II. Special Featured Papers

MONDAY NIGHT LECTURE

DECISIONMAKING IN INDUSTRY AND ITS IMPLICATIONS FOR ENERGY AND OTHER RESOURCES

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Engineering materials are always a means to an end: the manufacture of a product, Any criterion for assessing their utility, from the point of view of performance or of economics, must be derived from this basic fact.

Metals technology exists to make objects of metal or objects containing metal; plastics technology to make objects of plastics or objects containing plastics; concrete technology to make objects of concrete or containing concrete. These technologies involve a whole range of activities, including the winning of raw materials and all aspects of the transformation of these into final products— with processes; with plant; with skills and know-how; with the design and manufacture, performance and profitable marketing of products; and with relevant aspects of the infrastructure. The full optimisation of a technology will be possible only if all these factors are considered, and this applies equally at all levels of economic activity.

The objective of the present paper is to place materials in the context of some other aspects of manufacturing technology and of the resources required for manufacture. Its concern is primarily with materials and industries in which economic considerations play a major role.

Competition in the Metals Industry

The need to consider a whole variety of facets of manufacturing technology may be illustrated by examining the nature of the competition facing metals and the metals industries as a consequence of the introduction of new materials,

It is commonly believed that many metal markets are safe because metals possess unique properties and combinations of properties. This statement may be true for a limited number of specialised applications with tight constraints on weight, size, performance, or processing. However, in many cases, perhaps in the majority of cases, it is possible to create designs based on any of a wide range of materials. The decision whether to use metals or other materials, or indeed one alloy rather than another, will be determined primarily by economic considerations, in which the processes and cost of manufacture will be the major factor.

It is, for example, perfectly feasible to design automobile bodies of similar performance on the basis of steel, aluminium, foamed polyurethane, fibre-glass, or of several of these in combination. Automobile performance apart, the material or combination of materials selected will be the one giving the lowest final product cost, Steel will be selected if the summation of the costs of all the processes necessary to convert iron ore into a car body is less than the summation of analogous process costs for the competing materials, The competitive position of materials is seen to depend on a whole range of factors influencing process costs in both the materials-using and in the materials-producing industries: such factors as scale of operation, percentage of process waste, cost of plant and tooling, productivity of capital and labour, cost of energy, etc.—each of which will vary with time and place, and with the degree of technical and managerial skill and sophistication.

Within the present general pattern of metals technology, productivity improvement in the metal-producing industries will, through its effect on costs and prices, clearly play a major role in the competitive position of metals. But attention to this aspect alone may not suffice to protect metal markets. One of the big advantages claimed for plastics in the manufacture of motor-car bodies, for example, is a very much lower tool-up cost per model. The invention and development of a lower-cost tooling system for steel could therefore be as important a factor in defending this market as an improvement in the properties or a decrease in the price of steel strip.

The factors controlling the substitution of one material for another is often seen to be less a matter of one material competing with another than of the processes associated with one material competing with the processes associated with the other— the sand casting of cast iron with the pressure die casting of aluminium; the pressure die casting of metals with the injection moulding of plastics; sheet and plate metal work with the casting, lay-up, rotational moulding, vacuum forming techniques, and so on for plastics and composites.

Consideration of the whole of final product engineering, of design as well as of manufacturing aspects, and of the relation of these to each other, will often be a prerequisite to the full exploitation of a material, and thus to the maintenance of its competitiveness, This may be illustrated by again referring to motor car bodies. One of the more promising methods of producing these is by the casting of self-foaming, self-skinning polyurethane, Awareness of the simple fact that the production of a relatively thick foam section could compensate for the low Young's modulus, and for the relatively high cost per unit volume of the solid plastic, has here led to the development of a completely new materials system. Is it possible that the aluminium industry might have captured some of the market now held by plastics by the successful development of analogous processes?

The importance of effective final-product engineering in establishing the competitive position of a material will obviously be affected by prices, but a 20 percent price reduction would be of no greater benefit than any improvements in quality, design, and manufacturing ingenuity or in design data or codes of practice, which would allow a decrease of 20 percent in the amount of metal required for the manufacture of the final product. The competition between materials is seen not to be so much a competition between alternative lumps of stuff, as between the whole of the technologies associated with the competing materials.

Many products, now, and probably to an increasing extent in the future, consist of systems of two or more materials, rather than of a single material. The steel industry already has a large market in construction by providing the materials for frameworks and for the reinforcement and pre-stressing of structures in which other materials are used to fulfill functions for which they are more appropriate, One so-called "all-plastic" car had a bumper made from bent tubular steel with rubber moulded around it. Some designs for plastic cars described by British Leyland are based on tubular steel frameworks and plastic body panels. The framework-reinforcement concept is again being sensibly employed to produce a design and manufacturing system combining the advantages of steel, its high strength and stiffness, with the ease of shaping plastics.

As materials are always a means to an end, it follows that the "qualities" and "properties," the attributes in terms of which materials are commonly characterised, have no absolute virtue. An attractive surface finish is of no value in objects which are not required to satisfy aesthetic requirements; a high-tensile-strength material has no advantage in a compressive member; a corrosion-resistant material has no advantage in a product which can readily be protected from corrosion. A material with a high

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ultimate tensile strength offers no advantage in making a component which is likely to fail under notch fatigue conditions, nor one with a high Young's modulus for making a component which can readily be thickened or reinforced to allow a cheaper, low Young's modulus material to be used.

The requirement for optimizing materials is relevance and utility, and in descriptions of what is relevant and useful, consideration must be given to the processes of manufacture, indeed to the whole of the technology associated with materials, as well as to the commercial and economic environment in which they are used.

Materials, Manufacturing Processes, and the Economy

How do materials relate to manufacturing processes, to the economy, and to other resources? Consider first the sequence of processes for the progressive conversion of iron ore into final products shown in table 1. The sequence confirms the earlier statement that materials and processes are inseparable aspects of manufacturing. Indeed, it is not obvious what a "material" is. The operator of each of the process stages will tend to call his input a "material" and his output a "product."

There are many stages in the sequence, and it follows that yield—the ratio of input to output —pIays an important role in resource consumption. This may be seen from table z, which shows the weight of material input required per ton of final output in a hypothetical lo-stage sequence with equal yields, in each of which an input weight "a" is required per ton of final output, If "a" = 1.1, then producing 1 ton of final output requires an input of (1.1)10 = 2,6 equivalent tons at the first stage. Improving the yield so as to reduce "a" to 1.05 reduces the input requirement at stage 1 to $(1.05)^{10}$ = 1.6 equivalent tons.

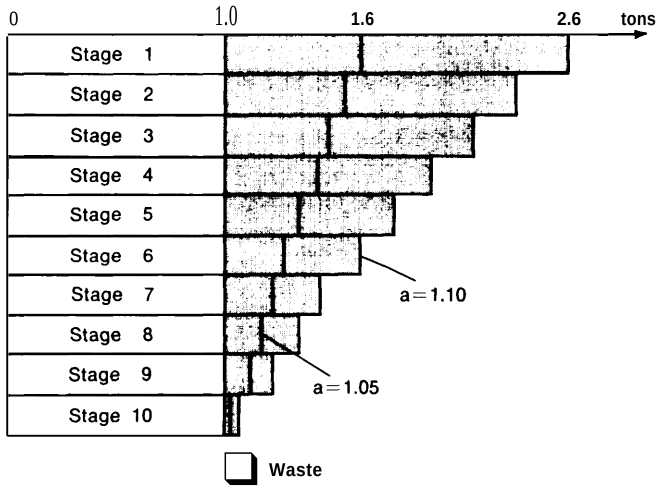
Many of the processes used in manufacturing waste materials. In the engineering industries, up to half, and sometimes more, of the materials purchased are turned into scrap during processes such as machining, forging, and stamping, This wastefulness is of importance not only in the direct way, but also indirectly for a wide range of manufacturing resources such as manpower and capital, and of natural resources such as energy and materials, In the United Kingdom (U.K.), for example, more than **3 x** 10^6 tons of the 16.3 tons of steel bought by the engineering industries in 1968 were resold, not in the form of products, but as process scrap. This means that roughly one in five blast furnaces, one in five steelmaking furnaces, one in five rolling mills, etc., are employed in making steel which will be degraded to scrap in later stages of manufacturing. Not only is a proportion

TABLE I, –Sequence of Processes and Intermediate Products Involved in the Manufacture of Final Products From Steel

Mining and beneficiation
|
Iron ore
(plus coke, limestone, and sinter)
|
Blast furnace
|
Pig iron
(plus ferro alloys, scrap, and fluxes)
|
Steel making processes
|
Molten steel
|
Teeming
|
Ingot
|
Primary cogging mill
|
Bloom
|
Rerolling
|
Billet
|
Rerolling
|
Hot-rolled products
|
(black bar, hot-rolled strip)
|
Pickling
|
Cold roll or cold draw
|
Cold-finished products
|
Machining, pressing, etc.
|
Engineering components
(car. bodies, machine parts, etc.)
|
Assembly and finishing
|
Final products

Source: Pick (1972).

TABLE 2. – Weight of Material Input Required Per Ton of Final Output in a 10-Stage Process Sequence With a Ratio of $\frac{\text{input weight}}{\text{output weight}} = a$; for a = 1.05 and 1.1



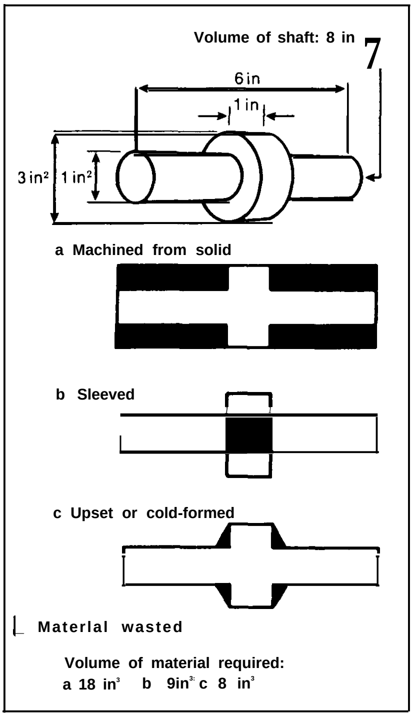
Source: Becker and Pick (1975).

of steelmaking capacity thus wasted, but so also is a corresponding proportion of the labour, electricity, coal and coke, etc., required for steelmaking. In addition, a proportion of the electricity generating, coal mining, and coke oven equipment which produced the wasted electricity, coal, and coke, is also wasted, as are some of the trucks and trains which take the steel to the engineering industries,

But even this is not the whole story, for the waste is spread to those industries which produced this capital equipment. The waste of steel by the engineering industries thus in turn implies a waste of some of the concrete, aluminium, rubber, plastics, and indeed of the steel required to make this capital equipment, Clearly, any reduction in material waste in the manufacture of final products could contribute much to conserve a wide range of resources.

This stresses the importance of design, as is illustrated by the simple example of table 3, which shows the effect of different design approaches on the input of material required for the manufacture of a given product. It also stresses the importance of material specifications: what is specified by an engineering firm will often have a profound influence on upstream process yield and process costs, a matter emphasized by M. Cohen and W. S.

TABLE 3.– The Effect of Design und Manufacturing Method on the Input Weight Required To Produce a Component Having a Volume of 8 Cubic Inches



Source: Pick (1972)

Owen (1975) in a review of the probable directions of steel development in the future.

An impression of the resources consumed in conversion may be obtained, if it is assumed that prices are approximately equal to costs (price = costs + profits) and a steel sequence in which United Kingdom (U. K.) 1975 prices are given is shown in table 4, This illustrates that the cost of materials as purchased by the engineering industries is really a summation of upstream process costs. The original iron ore, a very high proportion of which is now imported into the U. K., accounts for a relatively small proportion of the total cost of final products. An analogous pattern is seen in table 5, which shows 1963 world output of aluminum in both quantity and value terms.

Material costs, then, are a summation of the costs of the factors of production, The range of these is diagrammatically illustrated in

TABLE 4. — Steel Sequence, Showing Approximate 1975 U.K. Prices

Iron Ore	£13
Pig Iron	£58
Molten Steel	
Ingot	£90
Billet and Bloom	£110
Hot-Rolled Products	£140
Cold-Finished Products	£180
Engineering Components	£700

Source: Pick (1972).

TABLE 5.– The Build-Up of Value in the Progressive Conversion *of* Bauxite to Wrought Semifinished AJuminum Products

World Aluminum Production--1963

VALUE ADDED VALUE OF OUTPUT AT VARIOUS PROCESSING STAGES

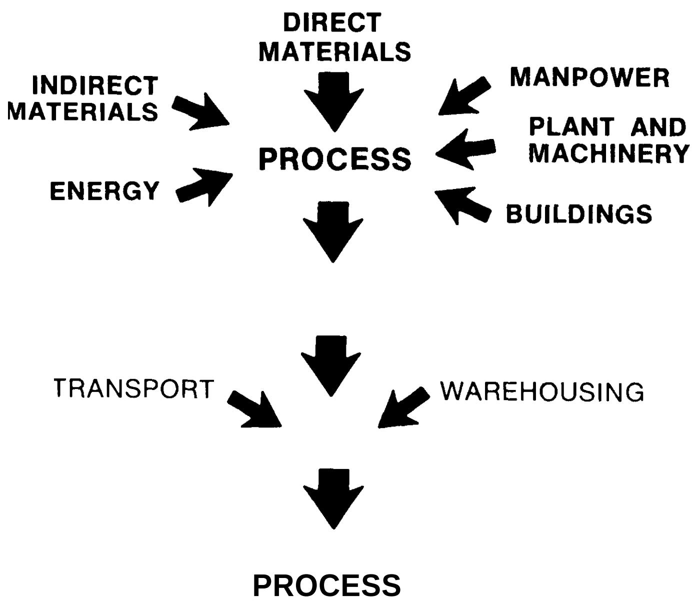
PROCESS	PRODUCT	TONS (MILLIONS)	INCREASE iN VALUE (MILLIONS)	VALUE IN DOLLARS (millions)
Mining	BAUXITE [$8/ton)	30	240	240
ORE REFtNiNG	ALUM! 14A ($75/ton}	12	680	900
A1.UMINUM SMELTiNG ANO REFINING	primary ingot ($450/ton)	6	1800	2700
FABRICATING AND CASTiNG	Wrought Semis CASTINGS ($1000/ton)	6	3300	6000

Source: Pick 1972.

table 6, which shows the inputs to a single stage of a process sequence, and also draws attention to the fact that resources are required for transport and storage between stages, The fact that a wide range of inputs is required for material conversion also means that total conversion costs are cushioned against a price change in any one, This is illustrated in table 7, which shows how the effect of 1972 oil price increases was diluted in the production of plastics products.

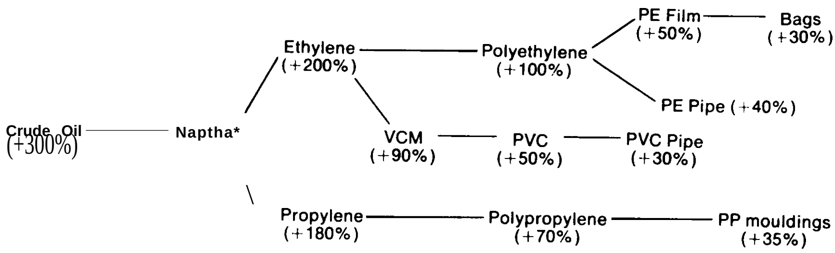
Prices, as has already been mentioned, reflect costs, and hence resource consumption, Relative price movements tend to reflect relative changes in technology and the efficiency of resource conversion. A chart showing the relative price movements of various U.S.A. goods between 1947 and 1970 is reproduced in table 8, which depicts the poor relative performance of metals and metal products during the period, This reflects the fact that improvements in process efficiency have been achieved only at the expense of very high expenditures on capital, According to Drucker (1969), this reflects a stale technology.

TABLE 6, –Symbolic Representation of Physical inputs Into Manufacturing Processes



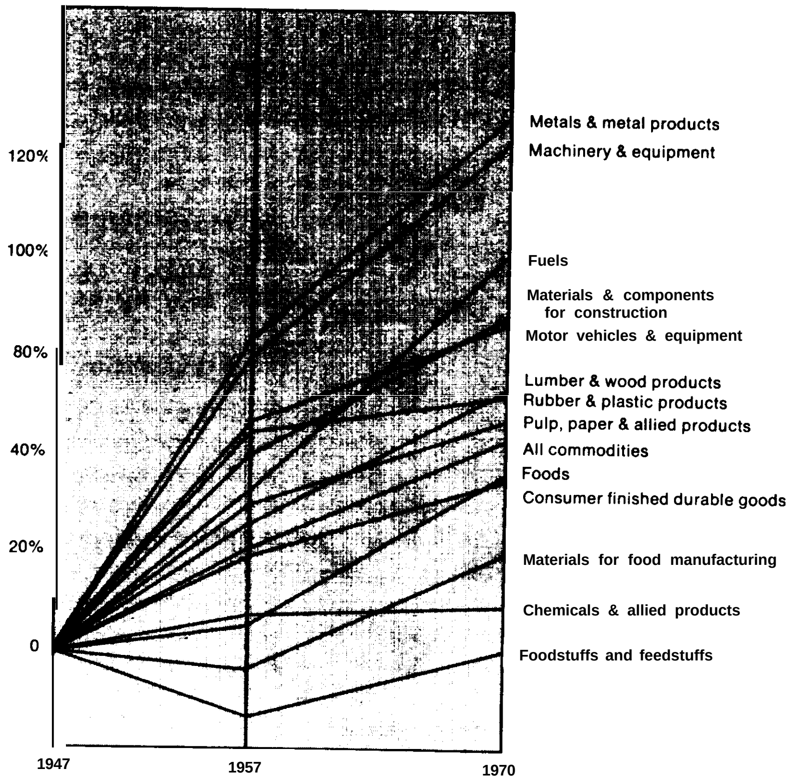
Source: ICI Limited.

TABLE 7, –Conversion Sequence for the Manufacture of Some Plastics Products, Showing the Percentage Increase in Price of Downstream Products Resulting From a 300 Percent Increase in the Price of Crude Oil



Source: ICI Limited.

TABLE 8. – U.S.A. Price Changes in Various Products Between the Years 1947-1970



Source: Data from the Economic: Report of the President, 1971.

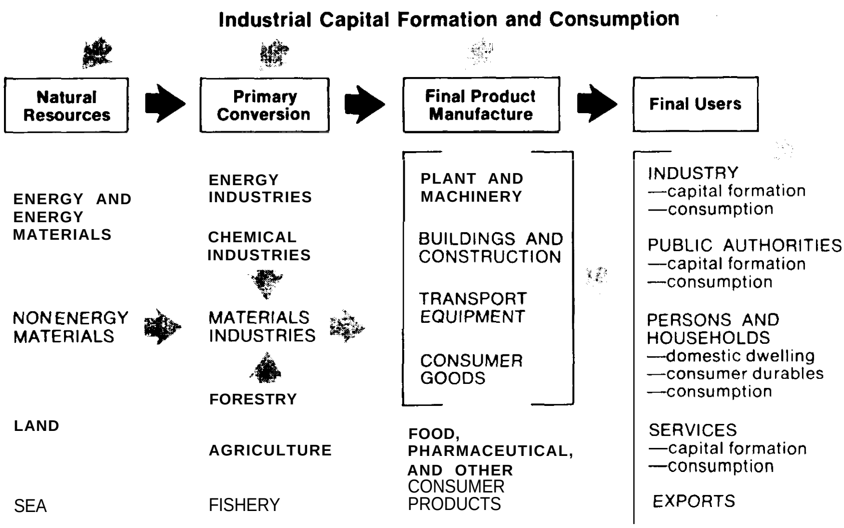
Description of Materials Flow Patterns

The flow of resources in materials conversion needs to be considered in the wider setting of the economy as a whole, and this may be done by reference to table 9, prepared for a forthcoming report on engineering materials for the U,K.'s National Economic Development office. The hollow arrows in this table show the flows which are normally considered to be the materials/engineering stream of manufacture. Leaving aside the question of ‘defense, it is presumably an objective of a national materials policy to take initiatives and precautionary measures which are likely to have an impact significant in the context of pattern of flows, or to create new knowledge and understanding to support such initiatives,

It is now proposed to indicate some features of this pattern of flow which may be of assistance in judging what is economically significant. The question of materials supply is being covered in other conference papers, thus only aspects of conversion beyond the raw materials stage will be considered.

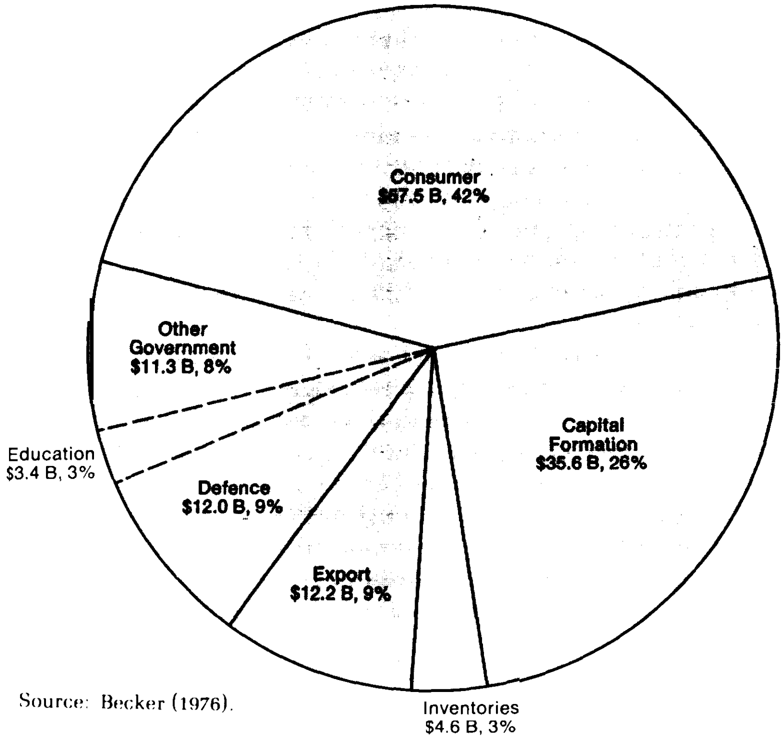
First is the question of the destination of the output of the materials industries. Table 10, based on work by Becker (1976), then a Research Fellow in the author’s University IAston], during a period as visiting Fellow at Brandeis University, shows that

TABLE 9.—The Flow From Natural Resources to Final Products Through the Manufacturing Industries



Source: Forthcoming (U.K.) National Economic Development Office Report.

TABLE 10. –Destination of the Output of the U.S.A. Materials Industries by Categories of Final Demand



Source: Becker (1976).

consumer expenditure in the U.S.A. accounts for 42 percent of the demand for materials, capital formation being next in importance, accounting for some 26 percent.

For a given level of conversion efficiency, the requirement for materials depends on the level of final demand; one possible response to material shortages is to reduce the level of final demand. But the materials content of various levels of final demand is not the same, as maybe seen from the data in table II. The materials content of consumer expenditure is, for example, only 12 cents per dollar, compared with 32 cents per dollar for capital formation. Any government measures leading to a uniform change in expenditure, spread across all categories of final expenditure, would have a much bigger effect on material consumption via the capital goods industries than on materials demand via consumer expenditure.

One of the most important features of the flows in table 8 is that the "materials" flows indicated by hollow arrows are inter-

TABLE II. — Materials Content of the Purchases by Various Categories of Final Demand

	Total Expenditure $ M	Material Content ¢ per $
Consumer	490.660	12
Capital Formation	110.443	32
Inventories	10.034	46
Export	45.923	27
Defence	71.333	17
Education	39.512	9
Other Government	68.274	17
Total	795.388	17

Source: Becker (1976c)

dependent with other flows, as a variety of inputs is required for each process stage in the manner previously symbolised in table 6. Among these are capital and manpower, and table 12 shows the distribution of capital stocks and employment in the U.S.A. manufacturing industries in 1968. Altogether, the listed materials producing industries account for 42 percent of the capital stock in manufacturing, compared with 32 percent in the material using industries. Employment, on the other hand, is greater in the material-using industries, but even so 5.5 million people were employed in producing the materials required by the 7.3 million in the remaining listed manufacturing industries.

It is of interest to note that there are wide discrepancies in the "efficiency" with which different industries use their resources of manpower and capital in the processing of materials, and indeed to produce their output, as is demonstrated in tables 13, 14, and 15. Tables 13 and 14, for example, show that the motor vehicles industry is by far the most efficient in the use both of capital and of manpower, if the ability of a unit quantity of these resources to process a given value of materials is taken as an indication of efficiency. The aluminium rolling and drawing industry on the other hand, while efficient in the use of manpower, is relatively inefficient in the use of capital. Indeed, it is seen from table 13 that the primary metal industries require more capital to process a given value of materials than any other of the listed industries. The traditional iron and steel foundries are relatively "inefficient" in the use of both machinery and manpower.

TABLE 12.—Distribution of Capital Stocks and Employment in U.S.A. Manufacturing Industry, 1968

TABLE A

Distribution of capital and employment in U.S.A. manufacturing industry, 1968.
(Taken from U.S. Department of Commerce, Annual Survey of Manufactures, 1968)

Row No.	S.I.C.* Code	Industry group and industry	Gross book value of depreciable assets (in millions of dollars)			Employment	
			Total	Structures and buildings	Machinery and equipment	No. of employees (1,000)	Total labour cost (million dollars)
			A	B	C	D	E
1		All operating manufacturing establishments, total[4]	231,779.1*	65,105.2	166,613.9	18,681.0	149,151.2
2	24	Lumber and wood products	4,999.4	1,321.7	3,677.7	551.6	3,341.3
3	26	Paper and allied products	16,623.1	3,462.8	13,160.3	642.5	5,305.0
4	282	Plastics materials and synthetics	7,147.5	1,596.9	5,550.6	179.5	1,639.5
5	2851	Paints and allied products	774.7	340.0	434.7	65.1	566.1
6	30	Rubber and plastics products, n.e.c.	6,308.3	1,532.6	4,775.7	541.9	4,237.4
7	31	Leather and leather products	752.5	276.8	475.6	334.1	1,741.9
8	32	Stone, clay and glass products	11,400.9	3,237.6	8,163.3	590.1	1,352.0
9	33	Primary metal industries	36,835.2	7,615.6	29,219.6	1,274.7	12,163.9
10	34	Fabricated metal products	12,720.5	3,638.4	9,082.1	1,357.8	11,301.6
11	25	Furniture and fixtures	2,005.4	852.1	1,153.3	433.4	2,705.6
12	35	Machinery, except electrical	16,638.4	5,044.3	11,594.2	1,848.8	16,564.1
13	36	Electrical equipment and supplies	12,810.7	4,331.6	8,479.1	1,882.7	15,445.4
14	37	Transportation equipment	16,976.0	5,695.1	11,280.9	1,887.6	19,346.4
15	38	Instruments and related products	3,260.6	1,258.9	2,001.7	400.0	3,343.2
16	39	Miscellaneous manufacturing industries	2,241.6	734.4	1,507.2	430.7	2,716.4
17	19	Ordnance and accessories	2,029.8	796.9	1,232.9	446.4	4,573.1
18		Food, textiles, etc.	Remainder				

*Standard (U.S.A.) industrial classification.

TABLE B

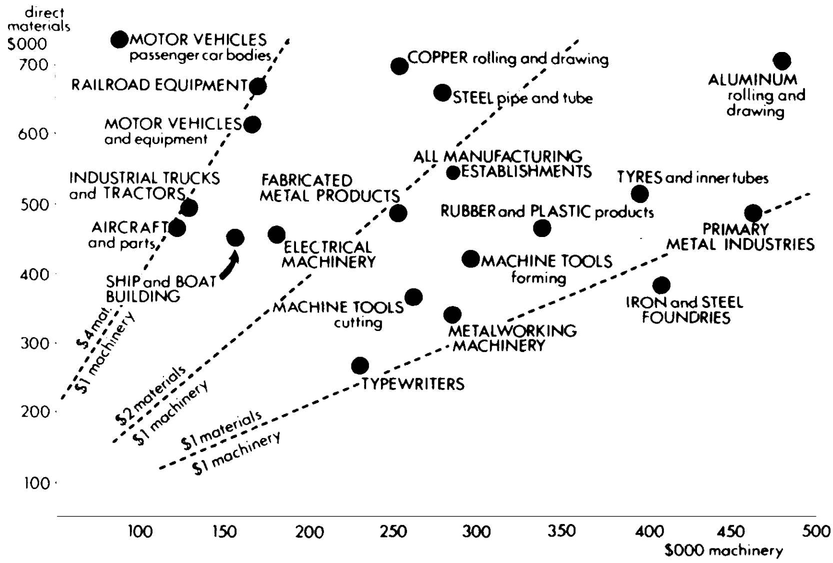
Analysis of data in Table A, for comparison of "materials-producing" with "materials-using" industries, U.S.A. 1968 (Figures in brackets are items expressed as percentage of equivalent quantity for all manufacturing)

	Gross book value of depreciable assets (dollars)			*Employment*	
	Total	*Structures & buildings*	*Machinery & equipment*	*Employees*	*Labour cost*
	A	B	C	D	E
Materials-producing industries (a)	\$98 × 10^9 (42%)	\$23 × 10^9 (35%)	\$75 × 10^9 (45%)	5.5 × 10^6 (30%)	\$42 × 10^9 (28%)
Materials-using industries (b)	\$74 × 10^9 (32%)	\$19 × 10^9 (29%)	\$37 × 10^9 (22%)	7.3 × 10^6 (39%)	\$62 × 10^9 (41%)
Food, textiles, etc.	Remainder				

(a) Rows 2-10 of Table 14A
(b) Rows 11-17 of Table 14A

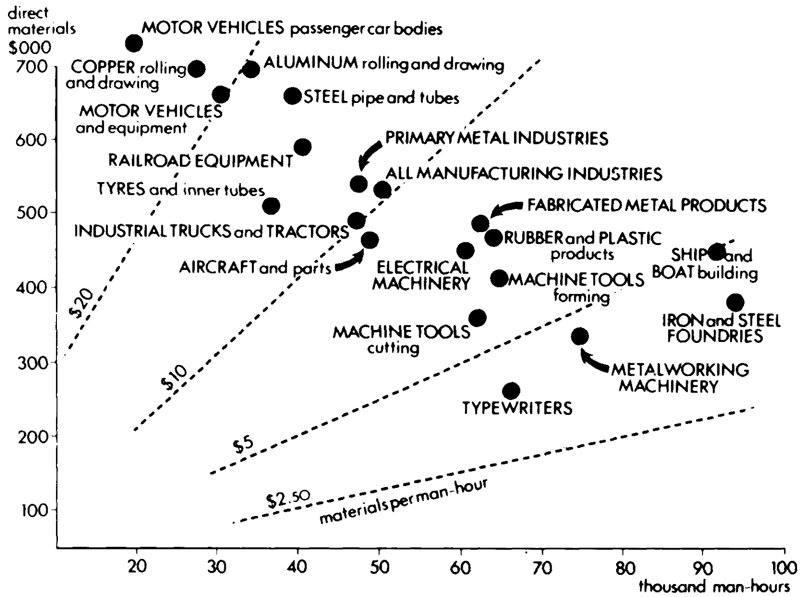
Source: Pick (1972

TABLE I3.– Relationship Between Direct Materials and Capital Required To Produce $1 Million of Output in 1967 in Various U.S. Industries



Source of data: U.S. Census of Manufactures for 1967.

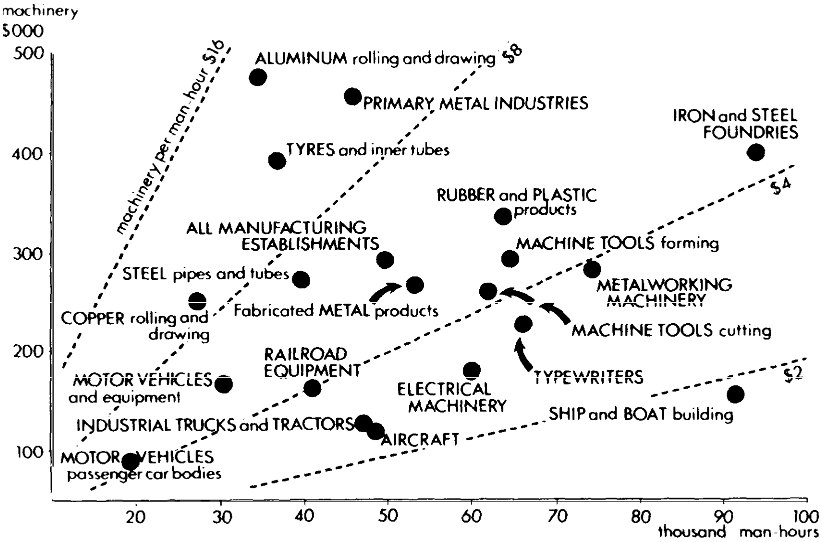
TABLE 14,–Relationship Between Direct Materials and Labor Required To Produce $1 Million of Gross Output in 1967 in Various U.S. Industries



Source of data: U.S. Census of Manufactures for 1967.

Table 15 gives an overall impression of the value of machinery and the thousands of man-hours required to produce a million dollar's worth of output in 1967. Any industry near the origin will be relatively efficient in the use of both these resources, It is seen that motor vehicles are again the best performer, and iron and steel foundries the worst. as assessed by this admittedly crude criterion.

TABLE 15. — Relationship Between Capital and Labor Requircments for the Production of $1 Million of Output in 1967 in Various U.S. Industries

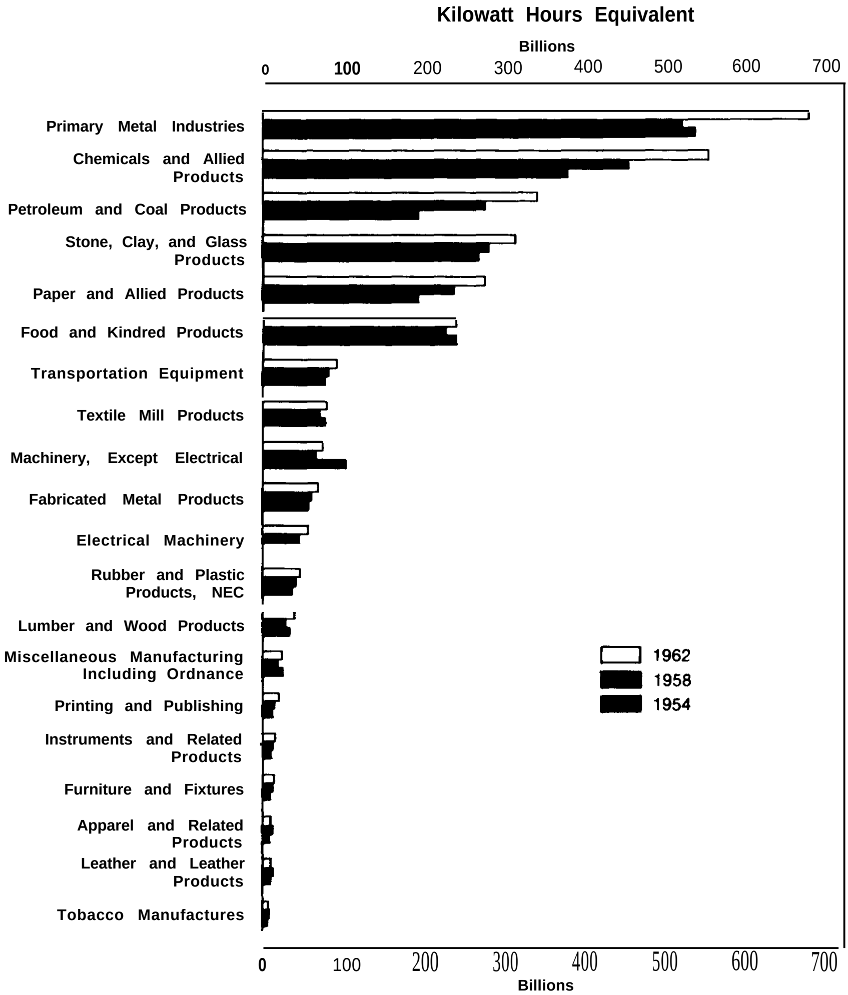


Source of data: U.S. Census of Manufactures for 1967

Materials Interdependence

The interdependence of materials with other resources may also be illustrated by reference to the role of energy in materials conversion. Table 16 shows that the primary conversion industries are the dominant energy consumers in manufacturing, with the primary metal industries in the lead, followed closely by the chemical industry, with two other materials groups (stone clay and glass products, and paper) also high on the list. Numerical values for the uses of fuels and purchased electricity in the U.S. material producing industries are given in table 17.

TABLE 16.– Purchased Energy Used in Manufacturing for Major Industry Groups: 1962, 1958 and 1954



Source: US. Census of Manufactures for 1963.

Energy purchases by the engineering industries, even by the huge transportation equipment industry (which includes land, sea, and air transport equipment), is relatively small. But this relatively low direct purchase of energy by the engineering industries is clearly only part of the story, For in order to assess the total energy content of the products of an engineering firm, it is also necessary to take account of the indirect purchases of the energy used by its suppliers of materials and components, of

TABLE 17. – U.S.A. Consumption of Fuel and Electrical Energy, 1963
(Taken from U.S. Census of Manufactures)

Industry	Cost (10^9 dollars)		
	Total	Purchased fuel	Electrical
All manufacturing industries. ... ., ...	6370	3410	2960
Materials and industries:			
Lumber and wood.	183	115	68
Paper and paper products	472	305	167 ‘
Rubber and plastics, ., ...	128	44	83
Stone, clay, and glass	576	403	173
Primary metal	1389	858	530
Fabricated metal products	240	100	139
Total for materials Industries . . .	2988	1825	1160
Materials industrles as percentage of all manufacturing industries .	47%	53%	39%

Source: H. J. Pick (1972).
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capital and transport equipment, and of services. As these suppliers in turn have their suppliers, a complex summation is required to assess total (= direct + indirect) requirements, Account must be taken of all the energy used by upstream firms in sequences of the kind illustrated in table 1,

This total, direct plus indirect, flow of energy may readily be computed by the use of industrial transaction matrices as published by most industrialised countries in the form of Input-Output tables. The results of such a calculation for the U.K. are shown in table 18, from which it is evident that for each of the industry groups, energy purchases via materials are considerably higher than direct energy purchases. And the results given in table 18 are likely to be conservative, since, for reasons of simplicity in calculation, they do not include the energy required to produce imported materials and to transport them to the U.K. Nor do they take account of the energy used to produce the capital stock of the materials producing and engineering industries.

Analogous results for U.S. automobile production were reported by Hirst (1972) who estimated that a direct purchase of 5,850 Btu/dollar of automobiles shipped was matched by an indirect purchase of 48,420 Btu/dollar shipped via materials and

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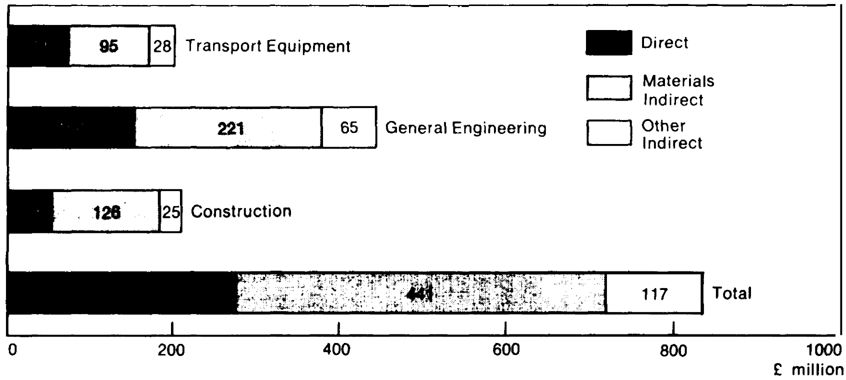
TABLE 18. – U.K. Direct and Indirect Purchase of All Energy by the Engineering-Type industries in 1968



Source: Becker and Pick (1975).

other supplies. Among these, iron and steel play a dominant role because these account for the bulk of the weight of the automobile.

From the above description, it follows that there is an intimate relation between the way materials are produced and used in design and production, and the use of national resources. It will also be evident that there is a gearing effect in the way in which materials are used: in the earlier discussion of the consequences of waste in engineering manufacture, it was shown that such waste produces ripples having effects on resource utilisation at points remote from the point of actual decisionmaking.

From the preceding description of the relation between materials and energy, it follows that any changes in specification, design, or manufacture of automobiles which would lead to reduction in weight would also have widespread consequences for energy requirements throughout the economy, partly through the obvious saving of fuel in running automobiles, but also through savings in materials manufacture, capital stock, etc., of the kind just described. Technical changes of this kind provide a large reserve-in-principle which could, given time for re-equipment, be used in the face of resource constraints, But, as such changes would also lead to a decrease in economic activity and to a change in social habits, their implementation, although widely discussed in the materials literature, in fact becomes an issue for industrial and social strategy rather than for materials policy as such,

Manufacturing Requirements of Materials

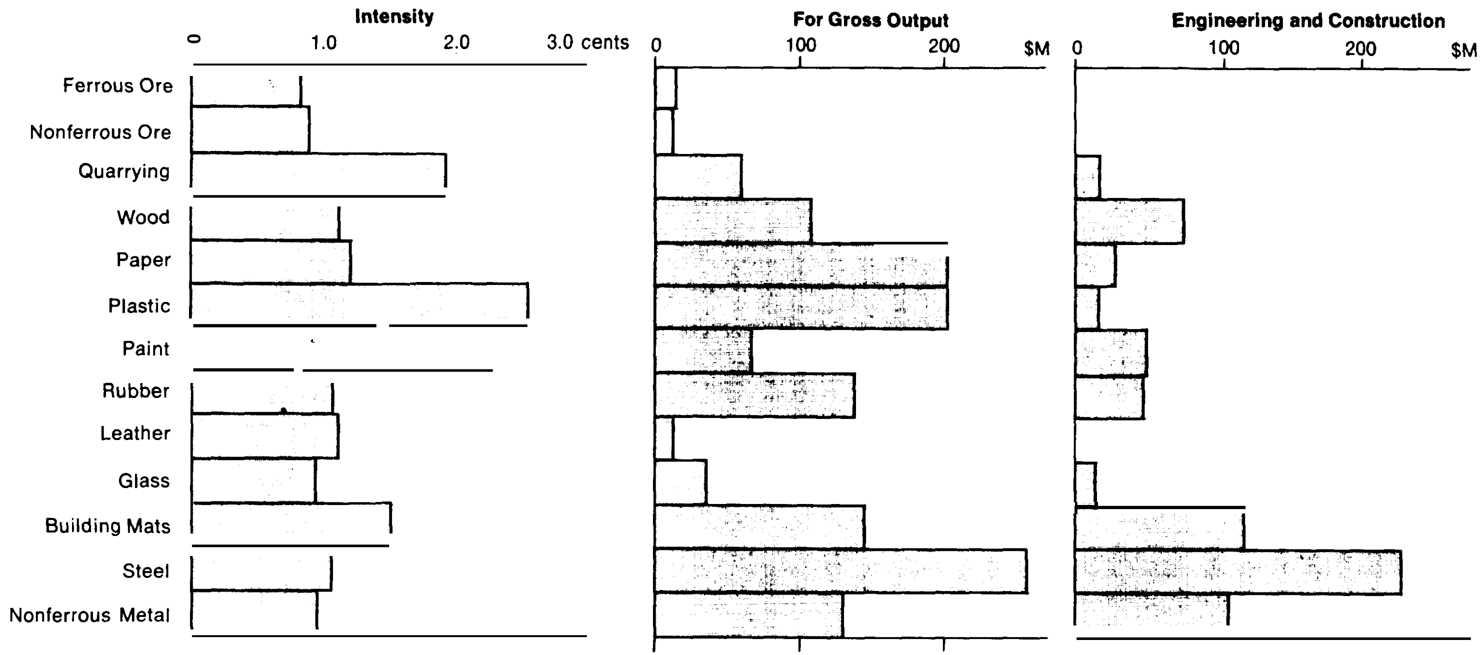
In this final section of the paper, it is proposed to consider the relation between specific materials and the resources of energy, capital, labour, and imports used in their manufacture. This may conveniently be done by using the concept of resource "intensities, " which may be defined as the value of a particular resource required to produce a dollar's worth of the output of a particular material.

For reasons previously discussed, it is necessary to take account of both direct and indirect requirements of a particular resource in order to assess the intensity of that resource in the manufacture of a material. For example, of the crude oil and natural gas required for the manufacture of plastics, very little reaches the plastics industry directly in the form of crude oil: 27 percent of it reaches it in the form of refined oil, 55 percent as chemicals, 5 percent as electricity, 2 percent as transport, and the remaining 11 percent in other forms. Altogether, 3.2 cents of crude oil and natural gas need to be produced in order to produce one dollar's worth of plastics, but this will reach the plastics industry only after being processed into other forms, as indicated in the previous sentence. Three and two-tenths cents per dollar is the crude oil plus natural gas intensity of plastics materials.

Extensive investigations of the total energy requirements for materials manufacture have been carried out in recent years, the most thorough probably those on behalf of the recent National Commission on Materials Policy. But values for resource intensities may also be read off directly from the total requirements matrix of published input/output tables, They have been plotted by Becker in easily interpretable form in tables 19 to 21. The first of these shows in the left-hand diagram of table 19, the intensities of crude oil and natural gas consumption by the various U.S. materials industries in 1967. As expected, the plastics industry is the most intensive user of these fuels, followed closely by paint, while other materials such as steel have a relatively low intensity. (From this it is possible, for example, to infer that any increase in the price of crude oil and natural gas will place plastics at a competitive disadvantage with products containing a smaller percentage of these fuels.)

In order to assess the effect of these resource intensities on the economy as a whole, however, it is necessary also to take account of the gross output of the various materials industries, and these are illustrated in table 19. These tables show that the primary metal industries, and in particular the primary steel industry, have an output considerably in excess of, for example, the plastics industry. The result is that, although steel has a relatively

TABLE 19.—*Crude Oil and Natural Gas Content of Materials*



Source: Becker (

low oil and gas intensity, the overall effect on the economy of a price increase in these fuels would be greater via steel than via plastics.

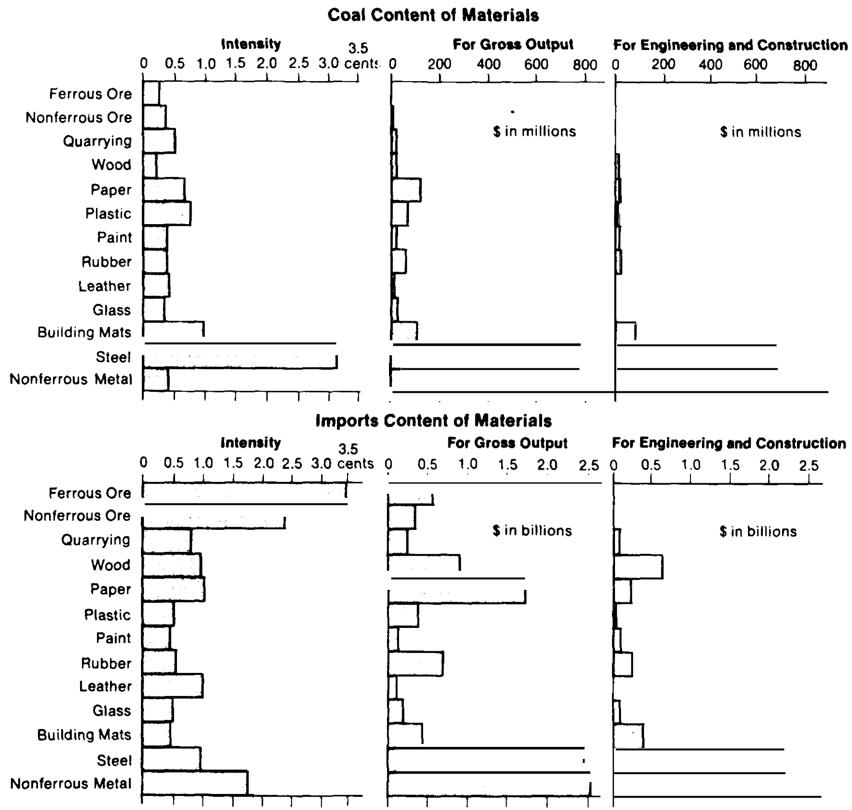
The middle diagram of table 19 shows the total (direct plus indirect) expenditure on oil and gas of the various industries listed, The right-hand diagram is analogous to the central one, but it only shows the oil and gas content of the output of the various materials industries, which has its destination in engineering and construction, From this it is seen that any price increase in oil and gas has its major effect via steel, nonferrous metals, and building materials. Analogous data for some other resources are plotted in tables 20 and 21, It is not proposed to analyze these in detail, but reference may be made to the case of labor to indicate that the labor intensities of different materials are not very widespread. But there are differentials. Wood, for example, is more labor-intensive than plastics, with the consequence that any uniform increase in wage rates would lead to greater price rise in wood than in plastics.

The foregoing discussion will have demonstrated that each type of material has specific quantifiable implications for a wide range of resources, which will be different from those required in the manufacture of other materials.

It is therefore of interest to assess here the effects of material substitution on the requirement of other resources. For the economy as a whole, these may again be calculated by the use of input/output analysis, Becker has developed a method of presenting the results of such a computation in the form of what he terms "Resource Isoquants," A series of these, indicating the effects of the substitution of plastics for steel on capital stock, on labor, and on oil and gas, is shown in table 23. These isoquants are plotted to enable the aggregated effect of substitution on resources to be assessed for a range of substitution ratios (i.e., the number of dollars' worth of plastic required to substitute for one dollar's worth of steel).

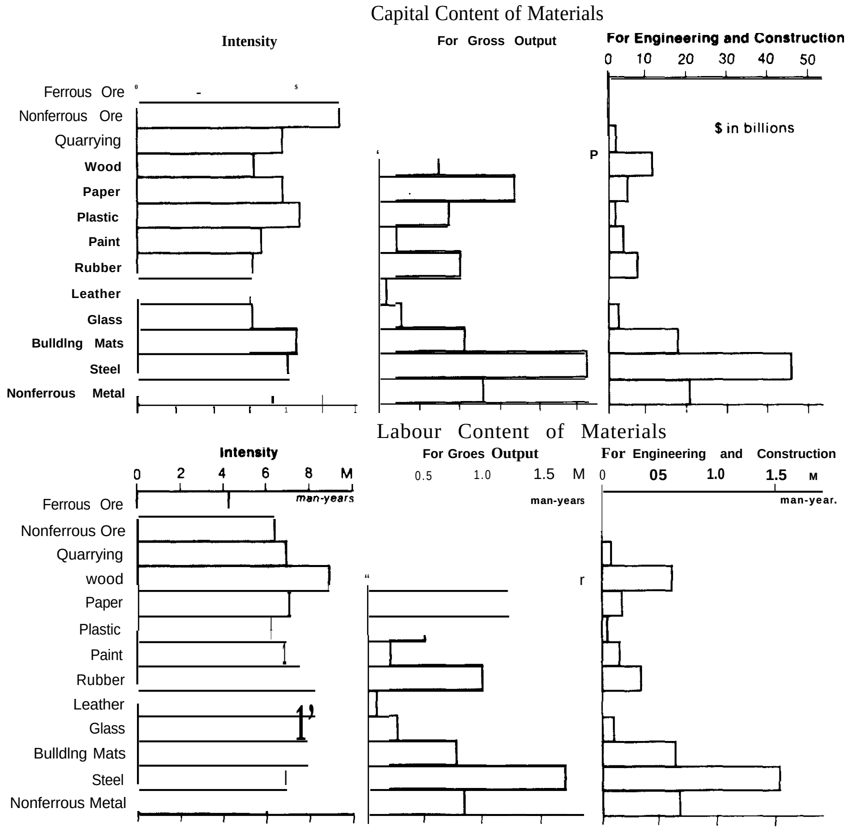
From table 23 it is thus seen that a substitution of $0.95 dollars of plastic for steel would have no effect on capital stock, while a substitution of 20 percent at a substitution ratio of 2 would lead to an increase in the requirements of capital stock by over $8 billion. Similarly, as plastics and steel have roughly the same labor intensity, substitution on a one-to-one basis in money terms would have relatively little effect on employment. To substitute a dollar's worth of plastic for a dollar's worth of steel would require an increase in the labor force. Plastics are very much more oil and gas intensive than steel, Any substitution which required more than about 40 cents' worth of plastic per dollar of steel would lead to an increased consumption of these fuels,

TABLE 20.—*Coal Content of Materials. Imports Content of Materials*



Source: Becker (1976).

TABLE 21. –Capital Content of Materials. Labour Content of Materials



Source: Becker (1976).

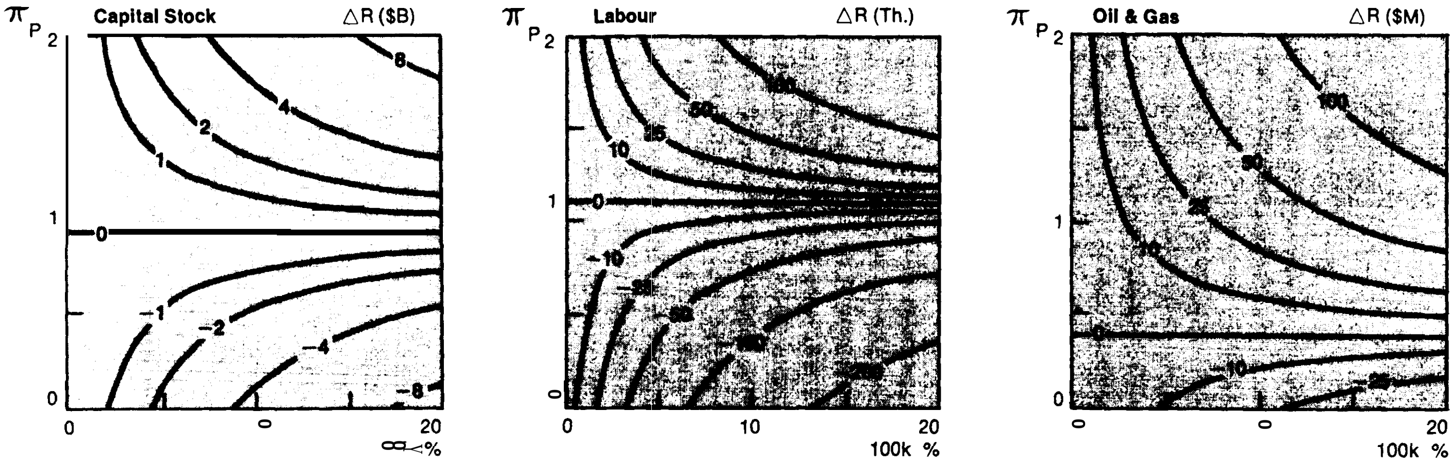
TABLE 22.– Value Added and Value of Shipments of a Number of U.S.A. Industries in **1967**

SIC.	Industry	Value of Shipments $106	Value Added $106
	All manufacturing	557	265
24	Lumber and wood products	11	5
26	Paper and allied products	21	9
282	Plastics, materials synthetics	7	4
2851	Paints and allied products	3	1
30	Rubber and plastics products, n.e.c.	13	7
31	Leather and leather products	5	3
32	Stone. clay, and glass products	14	8
33	Primary metal industries	47	20
34	Fabricated metal products	35	18
25	Furniture and fixtures	8	4
35	Machinery, except electrical	48	28
36	Electrical equipment	43	24
37	Transportation equipment	69	28
38	Instruments and related products	11	6
39	Miscellaneous manufacturing industries	9	5
19	Ordnance and accessories	11	6
20	Food	84	27
	Textiles, etc.	Remainder	

S.I.C,	Industry	Value of Shipments 10^6	Value Added $106
2821	Plastics materials and resins	3-5	1-6
2822	Synthetic rubber	0-9	0-4
3011	Tyres and inner tubes	3-7	1-8
3069	Fabricated rubber products. n.e.c.	3-1	1-7
3079	Miscellaneous plastics products	5-4	3-0
331	Blast furnace and basic steel products	23-1	10-2
332	Iron and steel foundries	4-3	2-6
333	Primary nonferrous metals	3-7	1-4
3341	Secondary nonferrous metals	1-6	0-3
335	Nonferrous rolling and drawing	9-9	3-3
336	Nonferrous foundries	1-9	1-1
3541	Machine tools. metal-cutting types	2-1	1-4
3542	Machine tools. metal-forming types	0-7	0-4
371	Motor vehicles and equipment	40-3	13-7
372	Aircraft and parts	21-1	11’3
373	Ship and boat building and repairing	3-1	1-7

Source: U.S. Department of Commerce, Census of Manufactures.

TABLE 23.—*Substitution of Plastic for Steel: Resource Isoquants*



Effect on capital stock, on labour and on oil and gas. Each curve passes through combination of π_2 (cost of plastic required to replace $1 of steel) and 100 k (percent of steel substituted for) with equal ΔR (changed resource requirement).

Source: Becker (1976a), (1976c).

Finally, it may be of interest to note that any substitution of materials for one another would have effects not only on total resource requirements, but also on regional requirements, because the production of various materials tends to be concentrated in specific regions. This is shown in table 24, drawn by Becker (1976), the top map of which shows how 915,000 men employed in the U.S. steel industry are distributed throughout the country. In addition to the manpower directly employed in the steel industry, an additional 808,100 men were required to produce the ore, coal, coke, electricity, and all the other inputs required for steelmaking. These were distributed as in the second map, Total employment in steel manufacture and in its supply industries is shown in the third map on table 24. From these maps it will be evident that any change in the pattern of steel usage will have an effect on regional employment, and that the total effect of this will be greatest in the East North Central and Middle Atlantic regions,

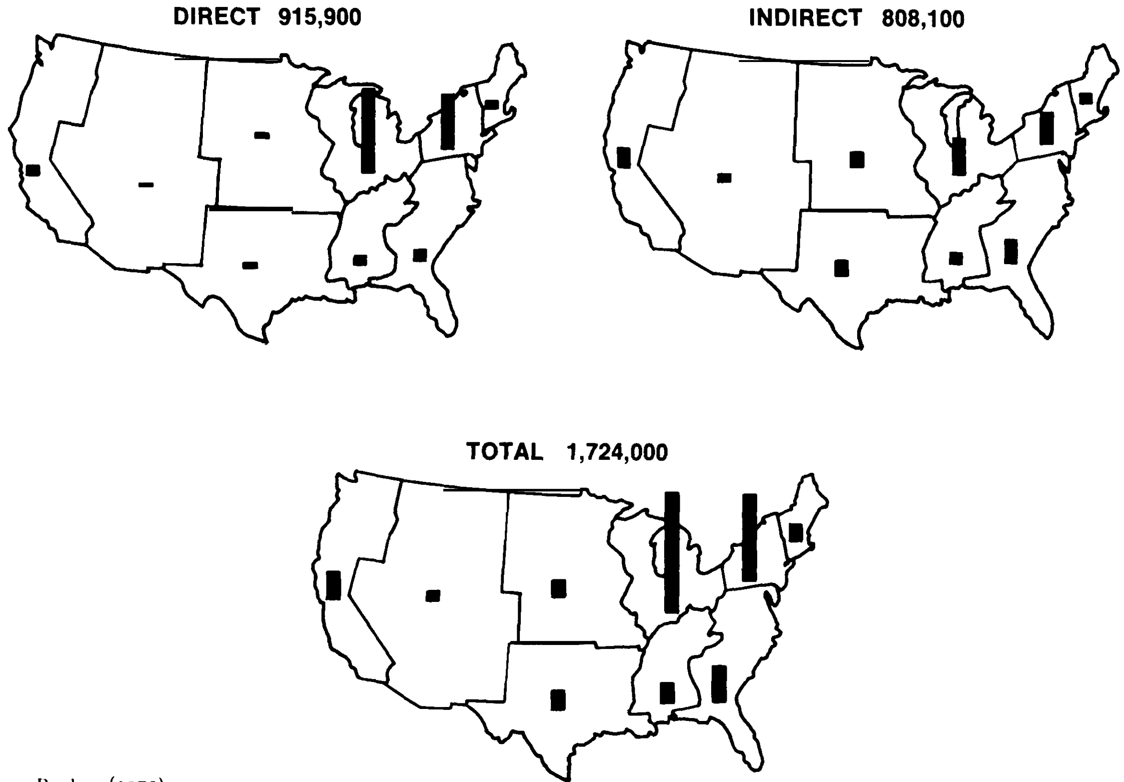
To assess the effect of changes of this kind on regional employment, one must allow for the fact that these regions are also characterized by high total population by calculating the regional intensity of employment for various materials industries (the proportion of the work force in a region employed in a materials industry), Maps indicating regional intensities have also been plotted by Becker, and these are reproduced in table 25, in which the black bars represent direct employment intensity; the hollow bars, indirect employment intensity. From these maps it will be evident that any changes in the use of one material relative to another or to industrial output generally would also have implications for regional employment,

Concluding Remarks

The field of materials is inseparable from manufacturing processes. The demand for materials is a derived demand depending on the demand for goods and services and on the efficiency of the processes involved in converting materials into final products, For a given volume of goods, the demand will depend on product and material specification as well as on design and production skills. The nature and quality of the materials specified in design will determine the range of resources required for manufacture. Conversely, design can only take place within the framework of what is available, feasible, and socially acceptable.

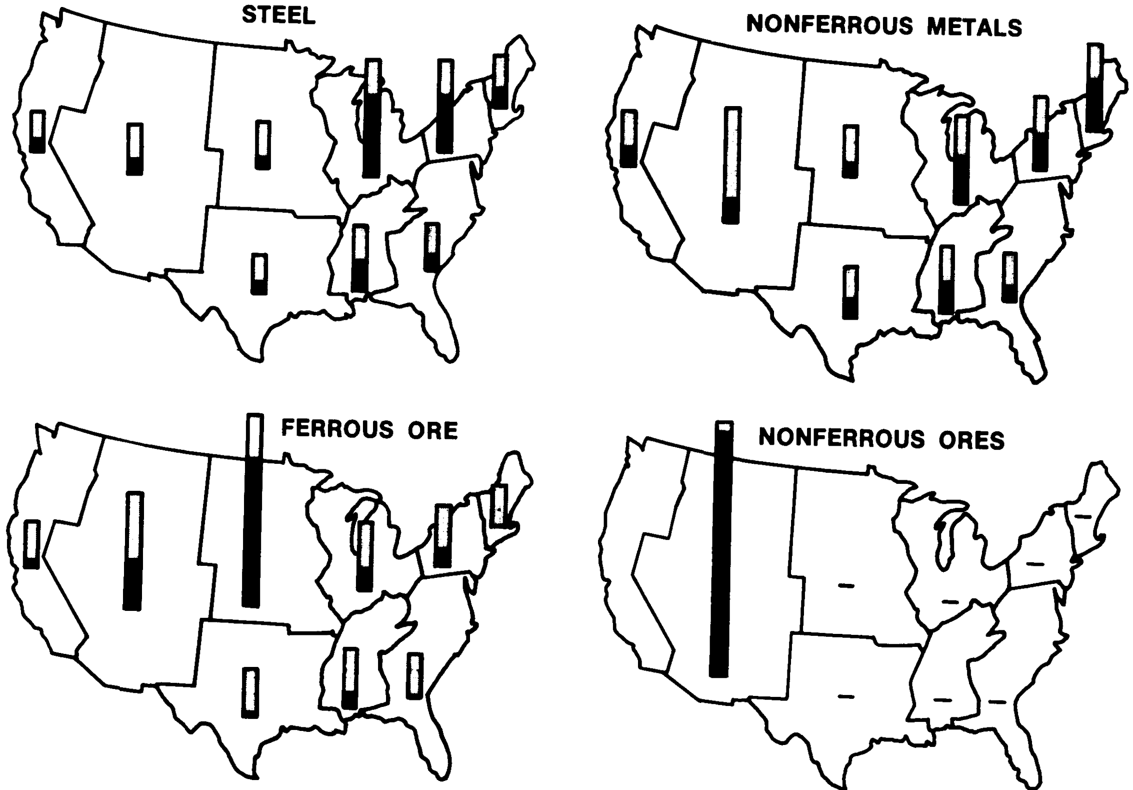
In this paper an attempt has been made to remind the conference of the vast capital stock involved in technology as it is. From this it follows that there is little short-term flexibility in the manufacturing system, other than a reduction in economic

TABLE 24.—Regional Employment in U.S. Steel Manufacturing; 1967



Source: Becker (1976)

TABLE 25.—*Regional Intensity of Employment In Materials Manufacturing—Steel, Nonferrous Metals, Ferrous Ore and Nonferrous Ores*



Source: Becker (1976 a), (1976 c).

activity, and that time is needed to effect change on a significant scale, particularly as any fundamental changes in materials technology will also need to be supported by appropriate changes in the infrastructure.

One of the themes developed in this paper is the interdependence of materials with other physical resources and with wider aspects of the industrial, economic, and social environment. Recognition of this interdependence has widespread consequences, At the practical level, any decisions on specifications, design, or investment at any point in the system will lead to full optimisation only if account is taken of interactions with other parts of the system. Recognition of this obvious fact may give rise to innovative action in industry and to new directions for research and development, At a more general level, the recognition raises the question whether' the development and optimisation of technology, which is largely determined at company level, is likely to take beneficial long-term directions unless a wider framework of knowledge and ideas regarding the system as a whole is also generated. This matter has hitherto tended to be the province of economists. Perhaps it is time for it to be explored in engineering terms.

Justifiable concern is often expressed, both in the United Kingdom and in the United States, that attention to materials in Government and industry tends to lack coherence. It is hoped that the description of interdependence contained in the present paper will strengthen the case for a coherent approach. At the same time, in a vast field like materials, a high proportion of the initiative and of the work will always need to take place at the level of the particular. It is suggested that obtaining the necessary coherence at the general level may require not only administrative measures, but the development of a coherent intellectual framework as well.

References

1. This paper is based on previous publications by the author and by P. Becker, These are listed below, and reference may be made to them for details of sources and methods.

PICK, H. J.

1968a "Materials and Processes in Component Production– The Interrelation Between the Requirements of Fabrication Service and Cost. "
In Avoidance and Failures in Fabrication and Service, Iliffe, London.

1968b “The Role of Materials in Engineering and in the Economy,” Metals and Materials, 1968, Vol. 2, pp. 263-279, 293.

1970a “The Challenge of the New Materials Technology,” Metals and Materials, Vol. 4, p. 145-151.

1970b “Some Economic Consequences of Technical Decisions,” Materials Science and Engineering, Vol. 10, pp. 301-323.

PICK, H, J.

1973 “The Relation Between Materials and Manufacturing Systems,” Development of Production Systems and the Need for Further Research, 2nd International Conference on Production Research, Copenhagen, ed. G. H. Gudnason & E. N. Corlett; Taylor & Francis, London.

PICK, H. J., AND BECKER, P.

1975 “Direct and Indirect Uses of Energy and Materials in Engineering and Construction, ” Applied Energy, Vol. **1,** No. 1.

1975 “Resource Implications of Materials Waste in Engineering Manufacturing,” Resources Policy, Vol. 1, No. 3.

BECKER, P.

1976a Materials, Engineering and the Economy: An Input-Output Study of TechnicaJ Decisions in the U. K., Ph.D. Thesis, The University of Aston in Birmingham, Birmingham, England.

1976b “The Economic Role of Engineering Materials in the U. K.” Resources Policy (forthcoming).

1976c James Watt Memorial Lecture, University of Aston.

2, Other References

COHEN, M. & OWEN, W. S.

1955 “A Forward Look at Steel Development,” Proc. Rosenhain Centenary Conference, p. 223.

DRUCKER P. F,

1969 “The Age of Discontinuity,” Heineman, 1969.

HIRST, E.

1972 “How Much Overall Energy Does the Automobile Require?” Automotive Engineering, July 1972.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF ECONOMIC ANALYSIS, Survey of Current Business, Input-output table given in Vol. 54, No. 2, 1974.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF ECONOMIC ANALYSIS, Input-Output Structure of the U.S. Economy: 1967, U. S. G. P. O., 1974.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, 1967 Census of Manufacturers, U. S. G. P. O., 1974.

U.S. DEPARTMENT OF LABOR, BUREAU OF LABOR STATISTICS, Employment and Earnings: States and Areas 1939-1972, Bulletin 1370-10.

U.S. DEPARTMENT OF COMMERCE, BUREAU OF THE CENSUS, Census of Mineral Industries, 1963, Vol. 11, Area Statistics, P. **C3.216/5.**