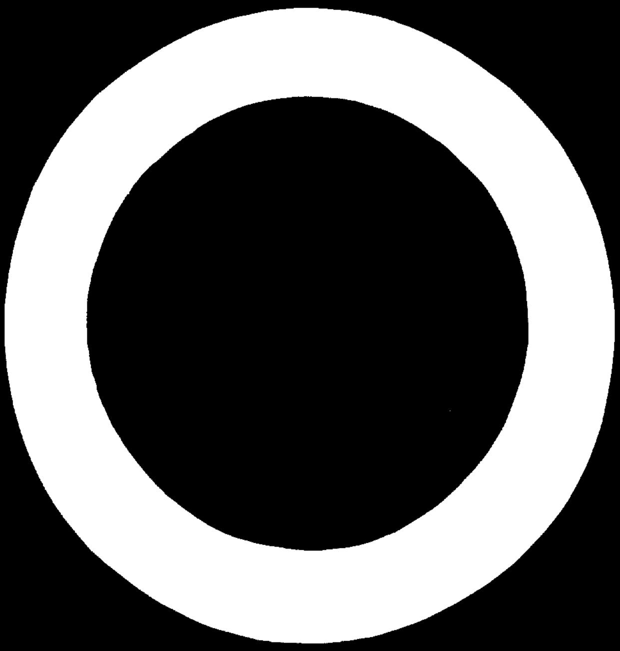
(b) Technical guidance for private companies;

(c) Research and development on behalf of private companies;

(d) Training of scientists and engineers sent from private companies;

(e) Applications research for domestic products and those made with foreign technology;

(f) Research and development in the regional and national interest from laboratory to pilot plant.



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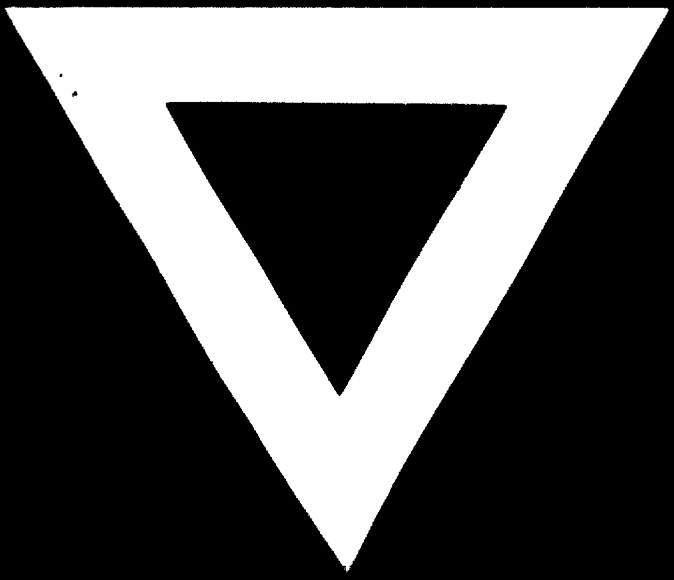

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