Chapter 5

Past and Future Domestic Use of Steel

Contents

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Summary

Steel is the most important engineering material in American society. There is literally no aspect of private or public life that is not in some way dependent on steel. Nevertheless, steel is taken largely for granted. Steel is not generally considered to be technology intensive, changing in character, or especially critical for economic or military security, Yet, steel is all these things. It plays such a pervasive and vital role in all primary manufacturing and construction that it will remain a strategic material for the Nation. With regard to military security, the strategic role of steel is increasing. In 1967 President Lyndon B. Johnson commented that "steel . . . is basic to our economy and essential to our national security;[1] that statement is still valid today.

Domestic consumption of steel continues to increase, although at a slower rate than during the early phases of U.S. industrialization when there were large increases in per capita income. Although the use of aluminum and plastics has greatly increased in the past several decades, the per capita consumption of these materials is only about 60 to 140 lb, respectively, compared to approximately 1,000 lb per capita consumption of steel, Steel competitiveness may improve as a result of future energy and raw material cost changes, which will have stronger adverse impacts on aluminum and plastics than on steel.

Although it may appear, according to some measures, that the use and role of steel are declining, it must be recognized that for many applications there are no cost-competitive performance substitutes for steel. One frequently mentioned exception is the use of steel in automobiles. Driven by the need to reduce vehicle weight, automobile manufacturers are reducing the amount of steel used in each automobile. Steady or decreased demand for steel in this market is likely. To the extent that foreign automobile companies produce more of their automobiles in the United States and use domestic steel, the decline in steel use per car may be partially offset by an increase in the number of cars produced. Some observers believe there will be a surge in steel demand for capital reconstruction of physical structures such as bridges, buildings, railroads, and primary manufacturing facilities, as those built during the past 50 years wear out.

Inadequate domestic steel capacity in the future is a distinct possibility. The modernization and expansion program for the 1979-88 period proposed by the industry, through the American Iron and Steel Institute (AISI), assumes a very low rate of increasing domestic demand for steel (1.5 percent per year). Should that projection be too low, the capacity planned for would be inadequate, and, according to other, higher demand growth forecasts, imports could rise to 20 percent of domestic consumption, or 27 million tonne/yr. This would be about 50 percent greater than any previous import tonnage. Without the modernization and expansion program the industry deems necessary, low domestic capacity might require the import of more than 44 percent of U.S. steel by the end of the 1980's. The current overcapacity in the world steel market is likely to disappear soon and that degree of import dependence could expose the United States to economic and national security problems not unlike those the Nation has encountered with petroleum.

[1]Presidential Proclamation 3778, Apr. 8, 1967.

The Importance of Steel

Steel has generally been considered a basic industry. There is good reason for this. Virtually every sector of the economy and all aspects of human activity depend on steel in some direct or indirect way. When steel is not used directly, it invariably has been used in the equipment that made the nonsteel materials being used and that transported them from original source to final application. Steel is the backbone of any industrialized society. From rails, to machines, to girders in buildings, to beverage containers, to eating utensils, steel is ubiquitous. Yet, steel is no longer thought of as a critical material in society. Overshadowed by high-technology products and industries, steelmaking is generally taken for granted and considered to be a simple and unchanging technology.

In fact, steelmaking has undergone great changes and continues to do so. Steel products have also changed dramatically as new alloys and coatings for steel have greatly enlarged its range of properties and applications. Other engineering materials, notably aluminum and plastics, have given stiff competition to steel, but by and large steel has held its own and remains the most important engineering material in society.

Steel is particularly important from a national security viewpoint. It is irreplaceable in military hardware like tanks and guns, but military needs for steel go far beyond the actual steel in weapons. Like the economy itself, the military establishment depends totally on steel for the manufacture and transportation of all its supplies. The Federal Emergency Management Agency estimated in 1979 that in a 3-year non-nuclear war, 26 percent of steel industry output would be required for direct military purposes.[2] This assumes that such an effort would be preceded by mobilization of both military and industrial resources. Another 56 percent of domestic steel would be needed for essential purposes in support of the military effort, leaving 18 percent for civilian purposes, The corresponding estimates in 1969 were 6 percent, 66 percent, and 28 percent respectively, an indication that the strategic role of steel has increased during the past decade.

‘Communication from P. Kruger of the Federal Emergency Management Agency, Jan. 15, 1980.

Steel Compared to Aluminum, Plastics, Cement, and Wood

For one material to be used in place of another, the substitute must perform adequately in a specific application. If it does, then economic considerations—both cost and price factors—play an important role in the competition between the materials. Finally, trends in technological innovation will influence the materials selection. *

Comparative Properties of Materials

To some extent, a particular steel may have unique properties that determine its selection, but more often it competes on the basis of cost with other materials capable of satisfying the requirements of the application. The two properties chosen for comparison here are strength and stiffness, but many other properties may be important in a given use. Although those properties have the same units (MPa), they represent quite different characteristics of a material. Strength represents material’s resistance to breakage (breaking or tensile strength) or to permanent deformation (yield strength). Stiffness on the other hand represents a material’s resistance to temporary deformation while a load or stress is being imposed on it—such deforma-

● More detail on steel innovation is provided in other chapters, particularly ch. 6.

tion as the deflection of a stairtread when stepped upon or the coiling of a spring. Using absolute values, steel can have a wide range of strengths, but all steels have approximately the same stiffness. However, the stiffness of one class of materials is generally quite different than another class; for example, steels are about three times as stiff as are aluminum alloys—even though, contrary to the general impression, some aluminum alloys are stronger than some steels.

The stiffness of material should be appropriate to its design application. For example, if an automobile were made of some flexible material, its doors might fit very snugly when empty but very poorly when loaded with passengers. Most plastics would be unsuitable for such an application because of their low stiffness. However, when very low stiffness plastics are combined with a very stiff material, such as graphite or glass fibers, then the reinforced plastic may have a composite stiffness as good as or better than steel.

Strength is important in materials applications, either in terms of yield strength (for ductile material) or breaking strength (for a brittle material). A ductile material has a yield strength below its breaking strength. A brittle material's yield strength is the same as its breaking strength, Once the strength is known, a material can be chosen for an application so that only some fraction of either the yield or breaking strength is realized in service. When the service condition involves an applied stress level greater than the design stress (an overload), then the material may fail, causing loss of function. Failure may be permanent (plastic) deformation, such as in a bent wheel, or actual breakage, such as in broken glass. The ability to deform prior to fracture is normally an asset; for example, some autos are designed to deform rather than break under low-speed impacts so that little or no damage occurs to the critical parts of the auto or to the passenger. The metal deformation absorbs some of the energy of the impacts.

As a general rule, materials with much stiffness, such as graphite fibers, are also brittle. An auto made of graphite would break into pieces upon overload. When the stiff graphite fibers are mixed with the more flexible plastics, the composite material is more likely to stay in one piece on overloading. The advantage that most metals have is that they combine reasonable stiffness with reasonable ductility. An auto made of steel will permanently bend when overloaded but usually will not break into pieces.

The properties of yield strength and stiffness can be given on an absolute and on a specific basis. The specific strength or specific stiffness shows the "strength-to-weight" or "stiffness-to-weight" ratio of each material. These ratios provide a means of comparing the size, volume, or mass of materials with different properties required to perform in an equivalent manner. For example, a large piece of a weak material may respond in the same way to the same load as a smaller piece of a stronger material.

Tables **48** and **49** present comparisons of the stiffness and strength, respectively, of steel, aluminum, cement, plastics, lumber, and composite materials. Table 50 provides data on temperature and chemical environment limitations to the use of these materials. Breakeven price indexes were also calculated for these materials. The indexes indicate the amount paid for alternative materials to steel, on a weight basis, for equivalent stiffness or strength. At prices below the index prices (determined by multiplying the index by the cost of steel), the alternative materials cost less than steel for equivalent stiffness or strength. Note that this index measures only one cost; comparisons among materials require consideration of a multitude of factors, including the practical means of obtaining the desired form and shape of the material.

Table 51 presents actual breakeven stiffness and breakeven strength prices for the various materials competitive with steel in 1976, and compares these prices with actual prices. From this limited type of consideration, it is found that certain plastics and cement could be more competitive than steel.

Table 48.—Comparison of Material Properties (I): Stiffness

Material	Elastic modulus (MPa x 10[3])	Specific gravity	Specific modulus[a]	Equivalent stiffness (steel = 1.000) Thickness ratio[b]	Weight ratio[c]	Breakeven price index[d]
Steel	207.0	7.870	26.30	1.000	1.000	1.000
Aluminum	69.0	2.699	25.60	1.442	0.495	2.020
Plastics						
Thermoplasts						
6/6 nylon	2.83	1.100	2.57	4.182	0.585	1.709
HDPE	0.83	0.950	0.87	6.295	0.760	1.316
ABS	2.10	1.060	1.98	4.619	0.622	1.608
Thermoses						
Epoxies	6.90	1.100	6.27	3.107	0.434	2.304
Wood (clearwood)						
Softwood						
Douglas fir (green)	8.14	0.400	20.40	2.941	0.149	6.711
Douglas fir (12% H_2O)	9.66	0.430	22.47	2.778	0.152	6.579
Hardwood						
White oak (green)	10.42	0.640	16.28	2.708	0.220	4.545
White oak (12°\0 H, O)	15.73	0.720	21.85	2.361	0.216	4.630
Composites						
Portland Cement concrete (reinforced)	34.50	2.410	14.30	1.817	0.556	1.799
Fiber-reinforced plastics						
S-glass/Epoxy (60% fiber, filament wound)	31.70	1.990	15.93	1.869	0.473	2.114
Graphite fiber/Epoxy Thornel 300 (resin-impregnated strand)	227.50	1.740	130.40	0.969	0.214	4.673

[a]Specific modulus = modulus ÷ specific gravity

[b]Thickness ratio = (steel modulus + alternative material's modulus) one.third power, derived from deflection of simple cantilever beams
For attainment of a desired stiffness with an alternative material, multiply thickness of steel by the thickness ratio, e,g., aluminum must be 1 442 times thicker than steel to provide stiffness equivalent to steel

[c]Weight ratio = thickness ratio X (specific gravity of alternate material + specific gravity of steel)
Determines the weight of an alternative material which will give stiffness equivalent to steel, e g , for aluminum need O 495 of the weight of steel

[d]Breakeven price index = reciprocal of the weight ratio
The multiplier of the steel price which is used to calculate the upper limit of how much may be paid for an alternative material to achieve same stiffness as steel, e.g., if steel costs $0.20/lb then aluminum must sell for $0 404/lb, or less, to compete with steel strictly on the basis of stiffness, Average 1976 prices used.

NOTE: S.I. metric units of Mega Pascals (M Pa) may be converted to customary English units (pounds per square inch, lb/in^2) by the following factor: 1 MPa = 145 lb/in', e.g., the elastic modulus of steel at 207 x 10^3 MPa con. verts to 207,000 MPa x 145 lb/in^2/MPa = 30 x 10^6 lb/in^2.

SOURCE: Office of Technology Assessment

Table 52 presents actual breakeven prices for engineering properties by material in the year 2000, assuming real rates of inflation in steel prices of 1, 3, and – 1 percent per year from 1976 to 2000. The inflation rates (in real terms) that will lead to parity pricing (for engineering properties of steel) of other materials—given the steel inflation rates assumed in table 52—are presented in table 53. Only some plastics and cement could undergo larger cost increases than steel and still remain competitive for the properties considered.

Comparative Economic Trends

Because the competitiveness of steel is normally related to price, as well as to engineering properties, it is useful to review the past pricing of steel and its competitor materials. Figure 16 presents price indexes in real terms for five engineering materials. From 1956 through 1972, steel prices in real terms were relatively constant. Cement and aluminum prices in real terms were, in general, declining, but plastic prices were plummeting. Lumber prices were quite level through the second half of the 1960's, after which their volatility increased. Since 1972, steel has exhibited relatively small price increases,

Capital costs, energy costs, the rate of technological change, and Federal and State regulations are all important elements in the cost of engineering materials, although lumber is to a considerable extent an exception.

Table 49.—Comparison of Material Properties (II): Strength

Material	Tensile strength (M Pa)	Specific gravity	Specific tensile strength[a]	Equivalent strength (HSLA steel = 1.000): Thickness ratio[b]	Weight ratio[c]	Breakeven price index[d]
Steel (wrought)						
Plain carbon (1010)	365.44	7.870	46.43	**1.150**	**1.150**	0.870
HLSA (970X).	483.00	7.870	61.37	**1.000**	**1.000**	1.000
Stainless (301)	1,275.58	7.870	162.08	**0.615**	**0.615**	1.626
Aluminum (wrought)						
Commercial purity (1060-H18)	131.0	**2.699**	48.54	1.920	**0.659**	1.519
Alloy						
Single-phase (5052-H38)	289.59	**2.699**	**107.30**	1.291	**0.443**	2.258
Multiphase (7178-T6).	606.76	**2.699**	**224.81**	0.892	**0.306**	3.268
Plastics						
Thermoplastics						
6/6 nylon. ., ...	81.36	1.100	73.96	2.437	**0.341**	2.936
HDPE	27.58	**0.950**	29.03	4.185	**0.505**	1.980
ABS	48.27	**1.060**	45.53	3.163	**0.426**	2.347
Thermoses						
Epoxies.	68.95	1.100	62.68	2.647	**0.370**	2.703
Wood (clearwood)						
Softwood						
Douglas fir (green).	24.82	0.400	**62.05**	4.411	0.224	4.460
Douglas fir (12% H^2O).	43.44	0.430	**101.02**	3.334	0.182	5.489
Hardwood						
White oak (green).	31.72	0,640	49.56	**3.902**	**0.317**	3.151
White oak (12% H^2O).	45.51	0.720	63.21	**3.258**	**0.298**	3.355
Composites						
Portland Cement concrete (reinforced).	34.50	**2.410**	14.32	3.742	1.146	0.873
Fiber-reinforced plastics						
S-glass/Epoxy (60% fiber, filament wound).	877.00	1.990	**440.71**	0.742	**0.188**	5.329
Graphite fiber/Epoxy Thornel 300	2,654.00	1.740	**1,521.20**	0.427	**0.094**	10.602

[a]Specific tensile strength = tensile strength - specific gravity.

[b]Thickness ratio = (HSLA strength – strength of alternative material), one-half power, as derived from formula for maximum surface stress in a cantilever beam

For attainment of a desired strength (load.bearing capacity) with a material other than HSLA steel by the thickness ratio, e g , a 1010 plain carbon steel must be 1.15 times thicker than HSLA while a 301 stainless steel need be only 0.615 times as thick as the HSLA.

[c]Weight ratio = thickness ratio X (specific gravity of alternate material + specific gravity of HSLA)

Determines the weight of a given material which will provide the load. bearing capability of a piece of HSLA steel, e.g., for 7178-76 aluminum only *0.306* kg of that material would be needed to replace 10 kg of HSLA

[d]Breakeven price index = reciprocal of the weight ratio

The multiplier of the HSLA steel price which determines the upper limit that should be paid for an alternate material in order to gain the same load bearing capacity as the HSLA steel, e.g., if HSLA steel costs $0 50/lb then 7178-76 aluminum must cost less than $1.634/lb to be competitive Average 1976 prices used

NOTE S I metric units of Mega Pascals (M Pa) may be converted to customary English units (pounds per square inch, lb/in^2) by the following factor: 1 M Pa = 145 lb/in^2, e g the elastic modulus of steel at 207 x 10^3 MPa converts to 207,000 MPa x 145 lb/in^2/MPa = 30 x 10^6 lb/in^2.

SOURCE Off Ice of Technology Assessment

Steel

The steel industry is the Nation's largest industrial consumer of energy. However, rising oil prices will affect steel less than they will most other energy-intensive industries. Most of the energy used in steelmaking is in the form of coal in coking operations, and domestic coal is abundant. World prices for coking, or metallurgical-grade, coal are likely to remain low relative to other energy sources for several reasons. First, consumption of coke per tonne of iron produced has been dropping steadily, and promises to continue to do so. Second, low-grade coal is coming into use for coking. The Japanese in particular have been using lower quality coals for coking, the United States is beginning to explore actively the use of formcoke technology that will permit the use of abundant low-grade coals, and the Soviet Union's development of dry quenching may also provide a technology for using lower quality coals. Coal-based direct reduction (DR) may also become commercial-

Table 50.–Comparison of Material Properties (Ill): Environmental Behavior

Material	Range of service temperature (°C)[a]	Resistance to chemical environment
Steel (wrought)		
Plain carbon (1010)	430 / – 20	F / P
HSLA (970X)	500[c] / -50	G / P
Stainless (301)	540/ None	VG/VG
Aluminum (wrought)		
Commercial purity (1060)	105/ None	VG/VG
Alloy		
Single-phase (5052)	105/ None	VG/VG
Multiphase(7178)	200[c]/ None	G / G
Plastics		
Thermoplastics		
6/6 nylon	150 / 20	G / E
HDPE	60125	G / E
ADS	100[c]/25[c]	G / E
Thermoses		
Epoxies	180/ N.A.	VG/I E
Wood		
Softwood		
Douglas fir	200[d]/N.A.	G[e]
Hardwood		
White oak	200[d]/N.A.	VG[e]
Composites		
Portland Cement concrete (reinforced)	1,170/ None	F / VG[f]
Fiber-reinforced plastics		
S-glass/epoxy	100/ N.A.	F[g]
Graphite fiber/epoxy Thornel 300	100[c]/N.A.	F[g]

[a]Service temperature limits due to (elevated temperature creep/low temperature brittle failure)
[b]Chemical environment resistance for (acidic/baste) environments; ratlng scale P = Poor; F = Fair; G = Good; VG = Very good; E = Excellent,
[c]EstImated
[d]Upper seervice temperature limit for wood defined as ignition temperature
[e]Wood measured in terms of decay resistance
[f]Poor in contact with alkali cations, reinforcing bar attacked by chlorides
[g]Susceptible to moisture or ozone or ironlzing radiation damage at fiber.resin interface; otherwise the acid/base resistance is as stated for epoxies

SOURCE: Office of Technology Assessment.

ized (see ch. 6). Finally, the recent opening of Australian mines has made major additions to world supply of coking coal. Problems with inadequate domestic coke capacity, discussed in chapter 7, appear to be only of a short-term nature.

Electric power costs are also important to steel industry costs. Electric power is increasingly being used to melt scrap and make steel in electric furnaces, to produce oxygen, and to operate high-horsepower rolling mills and other equipment. Thus, the apparent trend toward closing the gap between industrial and residential power rates in the United States has important implications for U.S. steelmaking costs.

Capital costs for steel are very high for integrated greenfield (new plant) capacity, but increased electric furnace capacity costs a great deal less than new integrated plants, as do expansions at existing plants. One way of obtaining steel capacity is to improve the mill yield on raw steel. Continuous casting (discussed in ch. 9) is clearly the most important route to such improvements. Computer control and new high-temperature sensor technology will also improve yields and provide savings both in raw steel and in labor costs as well. Future changes in steelmaking are fully analyzed in chapter 6. In the long term, these are promising developments that could offer substantial production and capital cost savings.

Table 51 .—Equivalent Prices for Engineering Properties by Material, 1976 (in cents per pound)

Material	Actual 1976 price	Breakeven stiffness price relative to carbon steel: Hot-rolled sheet	Breakeven stiffness price relative to carbon steel: Cold-rolled sheet	Breakeven strength price relative to carbon steel: Hot-rolled sheet	Breakeven strength price relative to carbon steel: Cold-rolled sheet
Carbon steel					
Hot-rolled sheet	**13.2¢**	**N.R.**	**N.R.**	**N.R.**	**N.R.**
Cold-rolled sheet	**15.2**	N.R.	N.R.	N.R.	N.R.
Aluminum mill product	65.0	26.7¢	30.7¢	23.O¢	26.5¢
Plastics					
HDPE	28.0	17,4	20.0	30.0	34.6
ABS	46.0	21.2	24.4	35.6	41.0
Portland Cement	1.8	23.7	27.3	13.2	15.3

N R. = not relevant.

SOURCE: Office of Technology Assessment

Table 52.—Equivalent Prices for Engineering Properties by Material, Year 2000 (in 1976 cents per pound)

				Forecast year 2000 prices			
				Breakeven stiffness price relative to carbon steel		Breakeven strength price relative to carbon steel	
	Assumed steel product price inflation (percent per year)	Actual 1976 price	Forecast year 2000 price	Hot-rolled sheet	Cold-rolled sheet	Hot-rolled sheet	Cold-rolled sheet
Carbon steel							
Hot-rolled sheet.	10/0	13.2¢	16.8¢	N.R.	N.R.	N.R.	N.R.
Cold-rolled sheet. ., . . .	1	15.2	19.3	N.R.	N.R.	N.R.	N.R.
Aluminum mill product. .,	1	65.0	N.R.	33.9¢	39.0¢	29.3¢	33.7¢
Plastics							
HDPE	1	28.0	N.R.	22.1	25.4	38.2	43.9
ABS.	1	46.0	N.R.	27.0	31.0	38.2	52.1
Portland Cement	1	1.8	N.R.	21.3	34.7	16.9	19.4
Carbon steel							
Hot-rolled sheet.	3	13.2	26.8	N.R.	N.R.	N.R.	N.R.
Cold-rolled sheet.	3	15.2	30.9	N.R.	N.R.	N.R.	N.R.
Aluminum mill product, .	3	65.0	N.R.	54.1	62.4	46.8	54.0
Plastics							
HDPE	3	28.0	N.R.	**35.3**	**40.7**	61.0	70.3
ABS.	3	46.0	N.R.	**43.1**	**49.7**	72.3	83.4
Portland Cement	3	1.8	N.R.	**48.2**	**55.6**	26.9	31.0
Carbon steel							
Hot-rolled sheet.	–1	13.2	10.4	N.R.	N.R.	N.R.	N.R.
Cold-rolled sheet.	– 1	15.2	11.9	N.R.	N.R.	N.R.	N.R.
Aluminum mill product, .	- 1	65.0	N.R.	21.0	24.0	18.2	20.8
Plastics							
HDPE ., ...	–1	28.0	N.R.	13.7	15.7	23.7	27.1
ABS.	–1	46.0	N.R.	16.7	19.1	28.1	32.1
Portland Cement	–1	1.8	N.R.	18.7	21.4	10.4	11.9

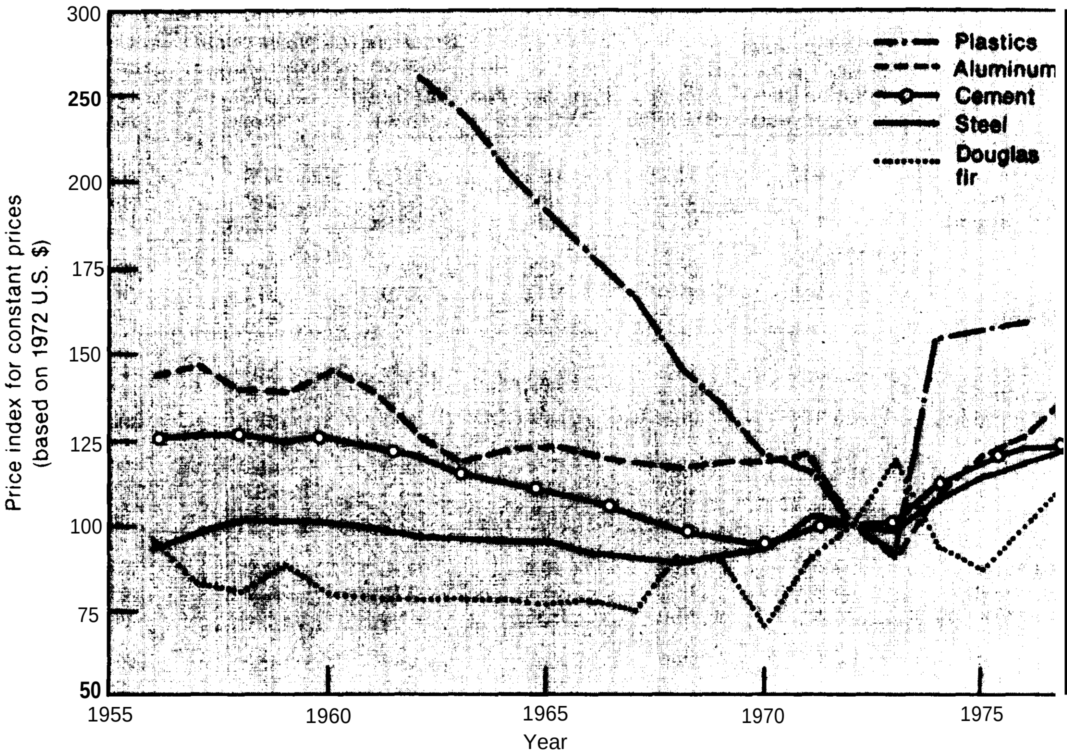
N R = not relevant SOURCE: Office of Technology Assessment.

Table 53.—inflation and Parity Pricing of Engineering Properties by Material, Year 2000
(in percent per year or average annual compound growth rate)

		Inflation rates for other materials that yield parity pricing with steel in 2000			
		Stiffness		Strength	
Material	Assumed steel product price inflation (percent per year)	Hot-rolled sheet	Cold-rolled sheet	Hot-rolled sheet	Cold-rolled sheet
Carbon steel	10/0	N.R.	N.R.	**N.R.**	**N.R.**
Aluminum mill product . . .	1	– 2.7%	– 2.1 %	**–3.3%**	**–2.7%**
Plastics					
HDPE.	1	– 1.0	-0.4	**1.3**	**1.9**
ABS ., ...	1	– 2.2	-1.6	– 0.1	0.5
Portland Cement	1	10.8	13.1	9.8	10.4
Carbon steel	3 ’	N.R.	N.R.	N.R.	N.R.
Aluminum mill product	3	– 0.8	– 0.2	– 1.4	– 0.8
Plastics					
HDPE.	3	1.0	1.6	3.3	3.9
ABS	3	-0.3	0.3	1.9	2.5
Portland Cement	3	14.7	15.4	11.9	12.6
Carbon steel	–1	N.R.	N.R.	N.R.	N.R.
Aluminum mill product	–1	– 4.6	– 4.1	– 5.2	– 4.6
Plastics					
HDPE, ...	–1	– 2.9	– 2.4	-0.7	– 0.1
ABS	–1	– 4.1	3.6	-2.0	– 1.5
Portland Cement	–1	10.2	10.9	7.6	8.2

N R = not relevant SOURCE Office of Technology Assessment

Figure 16.—Real Price Trends in Engineering Materials



SOURCE: Office of Technology Assessment.

Aluminum

Like steel, aluminum suffers from very high investment costs for new capacity relative to historical costs. Unlike steel, no major technological alternatives exist or appear likely in the future for producing primary aluminum. The aluminum industry is and will continue to be almost totally dependent on imports of ore (bauxite) or down-line products. The cheapest form of additional aluminum capacity will be increased recycling and growth in the secondary smelting industry.

The most likely source of scrap is the two-piece beverage can. In 1978, of the 1.1 million tonnes of aluminum sheet that went into cans, some 270,000 tonnes, or 25 percent, were recycled. The price paid for scrap was one-third of that for ingot. The ceiling on the recycle rate is probably 75 to 80 percent, judging from the experience of the Adolf Coors Co., which requires distributors to recycle cans and reports recycle rates of 75 percent. A recycle rate of 75 percent in two-piece beverage cans in 1978 would have supplied on the order of 10 percent of total apparent aluminum consumption.

Electric power costs are at least 20 percent of the manufacturing costs of aluminum ingot, and they increased by a factor of three from 1950 to 1977, from 16.6 to 51.3 cent/lb. Although smelters now use considerably less electric power per pound of aluminum than formerly (see the section on comparative innovation trends), the rate of change is slow. A new Alcoa process promises lower power consumption, but commercialization is at least a decade away, judging from public pronouncements. About one-third of the primary smelting capacity in the United States is located in the Pacific Northwest and uses electric power from the Bonneville Power Administration's hydroelectric plants. Supply contracts between Bonneville and these smelters will begin to expire in the early 1980's. The industry clearly will not be able to renew the contracts at rates based on hydroelectric generating costs. * At best, the smelters in the area will pay a weighted average cost of electric power from hydroelectric, coal, and/or nuclear rates. However, the rates are structured in such a way that one-third of the aluminum industry's smelting capacity will suffer a severalfold increase in the cost per kilowatthour.

A conservative estimate is that these increases alone will double the average cost of electric power for the entire U.S. aluminum industry. As a result, aluminum prices are expected to rise very sharply in the future. Indeed, in the past year, prices have already begun to increase sharply.

Plastics

Capital costs are important in plastics production, but with feedstock prices set by the alternative-use values for liquid and gaseous hydrocarbon fuels, plastics prices are very sensitive to imported oil prices. Technological change in resin and monomer production is more rapid for plastics than for more traditional materials and provides some cushion for these materials. U.S. natural gas pricing policy will set the prices for the feedstocks of the most important monomer, ethylene. U.S. gasoline demand and Government policies on octane additives will be critically important to the other major class of derivatives, the aromatics. It is reasonable to expect that the prices of the thermoplastics, which have remained relatively stable in the past (for some types of plastics, i.e., high-density polyethylene and polypropylene), will increase significantly in the future.

*The total price per kilowatthour paid for hydroelectric power does not even pay for the fuel required to generate a kilowatthour with coal.

Cement

The cement industry is capital intensive and new capacity is likely to set prices in most regions. Although capital costs are an undeniably strong upward cost pressure on cement prices, several favorable cost influences are also at work on future prices. After World War II, cement producers switched from coal to fuel oil to provide the required process heat. They are now in the process of switching back and will benefit from the ability to use high-sulfur coals, which will be a relatively low-priced and available fuel during the next two decades.

Even though raw materials for cement are ubiquitous, and their cost is equal only to onsite extraction costs, an even cheaper raw material may be available. Pollution control of coal-fired electric power generation produces a cementitious material on which utilities can "make" money by giving it away to avoid disposal costs. It is unlikely to be free, but it will no doubt be inexpensive. Not all grades of cement can be produced from this material, but it is an important cost factor nevertheless.

In spite of these factors, cement prices, which increased less than steel in the last three decades, are expected to rise, principally because of increasing capital costs.

Lumber

The most important factors in lumber prices are U.S. Government forestland management strategy and homebuilding trends. Recent forestland practices have tended to remove more land from active forest management, reducing the supply of lumber and pressuring prices upward. These practices are currently going through a major policy review. As other factors drive new home costs up, pressure increases to free more timber in order to keep building costs down.

Prices have increased in the last two decades by a factor of three for Ponderosa pine and slightly less for Douglas fir and Southern pine. They can be expected to increase more rapidly in the future unless economic conditions significantly dampen housing construction.

Comparative Innovation Trends

Opportunities for technological gains may be found in the way materials are processed, in the quality of their performance, and in the forms in which they are marketed. Advances in material processing can play a major role in reducing production costs; modification or better control of the composition, structure, and properties of materials can make them easier to form, stronger, more resistant to corrosion, and the like; and new methods of fabrication can open up new markets or widen old ones.

Material Processing

Electric power consumption per pound of aluminum ingot and coke consumption per tonne of iron have decreased gradually over the past decades. Average data like these reflect a mix of new state-of-the-art plants and older plants with varying degrees of efficiency. As an industry matures, the rate of capacity replacement slows and with it the rate at which technological improvements, other than those that can be accomplished through retrofit, can be implemented on an industrywide basis. This has been a particularly acute problem for domestic steel.

In the post-World War II period the basic oxygen process effected steel production economies. By using oxygen and reducing the time required per heat (batch), the basic oxygen furnace made continuous casting feasible on the scale required for commercial development, The main advantage of continuous casting is that it improves yield by about 10 percentage points. This improvement in yield reduces unit energy, capital, labor, and pollution control costs. *

Electric arc furnace capacity can be added in much smaller increments than can oxygen furnaces. Their smaller scale and lower capital costs per annual tonne reduce the risk in building a mill. Rolling mills too have become more efficient with the installation of multistand continuous mills. The continued evolution of process-control computers, coupled with better gauge-detection technology, will improve yields significantly.

In aluminum production, electric power consumption rates have improved, and there have been substantial gains in labor productivity in rolling and drawing operations—about 5.5 percent per year during the last two decades. Continuous casting has also found its niche in the aluminum industry, one that is likely to widen. Scale gains have been impressive: for continuous casters, the production rate has grown from 1 tonne/hour in 1960, to 1.7 in 1970, to 4 in new units. These gains followed increases in the diameter of casting rolls and the width of slabs.

The main reason continuous casting has higher yields than the ingot pouring method (for both aluminum and steel) is quite simple. The ends of ingots must be cropped for proper performance in finishing operations; metal is lost on each end of each ingot. In processing a slab, metal is lost only at the beginning and the end of a long, continuous strand of metal. The slab ends are squared off properly when they are severed from the continuous strand. Future process innovations are possible for aluminum, but a broader range of major steelmaking changes may be commercialized during the next decade,

For plastics, technological change has been rapid, as is to be expected for a new industry. From the early 1950's through the early 1970's, the real decline in plastics prices was substantial. Lower prices were the result of several factors:

- product standardization made it much easier for new producers to enter the market, which widened competition;
- accumulated experience lowered the manufacturing costs in a dramatic way, and
- market growth permitted plant-scale economies that brought substantial sav-

*The adoption of these two major technological changes in steelmaking is reviewed in ch. 9, and future changes are discussed fully in ch. 6.

ings in capital costs per annual pound of product.

The final two factors are technological in nature, but market growth and size were essential to both. The experience curve is a well-documented phenomenon repeated in industry after industry. Mathematically, value added in real terms for a particular product or group of products is stated as a function of cumulative experience; the relationship is usually stated in terms of the percent decline in real value added for each doubling of production. Typical for average industries are experience curves of 15 to 20 percent; petrochemicals, in particular the commodity thermoplastics, have achieved declines in real value added of 20 to 30 percent, with some monomers and polymers boasting gains over decade-long periods of 40 to 50 percent.

Scale gains are particularly important in plastics production, Sharing of infrastructure is an important element in these gains. In some industries, rules of thumb have been worked out to estimate the relationship of scale to total capital costs, The capital cost of a plant double the size of another plant will be only about 1.5 times the capital cost of the smaller plant. Each pound of product from the larger plant will therefore have to bear only three-fourths of the capital costs—profit, interest, and depreciation—carried by the product from the smaller plant.

Probably the most significant future process innovation for plastics will be the use of nonpetroleum feedstocks. Although this can remove a dependency problem, it may not lead to actual cost savings for quite some time.

For lumber, the most important technological gains have come in land management practices and the development of faster growing species, In the cement industry, the regional nature of markets limits the scale of plants, and no great scale economies are available, anyway. The development of suspension preheating has lowered costs, and flash calcining is expected in the coming decades, but no major technological changes that profoundly affect costs are likely for cement,

Materials Performance

Technological innovations in production techniques or in alloys and additives that modify material properties can have major market impacts by influencing the choice of material and by changing the amount of material required for a particular application.

In steel, perhaps the most talked about new material is high-strength low-alloy steel, which is not really new. The use of these steels in automobiles to reduce weight offsets part of the decline in steel use per vehicle in the United States. Their effect on total steel demand is important in this one market alone.

The ever-increasing awareness of the massive cost of corrosion has major implications for national materials policy. One steel industry response to this problem was the development of one-sided galvanized steel. Galvanized steel has been available for years, but only with the costly coating on both sides. Galvanizing only one side has lowered the cost of corrosion resistance. (This is discussed more fully in ch. 9.) More new steels are on the horizon. Dual-phase steels, which are strengthened as they are formed, offer users a material easier to form than other steels but just as strong when finished. This product, which is just coming onto the market, might account for significant tonnages of steel in the coming decades. Another major steel product innovation just evolving from much basic research is amorphous or glassy (noncrystalline) steels. They may offer a host of new properties, but major commercial use is probably several decades off.

In aluminum, one of the most interesting lines of development is the search for an alloy usable for both body and end stock. The effort would have the major benefit of enabling aluminum cans to be recycled into high-value aluminum can sheet. This would not only lower the cost of can sheet, it could also raise the price for used aluminum cans, thereby increasing the recycle rate. This could have a very positive effect on U.S. aluminum supply.

In the early years of its commercial use, a major problem in using polyvinyl chloride

(PVC) for residential siding was the heat expansion of extruded PVC. Because of this problem, only light colors of siding could be produced. Now, recently introduced additives permit the use of a broad range of colors, which greatly enhances the marketability of PVC siding.

A particularly attractive market to high-density polyethylene producers is the 55-gal drum market, now held primarily by steel. One method of producing plastic drums is rotational casting. This process has very low tooling costs and is appropriate for short production runs of specially designed containers. To be able to take advantage of this competitive edge, though, a more expensive grade of cross-linked polymer is required. Plastics processors believe that in time they may learn enough about rotational casting to use the regular grade of polymer, which is considerably less expensive than that now used.

An enormous number of examples of plastics innovation could be cited. Two particularly important ones for high-strength applications are fiber reinforcements and fabrication techniques, like reaction injection molding with faster curing times. These developments prove that gains in technology will be the result of progress both in material properties and in fabricating practices.

Fabrication of End-Use Products

Innovations in this area affect materials demand through materials substitution and through changes in material consumption per product. Metal cans are an example of how new forms affected the choice of materials. Before the advent of the two-piece aluminum can for beverage packaging, the three-piece, tin-plated steel can held that segment of the market. When the aluminum can hit the market, the use of metal cans for beverage packaging grew, and aluminum took most of that growth and some of the existing market away from steel. But steel producers began to experiment. They produced a steel two-piece can, but they could not match the operating efficiencies achieved in aluminum can production. The difference is now minimal, and steel is making a comeback in the beverage can market. The steel two-piece can is first replacing the steel three-piece can, then aluminum. Most can plants now include several lines for aluminum cans and several lines for steel. This dual tooling approach is being adopted in other industries as well; some auto plants have tools designed to work with either steel or aluminum.

The auto industry offers the most conspicuous example of how fabrication affects materials demand, but there are many others. For example, until recently the standard 55-gal drum sported sides of 20-gauge steel and a top of 18-gauge steel. By making both the top and bottom out of X)-gauge steel, producers saved 4 lb of steel per drum (thickness decreases as gauge rating increases), Although impact of that change on total steel demand is relatively minor, the cumulative effect of all such changes is quite substantial, and they play an important, if unquantified, role in the decline in per capita consumption of steel in developed economies.

Impacts of Changes in Energy Costs on Steel and Other Engineering Materials

OTA has estimated the effects of some projected fuel price changes on the costs of producing steel in: 1) U.S. integrated plants, 2) U.S. nonintegrated plants, and 3) plants in Japan, Europe, and Brazil. Transportation energy costs have been estimated and added in for imported steel. In addition, the energy costs involved in the domestic production of aluminum, engineering plastics, and reinforced concrete are compared with the energy costs of domestically produced steel. In all cases, technology was assumed not to change and all electrical energy is user plantsite energy.

Four Energy Price Scenarios

Many possible combinations of high and low price-growth rates for five fuels are listed in table 54. From these combinations, four scenarios were selected for comparison of future energy costs; these are shown in table 55.

These scenarios appear to be logical choices to show relative changes in energy costs in 2000. Scenario A reflects a scarcity of natural gas, which results in a substantially higher price-growth rate for it than for other fuels. Scenarios B and C reflect a scarcity of both natural gas and oil, but in scenario B, electricity prices are independent of oil and natural gas, implying coal and nuclear generation of power. Scenario C has a high electric price-growth rate too, which could result from the high capital costs of constructing nuclear and environmentally acceptable coal-burning powerplants. Scenario D reflects a shortage of coking coal.

Other possibilities were not selected for a variety of reasons. In a situation where coal and coke have high price-growth rates, the other rates would be high also, so there would be no relative change in prices among the various fuels. A price scenario with a low price-growth rate for steam coal, but high rates for coke and electricity, would closely approximate an all-high growth-rate scenario because little steam coal is used *directly* to produce engineering materials.

Table 54.—0TA Data on Future Energy Costs (in 1976 dollars)

	Annual cost growth rates			1976	1980		1985		1990		2000		3rd-quarter actual
Energy source	Low	High	Item	Base	Low	High	Low	High	Low	High	Low	High	1979a
Electricity	10/0	4.7%	¢/kWh	1.9	2.0	2.3	2.1	2.9	2.2	3.6	2.4	5.7	2.37
			$/MBtu	5.57	5.86	6.74	6.15	8.50	6.44	10.55	7.03	16.70	6.94
Natural gas	4%	5%	$/10³ft³	1.31	1.53	1.59	1.86	2.03	2.26	2.59	3.35	4.22	1.81
			$/MBtu	1.27	1.48	1.54	1.80	1.96	2.19	2.51	3.24	4,09	1.76
Oil	1,70/0	4.80/.	@US gal	28.6	30.5	34.4	33.2	43.6	36.2	55.1	42.8	88.1	35.7
			$/MBtu	1.66	1.77	2.00	1.93	2.53	2.10	3.19	2.48	5.11	2.07
Steam coal. . .	1 %	5%	$/tonne	32.6	33.9	39.6	35.6	50.5	37.4	64.5	41.4	105.0	36.0
			$/MBtu	1.31	1.36	1.59	1.43	2.03	1.50	2.59	1.66	4,22	1.45
Coke.	1 %	5%	$/tonne	74.3	77.3	90.3	81.2	115.2	85.4	147.0	94.3	239.5	82.05
			$/MBtu	2.60	2.70	3.16	2.84	4.03	2.98	5.14	3.30	8.38	2.87

aFrom Energy Information Agency, monthly energy report for all *Industry,* January 1980. Steel Industry costs for natural gas and electricity are likely somewhat less than average prices paid by al I domestic Industry

NOTE The original projections were made in early 1979 before very large Increases in 011 prices occurred The actual 1979 third.quarter data show that 011 prices have risen much faster than originally anticipated but the results of the analysis are not affected qualitatively

SOURCE Off Ice of Technology Assessment

Table 55.—Four Energy Cost-Growth Scenarios (percent annual increase)

	Scenario			
Energy source	A: all low growth rates	B: low rate only for electricity	c: all high growth rates	D: high rate only for coke
Electricity.	1.0%	1.0%	4.7%	1.0%
Natural gas.	4.0	5.0	5.0	4.0
Oil	1.7	4.8	4.8	1.7
Steam coal	1.0	5.0	5.0	1.0
Coke	1.0	5.0	5.0	5.0

SOURCE Off Ice of Technology Assessment

Energy Use Factors

Energy Used to Produce Domestic and Imported Steel

The quantities of the various energies used to produce steel are shown in table 56. The U.S. integrated plant assumed here is a large multimillion-tonne-per-year type. Energy data for a nonintegrated, scrap/electric arc furnace plant were obtained by adding finishing energies to the energy needed to produce liquid steel. The nonintegrated plant is assumed to produce 0,9 million tonne/yr.

All the foreign data were taken in aggregate form. The European data listed in table 56 represent an average for the United Kingdom, France, and West Germany. Data from Brazil are incomplete: no natural gas data were available; it is not certain whether the electricity is total or purchased; and the value per tonne of steel of the biomass energy that Brazil uses was unavailable. The United States, Japan, Europe, and Brazil all have different production yields, mostly because each country has a different product mix and various adoption rates of continuous casting. Therefore, all energy values have been normalized to a common yield of 0.64 tonne shipped per tome produced. A common yield statement corresponds somewhat to a common shipped product, such as cold-rolled sheet.

Table 56.—Energies Used to Calculate Energy Costs to Produce Domestic and Imported Steel and Domestically Produced Aluminum, Plastics, and Concrete[a]

	Steel					Other engineering materials (U. S.)		
	United States[b]					Aluminum	Plastics[d]	Concrete
Energy source	Integrated	Non integrated (scrap/EAF)	Japan	Europe[c]	Brazil	(ingots)	(polyethylene)	(reinforced)
Electricity (10^6 Btu/tonne) (buss bar) .	1.61	4.05	1.93	1.82	3.02[e]	64.1	N/A	0.274
Natural gas (10^6 Btu/tonne)	6.43	5.53	—	3.24	N/A	12.98	N/A	1.11
Oil (10^6 Btu/tonne).	3.46	2.55	4.79	6.03	6.69	40.3	95.5	0.466
Coal (10^6 Btu/tonne)	1.01	—	—	N/A	—	0.57	N/A	0.476
Coke[f] (10^6 Btu/tonne) . . .	19.16	0	15.62	18.36	11.1 [g]	14.04	N/A	1.386

aEnergy per tonne of steel shipped is for common 70% yield from liquid steel
bFrom World Steel Dynamics
cAverage of United Kingdom, West Germany, and France
dBased on yield of oil feedstock to produce polyethylene processing energy not available
eWhether this is total or purchased electricity is unknown
fDoes not include energy to make coke
gBrazil uses fair amount of biomass, amount unknown
SOURCE Office of Technology Assessment

Transportation Costs to Ship Steel to the United States

The transportation costs of shipping steel from Japan, Europe, and Brazil were estimated from daily operating costs reported by Gilman.[3] Gilman's data include daily fuel, capital, labor, and maintenance costs at sea and in port for various freighters. He also provides freight dock-handling charges for Japan, England, the Third World, and the United States. Using Gilman's data, it is estimated that fuel costs in 1976 dollars are about $0.64/tonne/1,000 statute miles. Fixed costs, which include maintenance, depreciation, and crew, are about $2.12/tonne/l,000 statute miles. All fuel for transportation was assumed to be oil.

Table 57 shows the average shipping distance and oil cost to ship steel products and various steelmaking materials to the United States. The distances from Japan, Europe, and Brazil are an average for shipping to the U.S. east coast and west coast. Shipping costs for ore were also considered. For Japan, the distance used is the average of South America to Japan, and Australia to Japan. A factor of **1.45** tomes of ore per tonne of steel shipped was used. One-half of Europe's ore is assumed to be imported from a shipping distance that is the average for South Africa and

[3] S, Gilman, *Journal of* Transport Economics and Policy, vol.II, No. 1 (1977).

Table 57.—Estimated Energy Costs for Shipment of Materials Involved in the Production of U.S. Consumed Steel[a] (per tonne of steel delivered)

	Production country							
	U.S. integrated		Japan		Europe		Brazil	
Item of shipment	Distance (1,000 miles)	Cost ($)	Distance (1,000 miles)	Cost ($)	Distance (1,000 miles)	Cost ($)	Distance (1,000 miles)	Cost ($)
Product to United States[b]	—		9.5	$ 5.04	6.8	$3.58	8.0	$4.12
Ore to production site[c]	1.0	$1.00	14.0	11.80	4,8	2.00[d]	0	0
Coking coal to production site	—	—	6.0	2.75	0	0	—	—
Oil to production site	0	0	12.0	1.00	0	0	—	—
Total costs		$1.00		$20.59		$5.58		$4.12

aIn 1976 dollars
bAverage distance used from production site to east and west coasts of the United States Estimated shipping cost was $0.58/tonne/1,000 mile
cLast figure includes correction for amount of item per tonne steel shipped
dAssume one half of European ore is Imported
SOURCE Office of Technology Assessment

South America to Europe. The shipping distance for the United States is for Great Lakes shipping. Japan's coking coal is assumed to be imported from Canada and Australia, and her oil from the Middle East. Domestic supplies or relatively short shipping distances were assumed for the rest of the fuels. An estimate of the total shipping costs was made for dock-to-dock imported steel product. An in-port rate of $0.73/tonne/d is used for an assumed total in-port time of 9 days. Freight-handling charges per tonne of steel are estimated from Gilman at $0.73, $1.82, and $1.21 between the United States and Europe, Japan, and Brazil, respectively.

Figure 17 shows the effect of rising fuel costs on the cost of shipping steel both to Los Angeles and to New York City. Two fuel cost curves are shown for each port-of-entry city in accordance with a 1.7- and 4,8-percent annual increase in fuel oil prices. The relative shipping distances are readily apparent in the shipping rates, with Japan to New York City being the longest and Europe to New York City, the shortest. These costs compare favorably with U.S. Federal Trade Commission (FTC)-reported shipping costs from Japan to New York City of $48/tonne.[4] However, estimated shipping rates of $33 to $40/tonne from South America appear to be slightly lower than FTC values. Fuel costs appear to be relatively a small fraction of the total shipping costs of imported steel, from 10 to 15 percent of the totals in 1976 for the six shipping routes shown. Depreciation is the highest single cost, ranging from 45 to 50 percent. Freight handling is about 20 percent of the total cost.

The import (or export) of iron ore has lower dock-to-dock shipping rates because of automated loading and unloading equipment. With reduced in-port time and handling costs, the fuel cost of shipping ore becomes a larger fraction of the total shipping costs than it is for finished steel products.

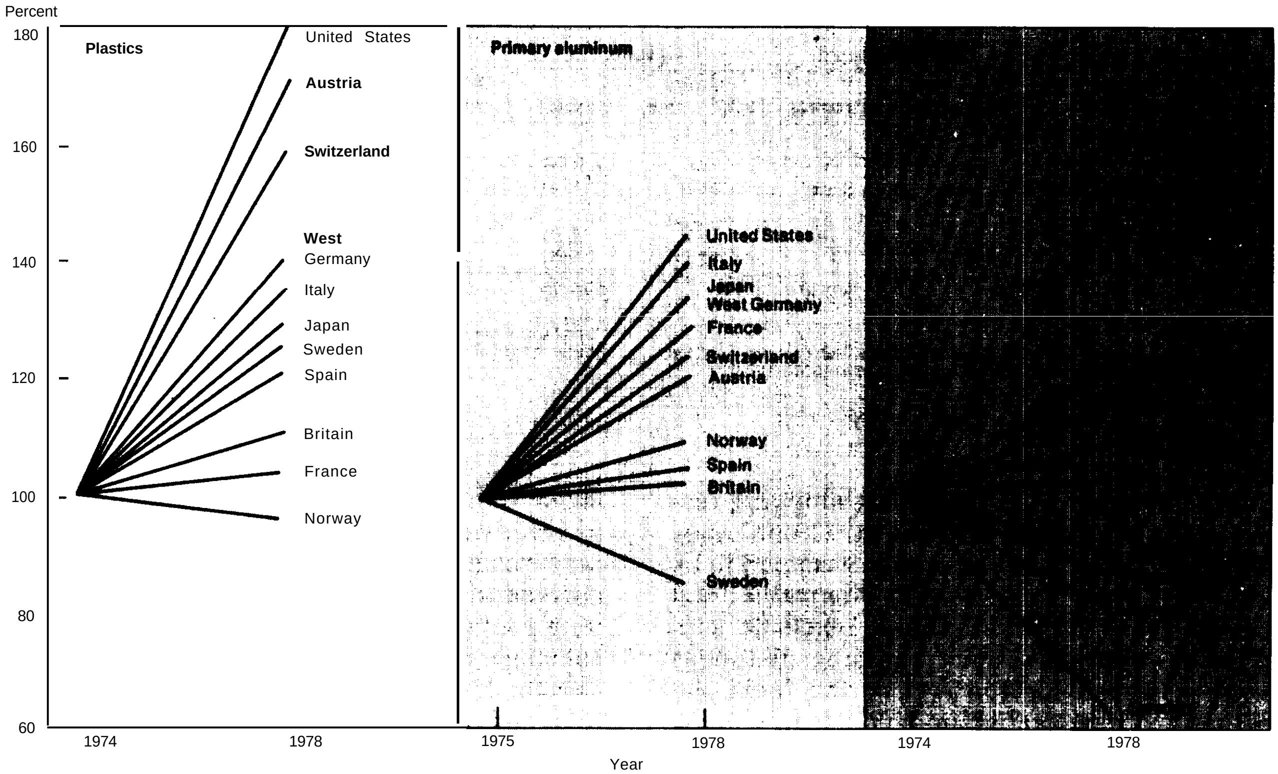
Energy Used to Produce Aluminum, Plastics, and Concrete

Table 58 shows the energies needed in the domestic production of aluminum, plastics, and reinforced concrete. The aluminum data are for ingot production. The production of aluminum alloys from ingots requires an additional 25 percent of energy of unknown type for milling and heat treating; these processes mostly use electrical and oil-based energies, and additional use of electrical and oil energies will have little influence on the comparisons among materials.

Industrywide energy consumption data for plastics production is difficult to find because

[4]U.S. Federal Trade Commission, "The U.S. Steel Industry and Its International Rivals," November 1977.

Figure 17.— Percent Growth in Per Capita Consumption of Plastics, Aluminum, and Steel in Selected Countries, 1974-78



SOURCE: *Economist* Intelligence Unit.

Table 58.—Projected Year 2000 Energy Cost for Domestic and Imported Steel and for Domestic Aluminum, Plastics, and Concrete, Using Four Price Scenarios (in 1976 dollars per tonne)

		Scenario A Low: all		Scenario B High: gas, oil		Scenario C High: gas, oil, electricity		Scenario D High: coke	
Item	1976 cost	2000 cost	Total energy growth rate[a]	2000 cost	Total energy growth rate	2000 cost	Total energy growth rate	2000 cost	Total energy growth rate
Steel; U.S. integrated (BF-BOF).	$ 74.7	$107.0	1 .5%	$120.0	2.00/0	$ 135.0	2.5%	$204.0	4.3%
Steel; U.S. non integrated (scrap-EAF) . .	33.7	54.5	2.0	65.9	2.8	104.0	4.8	54.5	2.0
Steel; Japan	79.9	108.0	1.3	123.0	1.8	142.0	2.4	187.0	3.6
Steel; Europe.	77.6	107.0	1.3	135.0	2.3	152.0	2.8	200.0	4.0
Steel; Brazil	60.9	80.8	1.2	104,9	2.3	134.0	3.3	137.0	3.4
Aluminum (ingot).	506.0	682.0	1.2	806.0	2.0	1,470.0	4.5	758.0	1.7
Plastic (polyethylene) . .	168.0	252.0	1.7	518.0	4.8	518.0	4.8	152,0	1.7
Reinforced concrete.	8.4	12.9	1.8	15.5	2.6	18.1	3.2	20.4	3.8

aGrowth rates are average annual growth rates for 19762000

SOURCE Office of Technology Assessment

of the multiproduct integration, the variety of production processes, and the product mix that characterize the petrochemical industry. The most common engineering plastic is nylon, and the most common reinforced structural plastic is thermosetting polyester. The starting monomer for polyester is p-xylene. Overall, the most used polymer is polyethylene, with ethylene as the monomer. Over the past few years, the cost of benzene, p-xylene, and ethylene has been steadily rising. Because these monomers are byproducts of crude oil refineries, their prices for the most part are controlled by crude oil prices. The limited data found for polyethylene production was used for purposes of comparison with other materials, even though bulk polyethylene is only about 40 cent/lb and bulk engineering polymers are generally twice as expensive. The yield of ethylene from oil was determined from published data for the C. E. Lummus process, which produces half of the world's ethylene. No statement could be found for other process production energies. The yield of polyethylene from ethylene is essentially 100 percent on a weight basis. The amount of electrical energy used in polymerization is minimal compared to the energy content of the polymer. The assumption can be made that no coal or coke is used in plastic production.

The energies required to make reinforced concrete were determined by using a typical composition of a structural concrete found in the Concrete Construction Handbook. Table 59 presents this composition and the relative amounts of each energy used to produce each component. The largest single energy item in concrete is the coke required to produce the steel reinforcing rods.

Projected Energy Costs

The energies listed in table 56 and energy costs in tables 54 and 57 were used to estimate total energy costs in 2000 according to the four price scenarios. Table 58 presents these estimates and also lists effective annual energy cost-growth rates.

In the steel projections, the deficiencies in the Brazilian data make it difficult to compare the Brazilian results with those for the United States, Japan, and Europe. All four price scenarios show little relative change in energy costs in 2000 for Japan, Europe, and the United States (integrated plant). In price scenarios with high oil price-growth rates (B and C), European and Japanese energy costs are the highest of any in 2000 because of added shipping costs. Japan's high coke efficiency is reflected in scenario D with an energy cost saving of about $16/tonne by 2000. Because the reductant energy for iron ore is not included in the U.S. nonintegrated (scrap/electric furnace) plant data, those energy costs are substantially lower than the other estimates.

Table 59.—Production Energies for Reinforced Concrete

Item	Volume percent	Weight percent	Electricity (buss bar)	Natural gas	Oil	Coal	Coke	Total energy
Steel (rod) . . .	2.9%	90/0	0.195	0.619	0.283	0.098	1.386	2.58
Cement	12.0	15	0.066	0.487	0.183	0.378	0	1.11
Water.	16.8	7	—	—	—	—	—	—
Gravel	43.8	45	0.010	0	0	0	0	0.01
Sand . . .	23.5	24	0.003	0	0	0	0	0.003
Air	1.0	0	—	—	—	—	—	—
Totals	100.0	100	0.274	1.106	0.466	0.476	1.386	3.70
Percent			7.4	30	13	13	37	100.4

SOURCE Off Ice of Technology Assessment.

Comparing absolute energy cost values for steel, aluminum, plastics, and concrete is much more risky than comparing values within the steel industry. Because of the wide variety of common applications for these engineering materials, the amounts of energy and material required to manufacture a specific product can vary immensely from material to material. As a result, the price per unit of weight or volume is not as significant as the rate of energy cost increases. Using scenario A, there is little difference in relative energy costs between 1976 and 2000. The annual energy cost-growth rates vary between 1.2 percent for aluminum and 2.0 percent for steel from a nonintegrated plant. Plastic (polyethylene) is clearly at an economic disadvantage in the high oil cost-growth rate scenarios, as is steel from an integrated blast furnace plant in the high coke rate scenario. Because the most energy-intensive component of reinforced concrete is steel rod, the cost-growth rates for concrete parallel the cost rates of steel. Scenario C is probably a good estimate of how aluminum is likely to lose competitiveness relative to steel made in integrated plants.

Conclusion

When a static technology for engineering materials is assumed, U.S.-produced steel will have the most energy cost advantage over imported steel if the prices of oil and natural gas increase worldwide at a higher rate than those of coal or coke (scenarios B and C). Steel will have the most energy cost advantage over aluminum and plastics if the prices of electricity, gas, and oil increase at a greater rate than coal and coke. Conversely, the worst situation for U.S. (integrated) steel will be if the price of coke is high, relative to all other energies (scenario D). This could be the situation if domestic coke capacity continues to decline and imports increase (see ch. 7).

Trends in Domestic Consumption of Steel and Competing Materials

General Trends

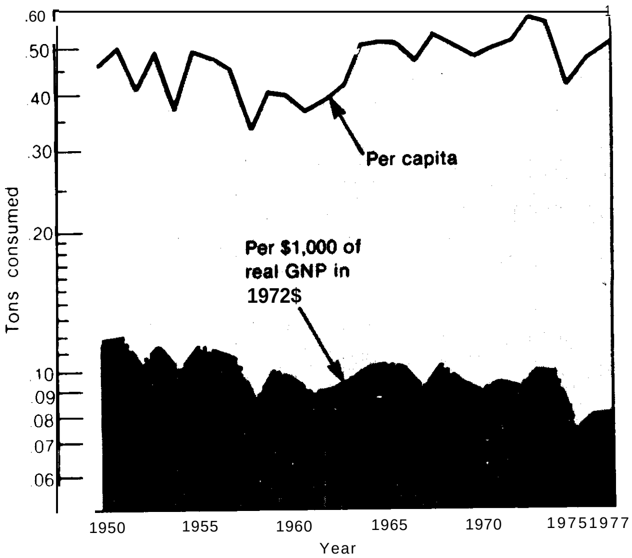
All sectors of the economy use steel and will continue to do so in the future. Further, because of technological developments in the production of alloy and specialty steels, applications of these products are increasing. Nevertheless, as shown in figure 18, steel consumption in some industrialized countries is declining relative to consumption of aluminum and plastics. In large measure, the effort to reduce automobile weights and, in some cases, lower prices for other materials are behind the deceleration in steel consumption.

Trends in per capita steel consumption in the United States (figure 19) show a very slight increase from 0.420 to 0.450 tonnes between 1950 and 1977. Measured in terms of tonnes consumed per $1,000 of real gross national product (GNP) (figure 19), however, steel consumption has declined slightly from 0.120 to about 0.074 tonnes per $1,000 of real GNP between 1950 and 1977. Comparable data for aluminum and plastics consumption are shown in figures 20 and 21. In absolute terms, the growth rate of steel consumption during the last several decades in the United States has averaged about 2 percent per year as compared to 6 percent for aluminum and 8 percent for plastics.

This slow-growth trend in steel consumption will probably continue. A recent, conservative analysis projects a growth rate of about 1.6 percent per year from 1977 to 2000.[5] (Future supply-demand forecasts are considered in detail in the next section.) It is

[5]Robert K. Sharkey, et al., "Long-Term Trends in U.S. Steel Consumption: Implications for Domestic Capacity," Industrial Economics Review, U.S. Department of Commerce, vol. I, May 1979, pp. 11-24.

Figure 18.—Trends in U.S. Apparent Consumption of Steel, 1950-77



Fiqure 19.—Trends in U.S. Apparent Consumption of Aluminum, 1960-77

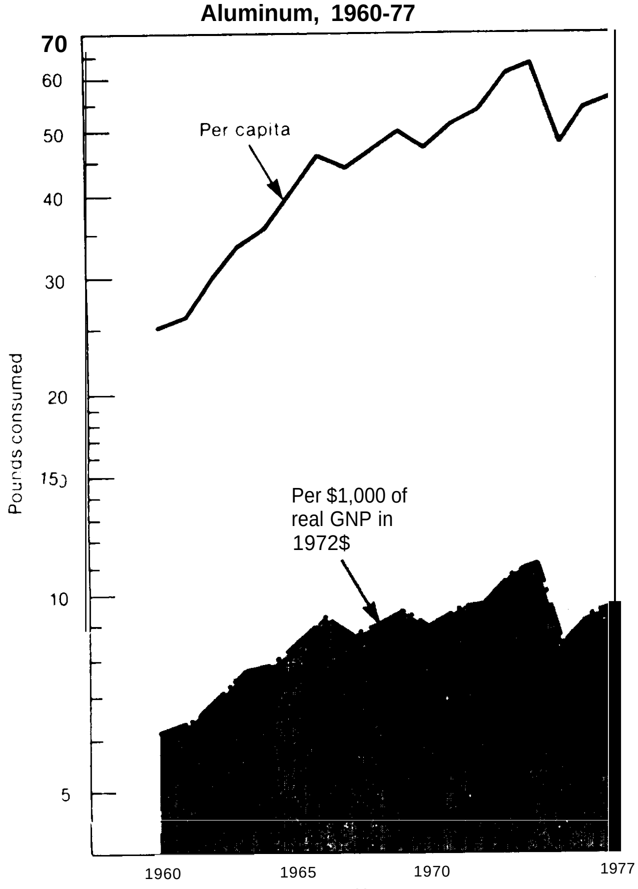
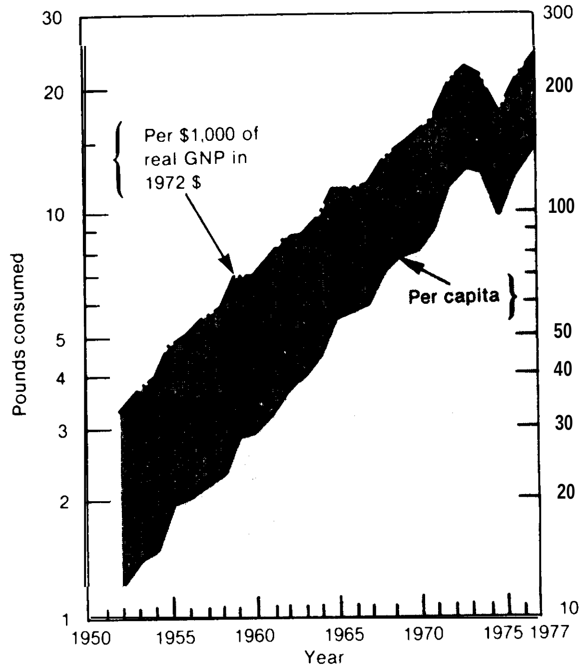


Figure 20.—Trends in U.S. Apparent Consumption of Plastics, 1952-77



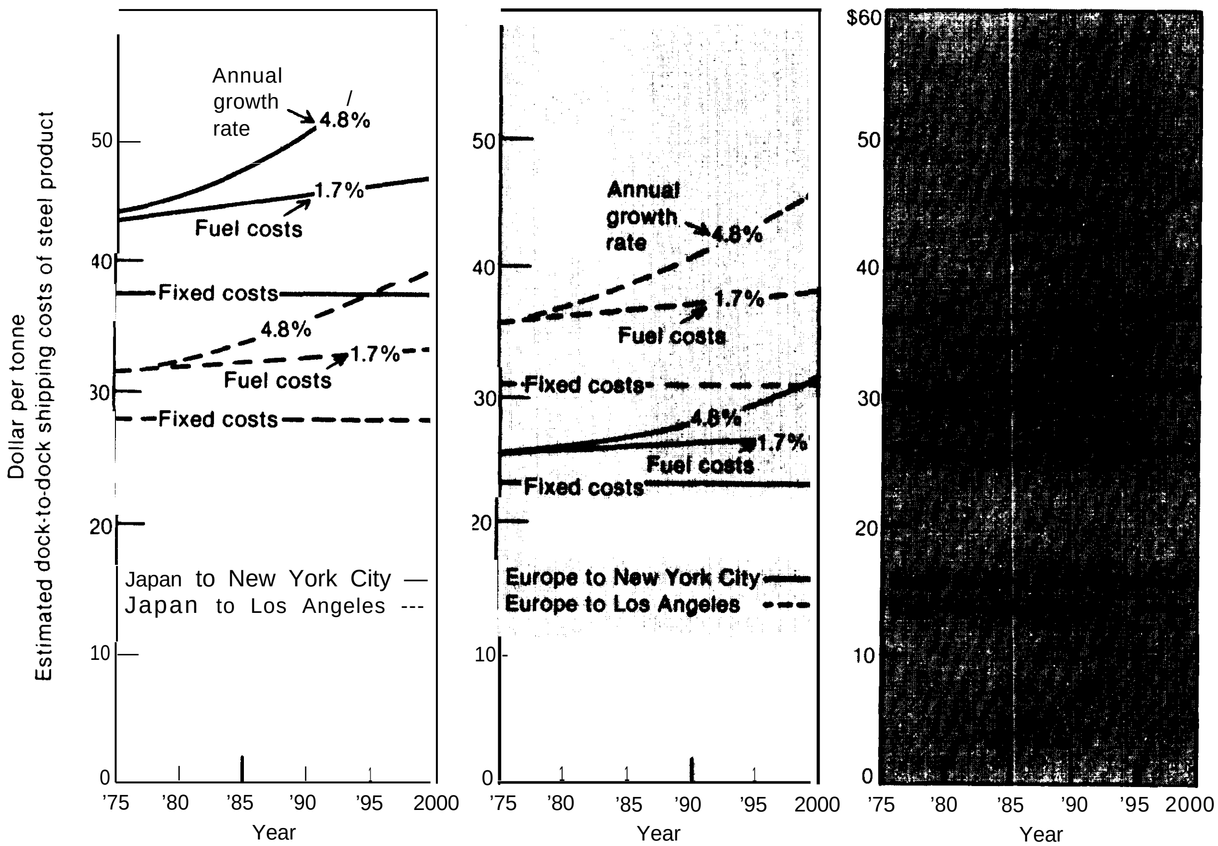
SOURCE: Figures 18, 19, and 20—Office of Technology Assessment.

expected that plastics will continue to capture some steel markets in the future, but aluminum could lose competitiveness in some markets. However, neither material, nor any other, can to a significant degree replace steel as the principal engineering material in any of the major steel-using sectors of the economy, and the demand for steel is likely to increase over time (see the next section).

Domestic Markets

The "service centers and distributors," which serve a multitude of users, are the largest market for steel. The next largest is the automobile industry, which consumed 21.7 percent of domestic steel shipments in 1978, and then building construction, which consumed 13.7 percent. Other important markets for steel mill products are equipment and machinery manufacturers, with 10.9 percent of total shipments in 1978, and container and packaging manufacturers, with 6.7 percent (see table 60). It is generally accepted that about 60 percent of steel consumption is related to capital expenditures.

Figure 21.—Effects of Rising Fuel Costs on the Shippinq Costs of Steel Products From Japan, Europe, and Brazil to Los Angeles and New York



NOTE. Due to the actual Increases in petroleum prices m 1979, shipping costs are shifted along the same axis to the right

SOURCE Off Ice of Technology Assessment

Table 60.—Steel Shipments by Selected Market, 1967-78 (in thousands of tonnes)

	Steel service centers		Automotive		Construction		Containers		Machinery		Rails		Total ship-ments
	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent	Tonnes	Percent	Tonnes
1967	12,127	15.9	14,955	19.7	12,234	16.1	6,580	8.6	8,534	11.0	2,925	3.8	76,095
1968	12,797	15.4	17,477	21.0	12,902	15.5	7,167	8.6	8,858	10.6	2,765	3.3	83,313
1969	14,315	16.8	16,576	19.5	12,649	14.9	6,481	7.6	8,771	10.3	3,033	3.6	85,146
1970	14,535	17.7	13,129	15.9	12,111	14.7	7,052	8.5	8,153	9.9	2,810	3.5	82,354
1971	13,083	16.6	15,857	20.1	12,346	15.6	6,541	8.3	7,824	9.9	2,725	3.4	78,943
1972	15,235	18.3	16,523	19.8	12,375	14.9	6,001	7.2	8,761	10.5	2,476	2.9	83,267
1973	18,487	18.3	21,058	20.8	15,591	15.4	7,085	7.0	10,404	10.3	2,928	2.9	101,067
1974	18,503	18.6	17,168	17.3	15,971	16.1	7,454	7.5	10,468	10.5	3,099	3.1	99,291
1975	11,519	15.9	13,799	19.0	10,926	15.1	5,490	7.6	7,959	11.0	2,859	3.9	72,521
1976	13,298	16.4	19,365	23.9	10,893	13.4	6,271	7,7	8,739	10.8	2,772	3.4	81,128
1977	13,909	16.8	19,493	23.6	10,886	13.2	6,092	7.4	8,964	10.8	2,936	3.6	82,906
1978	15,760	17.8	19,277	21.7	12,127	13.7	5,497	6.7	9,667	10.9	3,224	3.6	88,827

aincludes agricultural and electrical

SOURCE American Iron and Steel Institute

The automobile market for steel is growing at a rate of 1.5 percent per year, the building construction market at 2.1 percent, the equipment and machinery market at 1.7 percent, and the container and packaging market at 0.8 percent (table 61). Major declines in steel consumption are occurring in transportation, oil and gas, military goods, and export markets. Steel imports have grown spectacularly, but there are no statistics on how that steel is used. Commonly used data on steel consumption also do not take into account the steel embodied in other imported products, such as automobiles.

Automotive Industry

The automobile industry is an important steel market not only for the amount it consumes but also for the form of its consumption. The type of steel demanded has an important bearing on the technologies used in steel production. Automotive applications account for more than 40 percent of sheet and strip shipments and the auto industry is clearly the key segment in future sheet demand. Thus, it will play a major role in determining the kind of raw steel capacity the steel industry needs to add. This is an especially pertinent point because the requirements for steel by domestic motor vehicle producers will continue to grow, albeit at a more modest rate than in the past.

The fundamental reason for the slowdown in future steel demand by the automobile industry is the need to manufacture lighter cars that will meet Government fuel-efficiency regulations. Although there has been little change in average steel consumption for vans and light trucks in the past few years, they too will be affected by increasing fuel costs and energy-conservation measures that will make steel substitutes attractive. There is a continuing effort to find appropriate lighter-than-steel substitutes like graphite-reinforced plastics, glass-reinforced polypropylene, and aluminum. In 1960, the average automobile incorporated 25 lb of plastics, and in 1979, approximately 200 lb; the forecast is that in 2000a car will contain 750 to 1,000 lb of plastics.

A number of factors may mitigate the rapid rate of substitution for steel in cars, Other usable materials have higher production costs and lower rates of production per unit of time than steel. Potential supply shortages of aluminum and the dependence of plastics on petroleum feedstocks are also significant factors. The cycle of automobile model changes and tool design also make any shift to new materials a gradual process. Table 62 presents a recent General Motors forecast of average material consumption per passenger car from 1978 to 1987. Such forecasts tend to change frequently, but this one shows declining steel consumption to be a function of down-sizing, not of major materials substitution, Steel's share of the vehicle net material weight remains relatively constant, even though the amount of steel used decreases substantially.

New technologies in steel materials for automotive applications also make steel more competitive with aluminum and fiber-reinforced plastics. The longstanding emphasis of the domestic steel industry on product could have substantial future payoffs in this market. Substitution for steel by other materials is, and will continue to be, offset by the availability of new types of alloy steel, such as high-strength low-alloy and dual-phase steels, and eventually perhaps by superplastic steels and amorphous alloys.

New fabrication techniques being considered also will sustain the use of steel in automobiles. These combine steel, aluminum, and plastics in relatively low-cost composites. Steel/plastic sandwich constructions, all-steel honeycomb constructions, and steel channel sections filled with polyurethane plastic foam all provide suitable combinations of strength and stiffness with reduced

Table 61.—Historical Growth Rates for Steel Product Shipments by Markets, Imports, Exports, and Apparent Consumption, 1951-77 (percent per year)

Market segment	Average annual compound growth rate: Trendline[a]	Compound analysis[a]
Building construction	1.9%	2.1%
Automobile	1.6	
Air, sea, and rail transportation	–0.5	–0.8
Equipment and machinery (industrial and electrical)	1.8	1.7
Agriculture and mining	1.4	1.2
Oil and gas industry	– 1.8[b]	– 1.8[b]
Containers and packaging	0.8	0.8
Consumer and commercial products	0.6	0.4
Military	-1.1	–3.6
Service centers and distributors	1.7	1.6
Steel converters	0.7	0.9
Other shipments	4.1	4.4
Total domestic shipments	1.4	1.3
Steel mill product exports[c]	-0.1	–0.3
Total U.S. mill shipments	1.4	1.2
Total exports[d]	0.6	0.6
Total imports	8.6	13.1
Apparent U.S. consumption	2.1	**2.0**

aBoth methods are based on annual average consumption during 5-year periods from 1951.75 The compound analysis is simply the average annual rate of change required to Increase (or decrease) average annual consumption from the level prevalent in 1951.55 to that in 1971.75 The trendline growth rate is derived from regression analysis of 5-year annual average shipment data, trend. line analysis of annual data yields almost Identical results
bInnacurate due to the importance of imported products and service centers in supplying this market segment
cAs reported by the American Iron and Steel Institute
dIncludes steel mill product exports

SOURCE Office of Technology Assessment

weight. Because of such developments in fabrication techniques and the developments in new materials, steel will likely continue to dominate the automobile market, even though the use of aluminum and plastics will grow. One forecast indicates 1985 steel use in the automobile sector at about the same level as in 1978.[6]

The projected growth of automobile industry consumption of steel to 2000 is shown in table 63. The projections were calculated by assuming growth rates for passenger cars and light trucks. Future steel consumption for these vehicles is then compared to 1978 consumption (determined by the same method) to derive the implied growth rate for steel. The present economic instability and various exogenous factors, such as future oil prices and import penetrations, subject any projection to considerable uncertainty, and this one should be regarded with suitable caution.

A more general belief is that total steel consumption will decrease. One recent forecast, for example, indicated a decrease by 1985 of 1,185 lb in the conventional iron and steel

[6]J. J. Tribendis and J. P. Clark, "An Analysis of the Demand for Steel in the U. S.: 1978-1985," *Materials* and Society, vol. 3, No. 4, 1979.

Table 62.–Material Consumption in Passenger Cars as Percentage of Total Weight, 1978-87
(net materials consumption as percentage of net weight)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Steel	59.5%	60.00/0	60.2%	60.0%	60.2%	61.3%	60.4%	60.50/o	60.60/0	59.90/0
Cast iron	17.9	17.1	16.2	16.0	15.1	12.9	12.2	10.7	10.5	10.4
Aluminum	**2.9**	**3.2**	**3.6**	**3.9**	**4.2**	**4.8**	**5.5**	**6.1**	**6.3**	**6.4**
Plastics	**5.4**	**5.6**	**5.7**	**5.9**	**6.6**	**6.7**	**7.6**	**8.3**	**8.5**	**9.0**
Glass	**2.7**	**2.3**	**2.7**	**2.7**	**2.6**	**2.7**	**2.8**	**2.8**	**2.8**	**2.8**
Other	**11.6**	**11.9**	**11.5**	**11.6**	**11.2**	**11.6**	**11.5**	**11.7**	**11.4**	**11.5**
Total	**100.0**	**100.1**	**99.9**	**100.1**	**99.9**	**100.0**	**100.0**	**100.1**	**100.1**	**100.0**
Steel weight (lb/unit)										
Gross[a]	**2,871[b]**	**2,831**	**2,763**	**2,734**	**2,715**	**2,666**	**2,526**	**2,385**	**2,364**	**2,316**
Net	**2,083**	**2,057**	**2,004**	**1,986**	**1,958**	**1,936**	**1,825**	**1,736**	**1,721**	**1,688**

aGross weight = amount of steel purchased Net weight = amount of steel in automobile
b1978 steel usage for pickups and vans was.

	Pickups	Vans
Gross	3,525	3,428
Net	2,580	2,596

SOURCE General Motors Corp , administrative services engineering staff, Apr. 2, 1979

Table 63.—Steel Usage in Passenger Cars and Light Trucks, 1978,1985,2000

	Passenger cars	Pickups	Vans	Total	Implied steel growth
1978 base					
Unit production (1 ,000)	9,153	2,791	698	N.R.	N.R.
Gross steel consumption per unit (kg) .	1,302	1,599	1,555	N.R.	N.R.
Gross steel consumption (1 ,000 tonnes).	11.917	4,462	1,085	17,708	N.R.
1978-85					
***Case* A—cars: 2.5% growth trucks and vans: 3.0% growth**					
Unit production (1 ,000)	**11,152**	**3,536**	**884**	N.R.	N.R.
Gross steel consumption per unit (kg)	**1,082**	1,599	1,555	N.R.	N.R,
Gross steel consumption (1 ,000 tonnes).	**12,062**	5,652	1,374	19,099	1.1 %
Case B—cars: 1.5% growth trucks and vans: 3.0°A growth					
Unit production ., ...	**10,311**	**3,270**	**818**	N.R.	N.R.
Gross steel consumption per unit (kg) .	**1,082**	1,599	1,555	N.R.	N.R.
Gross steel consumption (1 ,000 tonnes).	**11,152**	5,227	1,272	17,651	0.1 0/0
Case C—cars: 2.5% ***growth trucks and vans: 3.0% growth —700/.*** **steel *reduction in* vans and *trucks***					
Unit production	**11,152**	**3,536**	**884**	N.R.	N.R.
Gross steel consumption per unit (kg)	1,082	1,559	1,555	N.R.	N.R.
Gross steel consumption (1 ,000 tonnes).	12,062	5,088	1,237	18,388	0.6%
1978-2000					
Case A—cars: 1.5% growth trucks and vans: 2.0% growth					
Unit production (1 ,000)	13,943	4,749	1,190	**N.R.**	**N.R.**
Gross steel consumption per unit (kg)	974	**1,295**	**1,260**	**N.R.**	N.R.
Gross steel consumption (1 ,000 tonnes).	13,576	6,164	1,498	21,238	1 .0%
Case B—cars: 1.O% growth trucks and *vans:* 1.5% growth					
Unit production (1 ,000)	**12,947**	**4,421**	**1,105**	**N.R.**	**N.R.**
Gross steel consumption per unit (kg)	**974**	**1,295**	**1,260**	**N.R.**	**N.R.**
Gross steel consumption (1 ,000 tonnes).	**12.606**	**5,726**	**1,391**	**19,724**	**0.50/0**

Growth rates are average annual compound rates
N R = not relevant

SOURCE Off Ice of Technology Assessment

materials that go into an average automobile. The loss would be partially offset by an increase of 450 lb in high-strength low-alloy steel.[7] A factor which most forecasts have not taken into account is the possible growth in domestic production of automobiles now made in other countries. This could lead to a net increase in purchases of domestic steel, especially for foreign-owned plants in inland locations in the United States. However, one study foresees no growth in automobile steel use in the 1980's even if Japanese plants in the United States buy one-half their steel domystically.[8]

[7] *Iron Age*, Jan. 8, 1979, p. 25. Another forecast, by Arthur Anderson & Co., leads to the same level of steel use per auto, 1,400 lb, but by 1990; American *Metal* Market, Dec. 24, 1979.

[8] C. A. Bradford, "Steel Industry Quarterly Review,"' February 1980, Merrill, Lynch, Pierce, Fenner & Smith, Inc.

Building Construction

Materials competition in the construction sector is considerable. The amount of steel consumed in building and construction is understated because some is purchased by service centers and distributors, and then sold to builders. Service center steel shipments to construction markets are not reported directly, but various sources which include estimates for these shipments, indicate the actual amount of steel used in construction is very large (see table 64). The proportion of shipments to this sector as a percentage of total steel shipments has remained relatively stable over the last three decades, and available information suggests that the volume consumed in construction activity will continue at the historical rate. However, if major

Table 64.—Estimated Usage of Iron and Steel Construction Materials (1,000 tonnes)

	1974	1975	1976	1977
Concrete reinforcing bars .	4,624	3,325	3,516	3,790
Galvanized sheets.	5,537	3,374	4,698	5,131
Cast iron pipe				
Pressure.	1,776	1,138	1,210	1,456
Soil	702	539	597	619
Fabricated steel products .	4,141	3,932	3,372	3,162
Plates and structural shapes	16,507	15,901	16,354	10,793
Piling.	600	385	299	318
Total	33,887	28,594	30,046	27,856

SOURCES "Iron and Steel, " MCP-15 Mineral Commodity Profiles, Bureau of Mines, U S Department of the Interior, July 1978
"Iron and Steel, " a chapter from *Mineral Facts and Problems,* 1975 edition, Bureau of Mines reprint from Bulletin 667, U S Department of the interior
"Steel Mill Products, " Current Industrial Reports, MA-33B (76).1, issued September 1977. Bureau of the Census, U S Department of Commerce
"Iron and Steel Products Shipments, Bookings and Backlog," Bureau of Mines, U S Department of the Interior, January/February 1978

capital spending for the U.S. industrial base occurs during the next decade, then this market could consume increased amounts of steel. Much steel for construction is used as a component of concrete in the form of reinforcing bar. Three basic types of commercial construction use steel in different amounts:

- standard steel construction, in which a floor deck is concrete and strong enough to span the high-strength steel beams on which it rests;
- composite construction, in which steel shear connectors are welded through the concrete deck to the steel beams below; and
- concrete construction, in which a great many steel reinforcing bars are used to take care of tensile stress.

Table 65 shows the variation in the amount of steel, energy, and labor used in these three types of construction. In spite of these differences, an analyst notes that "assuming a large project with many repetitive sections, the dollar costs of the three systems are approximately the same."[9] In general, the choice of system is made for other reasons, including material availability, labor availability, and scheduling needs.

Table 65.—Summary of Materials, Energy, and Labor Used in Comparative Floor Bay Construction

	Labor	Energy	Materials	
Commercial building bays	Man-hours/ft^2	Btu x 10^3/ft^2	Steel lb/ft^2	Concrete ft^3/ft^2
Standard steel .	0.49	284	10.3	0.33
Composite steel	0.44	250	8.9	0.33
Concrete.	0.36	172	5.7	0.80

SOURCE B. Hannon, "Materials, Energy, and Labor Impacts in Typical Building Floor Bay Assembles, " University of Illinois, August 1978

Containers and Packaging

This segment of the steel market has consumed a constant share of steel shipments. Nevertheless, steel's share of the total packaging market has declined in the last quarter century. From 1972 to 1975, aluminum's share of the can market increased from 13 to 25 percent.[10] The growth of both aluminum and plastics has relied heavily on this market. For instance, containers and packaging accounted for 10 percent of total aluminum shipments in 1960 and 20 percent in the mid-1970's; packaging accounts for 25 percent of total plastics use, The growth of aluminum and plastics in packaging has come in part from new products and from products not appropriate for steel, but both materials have also penetrated steel markets.

Because aluminum prices may escalate sharply, it may not continue to displace steel in the container market at the historical level; thinner steels are being used to retain the market share on a unit basis. One study has forecast a 1985 consumption level of steel for

[9] B. Hannon, "Materials, Energy and Labor Impacts in Typical Building Floor Bay Assemblies, " University of Illinois, August 1978.
[10] U.S. Bureau of the Census,

this market at about 10.4 million tonnes, a 30-percent increase over 1978.[11]

Equipment and Machinery

For most equipment and machinery applications, steel has no major competitors. This market has become somewhat less steel intensive over time, though. In large part, this is because of the rapid growth of computer-aided machinery, which uses less steel per unit of output than machinery relying on mechanical components. Also, the United States has lost some of its export market in machinery, and domestic industrial capital spending has been at relatively low levels. No significant growth is expected in this sector through 1985 unless there is a turnaround in capital spending.[12]

Other Consumers of Steel

Agriculture and Mining.—Steel has almost no substitutes for agricultural and mining equipment. Nevertheless, that market has only retained its share of total steel product shipments.

Air, Sea, and Rail Transportation.—The transportation market segment has declined in relation to total steel demand. Little new rail mileage has been laid in the United States in recent years, and railroad expenditures for maintenance have been severely depressed by that industry's economic malaise. This trend appears to be changing now, and rails could represent a growing steel market in the next decade.

Because of weight restrictions, use of titanium and aluminum is more important than steel in aircraft manufacture.

Although the worldwide shipbuilding industry has enjoyed intermittent booms in tanker construction, particularly growth in tanker size, the U.S. industry has not captured much of this market. The Japanese steel industry reaped major benefits from the Japanese shipbuilding industry's role in tanker construction. In fact, demand for steelplate served as a "base load" for new steel capacity during the 1960's and 1970's. However, the future trends in domestic steel demand for this use are expected to continue at the historical rate.

Consumer and Commercial Products.—The rate of household formation directly affects demand for steel because it governs the course of appliance sales. Plastics, however, have provided steel with competition in some major appliance components, such as refrigerator door liners and washing machine tubs. The best estimate of future demand for steel by the consumer sector indicates a continuation of past trends, with relatively little growth.

[11] Tribendis and Clark, op. cit.
[12] Ibid.

Domestic Supply-Demand Forecasts for Steel

There are many uncertainties in supply-demand forecasting for a commodity such as steel, which is very sensitive to general domestic economic conditions and world supply factors. Nevertheless, relatively good agreement exists among various steel demand forecasts. Table 66 shows forecasts from several sources and, with the exception of Wyman's forecast,[13] the range is not wide. For 1985, the demand forecasts vary from a low figure of 114,7 million tonnes, representing the opinion of industry itself,[14] to a high of almost 133.4 million tonnes projected by Tribendis and Clark[15] on the basis of a high-economic-growth scenario. For 1990, the industry projects steel demand in the United States at 125.0 million tonnes and Chase Econome-

[13] Shearson Hayden Stone and J. C. Wyman, "Gold, Technology and Steel," February 1979.
[14] American Iron and Steel Institute, "Steel at the Crossroads: The American Steel Industry in the 1980s," 1980: U.S. Steel Corp., *Steelweek*, Feb. 11, 1980.
[15] Tribendis and Clark, op. cit.

Table 66.—U.S. Steel Demand and Capacity, Comparison of Various Forecasts, 1980-2000 (millions of tonnes)

	Demand (total consumption = domestic shipments – exports + imports)								Capacity			
Year	Bureau Mines[a]	Chase[b]	DRI[c]	Commerce[d]	Shearson Hayden Stone's	Industry analysts[f]	AISI[g]	MIT[h]	Chase[b]	World Steel Dynamics'	AISI[g]	MIT[h]
1980. . . .			110.5T 111.7[c]	111.0	141.3	105.2	107.1			105.5	94.1	
1981					145.9							
1982. . . .					150.7							
1983. . . .					155.6					106.6		
1984. . . .					160.6							
1985. . . .	119.3		124.7T 124.1 C	119.4	165.9	117.9	114.7	133.4 High 121.7 Base 112.0 Low			111.8	115.8
1986. . . .		126.8							117.8			
1990. . . .		137.3	137.1T 129.4C	129.3		131.5	125.0		129.6		121.8	
1995. . . .												
2000. . . .	151.1											

aBureau of Mines, *Iron and Steel,* MCP-15, July 1978, *p.* 25.
bMichael F Elliot-Jones, "Iron and Steel in the 1980's The Crucial Decade," Chase Econometric Associates, Inc. Apr. 19, 1979 (assumes yields from raw: 1977 = 72, 1986 = 74, 1990 = 77)
cDRI Long Range Forecasting Model cited in (d), T = trend, C = cycle.
dRobert K. Sharkey, et al, "Long Term Trends in U.S. Steel consumption: Imlications for Domestic Capacity, " *Industrial Economics Review,* U S Department of Commerce, vol. 1, May 1979, pp. 11-24
eShearson Hayden Stone and J C Wyman, "Gold, Technology and Steel, " February 1979 (Includes Indirect steel Imports and steel used in foreign industries to construct factories producing exports to the United States
'Cited in (d)
gAmerican Iron and Steel Institute, *Steel* at *the Crossroads The American Steel Industry in 1980's, 1980,* assuming raw yields of 1960 = 72, 1985 = 74, 1990 = 77 and an operating rate of 90%
hJ J Tlbendls and J p Clark, "An Analysis of Demand for Steel in the US 1978.1985," *Materials and Society,* vol *3, No 4, 1979* Demand based on three economic scenarios with Imports a variable Capacity calculated from maxi. mum domestic shipments (min imports of 140/.) assuming 90% operating rate
'World Steel Dynamics, Apr 25, 1979 (assuming raw yields of 1980 = 72, 1983 = 73)

tries" at 137.3 million. Only one steel demand projection, that of the U.S. Bureau of Mines,[17] is available for the period beyond 1990. This forecasts steel demand in the United States for 2000 at 151.1 million tonnes.

The low projections of AISI and the U.S. Department of Commerce[18] are based on low growth rates in steel demand, 1.5 percent and 1.6 percent annually, respectively. The Tribendis and Clark low-growth-rate scenario calls for a 1.9-percent annual increase in steel demand, their high-growth scenario has a growth rate of 3.7 percent annually.

The methodologies used in these projections vary. For example, the Bureau of Mines used the following methodology:

> In a mature economy, such as that of the United States, it is believed that iron and steel demand closely follows population. The demand forecasts were therefore based on a curvilinear regression of steel demand (steel mill shipments plus imports) on population. The relatively rapid rise in steel usage at the beginning of the 20th century, caused by the advent of the automobile, was eliminated by beginning the regression line with 1915 data, establishing a 62-year trend. The demand projections for 2000 were based on Bureau of the Census population projections Series I-111, Although the demand data used in the regression included exports, the projections were made on the basis of domestic consumption excluding exports, Exports were assumed to remain at the average of 3 percent of steel demand (including exports) established over the past few years.[19]

Apparently the Bureau of Mines did not take into account any surges in capital spending.

The Department of commerce forecast methodology was as follows:

> The forecast model for apparent steel consumption for 1980, 1985 and 1990, developed by the Office of Industrial Economics (OIE) for this study, is a partial adjustment multiple linear regression model with three explanatory variables: (1) residential fixed investment, (2) non-residential fixed investment, and (3) motor vehicles and parts,
>
> One advantage of using major components of GNP as as explanatory variables is that

"Michael F. Elliot-Jones, "Iron and Steel in the 1980s: The Crucial Decade," Chase Econometric Associates, Inc., Washington, D. C., Apr. 19, 1979.
[17]U.S. Bureau of Mines, Iron and Steel, MCP-15, July 1978, p. 25,
[18]R. K. Sharkey, et al., op. cit.
[19]U.S. Bureau of Mines, op. cit., p. 23.

they have been projected through 1990 using the Data Resources, Inc., (DRI) long-term macroeconomic model. The DRI model provides alternative growth paths for the economy. The higher growth rate scenario is termed "trend," which is a stable growth long-run simulation of the DRI quarterly model of the U.S. economy, and a lower growth rate is termed "cycle," which is a less optimistic view of long-term growth embodying periods of recession and strong growth.'"

The reason for the high-demand forecast of Wyman can be found in several unusual, but perhaps ultimately correct, underlying assumptions:

> In assessing the real amount of steel usage associated with the U.S. economy, one must count both the indirect imports of steel and the steel used to construct the factories in which the foreign cars used in the U.S. were built. Similarly, steel used for overseas plants that exported steel directly to the U.S. must be included, as well as the shipyards which were "exported" from the U.S. In short, we end up noting that since 1955, i.e., since capital spending of the industrial world began to outpace that of the U. S., domestic steel consumption statistics became progressively understated.
>
> . . . whereas it typically is assumed that steel consumption has grown by 2.39 percent annually since 1955, we think it, in fact, has grown by more, and perhaps by as much as 3.26 percent. The latter figure still would be well below the actual 5.15 percent annual growth for the Free World . . . Thus, our calculations indicate that U.S. steel consumption grew 36.7 percent less quickly than that of the Free World (instead of 53.6 percent). Steel consumption of the U.S. should have grown at a slower rate than that of the Free World because the U.S. is the more mature economy and because substitution of steel by other materials is probably much more advanced in the U.S. than in other areas. However, a U.S. consumption growth rate of less than half that of the Free World, as the traditional statistics show, is much harder to understand than a growth rate of somewhat less than two-thirds of the Free World's. Therefore, we think our estimated growth rate is more plausible than the traditionally assumed growth rate for steel consumption in the U.S.[21]

[20] R. K. Sharkey, et al., op. cit.

There are few domestic steel production capacity projections. Such projections involve major uncertainties: the extent of import penetration and of investment, modernization, and expansion in domestic capacity. World Steel Dynamics[22] has projected domestic steel industry capacity at 106.6 million tonnes in 1985. Chase Econometric Associates[23] estimates capacity will be 117.8 million tonnes in 1986 and 129.6 million tonnes in 1990, and industry" itself forecasts 100.7 million tonnes in 1985 and 109.7 million tonnes in 1990. The industry forecast assumes that a substantial modernization and expansion program takes place (see ch. 10).

To compare the capacity and demand projections, it is necessary to assume an operating rate; a 90-percent operating rate assumption yields a realistic production level. The demand projections exceed those for domestic production, and the difference is made up by imports. Most forecasters assume some level of imports, but Tribendis and Clark used their modeling technique to generate imports.[25] Their model predicted an import level of 18.1 million tonnes for 1979, when the actual value was 15.9 million.[26] In their moderate-growth case and without import controls other than the trigger-price mechanism, imports capture 26 percent of the domestic market in 1985, a very high fraction; domestic steel shipments would then be 90.1 million tonnes. If they assume a lower level of imports, 141 percent, domestic shipments would be 104.2 million tonnes in 1985. AISI forecasts assume a 15-percent import level, which results in domestic shipments of 102 million tonnes in 1985.

[21] Wyman, op. cit. Wyman arrived at his U.S. steel demand projections by extrapolating 1956-76 data by use of "best fit" curves.
[22] World Steel Dynamics, Apr. 25, 1979.
[23] M. F. Elliot-Jones, op. cit.
[24] American Iron and Steel Institute, op. cit.
[25] Tribendis and Clark, op. cit.
[26] *American Metal Market*, Jan. 31, 1980.

The various supply-demand projections suggest two alternate possibilities for the next 10 years.

1. The AISI low-demand-growth (1.5 percent) forecast with current levels of imports (15 percent), if incorrect, could lead to inadequate domestic steel capacity—if demand is higher because of a substantial capital-spending period or faster economic growth, for example. With 1990 steel consumption of 137 million tonnes (forecast by Chase Econometrics and DRI) and capacity of 122 million tons (by AISI), imports would be 20 percent, or 27 million tonnes; this would be about 50 percent more than the maximum of actual imports to date. If the world steel oversupply of the past few years does not persist, and this is quite likely, then imports would be both costly and difficult to obtain, Operating rates and profitability for the domestic industry would be high, particularly if Government policies allow domestic prices to rise to meet high import prices. The AISI forecast presumes a substantial modernization and expansion program for the next 10 years. Without such a program domestic capacity would be only 85 million tonnes in 1988 (AISI). With a high demand of 137 million tonnes, this would lead to a more than 44-percent level of imports in 1990.

2. Alternatively, the domestic capacity in 1990 might be greater than the AISI forecast. This could result from aggressive nonintegrated plant construction and possibly from an influx of foreign capital into steelmaking. If the Chase Econometrics capacity forecast of 130 million tonnes is coupled with the low-demand forecast of AISI, then either imports would drop to 7 percent with a domestic operating rate of 90 percent or operating rates would decrease to 82 percent while imports are maintained at 15 percent, If the Chase capacity forecast is coupled with their high-demand forecast of 137 million tonnes, the 15-percent import level is compatible with a domestic operating rate of 90 percent.