THE PLASTICS INDUSTRY: A COMPARATIVE STUDY OF RESEARCH AND INNOVATION

Square-bracketed references, thus [1], *are to the list of sources in Appendix* III. *Other references, thus* (1), *are to the footnotes at the bottom of the page.*

Summary

Plastics are already one of the world's main groups of industrial materials; in volume terms, world plastics consumption is now greater than that of all non-ferrous metals combined. The main point that emerges from international comparisons is West Germany's predominance in production and exports (and also in exports of plastics machinery). German production of plastic materials in 1961 was 19 kilograms per head, compared to 17½ in the United States and 12 in Britain. This is not due to lower costs. In material costs, Germany has been, if anything, at a disadvantage: she had only a small petro-chemicals industry in the early post-war years, and she has very little natural gas. In labour costs (which in any case are not very important in this industry) and in plant costs, again there is no evidence of any marked German advantage over her competitors. In general her quoted prices were not below those of other countries.

Technical progress seems to be the main explanation of Germany's lead: this needs a long time-span for analysis, since scientific advances may need a decade or more before they show themselves in commercial production. Three measures of technical progress are attempted in this article: research expenditure; the analysis of patents; and the analysis of innovations. On all three counts, the most noticeable fact is the dominating position of the German firm of I.G. Farben in the inter-war years and up to 1945. There is little doubt that this firm spent more on plastics research than any other chemicals firm; in the period 1931-45 it took out more than twice as many patents as its nearest competitor—and this is still true if the analysis is restricted to key patents only; finally, I.G. Farben was the innovator of a large number of the materials which now make up the bulk of plastics output. The success of this firm was no doubt helped by the fact that in the inter-war years as well as in wartime the development and production of substitute raw materials was an important strand in German economic policy.

From 1945 to 1952 I.G. Farben was being reorganised. In this period, American firms took the lead in technical progress in plastics, and British firms—notably ICI—also appeared among the leaders. By the second half of the nineteen-fifties, the successor firms to I.G. Farben were again coming back into prominent positions in research, development and innovation.

Technical progress results in leadership in production in this industry, because patents and commercial secrecy together can give the innovator a head start of as much as 10-15 years. Other countries, it is true, may shorten the catching-up process if they are in a position to purchase the technical know-how, or if they are countries in which the innovating firms set up subsidiaries (as American firms have done in Japan). Even after patents expire, accumulated experience will help to keep the innovator in the lead, and he will be in a better position to produce new and improved grades of material. But, for the standard grades, new producers with cost advantages may after 15-30 years eventually challenge the innovating firms. Thus, some thirty years after the United States and West Germany first produced PVC, Italy and Japan are now overtaking these countries in per capita production; for they have advantages in costs of production and are able to quote lower prices.

In explaining the country pattern of consumption, other factors come in; it is not wholly a matter of technical progress in production—for instance, Sweden, with no production of polyethylene, has a higher level of consumption per head than either Britain or Germany. The progressiveness of the user industries is important here. On this point, the comparison of the British and German patterns of use is instructive—in so far as our inadequate statistics of plastics consumption by industry permit a comparison to be made. The differences in the use of plastics between the two countries are much more marked in the old industries, such as construction, than in the new industries, such as vehicles and electrical engineering. German plastics materials manufacturers have stimulated applications in these old industries: for instance, they encouraged the development of chipboard, whose output in Germany in 1961 was over 1 million cubic metres, compared to 85 thousand cubic metres in Britain. This industry consumes enormous quantities of glue made from plastic

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materials which were developed by I.G. Farben. Apart from this, plastics are used much more widely in the German construction industry for roofing, panelling, thermal insulation and interior fittings of all kinds.

Two other general factors are briefly considered. First, there is the possible connection between faster economic growth and high plastics production—there is some evidence that in fast-growing economies the switch to new materials is made more easily. Secondly, there is the question of the importance given to the plastics industry in those countries with economic planning. In the USSR it seems that the planning agencies, by excessive devotion to steel, have hitherto held back the growth of the plastics industry, but in Japan they have apparently provided a stimulus.

Introduction

Although its ' centenary ' is being celebrated this year, the plastics(1) industry is really not much more than 50 years old. The production of cellulosic plastics (celluloid) began in the latter part of the 19th century, and the commercial production of protein plastics (Galalith) began at the turn of the century. But these early materials were based on naturally occurring polymers, which today account for less than 10 per cent of world production. The truly synthetic phenol-formaldehyde plastics (better known as Bakelite) were introduced just before the First World War. The three best-known plastic materials today are probably PVC (polyvinyl chloride), polyethylene, and polystyrene, and all of them are less than 35 years old. Together they now account for over half of total world plastics output.

Plastics, although comparatively new, are already one of the world's main groups of industrial materials. World plastics consumption, by weight, is now larger than that of either copper or aluminium. However, the low specific gravity of most plastic materials gives them a weight advantage over most metals, so that in volume terms world consumption is greater than that of all non-ferrous metals combined, although still less than a quarter of world steel consumption. Plastics, judging from past growth rates (table 1), will continue to gain rapidly on conventional materials. Their production, although not necessarily their fabrication, is now undertaken mainly by chemical firms, and they are the fastest growing main sector of the chemicals industry, which is itself a ' growth industry '.

Their growth rate is high mainly because plastic materials have outstanding technical and cost advantages in a wide range of applications.[1] Plastics are light, easy to fabricate and install ; they have good electrical insulation, excellent resistance to corrosion and pests and low maintenance costs ; many can be made in a wide range of colours, or transparent. Plastics have some disadvantages—for example, the rather limited temperature range within which many of them can be used. Nevertheless their remarkable success in a very short space of time suggests that they will be increasingly important in the later part of this century.

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(1)Plastics are man-made materials which can be made to flow on the application of adequate heat and pressure, and take up a desired shape. This shape is retained when the applied pressure and heat are withdrawn. They differ from similar man-made materials, such as glass and ceramics, in their organic origin. They are composed of giant molecules of organic substances based on chains of carbon atoms. For casein and cellulosics, these chains (polymers) are of natural origin, but the great majority of polymers are now synthesised from simple chemical units, or monomers.

The classification of plastics is necessarily somewhat arbitrary and there are synthetic materials which correspond to this definition but are still not considered as plastics here. An OECD Working Party has been attempting for some years to establish an internationally acceptable classification and for the purpose of this article plastics are defined on the same basis as in the Chemical Reports of the OECD.[2] Synthetic fibres and synthetic rubber, although belonging essentially to the same group of materials, are excluded from this definition. Where materials such as nylon can be used both as a fibre and as a plastic, that part of the production which is for fibres is excluded. The OECD Classification (and the Brussels nomenclature) divides plastics into four groups :

(i) Condensation products (39.01 *in the Brussels nomenclature*), including poly-condensation and poly-addition products ; these are mainly but not exclusively thermo-setting products—that is to say, they become soft and plastic on the first application of heat, but then undergo a chemical change and set hard. The most important of these are phenolics made from phenol and formaldehyde (best known as Bakelite) and aminoplastics made from urea and formaldehyde and from melamine and formaldehyde.

(ii) Polymerisation products (39.02 *in the Brussels nomenclature*), including co-polymerisation products. These are mainly thermo-plastic : that is to say that although they will harden on cooling, they will re-soften on re-heating. The best known are PVC (polyvinyl chloride), polyethylene (of which ' Polythene ' is a brand name) and polystyrene. Still small in volume of production is polypropylene, which is often classed together with polyethylene under the single heading of poly-olefins. Other important polymerisation products are acrylics (for example Perspex), polyvinyl acetate and poly-tetra-fluorethylene (PTFE).

(iii) Cellulosics (39.03 *in the Brussels nomenclature*), of which the best known are celluloid and regenerated cellulose film (Cellophane).

(iv) Hardened proteins (39.04 *in the Brussels nomenclature*) such as casein.

This classification is used in this article. Fuller details of the materials included in each sub-division are shown in the Appendix on Sources and Methods (page 50).

The producers of plastic materials use basic raw materials—such as petroleum products, natural gas, coal, cellulose, etc.—or intermediates derived from these materials, such as ethylene, propylene and acetylene—to produce plastic materials. These materials may be in the form of moulding and extrusion compounds, solid or liquid resins, emulsions, dispersions, and so forth. The materials producers may themselves turn out film, sheet, rods, tubes, mouldings, extrusions, and other fabricated products ; or this may be done by specialised fabricators, who purchase the materials from the basic producers. The materials producers and the fabricators are together described as the plastics industry.

Table 1. World[a] production and growth rates of various materials

	Production (Thousand metric tons[b])				Compound growth rates (Per cent per year)				
	1913	1938	1950	1960	1913 to 1938	1938 to 1950	1950 to 1960	1938 to 1960	1913 to 1960
Plastics	35	300	1,500	5,700	9.0	14.3	14.3	14.3	11.5
Rubber, synthetic	—	6	543	1,914	—	45.0	13.4	30.0	..
Rubber, natural	122	925	1,890	2,010	8.4	6.1	0.6	3.6	6.1
Copper[c]	1,000	1,840	2,280	3,660	2.5	1.8	4.8	3.2	2.8
Aluminium[c]	70	530	1,280	3,610	8.4	7.6	10.9	9.1	8.8
Zinc[c]	800[d]	1,400	1,810	2,420	2.0	2.1	3.0	2.5	2.3[d]
Steel[b]	53[e]	88	153	241	1.8	4.7	4.7	4.7	3.1[e]

Source : UN Yearbook of Statistics, H. Saechtling, *Werkstoffe aus Menschenhand.*

(a) Excluding USSR, China and Eastern Europe.
(b) Million metric tons for steel.
(c) Primary refined production.
(d) Zinc 1909.
(e) Steel 1910.

The willingness to change from traditional to new methods and materials is one of the factors in any country which make for faster economic growth and greater competitiveness. A country which is ahead in the use of plastics, for example, may have significant technical and cost advantages over countries which rely on older materials and techniques. So it is illuminating to establish which countries are in fact ahead in the production and consumption of plastic materials, and why ; that is the purpose of this article. The comparison concentrates on West Germany and Britain.

The figures

Partly because it is a young industry, it is not easy to obtain figures for plastics production, consumption and trade which are consistent from year to year and which are internationally comparable. (The statistical problems, and the methods we have used, are discussed in more detail in the Appendix, page 50.) The figures for the principal countries have been much improved in the last few years, and those for 1960-62 are probably reasonably reliable and comparable. Those for earlier years have a wider margin of error. However, this margin is not wide enough to vitiate the conclusions drawn in the article. It is significant that if we compare our estimates with those made independently by others,[1] the differences are not very big.

One of the problems is that the basic materials are often mixed with reinforcing agents—' fillers ' or ' plasticisers '. For production or sales, figures are in general[2] available which exclude these fillers : that is, they are on a ' net resin basis '. But in the statistics of international trade the fillers are normally included, and we have had to make estimates of the net resin content of imports and exports of plastics. All the figures in the article are in terms of net resin content, unless otherwise stated.

Another problem is the general inadequacy of the figures, particularly for the end-uses of plastics. At the moment nobody, inside or outside the industry, can make useful estimates of the future size and pattern of the demand for plastic materials in Britain ; for there is inadequate detailed knowledge about which industries use plastics now, how much they use and for what purpose. Such figures as there are (some are given in table 14) are based on trade estimates and market research surveys.

Throughout, we have relied to a considerable extent on the advice and assistance of the firms involved in the industry ; and we are grateful to all the firms who helped us—and in particular to the principal producers of plastic materials in the United Kingdom, ICI, Shell, Distillers, Monsanto.[3] The analysis and conclusions of the article are the responsibility of the National Institute alone.

International comparisons

A few advanced countries predominate in world[4] production and exports. The United States, West Germany, Japan and Britain—in that order—account for 80 per cent of world output (table 2). Japan, in spite of her large volume of production, is still a net importer ; and the other three countries between them

[1] Appendix, page 52, table 17.
[2] With certain exceptions noted in Appendix I, page 50.

[3] A list of all firms and organisations who have co-operated in providing information, views and advice, is given in Appendix IV, page 62.
[4] The term ' world ' throughout the article excludes the USSR, Eastern Europe and China.

Table 2. Production, consumption and trade in plastics materials

	United States	United Kingdom	West Germany	France	Italy	Japan	Sweden	Netherlands	Belg./Lux.
Total figures (*thousand metric tons*)									
Production 1955	1,744.2	323.4	355.2	110.1	89.7	113.7	29.5	24.1	16.4
1961	3,239.2	615.0	1,028.8	367.0	384.4	781.0	65.7	76.1	46.6
Per cent increase .. 1955-61	*86*	*90*	*190*	*233*	*328*	*587*	*123*	*216*	*184*
Consumption 1955	1,644.8	263.9	294.4	119.0	81.8	120.3	38.2	32.6	21.9
1961	2,866.6	507.7	829.0	367.8	333.8	793.7	95.0	92.7	97.7
Per cent increase .. 1955-61	*74*	*92*	*182*	*209*	*308*	*560*	*149*	*183*	*346*
Exports 1955	131.6	85.6	78.8	14.6	19.7	4.9	7.5	13.1	6.6
1961	383.2	192.3	298.1	69.5	111.9	44.4	31.1	61.6	24.5
Exports as per cent of production 1961	*12*	*31*	*29*	*19*	*29*	*6*	*47*	*81*	*53*
Imports 1955	2.2	26.1	18.1	23.5	11.8	11.5	16.2	20.6	12.2
1961	10.6	77.3	98.4	70.3	61.3	57.1	60.5	78.2	75.6
Imports as per cent of consumption 1961	*1*	*15*	*12*	*19*	*18*	*7*	*64*	*84*	*77*
Net exports 1955	129.4	59.5	60.7	− 8.9	7.9	− 6.6	− 8.7	− 7.5	− 5.5
1961	372.6	115.0	199.8	− 0.9	51.1	− 12.7	− 29.3	− 16.6	− 51.2
Per head figures (*Kg*)									
Production 1955	10.70	6.34	6.95	2.54	1.87	1.28	4.06	2.24	1.78
1961	17.64	11.80	19.00	7.98	7.76	8.31	8.74	6.54	4.90
Consumption 1955	9.91	5.19	5.87	2.75	1.70	1.35	5.26	3.03	2.37
1961	15.61	9.61	15.29	8.00	6.74	8.44	12.64	7.93	10.28

Source : See Appendix II, page 52.

provide 70 per cent of world exports. There are still a large number of countries where important materials are not produced at all.

In absolute terms, the United States is of course the largest producer, consumer and exporter ; but on a per head basis, West Germany comes first in production and exports, and is a close second to the United States in consumption (table 3). If we relate consumption to national product, again the German figure (together with that of Japan) is exceptionally high (chart 1). West German consumption in 1961 was almost as big as that of France and Britain together, and her production was larger.

This German pre-eminence might be explained by lower costs or prices, or by a different industry structure—if plastics-consuming industries were much more important than elsewhere in Europe. Or it might be due to technological factors : earlier discovery and development of new plastic materials, and earlier innovation in finding applications for existing materials. This, in turn, might be related to the degree of conservatism among users and potential users of plastics, and to the rate of change in the economy as a whole. We discuss these possible explanations in turn.

Costs of production

It was the almost unanimous opinion of the firms and organisations interviewed that the West German plastics industry did not have any major input-cost advantages over her main competitors—that there was nothing equivalent, for instance, to the advantage Canada derives for her aluminium production from cheap electric power. This consensus of opinion is not proof, of course ; and proof is hardly possible since, for the plastics industry as for most new industries, detailed production cost figures are hard to come by.

Table 3. Estimates of per capita production and consumption of plastics materials, by type, 1961

Kg. per head

		USA	UK	West Germany	France	Italy	Japan	Sweden	Netherlands	Belg./Lux.
Condensation (*39.01*)										
Phenolic	Production ..	1.31	0.97	1.01	0.40	0.46	0.59	1.23	0.56	..
	Consumption ..	1.25	0.73	0.85	0.43	0.44	0.60	1.31	0.46	..
Aminoplasts	Production ..	0.98	1.39	2.76	0.61	0.83	1.83	2.14	0.24	..
	Consumption ..	0.93	1.12	2.56	0.79	0.82	1.83	2.03	0.94	..
Other	Production ..	2.18	1.56	3.51	1.21	0.74	0.21	1.54	1.95	..
	Consumption ..	2.10	1.61	2.86	1.20	0.89	0.18	1.31	1.30	..
Total	Production ..	4.47	3.92	7.28	2.22	2.03	2.63	4.91	2.75	1.27
	Consumption ..	4.28	3.46	6.27	2.42	2.15	2.61	4.65	2.70	3.84
Polymerisation (*39.02*)										
PVC	Production ..	2.41	2.06	3.61	2.60	3.03	3.29	1.53	0.77	..
	Consumption ..	2.26	1.90	3.08	2.28	1.97	2.97	2.13	2.02	..
Polystyrene	Production ..	2.83	1.00	2.03	0.92	0.79	0.31	0.54	—	..
	Consumption ..	2.48	0.77	1.29	0.87	0.43	0.41	0.99	0.43	..
Polyolefins	Production ..	4.21	2.59	1.94	0.65	1.13	0.62	—	1.55	..
	Consumption ..	3.31	1.53	1.55	1.08	1.15	1.07	2.23	1.29	..
Other	Production ..	1.99	0.93	2.43	0.57	0.48	0.97	0.59	0.84	..
	Consumption ..	1.68	0.89	1.43	0.52	0.66	0.93	1.77	0.97	..
Total	Production ..	11.44	6.58	10.00	4.74	5.43	5.19	2.66	3.16	3.64(a)
	Consumption ..	9.73	5.09	7.36	4.75	4.21	5.38	7.11	4.72	..
Cellulosic (*39.03*)										
Total	Production ..	1.73	1.27	1.69	1.02	0.28	0.49	1.17	0.94	..
	Consumption ..	1.60	1.03	1.65	0.82	0.37	0.44	0.88	0.50	..
Protein (*39.04*)										
Total	Production ..	..	0.03	0.02	0.01	0.02	—	—	..	..
	Consumption ..	..	0.03	0.01	0.01	0.01	..	..	..	..
Total, all materials										
	Production ..	17.64	11.80	19.00	7.98	7.76	8.31	8.74	6.54	4.84
	Consumption ..	15.61	9.61	15.29	8.00	6.74	8.44	12.64	7.93	10.28

Source: See Appendix II, page 52.
(a) Including 39.03 and 39.04.

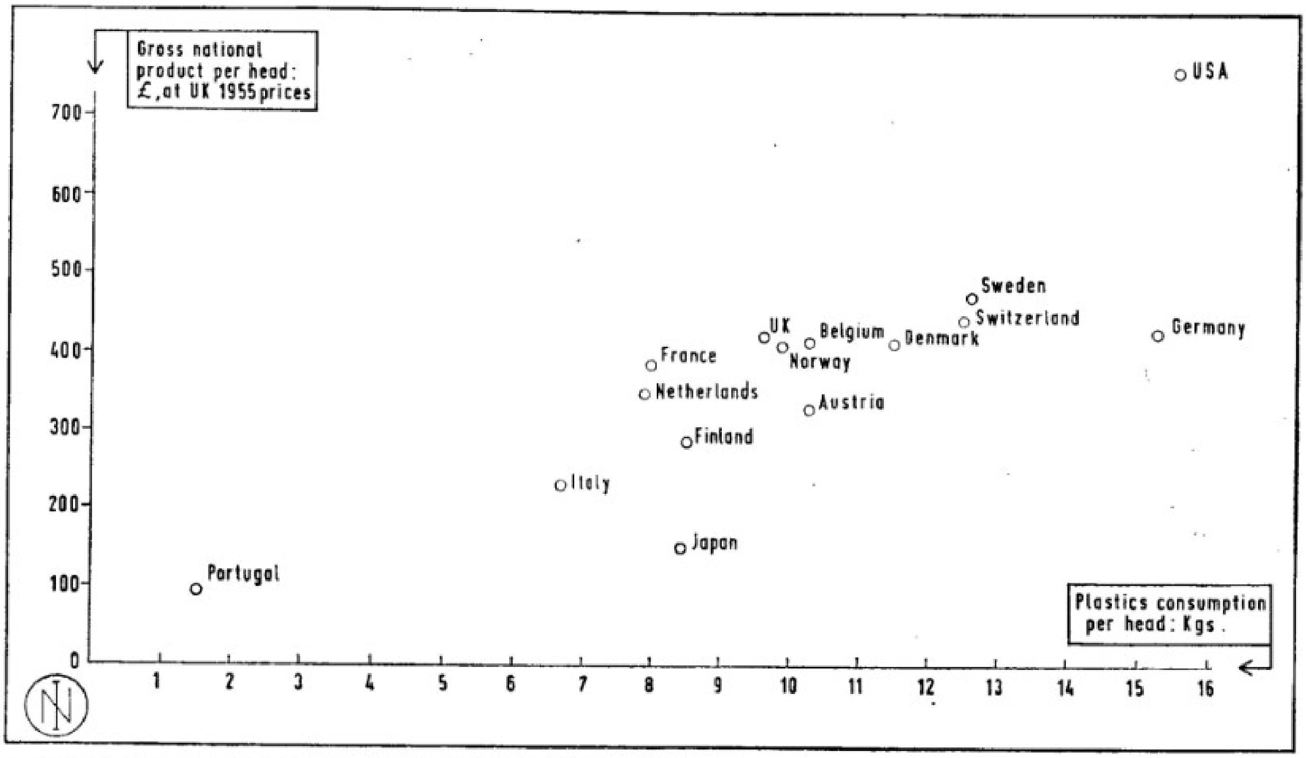
But such evidence as there is on costs, and such price figures as are published, support this conclusion.

The pattern of costs varies considerably between the different plastic materials, and for the same material between different firms and processes, depending largely on the degree of integration. But typically costs of operating labour are low, and raw material and capital costs are high. For most plastic materials the range of costs (excluding return on capital) would be roughly as follows:

	Per cent of cost
Materials and process chemicals	40–70
Fuel and power	3–7
Operating labour	3–7
Maintenance	4–8
Depreciation	5–15
Research and royalties	3–7
Overheads, including administration, supervision, testing, sales	15–25

For PVC, polyvinylacetate and melamine-formaldehyde, electric power costs are much higher than the range shown above. Capital costs are particularly high for polyethylene, polypropylene and acrylics, but relatively low for some condensation products, where plant economies of scale are not very important. Average capital employed per man in the United States plastics industry has been estimated at $22 thousand,[3] but it is higher than $40 thousand in some poly-olefin plants, where an investment in one plant of over $20 million is not uncommon. Overhead costs are generally high, because of the need for expensive facilities for testing and control, and for a technical sales service. They are particularly high for new plastic products which have not yet reached a high volume of production.

Chart 1. Plastics consumption and national product, 1961[(a)]



Source : Tables 2 and 3, OECD *Chemical Industry in Europe* and NIESR estimates.
(a) 1960 for Finland, Denmark and Portugal.

Material costs

The most important single element in costs for almost all plastics is material costs, including chemicals, such as catalysts, which are consumed in the production process, although not embodied in the end-product. It appears that West Germany has had no general advantage over her competitors in material costs, and indeed was at a disadvantage compared with some of them.

Originally coal and cellulose were the most important sources of the basic materials and other chemicals needed for plastics manufacture ; but since the Second World War they have been increasingly replaced by oil and natural gas. As long as coal was the source, Germany was not at a disadvantage—although she had no special advantage either over other coal-producing countries, except in know-how. But as oil became more important, she was at a disadvantage compared with the United States, and to a lesser extent with Britain, where the post-war refinery-building programme started earlier than in Germany.[(1)] The United States had a big lead in petro-chemicals, and Britain's output was ahead of West Germany's up to 1960 (table 4). As late as 1957, only 12 per cent of West German production of ethylene and acetylene, as against 74 per cent of American production, came from oil or natural gas.

Such gases as ethane, propane, ethylene, propylene and acetylene can sometimes be made available from oil refineries very cheaply. In the United States they were in fact often ' waste ' products which were flared before petro-chemical complexes were built to use them.[4] Manufacturers of plastic materials who could site their plants within pipe-line distance of refineries

(1)However, Britain was also handicapped in the early post-war years by a lack of refinery feedstock : thus she used an expensive process for producing ethylene from alcohol made from molasses.

Table 4. Output of petro-chemicals

Thousand metric tons of carbon content

	1953	1954	1955	1958	1959	1961
West Germany	55	70	110	246	335	858
France	16	28	37	118	260	510
Italy	12	16	29	82	180	246
Netherlands ..	12	27	28	50	54	85
United Kingdom	124	164	197	302	378	618
Others	..	..	..	15	18	156

Source : *Chemische Industrie XIII* 1961, December, p. 767.

had an advantage compared with those still based on coal-derived chemicals, imported petro-chemicals or other materials. More recently, there has been a tendency for chemical firms to set up their own specialised cracking plants to provide their feedstock, instead of relying on oil refinery by-products.

In the last decade, natural gas has become an increasingly important source, as it is often an even cheaper feedstock than oil. Here again, West Germany (together with Britain) has been at a disadvantage, compared with Italy, France and the United States.(1) Italy in particular has been exploiting this natural advantage, with big new plastic plants in Ravenna and Ferrara ; the recent rapid growth of the Italian plastics industry and the rise in exports may well be due in part to this factor, as well as to generous Government support of new investment projects in the South.

Consequently, the success of the German plastics industry in the 1950s cannot be explained by lower material costs.(2) Indeed, the industry was at some disadvantage in this respect—particularly for polyethylene, polystyrene, acrylics and epoxy resins. The disadvantages were less serious for PVC, which can be manufactured by various alternative processes ; however, the manufacture of carbide both for PVC and polyvinylacetate needs considerable amounts of electric power, and West Germany is not a cheap power producer. Japan and Italy have advantages over her in power costs, and this is one reason for their relatively high output of PVC (table 3).

(1)West Germany has in fact a very small amount of natural gas, some of which is used in the polystyrene plant at Hüls.
(2)This does not mean, of course, that none of the materials used was cheaper in Germany. Her coke and acetylene technology were particularly advanced, and she undoubtedly derived some benefits from this. There is also evidence of differences in pricing policy between chemical firms in Britain and West Germany which may have resulted in higher prices in Britain for such chemicals as formaldehyde.

Other costs

Although she had no advantage in raw material costs, West Germany did have a slight advantage in capital costs over Britain, but not over most other European countries or Japan. It is not at all easy to compare the costs of erecting chemical plants in different countries : even for similar products, plants vary in the proportion of process equipment delivered to the site, in the plant's specifications, in the volume of on-site building work, in design costs and in many other respects. General building cost indices or labour cost indices are not much use in an industry such as chemical engineering. However, a useful comparison has been made by Mr. E. A. Stallworthy of Bataafsche Internationale Chemie Maatschappij N.V. (Shell)[5]; this has the advantage that it is based on actual experience of erecting a similar standard styrene plant in eight different countries (table 5). He suggests that the capital cost of erecting plant in West Germany was about 10 per cent lower than in Britain or Sweden, but higher than in most other European countries. Some other estimates put British costs in a slightly more favourable light, but it is probable that West Germany did enjoy some advantage in the 1950s. However, in the last year or two, there is evidence that costs have tended to level in Western Europe (including Britain), although in very advanced types of equipment, the United States and West Germany may still have advantages, based on chemical engineering know-how.

In labour costs too, although West Germany had an advantage some years ago, this has now disappeared, and her labour costs are higher than Britain's. It was in any case a relatively unimportant advantage, since labour costs are so small a part of total costs. It is true that there is also a labour cost element in overhead costs ; but German sources believe that for this type of labour her advantage was

Table 5. Comparative costs of building a styrene production unit in various European countries, 1959-1961

Percentage of total cost

Country	United Kingdom	Belgium	France	Holland	Italy	Spain	Sweden	West Germany
Total materials	50.6	55.4	55.8	59.3	59.3	62.5	50.6	55.8
Freight, purchasing, import duties, etc.	5.5	6.6	6.5	7.0	7.0	9.4	9.3	6.5
Erection	34.8	27.7	29.1	22.2	24.1	18.4	32.4	29.1
Piling	0.3	1.7	—	3.0	0.4	—	—	—
Design	8.8	8.7	8.6	8.5	9.3	9.8	7.7	8.6
Total estimated cost	100	100	100	100	100	100	100	100
Ratio, with UK = 100	**100**	**87**	**88**	**82**	**82**	**77**	**98**	**88**

Source : E. A. Stallworthy, *Comparative Investment Costs in Western Europe* (Paper presented to the Association of Cost Engineers, and A.A.C.E., May 1963).

less, and not significant. In fact, overhead costs may have been higher in Germany than in other countries : American estimates place German sales and administrative costs a little higher than Britain's but lower than those of the United States.[6] German chemical firms spent more on research and development (in relation to turnover) than the largest British firms did, and probably more than most other European producers as well.

The analysis of employment at BASF, Ludwigshafen, gives some indication of the importance of overhead costs in general. In 1956, only 28 per cent of their employees were engaged on production, and in 1961 only 23 per cent ; the rest—72 and 77 per cent respectively—were in technical departments, in research and development, in administration, or were trainees or apprentices.(1) These figures are for total employment in all types of chemicals ; the overheads in plastics are probably well above the average.

In sum, it does not seem at all likely that lower costs explain the success of the German plastics industry. In the early fifties, when the German industry did have lower capital and labour costs than Britain, its raw material costs were higher. By the time these had fallen—as the German petro-chemicals industry caught up—capital and labour costs had risen to the British level. On balance, there was probably no significant net advantage.

Prices of plastic materials

Price figures can also provide some suggestive evidence on costs ; for if West Germany had enjoyed a general advantage over other producers in lower production costs, it might well have shown itself in a lower price level for German plastic materials.

In fact, from 1950 to 1955 prices of most plastic materials appear to have been a little higher in Germany than in Britain or the United States. Nonferrous and steel prices were also slightly higher, [7] so that the ratio of plastics prices to those of the principal competing materials was probably similar in all three countries. German polystyrene prices were about 10 per cent lower than in Britain ; but about 10 per cent higher than in the United States (table 6). Conversely, prices of PVC were higher than in Britain, lower than in the United States. The prices of most other materials were a little higher than either in Britain or the United States ; polyethylene prices were far higher. These comparisons are summed up in an index of the prices of six principal standard materials (table 6) ; this index, it is true, does not take account of all specialised grades, and—particularly later on—quoted prices may not be an entirely reliable guide. Even so, it is fairly clear that the recovery of German plastics consumption in the first half of the 1950s cannot be attributed primarily to lower relative prices than those prevailing in Britain and the United States.

From about 1955 onwards, prices of many plastic materials began to fall more sharply ; trade barriers were diminished, tariffs and quotas were reduced, and international competition became more intense. Surplus capacity began to be a serious problem and there was widespread ' dumping ' of temporary surpluses on the international market. For some plastics this caused prices to fall very sharply, particularly in unprotected markets ; so the quoted prices of domestic manufacturers may not reveal the full extent of these price falls. The markets most severely affected were Belgium, the Netherlands, Scandinavia and Britain, all of which have low tariffs. For example, the real price of PVC in Britain in 1961 and 1962 was probably 10-15 per cent below the quoted prices. In the United States, where tariffs are very high, domestic competition became much more severe, and prices fell even more sharply, partly as a result of the entry of a number of new producers.[9] The West German market was affected by the more acute international competition, but not in such a way as to provide a price stimulus to consumption greater than that in other European countries. German prices fell with the rest, but were not below the general international level, except for polystyrene.(2)

The price index for six materials (table 6) suggests that by 1960 German prices were only fractionally higher than British prices, but were still significantly higher than American prices. By this time also French prices had fallen close to the German level, and Italian prices were below them. In 1961 and 1962 prices fell still lower, and both British and German producers complained of dumping in their home markets ; there is little doubt that, because of higher tariffs,(3) West Germany suffered less. However, by 1963, German quoted prices had fallen slightly below Britain's.

(1)The breakdown of the numbers employed at BASF Ludwigshafen,[8] was as follows (in thousands) :—

	1956	*1961*
Production..	10.0	10.4
Technical department, including maintenance	12.0	16.0
Research and development ..	3.6	6.5
Administration, managerial, trainees and apprentices ..	10.4	13.1
	36.0	46.0

(2)However, by this time the greater part of German polystyrene production was no longer of standard grades but of more specialised high impact materials, for which her prices were not particularly low.

(3)A comparison of tariffs on plastic materials is given in Appendix II, table 26.

Table 6. Prices of plastic materials.

Quantity lots, annual averages, DM per kilo

		USA	UK	West Germany	France
PVC, granular	1953	3.55	2.30	2.50	..
	1955	3.20	2.25	2.25	2.80
	1957	2.70	2.20	1.90	2.50
	1960	1.85	1.65	1.75	1.90
Polyethylene, high pressure	1953	4.30	4.80	7.00	..
	1955	3.75	4.10	5.40	5.20
	1957	3.20	3.65	4.35	4.75
	1960	2.40	2.70	*3.00*	3.55
Polystyrene, standard crystal	1953	3.00	3.65	3.20	..
	1955	2.70	3.35	3.00	3.15
	1957	2.35	3.35	2.90	2.85
	1960	1.60	2.60	2.10	2.30
Phenol-formaldehyde	1953	1.80	2.05	2.30	..
	1955	1.75	1.90	1.90	2.50
	1957	1.95	1.85	1.90	2.25
	1960	1.95	2.00	1.90	1.90
Urea-formaldehyde	1953	3.00	*3.00*	3.00	..
	1955	3.00	*3.00*	3.00	3.20
	1957	3.10	*3.00*	3.00	2.80
	1960	2.90	*2.80*	*2.80*	2.35
Melamine formaldehyde	1953	4.10	*5.15*	5.15	..
	1955	4.10	*5.15*	5.15	4.60
	1957	4.30	*5.15*	5.15	4.15
	1960	4.30	*4.90*	4.90	3.45
Materials index[(a)] West Germany = 100	1955	96.3	96.1	100.0	109.2
	1960	90.5	99.7	100.0	103.2

Source : Information from firms, and published prices ; H. Saechtling, *Chemie und Technologie der Kunststoffe*. Italicised figures are estimates.
(a) Weighted by 1955 and 1960 combined consumption of each material in USA, UK, West Germany and France.

So far, the evidence rests on international comparisons of quoted prices. There is no way of knowing what special prices may have been made in the various countries. But there is no reason to think that there was any particular pressure forcing prices down more in Germany than elsewhere : domestic competition in Germany does not seem to have been exceptionally severe. Typically, the manufacture of plastic materials is undertaken by large or very large firms. This is especially true of thermoplastic products, which in most manufacturing countries are made by fewer than half a dozen producers, with often only two or three of any importance (table 7). In small countries there is not usually room for more than one or two producers, because of the economies of scale and the great importance of manufacturing know-how, research facilities, and technical sales service. It is true that there are a few more producers of the main thermoplastics in West Germany than in Britain or in France (except for polystyrene) ; but the firms are not by any means independent of each other. Taking account of interlocking shareholdings,[(1)] the German market structure was no less oligopolistic than that of the other main producing countries. There are slightly more producers of most thermo-setting plastics in all manufacturing countries ; these materials need less capital, and—since they are older—technical know-how is more widely diffused.

There is, in sum, no evidence that Germany's leading position in plastics was explained either by lower costs of materials and other inputs, or by lower prices. It is true that there are individual plastic materials, for Germany and other countries, where

[(1)]For instance, Rheinische Olefinwerke is jointly owned by BASF and Shell ; Hoechst owns 50 per cent of the capital of Wacker and 33 per cent of the capital of Ruhrchemie ; and BASF, Hoechst, Dynamit Nobel, Bayer and Hüls were all part of I.G. Farben before the post-war reorganisation of the German chemical industry.[10]

Table 7. Production capacity for principal thermoplastics in various West European countries, end 1961

	PVC		Polystyrene		High pressure polyethylene		Low pressure polyethylene		Polypropylene	
West Germany ..	Wacker-Chemie	A	BASF	A	Rheinische Olefin	A	Hoechst	B	Hoechst	D
	Hoechst	B	Hüls	B	BASF	D	Rheinische Olefin	C	BASF	D
	BASF	B	Dynamit Nobel	D			Scholven-Chemie	C	Hüls	D
	Hüls	B					Hüls	D	Hibernia	D
	Dynamit Nobel	C					Hibernia	D	(Rheinische Olefin)	..
	Deutsche Solvay	D					Ruhrchemie	D		
	Anorgana	D					(BASF)	(D)		
United Kingdom ..	ICI	A	BX (DCL)	D	ICI	A	British Hydrocarbon	C	ICI	C
	British Geon (DCL)	B	Distrene (DCL)	C	Union Carbide	B	Shell	D	Shell	D
	Bakelite	D	Monsanto	C	Monsanto	C				
			Sterling	D	(Shell)	(C)				
			Styrene Products	C						
			Kaylis	D						
France	Pechiney	B	Plastichimie	B	Ethylene Plastique	B	Manufacture Normande	C	Pechiney	D
	Solvic	B	Dispersions plastiques	D	(Petroplastique)	(B)	Soc. Normande	D	Soc. Normande	D
	St. Gobain	C	Huiles Goudrons	D			Naphthachimie	D		
	Kuhlmann	D	Lorraine-Kuhlmann	C						
	Rhone-Poulenc	D	Monsanto-Boussois	C						
			Resines et Vernis	D						
Italy	Montecatini	A	Montecatini	C	Montecatini	B	Montecatini	D	Montecatini	C
	Sicedison	B	Italiana Celluloide	C	Celene	C	Solvay	D		
	Chimica Ravenna (ENI)	C	Sicedison	C	Asfalti Bitumi	C	(SIR)	(B)		
	Solvic	C	(Dow)	(C)	(Anic-Gela)	(B)				
	(Chimiche Meridionali)	(B)	SIR	D	(SIR)	(C)				
	(SAICI)	..								
	(Rumianca)	..								
Sweden	Stockholme Superfosfat	C	Svenska Polystyren	D	(Uni-Kemi)	(C)			(Esso)	(D)
					(Esso)	..				
Netherlands	Shell	C	(Dow)	..	Staatsmijnen	B	(Staatsmijnen)	(D)	(Rotterdamse Po)	(D)
	(Caltex)	..			(Du Pont)	(B)				
Belgium	Solvic	B			(Cobenam)	(C)			(Argus)	..
					(Argus)	..				
Austria	Halvic	D			(OMV/Hoechst)	(D)			(Danubia)	(D)
	(Salzburger Aluminium)	..								

Source : Information from firms. A = Over 50,000 tons a year ; B = 21,000 to 50,000 tons a year ; C = 11,000 to 20,000 tons a year ; D = Up to 10,000 tons a year. See Appendix I, page 51, for the spelling out of the abbreviations. Firms shown in brackets are those which have set up or announced plants in 1962 or 1963.

prices were relatively low and consumption particularly high, and conversely. This was true, for example, of polystyrene in Germany. But here the relatively low price seems to have been the consequence, not of lower costs of materials, but of technical advance ; quantity production of this material began earlier in Germany than elsewhere. Indeed, it may be more generally true that, although German costs of inputs and prices were no lower than in Britain, costs per unit of output may still have been below those of other countries because of more advanced production methods—and that consequently German profits were higher. There is no direct evidence on profits from production of plastics—nearly all the big firms are large chemical combines which do not show profits of their plastics divisions separately. But it may be perhaps significant that it is British firms, rather than German, which have recently emphasised very strongly the danger of ' profitless prosperity '—a high level of output at unremunerative prices. In their view this would jeopardise the whole future growth of the industry by compelling firms to cut back on research, development and technical services. It is, incidentally, interesting that this view implies that research and technical factors are likely to be more important for long run growth than temporary price reductions.[11]

Technical factors

Cost and price factors do not explain the German lead in plastics production and consumption. Technical factors appear to have been more significant. Since the industry is based entirely on the discovery and application of completely new man-made materials, scientific research and development are its foundation, and their importance does not stop with the discovery and first commercial production of a new material. This is only the beginning, and must be followed by years of intensive applied research and development work to explore potential applications, to modify the material and create a variety of grades suited to each application, to blend it with other materials, to improve and cheapen the production process, and to find the best ways of processing the material, which may involve the design of new machinery. The benefits of this research and development are to some extent cumulative. A country which has a large number of scientists and engineers experienced in applied research and development with some plastic materials, will probably find it easier to develop others. Furthermore, the chemistry and technology of other materials such as synthetic rubbers and synthetic fibres are so closely related to plastics, that advances in any one of these fields will help progress elsewhere.[12]

Partly because of this, and partly because of the high costs of research and development, there is a strong tendency for research to be concentrated in a few very large concerns in each country. Since the early part of the 20th century, the importance of individual inventors in the research and development process has been declining. The patent statistics for the industry suggest this (table 8). The proportion of patents issued to individuals declined from nearly half in the period 1791-1930, to fewer than 10 per cent in the postwar period, although strategic patenting (see page 35) by large firms may to some extent inflate their figures. Of course, gifted individuals still play an extremely important part in the inventive process. But they do so more and more as employees of large corporations (Carothers, for instance, discovered nylon while working for Du Pont) or in association with large corporations—thus Professor Natta co-operated with Montecatini in the development of polypropylene. Frequently, the costs of building and operating the pilot plant required for the development of synthetic materials are far beyond the capacity of individual inventors or small firms, and research into applications also needs substantial resources. Furthermore, those small firms which have patented new inventions have often subsequently been absorbed ; for example, the Naugatuck Chemical Company, which did important research work in the field of polystyrene, sold its patents and know-how to the

Table 8. Patents issued for the principal groups of plastics, 1791-1955

	1791-1930		1931-1945		1946-1955	
	Number	Per cent of total	Number	Per cent of total	Number	Per cent of total
Patents taken out by :						
Individuals	1,803	43	791	15	489	8
Firms	2,436	57	4,341	85	5,749	92
Total	4,239	100	5,132	100	6,238	100

Source : J. Delorme, *Anthologie des Brevets sur les matières plastiques*, (3 vols.), Amphora, Paris, 1962.

Dow Chemical Company in 1937, which then successfully launched commercial production. The British firm of Petrochemicals, which had done some work in the field of styrene polymerisation and had acquired the patents for the new Ziegler low pressure polyethylene process, was taken over by Shell in 1955. So, because large firms dominate the industry, the examination here of the process of technical advance concentrates on them.

The analysis of technical factors needs a much longer time span than the analysis of prices or costs. There is usually a period of five to twelve years between research and normal commercial production ; and it is sometimes even longer before production is large enough to show up significantly in the statistics. High pressure[1] polyethylene was discovered by ICI and first successfully produced in the 1930s ; it had extremely important radar and other applications in the war ; but it was not until the 1950s that it came into large volume consumption in Britain. The vital research and development on low pressure polyethylene and on polypropylene was done in the late '40s and early '50s, and the patents taken out between 1951 and 1957, but it is only in the '60s that they are beginning to be produced in large quantities. Thus the pattern of plastics production and consumption in the 1950s depended largely on the research and development of previous decades.

The problem of measuring the resources which go into research and development, and of assessing their output, has only recently begun to attract economists' attention. There are considerable conceptual difficulties, and not many figures to work on. Three different measures are used here : first, statistics of expenditure on research and development ; secondly, patent statistics ; and thirdly, the dates and origins of major innovations. These measure three distinct but overlapping aspects of a complex process. Expenditure on research is usually necessary before an innovation can be made—but it also continues after the innovation has become successful commercially. Patents may be taken out at any stage of a research project, and will usually be followed by 'patents of addition' after commercial production has begun. So events do not often follow the simple time sequence—research : development : patents : innovation : production.

The three methods of measurement supplement each other. The figure for the sums spent on research and development is inadequate by itself, since research can be quite fruitless. In the same way a large number of patented processes fail to reach the stage of commercial production. If we take the three methods together, then we have first an assessment of the resources committed to the search for new inventions and the improvement of old ones ; secondly—in patent statistics—a measure of the actual output of inventions ; and thirdly, in the figures for innovations, a measure of success in passing from the development stage to full-scale commercial production. This triple assessment should provide a reasonable indicator of the capacity of a firm, or a country, for undertaking successful research.

[1]The high pressure method is used mainly for manufacturing low density polyethylene, and the low pressure method is used for high density (or linear) polyethylene.

Research expenditure

The figures available on research and development in the chemical industries are of limited usefulness, because they do not separate expenditure on research into plastic materials from other chemicals expenditure. Nevertheless they can be used to provide clues to the scale of plastics research and development activity in various firms and countries.

The most striking feature of the figures is the outstanding position of the German chemical combine I.G. Farben from the time of its formation in 1925 until it was dissolved after the Second World War. This firm's research expenditure averaged just over 7 per cent of its turnover from 1925 until 1939. From 1926 to 1931 it was between 7 and 10 per cent. It cut back research spending fairly drastically in the world recession—to 4.9 per cent of turnover in 1933. The main economies were in development costs, and the research staff was maintained throughout at over 1,000 qualified scientists and engineers.[13] From 1934 to 1939 research expenditure rose again to between 5 and 6 per cent of turnover. During the war, the level of research was maintained, but it probably fell just below 4 per cent of turnover, since turnover was rising rapidly.

Throughout this period the firm spent more on research than it distributed in dividends. These figures exclude extra-mural expenditure, technical services and donations to universities, etc. I.G. Farben must have been one of the most research-intensive large firms in the world before 1939, with a ratio of expenditure to turnover more than twice as high as that of most comparable firms. Moreover this firm seems to have devoted a far higher proportion of its resources to research in synthetic materials than multi-product chemical firms in other countries. There is the evidence of the patent statistics (page 36) ; there is also the evidence of the wide range of new materials, such as PVC and polystyrene, which this firm initiated. According to one account,[14] it was the need to concentrate research resources and make large investments in high polymer chemistry and synthetic materials that finally persuaded the individual firms to form I.G. Farben itself. Later, the whole trend of the economic policy of autarky in Germany under the Hitler regime favoured the production of 'ersatz' or synthetic materials. Altogether, there are strong grounds for believing that I.G. Farben spent more on plastics research and development than any other firm in the world.

This research programme was disrupted from 1945 to 1952, when the whole future structure of I.G. Farben was in doubt, but it was not completely broken off, and the research teams remained in existence.(1) The successor firms, especially BASF, Bayer and Hoechst continued to spend heavily on research throughout the 1950s, averaging between 4 and 5 per cent turnover(2) (or between 5 and 6 per cent if capital expenditure is included).

The leading American firms, Du Pont, Union Carbide, Dow and Eastman Kodak also now spend over 4 per cent of turnover on their research and development,[15] but among British firms only ICI reaches this level. (I.C.I's. ratio in 1961-2 was about 4 per cent(2) calculated on the sales and research of U K companies only—that is, excluding the sales and research of overseas subsidiaries). There are no data for French firms but there is little doubt that they spend significantly less[16] and the same is probably true for most other firms in Europe with the exception of CIBA.

Turning from the figures for individual firms to those for the chemical industry as a whole, it seems that now the United States is well ahead, in absolute terms ; the amount of research done in the United States chemicals industry is probably about 4½ times the British figure(3) and 3 times the German. But the United States' lead in plastics is probably less than this, for two main reasons. First, a higher proportion of American research goes into rather specialised military/space applications. Secondly, plastics research is almost certainly a larger part of total chemicals research in Germany (and Japan) than in the United States—simply because the plastics industry is a larger part of the total chemical industry in those two countries. Research expenditure is usually a higher proportion of the value of plastics output than of the output of the general run of chemicals.(4)

Then we must take into the reckoning as well the ' infra-structure ' of research : the work of universities and other research institutions. Teaching and basic research in chemistry were particularly advanced in Germany in the first part of this century, and the theoretical work of Staudinger and his school in high polymer chemistry were an essential foundation for the achievements of I.G. Farben.(5)[17] However, the fundamental research undertaken in universities and such government-aided laboratories as the Kaiser Wilhelm Research Institutes or DSIR stations is generally available throughout the world ; industrial firms anywhere may benefit from it, so long as they are alert to scientific developments outside their own country. Consequently the advanced state of basic chemical research in Germany may not be as important, in explaining German pre-eminence, as the development work in the chemical firms themselves. Industrial or co-operative institutes outside the chemical firms do not appear to have made any notable contribution in Germany until after the war. Since then two organisations have been set up specifically to serve the plastics industry. An Institute for Plastics Fabrication, established in Aachen in 1951, concerns itself mainly with the processing and testing of materials including welding, extruding, moulding and glueing. In 1953 a larger Plastics Institute was set up in Darmstadt, which is concerned primarily with the fundamental properties and structure of plastic materials and with methods of testing and documentation. Together these Institutes employ a staff of over a hundred, but their total research expenditure is of course only a small fraction of the annual expenditure of the chemical firms themselves. In Britain there has for some time been anxiety over the lack of adequate fundamental research into plastics materials and technology.[19] It was not until 1962 that the Rubber Research Association also took in plastics and became the Rubber and Plastics Research Association, so that its work in this field has only just begun.(6) It seems that co-operative or state research institutes are not important in other countries, except for the TNO Plastics Research Institute at Delft in the Netherlands.

Patent statistics

There are one or two big differences between the industrial patterns of patent figures and of research expenditure figures. In defence-oriented industries,

(1)' The German research teams, as exemplified in the I.G. laboratories, were outstanding instruments of accomplishment. What could be done with these groups ? Should they be given picks and shovels ? Should they be broken up and transferred as individuals to laboratories in other countries ? Should they be allowed to continue in their present location ? Many hours were spent arguing the pros and cons of this situation and we inevitably arrived at the conclusion that humanity's interest would best be served by putting these groups to work in the surroundings and with the associations to which they were accustomed, but under a competent allied commissioner who would merely insist that no direct war projects be worked upon. Certainly some of the results would have war applications ; but the tremendous good which could come from these able groups should outweigh that risk.' *German Plastics Practice*—J. DeBell, W. C. Goggin, W. E. Gloor, pages 10-12.

(2)These figures exclude technical services and capital expenditure.

(3)The absolute figures are : United States £390 million, West Germany £55 million, Britain £37 million, Japan £18 million in 1961. But because of differences in research costs a ' research exchange rate ' must be used.[18]

(4)Thus for example the plastics section of one of the larger British chemical firms spends about 5 per cent of turnover on research and development, which is above the general average for the firm.

(5)Among the distinguished scientists who worked for this firm were two Nobel prize-winners.

(6)A small amount of work was however already being done at the National Chemical Laboratory.

Table 9. Patents delivered in various branches of British and French industry, compared with research expenditure, 1961

	France	United Kingdom	United Kingdom	
	Percentage of total number of patents delivered		*Percentage of total research expenditure, manufacturing industry*	
			Excluding aircraft	*Including aircraft*
Aircraft	1.8	1.7	—	38.4
Electrical engineering	17.3	22.2	38.3	23.5
Instruments	10.6	6.3	4.1	2.5
Chemicals	20.6	24.0	20.3	12.5
Vehicles	6.6	5.0	4.3	2.7
Engineering	16.3	18.0	13.1	8.0
Metals and metal products	7.5	9.5	6.1	3.7
Building materials, wood and furniture, building	11.0	6.4	6.0	3.7
Textiles and clothing	6.3	5.4	3.8	2.4
Food, drink and tobacco	1.9	1.5	3.2	2.0
	100.0	100.0	100.0	100.0

Source : Y. Fabian, *Measures of output of R and D*, OECD 1963 ; *Report of the Comptroller General of Patents*, 1961 ; *Bulletin de la Propriete Industrielle—Statistiques*, 1961 ; *Report of Advisory Council on Scientific Policy*, Cmnd. 1920, 1963.

such as aircraft and electronics, the exigencies of security and the effect of government contracts is to produce a very low ratio of patents to expenditure. But if some allowance is made for these industries, then there is a broad correspondence between research expenditure and patenting in the principal branches of industry (table 9).(1) The similarity of pattern suggests that patent statistics, if used with care, can help to build up a rather more detailed picture of the structure and direction of research activity than the expenditure figures provide. Further, the industrial pattern of British and French patents is similar : this suggests that although international differences in patent procedure may affect the total number of patents granted in each country, they probably do not affect the distribution between industries.[20]

The main difficulty of patent statistics is one of weighting : some patents are extremely important whilst others are negligible. Some are taken out partly for strategic commercial reasons, rather than to register any original invention. For example after taking out patents on moisture-proof cellophane in the 1920s, Du Pont then proceeded to take out a large number of patents on alternative methods to block the possibility of competitors circumventing their key patents.[21] This procedure is not, of course, confined to any one firm or country.

But for a large group of patents over a fairly long period, the distortions arising from this factor are less important. An experimental attempt has therefore been made to compare the research effort of the principal firms by using the numbers of patents they have taken out for plastic materials at various stages in the growth of the industry(2) (tables 10 and 11).

The outstanding feature of this analysis, as of the analysis of research expenditure, is the dominant position of the German chemical combine I.G. Farben in the period before and during the Second World War. From 1930 to 1945 this one firm accounted for nearly a third of all the patents taken out by the 30 leading firms, and for over 17 per cent of the patents

(1)An exact correspondence should not in any case be expected because of some variations in the propensity to patent between firms and industries and because patent statistics are analysed on a product field basis while research expenditure statistics are on a company classification.

(2)For the analysis made here the main source has been a French publication[22] which systematically lists all the patents delivered for plastic materials from 1791-1955, dating them from the year of their acceptance. Since there is often a delay of one to four years between application, acceptance and publication, this covers most patents published up to 1959. This French source covers American, German, French and British patents (without double counting) and classifies them into various groups (Appendix table 27). It can be assumed that almost all patents of any significance would be published in one (and in many cases all) of these four countries. Unfortunately it has not been possible to analyse the patents according to the number of years which they have remained in force.

In order to make some comparison with the most recent period an analysis has also been made of patents taken out in Britain in the field of plastic materials up to 1962. This could be expected to have some bias towards British firms, since there will be a number of patents taken out by them in London but not elsewhere.

Table 10. The share of some leading firms in patents delivered for plastics materials

Percentage of total for 30 leading firms[(a)]

Country	Firm	1791–1930	1931–1945	1946–1955
United States	Du Pont	8.4	13.0	17.6
	Monsanto	0.1	1.5	7.8
	American Cyanamid	0.7	2.4	7.4
	Dow	0.4	4.7	5.2
	B.F. Goodrich	0.3	1.3	4.4
	U.S. Rubber	—	—	4.3
	Rohm & Haas	0.3	0.8	4.3
	Eastman Kodak	18.3	4.9	3.9
	Standard Oil	0.4	1.7	3.4
	Celanese Corp.	0.8	2.7	2.0
	Union Carbide (Carbide & Carbon)	1.6	3.6	1.9
	Hercules Powder	1.4	5.3	1.8
	Phillips Petroleum	—	0.1	1.5
	GEC	4.1	5.2	1.2
	Total	36.8	47.2	66.7
West Germany	I.G. Farben	37.4	36.0	0.7
	BASF	4.1		3.2
	Bayer	6.0		3.1
	Hoechst (Meister, Lucius & Brüning)	6.0		1.6
	Ruhrchemie	0.1		
	Hüls	—	—	1.1
	I.G. Farben and successors	53.6	36.0	9.7
	Wacker	—	2.6	0.7
	Röhm & Haas	0.9	4.9	—
	Total	54.5	43.5	10.4
United Kingdom	ICI	2.7	3.6	7.0
	Distillers	—	0.8	2.0
	Total	2.7	4.4	9.0
France	St. Gobain	—	0.4	2.1
	Rhone Poulenc	1.4	1.1	1.2
	Total	1.4	1.5	3.3
Italy	Montecatini	—	0.1	0.1
Switzerland	CIBA	4.5	2.3	2.8
International	Shell/N.V. de Bataafsche	0.1	1.0	7.8
	Total of above	100.0	100.0	100.0

Source : J. Delorme : *Anthologie des Brevets sur les Matières Plastiques*, Paris 1962. For the spelling-out of the abbreviations, see Appendix I, page 51.

(a) These are thirty of the leading firms in 1946-55 in patents taken out in UK, USA, France and Germany : see table 11.

from all sources. At this time the most important new developments were taking place in the field of thermoplastics, especially the vinyl resins. In this group I.G. Farben were alone responsible for a quarter of all the patents taken out in the world. But they were also the leading firm in every other group of plastic materials.

American and German firms dominated the picture in this period, being responsible between them for 90 per cent of the patents taken out. Amongst other firms, only two British firms (ICI and British Celanese) were in the first 30, only two French (Rhone Poulenc and Cie Fr. Thomson-Houston) and one Swiss (CIBA). The remaining 25 were all American and

Table 11. Patents in plastics materials taken out by leading firms

30 leading firms' patents taken out in UK, USA, France, Germany

	1791-1930	No.
1.	I.G. Farben	346
2.	Eastman Kodak	169
3.	Du Pont	78
4.	Ceulluloid Mfg. Co.	66
5.	Bakelite Corp.	59
6.	Bayer & Co.*	55
6.	Meister, Lucius & Brüning*	55
8.	CIBA	42
9.	Bakelite GmbH	40
10.	BASF*	38
10.	GEC	38
12.	Br. Thomson-Houston	35
13.	Consortium für Elek.[(a)]	33
14.	Br. Celanese	28
15.	Chem. Fab. Albert	26
16.	Barrett Co.	25
16.	Ellis-Foster	25
16.	ICI	25
19.	Cie. Fr. Thomson-Houston	24
19.	Naugatuck	24
21.	Kroll & Co.	23
21.	Canadian Electric	23
21.	Pathe et Cie	23
24.	A.G. für A.F.	21
24.	Kunstharz Pollak	21
26.	Chem. Fab. Griesheim	16
27.	Carbide & Carbon	15
27.	PF Instruments	15
29.	E. Schering	14
30.	Hercules Powder	13
30.	Soc. Chem. des usines du Rhone	13

	1931-1945	No.
1.	I.G. Farben	889
2.	Du Pont	321
3.	Röhm & Haas[(b)]	145
4.	Hercules Powder	132
5.	GEC	120
5.	Eastman Kodak	120
7.	Dow	115
7.	Kodak-Pathe & Kodak Co.	115
9.	ICI	90
10.	Carbide & Carbon	88
11.	Phrix Arbeitsgemeinschaft	73
12.	Celanese Corp.	67
13.	A. Wacker Ges.	65
14.	American Cyanamid	60
15.	CIBA	56
16.	Ellis-Foster	51
17.	Bakelite Corp.	48
18.	Deutsche Hydrierwerke	46
19.	Pittsburg Plate Gl.	44
20.	Br. Celanese	42
21.	Standard Oil	41
22.	Bakelite Ges.	40
22.	Cie Fr. Thomson-Houston	40
24.	Monsanto	37
25.	Deutsche Kelluloid	35
26.	B. F. Goodrich	32
27.	Thuringische Zellwolle	30
28.	Rhone-Poulenc	26
29.	Harvel Research	24
29.	Consortium für Elek.[(a)]	24

	1946-1955	No.
1.	Du Pont	637
2.	Monsanto	283
3.	American Cyanamid	266
4.	Shell/N.V. de Bataaf.	263
5.	ICI	253
6.	Röhm & Haas[(b)]	210
7.	Dow	187
8.	B. F. Goodrich	160
9.	US Rubber	156
10.	Eastman Kodak	140
11.	Standard Oil/Esso	131
12.	BASF*	115
13.	F. Bayer*	111
14.	CIBA	101
15.	St. Gobain	77
16.	Distillers	74
17.	Gen. Aniline & Film Co.	73
17.	Celanese Corp.	73
19.	Wingfoot	72
20.	Cie. Fr. Thomson-Houston	69
20.	Carbide & Carbon	69
22.	Hercules Powder	65
23.	Hoechst*	57
24.	Phillips Petroleum	55
25.	Kodak-Pathe	47
26.	American Viscose	45
27.	Chemstrand	44
28.	Rhone-Poulenc	43
28.	GEC	43
30.	Chem. Werke Hüls*	42
30.	Koppers Co.	42

30 leading firms' patents taken out in UK only[(c)]

	1954-1958	No.
1.	ICI	299
2.	Du Pont	288
3.	Standard Oil/Esso	243
4.	F. Bayer*	199
5.	US Rubber	170
6.	Midland Silicones	168
7.	Monsanto Co.	143
8.	GEC	128
9.	Celanese Corp.	113
10.	Courtaulds	109
11.	Shell/N.V. de Bataaf.	108
12.	Union Carbide	107
13.	BASF*	106
14.	Dow Chemical Co.	100
15.	Röhm & Haas Co.	87
16.	American Cyanamid	76
16.	Dow Corning	76
18.	B. F. Goodrich	75
19.	Hoechst*	68
20.	Hercules Powder	64
20.	Distillers	64
22.	Dunlop Rubber	60
23.	Phillips Petroleum	57
24.	CIBA	56
25.	Wingfoot	38
26.	Minnesota Mining	28
27.	Chemstrand	23
27.	Rhone-Poulenc	23
27.	Wacker-Chemie	23
30.	Gen. Aniline & Film Corp.	20

	1959-1962	No.
1.	ICI	485
2.	Du Pont	428
3.	F. Bayer*	346
4.	Union Carbide	327
5.	Standard Oil/Esso	246
6.	Hoechst*	207
7.	Montecatini	205
8.	CIBA	168
9.	Dow Chemical Co.	162
10.	Phillips Petroleum	153
11.	BASF*	145
12.	Röhm & Haas Co.	132
13.	Shell/N.V. de Bataaf.	118
14.	American Cyanamid	112
15.	US Rubber	110
16.	Midland Silicones	109
17.	Monsanto Co.	100
18.	GEC	92
19.	B. F. Goodrich	83
20.	Dunlop Rubber	79
21.	Minnesota Mining	77
22.	Courtaulds	73
23.	Celanese Corp.	63
24.	Hercules Powder	60
25.	Distillers	53
26.	Chemstrand	51
27.	Rhone-Poulenc	47
28.	Chem. Werke Hüls*	42
29.	Wacker-Chemie	41
30.	Dow Corning	34

Sources: Delorme, *Anthologie des Brevets sur les Matières Plastiques ; Abridgements of Specifications*, Patent Office, London. For the spelling-out of the abbreviations, see Appendix I, page 51.

* — Part of I.G. Farben.

(a) Undertaking research in association with A. Wacker.

(b) The German and American parts of Röhm and Haas are listed together here. For breakdown see Appendix table 27.

(c) See footnote (2), page 35.

German. In the period before 1930 American and German firms were also responsible for over 80 per cent of the patents taken out by firms. The I.G. Farben combine was only formed in 1925 but by 1930 it had registered more than twice as many patents in this field as any other firm in the world in the whole period from 1791-1930.(1) Moreover its research was already at this time spread over the whole field of materials from cellulosics to the new vinyl and acrylic plastics.

With the exception of Du Pont, the leading American chemical firms came relatively late into this field, although Eastman Kodak (from the film side) and G.E.C. (through their interest in insulating materials) both played an important part in the earlier period and are still amongst the leaders, for example in poly-acetals and poly-carbonates. Röhm and Haas was at this time based primarily in Germany and was principally concerned with the development of acrylic materials. By the 1930s ICI was among the leaders, although still far behind I.G. Farben in the range of its plastics research and production. Over a long period, the Swiss firm CIBA, has been consistently among the leading firms in numbers of patents taken out. But with these exceptions it was not really until the post-war period that British, French and other European firms began to compare with the American and German leaders.

From 1946 to 1952 I.G. Farben was being reorganised by the Allied Military Governments, and was not in a position to take out any patents. Moreover many of its secrets were compulsorily made available to British, French and American firms in 1945 to 1946. It was not until 1952 that the successor firms to the dissolved combine—principally BASF, Bayer, Hoechst, and Hüls—were able to resume normal production and research activity. Consequently the figures for 1946 to 1955 show American firms in a dominant position with 8 of the 10 leading firms, and Du Pont well ahead of the field. However, the combined total of patents taken out by the I.G. Farben successor firms even in this period was greater than that of any firm except Du Pont. By this time British firms had begun to catch up with the Americans and Germans, and the three big British producers—ICI, Shell and Distillers—were all among the first 20 firms in terms of numbers of patents.

The most recent patent statistics suggest a continued recovery by German firms, with all three of the principal I.G. Farben successors in the top twelve. From 1959 to 1962 ICI's position was extremely strong, but the other British producers were still somewhat behind the leading American and German firms and behind the Italian chemical combine, Montecatini, which has risen very rapidly in the 1950s. Again, with the exception of CIBA, other European chemical firms were still well behind and Japanese patents were only just starting to appear.

The patent figures were also analysed in another way, to meet the objection that the simple total of patent numbers might be so distorted by strategic patenting that they did not genuinely represent successful research. With the assistance of a scientific consultant, Dr. C. A. Redfarn, all the patents taken out from 1790-1955 were scrutinised, and the most important ones—those which marked the major technical advances necessary for the successful large-scale production of 30 plastic materials—were selected. These key patents were then entered to the firm and country responsible for them. Out of 117 major technical advances,(2) 51 originated with German firms or individuals (30 from I.G. Farben), 43 with American (12 from Du Pont) and 15 with British (7 from ICI). Only 8 came from all other countries (France, Italy, Switzerland and Netherlands). This suggests that if the total number of patents could be weighted by quality of achievement, the result would not differ very much from the analysis of unweighted patent numbers, provided the sample is sufficiently large and the period sufficiently long. The much larger numbers of patents taken out by American firms in the post-war period would not show up fully in the analysis of key patents, as it is still too early to assess the importance of some of them.

An analysis was also made of the first mention of these materials in scientific literature, as they were often known on a laboratory scale before they could be successfully produced commercially. For example, polystyrene is first mentioned in 1831 and vinyl chloride in 1835 ; Professor Kipping devoted a life's work to basic research on organic silicon compounds before the silicone resins were produced commercially. In these early mentions, which reflect basic research findings rather than applied research and development work, the names of British and French scientists occur more frequently. This gives some substance to the view that in these countries a disproportionately large part of the scientific effort was devoted to fundamental research—or perhaps more correctly that too small an effort was directed to the commercial development of promising fundamental work. The social barriers between the academic world and industry may also have been lower in Germany and the United States than in France and Britain.[23]

(1)Already during the First World War, before the formation of I.G. Farben, there had been a considerable amount of research in Germany on synthetic materials.

(2)An ' advance ' may be marked by one or several related patents.

Principal innovations

A third way of measuring technical capability is to compare the dates at which the principal new inventions in the industry were introduced in the various countries. The main problem here, as in listing key patents, is to distinguish the innovations and assess their relative importance. The most obvious milestones in the history of the plastics industry are the dates at which commercial production of the various new materials began. A country with a strong independent research tradition would frequently be the first to produce new materials, whereas one lacking in research capability would often be ten or more years behind the leaders, since it depended upon licensing and know-how agreements. Hufbauer has prepared a list of over thirty plastic materials and dated the first commercial production of these materials in a number of countries[24] (table 12). His study shows clearly the German and American lead. Each of these countries has been responsible for the first commercial production of fourteen materials ; Britain has been responsible for two (high pressure polyethylene and urea-formaldehyde) and France (cellophane), Italy (polypropylene) and Switzerland (epoxy resins) for one each. A technical ' imitation lag ' can be calculated for each country, based on the number of years between first commercial production anywhere in the world, and first commercial production in that country.(1) On this basis, Hufbauer estimates that the German and American weighted average imitation lag was two to three years in 1939, 1950 and 1960.[25] This includes the products which they were the first to manufacture, for which the lag was of course nil. The British lag was 5 to 7 years and the French lag a little longer. In 1950 and in 1960 the Japanese lag is 12 to 13 years, and the Italian 14 to 15 years. Most other countries, except Canada, Sweden and Switzerland, show a lag of more than 20 years both in 1950 and 1960.(2)

This brings out once again the key role of a few large firms in this industry. Firms such as Du Pont, I.G. Farben and ICI, when they were not the world's first producers of a new material, were frequently the first imitators or producers via a new process. This is possible because research in all technically advanced countries is proceeding to some extent on similar lines, so that when a major new discovery is made in one country, research teams in other large firms are much more quickly able to assimilate and imitate it. Frequently the obstacle to imitation may be a difficult patent situation rather than lack of technical know-how. Thus during the war I.G. Farben were able independently to launch production of polyethylene (ICI discovery) and of nylon (Du Pont), while ICI was able to launch production of PVC in 1940. More recently several American firms were able to start production of polypropylene, challenging the Montecatini patent position within a few years of the first discovery. The larger firms sometimes makes agreements with one another for the exchange of know-how, and a firm which has something to offer in the way of its own research and development may be able to obtain more favourable terms. Thus Distillers were able to enter into mutually advantageous arrangements with American firms such as B. F. Goodrich (for PVC), Dow (for polystyrene) and later with Union Carbide (for the whole range of plastic materials). GEC (US) and Bayer cross-licensed each other in carbonates.

German firms were not in a position to launch innovations in the early years after the war. But since the early nineteen-fifties, the successor firms to I.G. Farben have again become prominent. For example, German firms have led in the introduction of low pressure (linear) polyethylene so that, although ICI was the world leader in high pressure polyethylene, West German consumption of polyethylene (taking both types together) is now as high as that of the UK, and her per capita production of low pressure polyethylene is the highest in the world.

But although an independent research and development effort is a good basis for speedy imitation, it is not the only way. Although British firms have been among the leaders in research and development since the war, they appear to have been rather rather slower to imitate some important new advances—for example, the production of high impact polystyrene, of acrylonitrile/butadiene/styrene (ABS) and of polycarbonates. More than half of total polystyrene consumption now consists of hardened grades of material. These new types of polystyrene, based on the incorporation of synthetic rubbers, were developed first of all by I.G. Farben during the war in Germany, and after the war by various American companies. The very strong material ABS was first produced in the United States soon after the war and by Bayer in Germany in 1955, but not until 1962 in Britain when Distillers started production, followed a year later by two other firms. Similarly polycarbonates and acetal resins have not yet come into production in Britain although they may do so in 1964 (ICI and Celanese). These materials have great potentialities in engineering applications

(1)The materials are weighted by their relative importance in world trade.

(2)It may be argued that the date of first polystyrene production in Britain and France should be set somewhat earlier as there was a small war-time production by Distillers in England which was discontinued in 1945 and not re-started until 1950 (the date which Hufbauer gives). Rhone-Poulenc had a similar small-scale production in France. There are other minor alterations which might be made to the dates, as it is difficult to draw the borderline between experimental and commercial production. But changing a date here or there by a year or two would not significantly modify the main outlines of the picture which emerges from his analysis.

Table 12. First commercial production of various plastic materials

I. Family group 1. Product (a) Form	United States	Germany (West Germany after 1945)	United Kingdom	France	Italy	Japan
I. Cellulosic plastics						
1. Cellulose Nitrate :						
(a) Celluloid	1870 Albany Dental Plate	1878 Rheinische Gummi & Zelluloid	1877 British Xylonite	1875 Cie Franco-Americaine	1924 SIC	1908 Nippon Celluloid & Artificial Silk
(b) Photographic film base	1884 Eastman Kodak		1932 ? BX Plastics	?	1920 Soc. Italiana Polvere & Esplosivi	1927 Dai Nippon Celluloid
(c) Low viscosity lacquer	1923 Du Pont	1923? many firms	1923? Nobel Inds.	?	1924 SIC	1928 Dai Nippon Celluloid
2. Cellulose Acetate :						
(a) Photographic film base	1908 Celluloid Corp.	1905 Bayer	1938 ? BX Plastics	1928 Soc. Chimique Usines du Rhone	1954 SIC	1953 Dai Nippon Celluloid
(b) Lacquer, glue, or airplane dope	1917 Eastman Kodak	1905 Bayer	1916 Br. Celanese	1912 Blanchisserie & Teinture		1927 Dai Nippon Celluloid
(c) Thermoplastic ..	1927 Celanese of America	1925 Kalle	1923 Br. Xylonite	1922 Soc. Chimique Usines du Rhone	1936 SIC	192 7Dai Nippon Celluloid
3. Cellulose Acetate Butyrate	1931 Eastman Kodak	1935 ? I. G. Farben (Bayer)				
4. Ethyl Cellulose ..	1935 Hercules Powder	1932 I. G. Farben			1939 Fab. Italiana Prodotti Speciali	
5. Methyl Cellulose ..	1939 Dow	1932 Kalle	1961 ICI			1957 Matsumoto Oil & Fat
6. Cellophane	1924 Du Pont	1925 Kalle	1930 Br. Cellophane	1917 La Cellophane	1946 SIC	1929 Tokyo Cellophane
II. Thermoset plastics						
7. Galalith	1919 Aladdinite	1899 Vereinigten Gummiwaren	1912 Erinoid	1900 Fr. Pellerin & Orosdi	1921 La Societa Polenghi	1927 Dai Nippon Celluloid
8. Phenol-formaldehyde :						
(a) Moulding powder ..	1909 General Bakelite	1910 F. Raschig ; Rutgerswerke	1916 Damard Lacquer	1919 Fr. du Ferodo	1922 Soc. Italiana Bakelite	1923 Nippon Bakel
(b) Adhesive or coating..	1909 Gen. Bakelite	1910 F. Raschig ; Rutgerswerke	1910 Damard Lacquer	1916 Fr. du Ferodo	1922 Soc. Italiana Bakelite	1923 Nippon Bakel
(c) Cast phenolic ..	1920 Gen. Bakelite	?	1919 Damard Lacquer	1916 Fr. du Ferodo		
9. Urea-formaldehyde :						
(a) Moulding powder ..	1929 American Cyanamid	1929 I. G. Farben (Dynamit AG)	1928 Br. Cyanides	1930 Kuhlmann	1936 Montecatini	1935 Keikoku Chemical
(b) Adhesive or coating..	1936 American Cyanamid	1932 I. G. Farben (BASF)	1934 Br. Cyanides	1936 ? Kuhlmann	1942 Montecatini	?
10. Melamine-formaldehyde:						
(a) Moulding powder ..	1939 American Cyanamid	1938 I. G. Farben (Dynamit AG)	1946 Br. Industrial Plastics	1955 Resines & Vernis Artificiels	1951 Montecatini	1951 DenkiKagaku ; Nippon Carbide
(b) Adhesive or coating..	1939 American Cyanamid	1935 Henkel	1938 Br. Industrial Plastics		1951 Montecatini	?
11. Alkyd	1926 General Electric	1927 ? I. G. Farben (Bayer)	1929 Nobel Chemical Finishes	1928 Kuhlmann	1927 Montecatini	1931 Kansai Paint
12. Polyester	1942 Pittsburgh Plate Glass	1953 Reichhold Chemie	1950 Catalin ; Bakelite	1950 Nobel-Bozel	1949 Montecatini	1953 Japan Cataly Riken Synthetic
13. Silicone	1941 General Electric	1950 Wacker	1952 Midland Silicones	1954 Rhone-Poulenc ; St. Gobain		1951 Shin Etsu
14. Epoxy	1947 Devoe & Reynolds	1955 Reichhold Chemie	1955 Bakelite		1958 ? Soc. Italiana Resina	

I. Family group 1. Product (a) Form	United States	Germany (West Germany after 1945)	United Kingdom	France	Italy	Japan
III. Thermoplastic plastics						
15. Polyvinyl acetate ..	1928 Union Carbide	1928 Wacker	1949 Dunlop Rubber	1937 Rhone-Poulenc	1954 Edison Settore Chimico	1936 Shin Nippon Chisso Hiryo
16. PVC	1933 Union Carbide	1931 I. G. Farben (BASF)	1940 ICI	1940 St. Gobain	1951 Montecatini	1939 Shin Nippon Chisso Hiryo
17. Polyvinyl alcohol ..	1938 Du Pont	1928 Wacker		1938 Nobel Fr.	1958 Edison Settore Chimico	1949 Nippon Synthetic Chemical
18. Polyvinyl butyral ..	1937 Shawinigan Resins	1948 Hoechst		1942 Rhone-Poulenc		1944 Shin Nippon Chisso Hiryo
19. Saran	1940 Dow			1961 Plastichimie		1950 Kureha Chemical
20. Polystyrene	1933 Naugatuck Chemical	1930 I. G. Farben (BASF)	1950 Distillers[a] Monsanto	1951 Pechiney[a]	1942 Montecatini	1957 Asahi-Dow ; Mitsubishi-Monsanto
21. Polystyrene/styrene-butadiene	1947 Dow	1942 I. G. Farben (Bayer)	1954 British Xylonite	1954 Monsanto	1954 Montecatini	
22. Polystyrene/styrene/acrylonitrile	1948 Rohm & Haas	1942 I. G. Farben (Bayer)		1962 Monsanto	1962 Sicedison	
23. Acrylonitrile-butadiene-styrene	1946 Naugatuck Chemical	1955 Bayer	1962 Distillers	1960 Kuhlmann		1963 Mitsubishi-Monsanto
24. High pressure polyethylene	1941 Du Pont	1944 I. G. Farben (BASF)	1937 ICI	1954 Ethylene Plastique	1952 Montecatini	1954 Sumitomo Chemical
25. Linear polyethylene ..	1956 Phillips Petroleum	1955 Hoechst	1959 Hydrocarbon Chemicals	1956 Rhone-Poulenc	1954 Montecatini	1958 Mitsui Chemical
26. Polypropylene	1957 Hercules Powder	1957 Hoechst	1959 ICI	1960 Pechiney ; Societe-Normande	1957 Montecatini	1961 Tokuyama Soda
27. Polymethyl methacrylate:						
(a) Adhesive or emulsion	1931 Rohm & Haas	1927 Rohm & Haas	1932 ICI	1937 Nobel Francaise	1957 Montecatini	1962 Mitsubishi Rayon
(b) Thermoplastic ..	1936 Rohm & Haas	1930 I. G. Farben (Bayer)	1933 ICI	1938 Nobel Fr.	1937 Italiana Plexiglas	1938 Asahi Glass ; Mitsubishi Rayon
28. Nylon	1941 Du Pont	1943 I. G. Farben (BASF)	1950 ICI	1943 Rhodiaceta	1946 ? Rhodiaceta	1953 Toyo Rayon
29. PTFE	1943 Du Pont ; M. W. Kellogg	1958 Hoechst	1945 ICI	1958 Soc. Resines Fluorees	1955 Montecatini	1963 Nitto Fluoro Chemicals
30. Acetal	1953 Du Pont					1963 Nippon Shokubai
31. Polycarbonate	1957 General Electric	1957 Bayer				1959 Kunoshima Chemical

Source : G. Hufbauer, *Synthetic Materials ; a study in international trade* (with minor amendments in agreement with the author). For the spelling-out of the abbreviations, see Appendix I, page 50.

(a) See footnote (2), page 39.

because of their hardness, good temperature range and resistance to creep. However ICI was well ahead of other European firms in the production of poly-tetrafluorethylene (PTFE). Japan, which was a long way behind Britain, France and Germany in the introduction of the older plastic materials, was ahead of both Britain and France in acetals and polycarbonates (table 12). Until recently Japan had a much smaller research effort than some European countries and did not innovate any of the principal materials, but she has been very successful recently in two of the various methods of imitation : the purchase of technical know-how from foreign firms and production by foreign-owned subsidiaries. Almost all the plastic materials were first produced in Japan under licence or by American subsidiaries. Thus although the evidence of key innovations confirms the German and American technical leadership suggested by the research and patent data, it also shows the importance of successful imitation by all available methods. In Japanese manufacturing industry as a whole, expenditure on royalties was rather less than half as big as research expenditure ; but in petrochemicals more was spent on royalties than on research.[26]

Plastics machinery

German pre-eminence in materials seems to have been accompanied by a similar lead in machinery and processing techniques. The methods of fabrication were at first based mainly on imitating the techniques used for metal-working and for processing rubber and ceramics, but it became increasingly necessary to develop new specialised machines. The most important of these are injection moulding machines. The first injection moulding machines suitable for large-scale production of thermoplastic articles were made by Eckert und Ziegler in Germany in 1926, and this firm together with F. Braun (Isoma) remained the principal European producers of plastics machinery until the war.[27] Eckert und Ziegler were owned by I.G. Farben who encouraged their development work in plastics machinery, and also undertook some research work in their own laboratories. Perhaps the most important single advance in design of machinery was made by a British firm, R. H. Windsor who in 1953 produced and marketed a twin-screw injection moulding machine. (Before the war, Windsor had acted as importers of Eckert und Ziegler machines). The use of the screw principle for plasticising in injection moulding machines was patented by Beck of I.G. Farben in 1943 and about the same time in France. But in Germany this patent was not actually followed up by the development of a prototype or a machine until 1956, when Ankerwerk, Gebr. Goller made the first single screw in-line injection moulding machine in collaboration with Beck, who was still working in the research laboratories of BASF. As a result of Windsor's work, that of BIP Engineering in compression moulding machines, and others, British firms were able to overtake Germany's technical lead to some extent after the war. In the immediate postwar period American firms also made important advances, but failed to recognise the importance of screw plasticising for injection moulding. This provides an interesting example of 'technological gap' trade[28] between advanced countries, as the technical lead of European producers enabled them to increase their exports to the United States and also to license American producers of screw plasticising machines.[29] United States imports of moulding machinery from West Germany increased from $1.2 million in 1960 to $4.9 million in 1962 ; from Britain they rose from $0.2 million to $0.5 million. In spite of the technical successes of a few outstanding firms, the British industry as a whole still lags a little behind the German. There appear to be only three British producers spending as much as 3 per cent of their turnover on research and development, and many of the others are producing under licence. In Germany there are half a dozen or more producers with a strong independent research and technical effort, and spending 3-5 per cent of turnover on research and development. But the largest producer, Battenfeld, has concentrated on simple, low-priced machines.

The evidence suggests that the technical leadership of Germany, United States and Britain was even more pronounced in plastics machinery than in plastic materials. These three countries account for 90 per cent of world exports (table 13) of rubber and plastics machinery, and Germany is particularly strong in plastics machinery. Japanese production of plastic machinery, as of plastic materials, is still largely under licence from American, German and British firms[30] and she is still a net importer.

Advances in machine design make possible new applications of plastic materials. For example, the present large-scale use of rigid PVC for rainwater systems in several European countries has been made possible because screw injection moulding machines are now available which can fabricate satisfactory joints on a large scale. Another example is the collaboration of ICI, Windsor and Rollex which enabled acrylic polymers to be used on a large scale for television screens and for natural skylighting.[31] These advances are, of course, not necessarily limited to the country producing the machines. For example, PVC injection moulded telephones are now being produced in Japan on the basis of development work by Ankerwerk (Germany) in co-operation with Japanese firms.[32] But generally speaking a technically advanced

Table 13. Exports of rubber and plastics machinery

$ million

	1954	1955	1956	1957	1958	1959	1960	1961	1962
United States	21.3	27.1	31.0	37.2	30.8	34.2	47.7	47.2	55.0
West Germany	7.9	11.2	15.7	20.5	23.9	30.5	39.3	67.1	66.7
United Kingdom	7.5	7.1	7.1	9.1	16.4	31.2	31.3	38.4	34.5
France[(a)]	1.4	2.0	0.8	1.5	2.6	5.6	6.6	7.9	8.5
Italy[(b)]	..	..	..	..	..	..	..	..	4.5
Total of above	38.1	47.4	54.6	68.3	73.7	101.5	124.9	160.6	169.2

Source : National Trade Statistics.

(a) Includes machinery for soap, stearin, perfume and pharmaceutical products.
(b) Plastics machinery only.

and progressive machine industry will principally benefit the country in which it is located, because material-suppliers, machine-makers and fabricators can more easily co-operate there in experiment, development and design. This tripartite co-operation appears to be closer and more satisfactory in Germany than in Britain.[33]

Technical progress : the consequences for production

Summing up the evidence from all three measures of technical progress—research expenditure, patents and innovations—it seems that in the years up to 1945 Germany, or one might say I.G. Farben, was well in the lead. Before the Second World War, only the United States was a serious rival ; after the war she was able to draw ahead, when German industry was dislocated and disorganised. But in the last five or six years the successor firms to I.G. Farben in Germany have again been prominent in patents and innovations. Britain's research effort in plastics has been very much greater since the war than before it.[(1)] The French and Italian research effort in plastics seems to come some way behind that of Germany, the United States and Britain.

In the analysis of the effect this research and innovation had on production and trade, it is useful to distinguish three phases : the research-development phase, the technical-commercial phase, and the open competition phase. During the first phase, which lasts typically between five and ten years, a new product is brought to the stage of successful pilot plant production. Most of the development work is done by specialised research and development teams, and typically towards the end of this phase, patents are taken out.[(2)] During the second phase, which lasts from 15 to 25 years, large-scale commercial production is launched ; research and development work continues, but its trend shifts to applications and process research. In this phase the innovating country has a decisive advantage, and is likely to be the leading country in per capita production and exports and often also in consumption. It has a head-start over its rivals and its lead in technical know-how is buttressed for at least 15 years by patents and commercial secrecy. Production may be licensed to other countries, but this is usually done on a limited scale only after a number of years.[34] Licensing is restricted in the early period so that prices may be held high enough to recoup development costs. Furthermore, the arrangements usually carry restrictive export provisions.

Acetal resins are an example of materials in this early phase. Although first produced by Du Pont in 1953, they were not licensed for production in Japan until ten years later, and are still not produced in Britain. More serious competition may develop at an early stage if several countries have simultaneously been doing the research and development necessary for a new product.

Soon after patents expire, the third phase begins. Imitation is easier and technical know-how begins to spread more quickly. The number of producers increases, attracted by the high profits, and prices begin to fall more sharply. But even now, 20 or 25 years after successful pilot plant production, the innovating country or countries still normally enjoy some major advantages in accumulated production experience and technical know-how. Thus, for example, 25 years after first producing high pressure polyethylene, ICI was still able to make arrangements for the sale of technical know-how to an industrially and scientifically developed country such as the USSR, as well as to many other countries.[35] With the exception of the United States, Britain still has the highest per capita production and exports of high

(1) The Annual Report of ICI for 1962, commenting on the firm's research expenditure, says ' The largest single component of this total was work associated with the invention, development, manufacture and use of organic polymers.'

(2) Some patents may of course be taken out at any stage of the project.

pressure polyethylene in the world.[36](1)

However, in this third phase of open competition, directly technical factors will become less important, and other factors—such as material costs—will matter much more. Thus, for example, some 30 years after the United States and West Germany first produced PVC, Italy and Japan are now overtaking these countries in per capita production and consumption : for they have cost of production advantages and are able to quote lower prices.[37](2) So they are able to challenge the innovators in export markets—or indeed in the innovators' home market : for example Italian sales of plastics in West Germany.

But even in this final phase the innovators will still benefit to some extent from their long experience, from their accumulated knowledge and from their still-continuing research and development. Other producers may overtake them in production costs and prices for standard grades, but they are able to introduce new and improved qualities in the old materials and in this way open up new markets and retain old ones. This is happening with all the three major thermoplastic materials—PVC, polystyrene, and polyethylene. The old producers are also able to some extent to offset other cost disadvantages by continuing technical progress in processing and sometimes also by economies of scale. Germany and the United States are still leaders in per capita production and consumption of condensation products and cellulosics (table 3), groups which contain a high proportion of materials now 40 years old or more.

The pattern of consumption

Technical progress, then, seems to throw a good deal of light on the country pattern of production. It cannot, of course, in the same way explain the country pattern of consumption. To take a straightforward example, Sweden, in 1961, had no production of polyolefins, and consequently no technical progress in it ; but her consumption per head was higher than in either Britain or West Germany (table 3). The level of consumption in a country will depend, amongst other things, on the level of national income, and possibly also on its rate of growth ; on differences in industry structure, since some industries use more plastics than others ; on whether user industries are themselves progressive and research minded ; on the level of tariffs ; and also on the extent to which producers of plastics are energetic in promoting its use.

Plastics consumption is in fact quite high in a number of countries which have little production of their own, but which have high incomes and liberal import policies. This is the position in Switzerland, Belgium and the Netherlands, as well as in Sweden ; all these countries have benefited from the export efforts of innovating countries, and indeed from the low prices of dumped materials. Importing countries like Australia, on the other hand, which protect their infant industries with fairly high tariffs, may take longer to reach high levels of consumption in spite of their high income levels.

Before assessing the effect of the structure of industry, it is useful to divide plastics consumption into two groups : consumption by fabricators of plastic products,(3) and consumption by other users. In the first group, which accounts for 60-80 per cent of consumption in the leading countries, packaging, construction and electrical engineering are the big users. In the second group, plastics are mainly used in the manufactures of glues and adhesives, paints, coatings, and auxiliaries used in the textile industries (table 14).

The electrical engineering industry and the paint industry are much bigger in Germany than in France or Italy : so this would explain part of the difference in per capita consumption. But in Germany and Britain the two industries were about the same size in 1961. The only significant structural differences between these two countries is that Germany has a bigger construction industry (both absolutely and relatively) and, partly as an indirect consequence of this, a bigger glue and adhesives industry.

Roughly speaking, German glue and adhesives industry consumes nearly 3½ times as much plastics materials as the British : the difference is about 120 thousand tons. Its output is about 2½ times as big. So, of this higher consumption of 120 thousand tons, about 75 thousand may be explained by structure, and 45 thousand by the fact that glue in Germany is made from plastics rather than from other materials. This higher utilisation is largely due to the technical progress of the plastics industry. I.G. Farben pioneered the urea-formaldehyde syrups and polyvinyl acetate adhesives which today contribute a large part of its total output.

But even the apparent ' structural ' difference is in a way misleading. A good part of it can be explained by the German chipboard industry, which consumes

(1)There are some special reasons for the high United States production of polyethylene. Under a special war-time agreement, ICI transferred all its technical know-how to two American companies, Du Pont and Union Carbide, so that they could launch large-scale production for allied military requirements. Furthermore, under the Ryan judgment arising from the United States Government anti-trust action in 1952, high pressure polyethylene was compulsorily licensed to half a dozen other American companies, and these were given the right to export to those countries in which ICI's basic patent was still in force.

(2)See Appendix table 25, page 59, for lower Japanese and Italian prices of PVC polymer.

(3)This includes cables.

Table 14. The industrial pattern of plastics consumption, 1961

	Thousand metric tons			*As per cent of total consumption*[(a)]		
	UK	Germany	Italy	UK	Germany	Italy
Plastics fabricating						
Packaging	86	75	48	17	9	14
Electrical engineering[(b)]	87	107	37	17	13	11
Domestic ware and other consumer goods	74	108	67	15	13	20
Construction, including flooring and interior fittings	60	154	64	12	19	19
Engineering, vehicles, instruments, belting and miscellaneous industrial	48	70	33	10	8	10
Total, plastics fabricating	**355**	**522**	**250**	**70**	**62**	**75**
Other plastics consumption (principally chemical industry)						
Paint	82	106	..	16	13	..
Adhesives, glue	50	168	..	10	20	..
Other	20	41	..	4	5	..
Total, other uses	**152**	**315**	**84**	**30**	**38**	**25**
Total, all uses	**507**	**829**	**334**	**100**	**100**	**100**

Source : NIESR, based on trade estimates ; *Chemische Industrie*, October 1961 ; Saechtling, *Werkstoffe aus Menschenhand* ; and Gesamtverband Kunststoffverarbeitende Industrie Reports and Statistics ; Instituto Italiano per gli studi sui consumi, *Consumi e impieghi di materie plastiche*.

(a) In terms of weight. In terms of value the share of construction would be much lower and that of engineering higher.

(b) Including cables, etc.

an enormous volume of glue.[(1)] Its output in 1961 was just over 1 million cubic metres, compared to 85 thousand cubic metres in Britain. The chipboard industry was the result of an intensive effort during and after the war, encouraged by the manufacturers of plastics materials, to utilise waste wood commercially.

So perhaps a better comparison is to consider the glue and adhesives industry as an input of the construction industry (which it is, to a large extent), and to compare Britain and Germany in this way. The German construction industry then—including the plastics content of glue—consumed over 300 thousand metric tons of plastics in 1961, compared to just over 100 thousand metric tons in Britain : and, at most, the construction industry in Germany is only one third greater than the British industry. On this way of assessing the effect of structure, it only explains some 30 thousand metric tons, of the difference of 200 thousand tons between the two countries.

Most of the difference, then, between the two countries can be put down to a higher utilisation of plastics within German industries. This was already well advanced before and during the War. Among the numerous applications which were already developed in Germany before 1945 were vinyl flooring, oriented polystyrene film, PVC film, PVC covered wires and cables, rainwear, a variety of PVC pipes and fittings for the chemical industry, vinyl coated bags, PVC shoe soles, hospital sheeting, curtains, food containers, insulating foams of PVC, polystyrene, and urea formaldehyde and magnetophone tapes.[38] In construction, also, plastics were and are much more widely used in roofing, panelling, thermal insulation, and interior fittings of all kinds.

(1) This explains the very high German consumption of urea-formaldehyde resins (table 3).

Producers, fabricators and users

The extent to which plastics are used in any industry—the utilisation factor—will depend on the total research and development effort put in by materials producers, fabricators, and users to extend its use. In most countries, the bulk of such research expenditure, perhaps four-fifths of it, is done by the materials producers themselves ; and, of the rest, the user industries seem to do more than the fabricators, whose share is very small.

Most of the fabricators are small and medium-sized firms who have no facilities for research and development. There were 789 fabricating firms in Britain in 1958, employing on average about 50 people and 1,100 in West Germany in 1960, employing an average of about 75. In both countries there are a few exceptional firms, such as Commercial Plastics, which themselves do research and development into new applications. But the great majority do little or no research. Some of the fabricators are 'trade-moulders', taking on work for a variety of customers as well as selling their own final products and varying their output continuously. Others are producing typically a small range of products for only one or a few customers, and are virtually the plastics departments of large consumers of plastic components. In both Britain and West Germany some of the largest users, especially in the electrical field, mould and extrude their own plastics, for example cable-makers and radio firms. But an electrical engineering firm like Lucas in Britain, which is one of the largest fabricators and users in the country, may also put out work to many other smaller trade-moulders ; and the plastics departments of large user firms may also take on trade moulding for outside customers when they have spare capacity. The fabricating side of the industry resembles the engineering industry, where sub-contracting also provides flexibility.

The large consumers, and those firms which are both fabricators and consumers, contribute more to the technical progress of the industry than the independent fabricators, because they have more facilities. But there is no evidence that such consumers are much more active in this way in West Germany than in Britain or the United States. As between Britain and West Germany, the difference in the use of plastics appears to be least in technically advanced industries such as electrical engineering, cables, paint, automobiles, and packaging, and greatest in relatively backward industries such as construction, domestic ware and furniture (table 14).

Thus, for example, in the car industry, it is true that some West German firms were earlier than the British in introducing new applications for plastics in vehicle manufactures. Volkswagen were already using over 22 lbs. per vehicle in 1959,[39] and now use up to 29 lbs. in over a hundred different parts. But there is probably now not much difference between British and German use in cars. The new BMC 1100 (August 1963) uses 35.6 lbs. of plastics per car, and the much lighter Mini uses 23.4 lbs. (table 15). British manufacturers have been ahead in the use of reinforced plastics for the cabs of commercial vehicles and other applications.(1)

Table 15. Weight of plastics in various British Motor Corporation vehicles

lbs.

Material	A.60 December 1961	Mini August 1963	1100 August 1963
PVC in leathercloth ..	13.3	10.5	11.9
PVC unsupported ..	3.5	2.75	5.0
Acrylics	2.0	0.5	1.1
Nylon	0.5	0.16	0.23
Polyacetal		0.016	0.016
Polypropylene	0.7	0.38	0.5
Polyethylene HD ..		0.33	—
Polyethylene MD ..		0.27	0.35
Styrene		0.27	0.34
Phenolics		1.0	0.95
ABS		0.35	0.38
Cellulose acetate ..		1.1	0.9
Polyurethane foam ..	—	5.75	14.0
Total	26.3	23.35	35.6
Weight of vehicle ..	21.5 cwt.	12.5 cwt.	16 cwt.

Source : K. C. Waldron (British Motor Corporation) 'Plastics in the car industry', paper presented to the Plastics Institute, London Section, October 8, 1963.

The cable industry is another industry where there is probably no great difference between Britain and West Germany in plastics utilisation factors, although here again German manufacturers switched over to plastics earlier. In packaging, Britain is ahead of West Germany in total plastics consumption (table 14). Chain-stores, multiples and other large firms have a larger share of the distribution network in Britain, and some of them have, on their own account, promoted new types of plastics packaging.[40] Also, the largest manufacturers of metal containers in Britain (Metal Box) recognised the potentialities of plastics very early, and undertook large-scale development work. Further, the materials producers themselves have ventured into this field.

The clock and watch industries provide an example of development work done by users. The British firm of Smith's has been able to make important savings by replacing expensive machined metal parts with plastics. Other firms had previously failed to do this, because their development work was inadequate, and they did not redesign components specifically for plastics. Smith's plastics development section succeeded in overcoming these problems, and the even more difficult problem of improving injection moulding techniques to the precise limits required for this industry.[42] When user-industries are technically advanced and alive to the possibilities of new materials and techniques, they may often initiate new applications either independently or in co-operation with material producers, fabricators, and machine-makers.[43]

Plastics in the construction industry

It is in the less technically advanced industries and especially in construction that the German lead is greatest. This is not primarily due to the efforts of the building industry itself, which is backward in

(1)Car manufacturers in all countries need to be alive to the possibilities of economy in materials as these account for 70 per cent of manufacturing costs. Savings of up to 80 per cent have been possible for some components (Appendix table 16) but plastics still account for only about 1 per cent of the weight of a Volkswagen to over 80 per cent iron and steel and 6 per cent non-ferrous metals. Development work which is now in progress in several countries is likely soon to lead to a radical change in these percentages.[41]

research in all countries. It accounted for less than half of one per cent of the total research expenditure by British private industry in 1961,[44] and the proportion is probably no higher in the United States and West Germany.

The German lead appears to be due to a greater experience of plastics over a longer period, and the applications research of plastics producers. No doubt also shortages of traditional materials before, during and after the war made users more willing to accept alterations. The pressure of demand on the German building industry was also very strong during the period of postwar reconstruction.

The potential applications of plastics in building and civil engineering are enormous, and even in West Germany and Japan, which have gone further than most countries, consumption is still relatively small. There are a number of reasons for this. The construction industry is mainly made up of small firms, which cannot afford the type of large-scale development work which is required. The responsibility for design and fabrication are separated—one is with the architect, the other with the contractor ; this tends to inhibit innovation and weaken the incentives to cost reduction through technical change.[45] National standards, and the specifications and regulations laid down by public authorities, all serve to slow down, sometimes to a standstill, the adoption of new materials. For instance, it is taking a very long time to get plastic pipes accepted for water supply in Britain. These institutional barriers to new materials are also important in the United States. There too—although firms like Monsanto produced experimental all-plastic houses several years ago—the building industry does not use plastics on any scale. This may be the biggest single reason for the low United States ratio of plastics consumption to national product, compared with West Germany and Japan.

This backwardness in the use of plastics in building has given rise to concern in several countries, and a number of proposals has been made for reform. These include co-operative research and development facilities for the building industry, and the use of Government contracts to promote innovation.[46] In Japan, building firms contribute to the cost of research carried out by chemical firms, and the Ministry of Construction also subsidises research programmes in building applications of plastic materials.[47] In Sweden building firms also contribute an annual levy to the National Council for Building Research which is co-operating with the Swedish Plastics Federation in the organisation of a joint research programme. In Britain the Royal Institute of British Architects convened a conference in October 1963 to work out a policy for the development of plastics as major building materials : the conference brought together builders, architects, plastics manufacturers and government representatives. The Minister of Works has already proposed a new building research and information association to be financed partly by the Government and partly by the industry.

Other factors

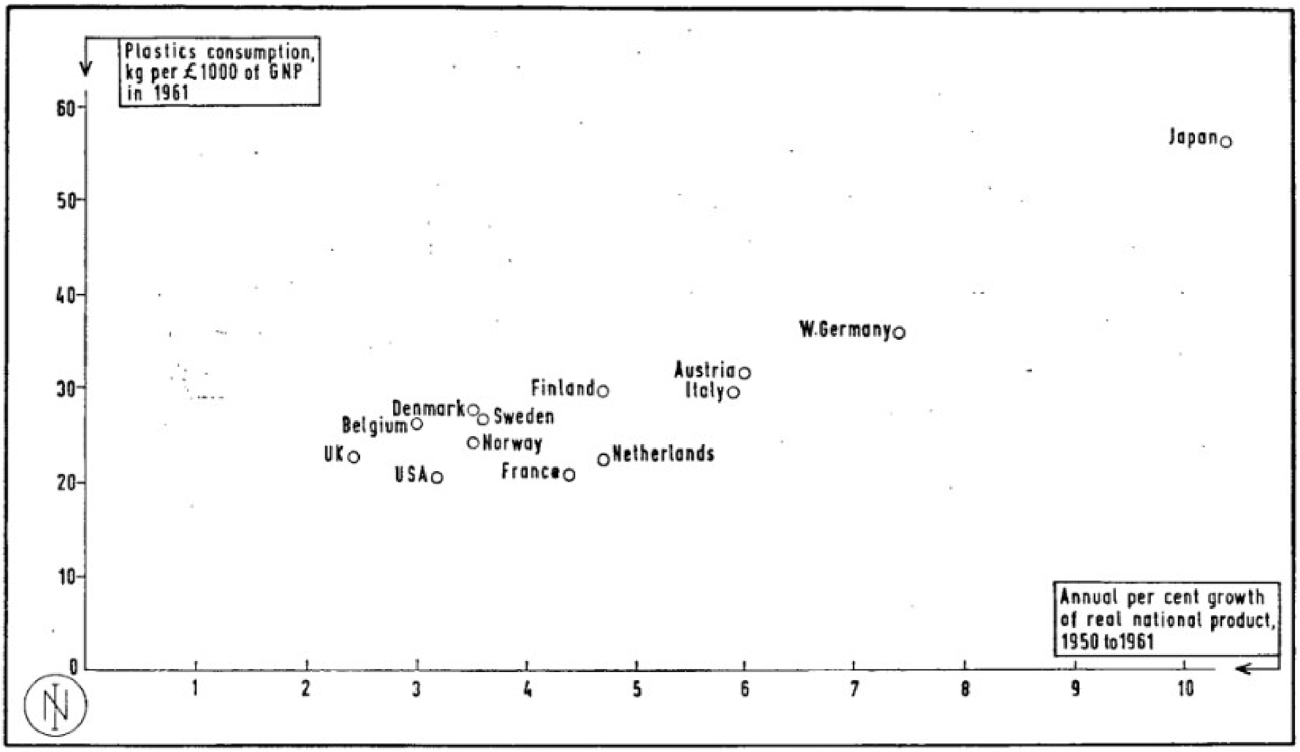
In an analysis of this kind, it is not practicable to discuss all possible factors, or to pursue every matter up the chain of causation to the end. For instance, it could be argued that the business decisions discussed here—to expand research, or to increase investment, or to experiment with new materials—are all management decisions, and that the comparative study of technical progress should be taken further into a comparative study of management. This is a much wider question, and beyond the brief of this article. Equally, we have not gone into questions of differences in taste, and psychological barriers to the adoption of plastics ; it is difficult to find any conclusive evidence on these matters.

Two other questions are perhaps worth raising. First, to what extent has the adoption of these new materials been linked to the rate of economic growth ? There does seem to be some link : it is perhaps significant that the first four countries in rate of economic growth in the last decade—Japan, Italy, West Germany and Austria—also rank in the same order in the intensity of their use of plastics (chart 2) : that is, in the ratio of plastics consumption to gross national product. It might indeed be expected that a faster rate of economic growth would both stimulate using industries to accept new materials, and also influence the investment decision of producers. Conversely, producers who have become accustomed to a rather sluggish rate of growth will naturally be less ambitious with their plans. The President of the European Council of ICI pointed out in 1962 that investment plans in the Common Market countries called for a 60 per cent increase in plastics capacity, whilst those in Britain provided for a 30 per cent increase, and commented : ' In Britain we are naturally conservative and cautious. It is rare to find a situation where substantial over-capacity has been deliberately provided . . . The British petro-chemical industry while planning ahead with reasonable boldness has avoided the problem of unsold surpluses and hence has not had to face the temptation of dumping because of too large plants'.[48]

Another question of some interest is the influence of the central plan in those countries which have one.

(1)One of the most important materials used in construction is rigid PVC. Appendix table 24, page 59, shows that Japan, West Germany and Italy all make much more extensive use of this material than the United States does.

Chart 2. Growth-rates and plastics ' intensity '(a)



(a) Plastics consumption is for 1961, except for Finland and Denmark, when it is for 1960. Growth-rates are for 1950-61, except for Finland, Norway and Belgium, where they are for 1950-60.

Here, Mr. Khrushchev's criticism of the planning organisations for their backwardness in recognising the importance of plastics is interesting. He said :(1)[49] ' Had planning and economic organs studied economic problems more profoundly they should have determined when and in what quantities ferrous and non-ferrous metals and other materials should be replaced by synthetic materials, and developed their production in every way. Unfortunately, economic and planning organs do not take sufficient account of the achievements of science and technology, do not use these achievements for the accelerated development of those categories of production and branches which are economically the most advantageous and promising...

' Production of steel is, so to speak, a well-worn road with deep tracks, and here even a blind horse will not swerve because the wheels will break. A material has appeared which is superior to steel and cheaper, but they still shout : Steel ! Steel ! If we had only fulfilled the plan for the smelting of steel but overfulfilled it for polyethylene we would have done better and would be much richer. But this is hard

(1)' At my request the State Planning Committee and the Committee on Chemistry have submitted a memorandum with calculations of the economic efficiency of using plastics in the economy as substitutes for lead, copper, zinc, ferrous metals, fabrics and timber materials. Here is what this memorandum shows :

' In the cable industry 67,000 tons of lead could have been replaced by polyethylene in 1962. Capital investments needed to organise the production of one ton of lead amounting to 1,630 rubles and for one ton of polyethylene, to 1,000 rubles. Each ton of polyethylene replaces three tons of lead. While capital investments totalling 108 million rubles are needed for building up capacities of 67,000 tons of lead, the building up of polyethylene capacities to replace this quantity of lead would require only 23 million rubles, or nearly 80 per cent less.

' In addition to a big saving in capital investments the national economy would also have a big saving by reducing the cost of cables, since the cost of insulating a cable when polyethylene is used is cut by half.

' Pipes also made of polyethylene could be used instead of steel gas pipes and waterpipes, in housing and industrial construction. Capital investments for building up production capacity of 1,000 metres of steel pipes amount to about 1,300 rubles and polyethylene pipes, to about 600 rubles, or nearly 54.6 per cent less.

' Calculations show that in organising the production of 100 million metres of pipes from polyethylene, instead of steel pipes, the saving on capital investments would total 72 million rubles ; moreover the cost of producing pipes from polyethylene would be 30 per cent less than of metal pipes. Flooring from polymeric materials is 30-40 per cent cheaper than wooden flooring.

' In the production of high-voltage transformers the use of one ton of epoxide resin makes it possible to release up to two tons of copper and nine tons of hot-rolled stock ; one ton of polyamide resin replaces about five tons of bronze in the manufacture of sanitary equipment.

' The use of plastics in engineering, and various other industries and construction reduces the weight of articles, and their size, cuts operating outlays and raises labour productivity.'

to do because there are people in the State Planning Committee who stop those who sensibly want to change the steel production targets in favour of synthetic materials.'

Japanese planning on the other hand probably helped the industry's rapid growth in that country as the industry was given a high priority and very ambitious targets were set.[50] The USSR has now also set extremely ambitious revised targets for plastics.