CHAPTER 9

Creation, Adoption, and Transfer of New Technology

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Summary

The domestic steel industry has a well-established record for generating product innovations, but it is less inclined to generate new steelmaking processes. The industry prefers to adopt proven technologies that have a record of successful commercialization. Even then, its adoption rates for new products, such as one-side galvanized steels, is very good; but it lags in adopting new process technologies, such as continuous casting and even the basic oxygen furnace. This lag is mainly a result of aging plant, poor industry growth, and lack of capital.

To the extent that adoption rather than creation reduces risk and R&D costs and provides near-term payoffs, it is a useful approach. But it also has major drawbacks: it leads to industry dependence on technologies that may be poorly suited to domestic needs; it reduces learning opportunities for innovative applications; and—most importantly—it does not enable the industry to stay ahead in the international market. Independent creation of new technologies and their successful adoption would enable the steel industry to gain technological advantage, rather than merely achieve delayed parity, This advantage would enhance the industry's competitive position in both domestic and international markets.

R&D expenditures by the domestic steel industry, as a percentage of sales, have declined over the years and are lower than in most other basic industries in the United States. The industry's basic research effort is particularly small. The low level of steel industry R&D may be attributed to a number of factors, including cautious management attitudes towards research, the high cost of demonstration projects, the industry's declining share of the domestic market, high regulatory costs, and low profitability.

Steel industry R&D has very little Federal support and is complemented by only a limited amount of steel R&D carried out by the Government and universities. Foreign steel R&D, on the other hand, is generally in a more vigorous state because of larger budgets and stronger government support, particularly for high-risk projects whose likely benefits promise to be widespread. Some foreign steel industries also benefit from the work of multisectoral steelmaking research institutes.

Domestic steel technology exports are limited. They are largely handled by equipment firms and are mainly in the area of raw materials handling. Foreign steel industries are increasing their efforts in technology transfer in order to offset declining steel product exports. To a much greater degree than domestic steelmaker, foreign companies have design, consulting, and construction departments that aggressively pursue the sale of both hard and soft technology to other nations, particularly the less developed countries (LDCs). Japan, West Germany, Austria, and Great Britain are major exporters of innovative steelmaking technologies.

Role of Technology in Solving Industry's Problems

In many industrial sectors in the United States and in foreign steel industries, technology is viewed as one of the principal means of reducing costs, gaining competitive advantage, and meeting societal needs and objectives. Some U.S. steel companies, however, are ambivalent and occasionally negative toward new technology and innovation. These attitudes are barriers to the development and adoption of new technology. Another impediment is the lack of emphasis on basic and applied research. This short-range orientation may result in failure to develop beneficial new technologies and in slow adoption of successful foreign innovations.

Many steel executives consider theirs to be a classic example of an industry characterized by a slow rate of technological change. They firmly believe that innovation is a risky undertaking with uncertain returns and that purchasing proven technologies is more cost efficient. This view, however, does not take sufficient account of the many recent major technological changes in steelmaking or of the changing competitiveness of the domestic steel industry.

Industry spokesmen contend—with considerable justification—that the rarity of major technological changes in the steel industry results from severe financial difficulties which prevent the construction of new facilities based on new technologies. However, not even increased capital availability and profitability—perhaps brought about with the assistance of appropriate Government policies—would ensure vigorous technological innovation unless the prevailing industry attitude toward new technologies also changes.

The robust and highly competitive Japanese steel industry can be used as a model of the maximum use of new technology: it achieved its premier position by applying innovative processes widely and improving them constantly. The real lesson of the Japanese experience, however, is that if Government policies facilitating capital formation are combined with a positive industry attitude toward the adoption of new technology, the widespread use of new steelmaking processes will indeed take place.

The U.S. steel industry needs new technology to cope with the changing nature of the economic, social, and political world in which it operates. New technology can improve the competitiveness of domestic steels with respect to quality and cost; it can also reduce industry vulnerability to inflation and other external factors. New and innovative technologies, some already commercially available and others with a significant likelihood of successful development and demonstration, offer potential for:

- reducing energy consumption, including the use of coke;
- making greater use of domestic low-grade coals;
- reducing production costs as a result of improvements in process yield (although yield improvements will also put upward pressure on the price of scrap):
- using more domestic ferrous scrap and other waste materials containing iron;
- improving labor productivity;
- reducing capital costs per tonne of annual capacity;
- shortening construction time of new plants; and
- allowing greater flexibility in using imports of certain raw materials and in importing semifinished rather than finished steel products,

Although new and improved steel technology, alone, is not sufficient to reverse unprofitability and inefficiency, it is an essential ingredient for the future economic health and independence of the steel companies.

Parity Versus Advantage

New technology may be developed through two processes: by true innovation, consisting of the creation and first successful commercial use of new technology: or by the adoption of innovations created by others. For production processes, most domestic firms stress adoption rather than innovation. They argue that the cost and risks of innovation outweigh the benefits and that it is cheaper in the long run to buy proven technology than to create it. Although the innovation process does in fact produce failures as well as successes, it also offers an opportunity for gaining the competitive advantages of earlier market penetration, cost reductions, and the possible sale of new technology.

Strictly economic analyses of the creation and adoption of new technology ignore two very important issues: the unique circumstances of the domestic steel industry, and the benefits of an ongoing learning process. Innovations from external sources, especially foreign sources, may not lead to new technologies appropriate to the particular characteristics and needs of the domestic steel industry. Domestic steelmaker understand this with regard to raw materials and products, but they undervalue the importance of developing unique process technologies, shaped by domestic resource opportunities. Furthermore, the domestic regulatory climate should be viewed as a constraint which can be dealt with most effectively through the creation of new technology specifically geared to meeting its requirements.

The industry admits that there is a gap in the adoption of new technologies between the United States and its competitors, but it denies that a knowledge gap exists. ' The industry gives little weight to the consideration that the foreign knowledge base is responsive to foreign needs and may be better suited to particular foreign conditions. A uniquely domestic steelmaking knowledge base cannot exist without domestic innovation based on research (basic and applied), development, and demonstration that are shaped by the current and anticipated needs and opportunities of domestic steelmaker. Even the Japanese, once noted for using foreign research and innovations, have now shifted their emphasis to creating their own.

The secondary effects of innovation from greater R&D experience are also lost in adopting rather than creating new technologies. The lessons learned in originating technology allow a firm or industry to move more rapidly up the learning curve of a major innovation. Japanese steelmaker, for instance, have benefited greatly from a constant flow of incremental innovations that spill over from their extensive experience with a major new technology and from their high level of improvement-oriented R&D on steelmaking software. These incremental innovations, based on new applications rather than on new fundamental knowledge, can significantly reduce production costs and increase productivity. The Japanese experience with continuous casting (discussed in a later section) is the most recent example of turning another nation's innovation into a host of incremental new technologies for use and sale. The U.S. steel industry, on the other hand, has relatively low levels of R&D, adoption, and experience with new technologies. As a result, the industry does not have the same opportunities for movement along learning curves or for incremental innovation.

Consequently, whatever new technology is purchased from foreign sources still leaves the purchaser one step behind the originator. By the time all is learned about the innovation, the foreign source is well on its way to exploiting the next one. It may be true that there is equality of knowledge among the world steel industries concerning fundamental innovations, yet it is an error to believe that knowledge about innovations is equivalent to innovating. Waiting to use someone else's innovation is a strategy likely to spell competitive loss in the long run. It takes years for steel plants to be designed and built, and those who innovate tend to stay ahead of their competitors.

IN. A. Robbins, proceedings of "The American Steel Industry in the 1980's—Crucial Decade."' AISI, 1979.

Major Versus Incremental Innovation

Possible technological solutions that might be considered for steel industry modernization are:

- to modernize existing operations by adding existing technology;
- to build new plants using the best available technology; or
- to develop and put in place at new plants radically innovative new technology.

These solutions differ in two major respects: in their capital costs, and in the amounts by which they can be expected to reduce production costs. The third, for example, is a high-cost, high-payoff solution; the second is somewhat less costly and somewhat less productive; the first is an incremental solution with incremental rewards. The choice among these solutions rests on how the costs and payoffs balance out,

The first solution, the extension of existing operations with available, improved technology (such as continuous casting), is generally considered to have the best balance between capital costs and reduction of production costs. The second option, involving construction of completely new plants using existing technology, would involve high capital costs that cannot be expected to be sufficiently offset by the limited production cost reductions it would bring. The third option, construction of new plants based on radically innovative technology, will not be technically feasible for at least a decade; once feasible, however, there is a possibility that high capital costs could be sufficiently offset by significant production cost savings. Thus, the first option, complemented with a vigorous research program in radical steelmaking innovations, could prepare the industry now for short-term revitalization with the potential for long-term, fundamental modernization.

Several important considerations argue against constructing new facilities using available incremental improvements. The major constraints are the high capital costs of greenfield construction and the need for immediate modernization and expansion. The capital costs of greenfield sites, estimated to be well over $1,100/tonne of annual capacity, * are very high compared to the other two investment alternatives—"roundout" expansion costing about $550/tonne, and nonintegrated (minimill) expansion costing only $154 to $275/tonne of annual capacity. Given the high cost of capital, any reduction in steel production costs gained by using advanced steelmaking technologies in greenfield integrated plants is outweighed by significant increases in financial costs. The domestic industry's low profitability would make it difficult to obtain the necessary funds for this type of expansion.

The industry's immediate need for capacity replacement and expansion** also makes construction of new integrated plants less attractive than the roundout option. Conservative estimates place the time required for design, permit approval, and construction at about 8 to 10 years, although plans exist for one greenfield plant to be built in half that time. Such a timelag is incompatible with the industry's current needs, and the long construction time would also dim the prospect of achieving technological parity through greenfield expansion: during construction, major steelmaking innovations could become available for commercial application elsewhere. Furthermore, once a substantial number of new domestic plants are in place, integrated steelmaking technology in the United States would be static for some years. The lifetime of such plants is long, and the need for additional steelmaking capacity will have been largely met for the immediate future; by the time new capacity is needed, it is probable that other nations will have moved ahead with newer technologies.

*Detailed analyses of these costs are presented in ch. 10.
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Research and Development

Technological supremacy is most likely to be achieved through deliberate and continuous research, development, and demonstration. A recent analysis of radical steelmaking technologies suggests that several offer sufficient economic advantages to merit further research. [2] These include direct steelmaking and direct casting of steel. However, with a leadtime of approximately 10 to 20 years for the development of these and other radically innovative technologies, they would not have any impact on the industry's current problems. Nevertheless, commitment to long-term technological competitiveness would dictate proceeding immediately with R&D activities aimed at developing and using radical steelmaking technologies. This position has been summarized by Bela Gold:

> The very future of the domestic steel industry over the long run depends on intensive programs to develop such (radical technological) advances . . . . Such efforts must be combined with a more immediate program to modernize and expand the domestic steel industry through effective utilization of already available technologies as well as of relatively straightforward extensions of them. To do nothing—as is implied by the COWPS Report—or to wait until some miraculous new technological advances are developed (which could not be reasonably duplicated by foreign competitors in relatively short order) is likely to prove catastrophic not only for the U.S. steel industry, but also for related industries and major geographical areas.

In addition to developing radical innovations in the long term, it is important for the domestic steel industry to adopt incremental innovations in the near term, using available steelmaking technologies. This approach would use the less costly roundout alternative for increasing capacity and would calI for constructing electric furnaces for use in combination with basic oxygen furnaces in nonintegrated plants (see ch. 10).

Long= Range Strategic Planning for Innovation

A number of industry difficulties, presented in chapter 4, might have been less severe had there been a well-prepared strategic plan for technological innovation. These problems include:

- increased production costs and declining eminence after World War II;
- lack of exports to meet rapidly rising steel demand in Third World and industrialized nations;
- lack of emphasis on exporting proven technology, which could have justified new investments in R&D and innovation activities:
- the large integrated steel producers' lack of response to demographic changes and to opportunities for using scrap in local markets by means of minimills; and
- lengthy and costly resistance to compliance with environmental regulations.

A number of studies[4] suggest that one of the principal reasons for the lack of U.S. steelmaking innovation lies in the lack of industry commitment to planning for technical innovation. Most domestic steel companies appear to conduct strategic economic planning, but few pay any attention to technological planning. This is reflected by their relatively low investments in R&D and pilot and demonstration work, and by their heavy reliance on foreign innovations. These factors

[2] See Julian Szekely, "Radically Innovative Steelmaking Technologies. report submitted to OTA (no date), and ch. 4 of this report.

[3] Bela Gold, "Some Economic Perspectives on Strengthening an Industry's Technological Capabilities: With Appllications to the U.S. Steel Industry, " prepared for the Experts Panel on Exploring Revolutionary Steel Technologies, Office of Technology Assessment, meeting at the Massachusetts Institute of Technology. Apr. 25, 1978.

[4] For example, B. Gold, "Steel Technologies and Costs in the U.S. and Japan, " Iron ond *Steel* Engineer, April 1978; and J. Aylen, "Innovation. Plant Site and Performance of the American, British and German Steel Industries, " Atlanta Economics Conference, October 1979.

combine to form a barrier against innovation. In addition, domestic firms are inclined to sell promptly whatever innovative technology they create: they maximize immediate profits, instead of keeping the technology proprietary long enough to gain a competitive advantage.

Domestic steel industry management must examine the consequences of continuing to concentrate on: low-risk, incremental technological changes to the exclusion of high-risk, major changes; product rather than process changes; promotion of R&D managerial personnel from within rather than recruitment from other industries, universities, and Government; the enhancement of raw material (iron ore and metallurgical coal) profitability; traditional domestic markets; and defensive rather than aggressive business strategies.

Domestic Funding and Structure

The U.S. position of leadership in steel production and technology through World War II and the decade thereafter was achieved as much by its size and economies of scale, and by its organization and business practices, as by technical innovation. A review of the principal technological contributions made by the U.S. steel industry during the past several decades indicates a practical orientation toward labor efficiency improvement and product development, According to an industry survey of a relatively small sample of large steel companies in 1975, 81 percent of steel industry R&D funds were allocated to development, 12 percent to applied research, and less than 7 percent to basic R&D work (table 107).[5] However, the annual National Science Foundation (NSF) data series, R&D in Industry, indicates that less than 2 percent of steel industry R&D spending is in basic research, compared to 3 percent for all domestic industry and nearly 4 percent for nonferrous metal companies, *

Table 107.—Allocation of R&D Funding by Selected Sectors of Industry, United States, 1975

	Percent basic	Percent applied	Percent development
Steel	6.9	12.3	80.8
Aerospace	1.5	39.2	59.3
Automotive	0.1	83.4	16.4
Chemicals	10.9	37.9	51.2
Electronics	2.1	27.0	70.9
Instruments	5.3	7.7	87.0
Office equipment, computers	1.9	5.3	92.8
Paper	1.4	21.1	77.5
Textiles	0	9.0	91.0

SOURCE National Science Foundation, *Support of Basic Research by Industry, 1978*, (based on sample of companies belonging to Industrial Research Institute (I RI) and a survey by IRI)

According to NSF data (table 108), steel industry R&D increased by about 10.2 percent annually from 1963 to 1977, from $105 million to $256 million. However, annual real R&D spending increased by only about 22 percent during this entire period. For all U.S. industry, the growth in real R&D spending during the same period was about 18 percent.[6] More importantly, expressed as a percentage of sales, steel research actually declined from 0.7 to 0.5 percent during the same period.

R&D data for several steel producers are given in table 109. These data illustrate several points: R&D spending as a percentage of profits is rather large and closer to other industries than R&D spending as a percentage of sales; alloy / specialty steel producers spend more than integrated companies on R&D; and the trend of decreasing R&D spending in the past few years shown by NSF data is confirmed by company data.

‘The following comment on basic research appears to summarize the situation well for the domestic steel industry: “Fundamental research is the most prominent casualty of the American industry’s need to adapt to the realities of high costs and low profits, a situation that has prevailed and worsened over the past two decades. “ (33 Metal Producing, June 1979.)

*When using NSF data, it should be kept in mind that they tend to overstate steelmaking-related R&D somewhat. First. nonmetals R&D conducted by diversified steel companies appears to be included in the NSF data for ferrous industry R&D. Secondly, the ferrous industry category also contains R&D foundries and other metals-processing facilities not included in the scope of this study. Nevertheless, since NSF data are the best available, they will be used.

‘National Science Foundation, R&D in Industry, 1977.

Table 108.—U.S. Steel R&D Spending (dollars in millions)

Year	Ferrous industry R&D spending	Percent of ferrous industry sales	Federal R&D spending	Percent of total Federal R&D spending	Steel industry environmental capital spending	Ferrous industry R&D – steel industry environmental capital spending
1963	$105	0.7	$2	1.9		—
1966	136	0.7	3	2.2	$56	2.43
1967	134	0.7	1	0.7	94	1.43
1968	134	0.7	1	0.7	102	1.31
1969	135	0.7	2	1.5	138	0.98
1970	148	0.7	1	0.7	183	0.81
1971	142	0,7	2	1.4	162	0.88
1972	144	0.6	3	2.0	202	0.71
1973	159	0.5	4	2.5	100	1.59
1974	177a	NA	NA	2,2a	267	0.66
1975	211	0.6	3	1.4	453	0.47
1976	252	0.6	4	1.6	489	0.52
1977	256	0.5b	4	1.5	535	0.48
1978	259	0.5	5	1.9	458	0.57

NA = not available
acalculated from total of $181 million, assuming $4 million for Federal spending
bFirst 8 companies 0.5 next 12 companies 0.6.

NOTES 1) Federal R&D spending is only for R&D in company laboratories, it does not include Federal R&D at Government facilities
2} NSF data based on sample of companies in the following SIC categories 331 blast furnace and basic steel products 332 iron and steel foundries 3,398 metal heat treating and 3,399 primary metal products not elsewhere classified. only the first is the traditionally defined domestic steel Industry as used in this assessment and for which AISI data apply One consequence of this is probably that R&D spending for just the 331 category is lower than that Indicated by the above figures particularly on a percent of Industry sales basis

SOURCES R&D data from NSF environmental capital spending from AISI

Table 109.—R&D Spending of Several U.S. Steel Companies, 1976-78

Company	Millions of dollars			Percent of sales			Percent of profits		
	1976	1977	1978	1976	1977	1978	1976	1977	1978
Integrated									
U.S. Steel	**$52.2**	**$49.8**	**$52.5**	0.6	0.5	0.5	66.2	36.1	21.7
Bethlehem	43,7	42.7	37.1	0.8	0.8	0.6	26.0	-9.5	16.5
Republic Steel	16.3	16,8	15.1	0.6	0.6	0.4	24.7	40.9	13.5
Average				0.7	0.6	0.5	40.0	22.5	17.2
Alloy/specialty									
Allegheny Ludlum	9.2	10.7	13,3	1.0	1.1	1.0	131.4	42.1	34.9
Carpenter Technology	7.5	9.2	9.4	2.8	2.8	2.4	30.3	32.2	27.8

SOURCES Business *Week* July 3 1978 July 2 1979, and company annual reports

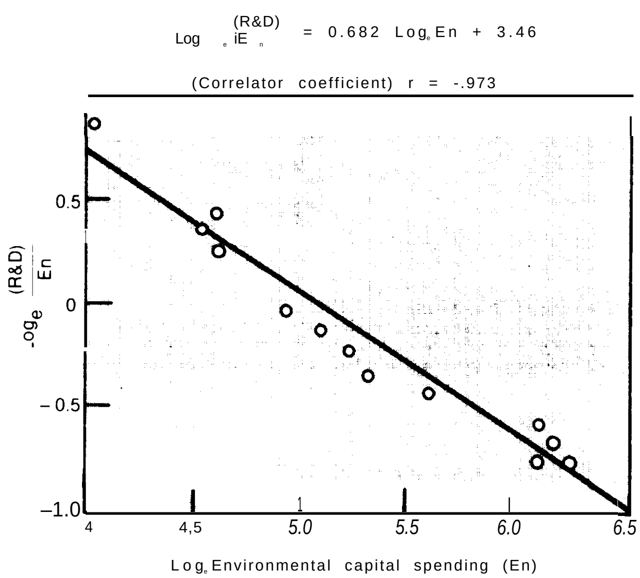
During the past several years, steel industry expenditures on research aimed at improving technological performance and reducing production costs have been lower than aggregate steel industry R&D spending levels indicate. This is because some R&D must be directed toward regulatory research necessitated by the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) policies. According to one steel R&D executive:

> There is a trend toward more defense tvpe research . . . more time being spent on shorter range projects and projects designed to meet government mandates and regulations, and less time being spent on the kinds of long-term, high risk, innovative projects which will lead to the new ways of making steel in the future.
>
> Part of the problem is that what we are doing with this money is not what everybody would call research and development . , . but is pointed more toward short term objectives for a variety of reasons and not so much on the real innovative work and the fundamental research work that you might define as research and development .-

'Proceedings, "The American Steel Industry in the 1980's—The Crucial Decade, "' AISI, 1979.

There is no obvious relationship between R&D spending and environmental capital expenditures (see table 108), but the ratio of industrial R&D funding to environmental spending does appear to be related to the level of capital spending (figure 36). As capital spending for environmental needs increases, R&D spending decreases relatively. That such a statistically significant relationship should hold over the 13-year period for aggregated industry data is curious: nondiscretionary environmental spending because of governmental regulations appears to be controlling the level of R&D spending. However, since environmental spending is in the capital category and R&D spending is in the expense category, the cause-effect relationship, if one exists, may not be as simple as this curve implies.

Figure 36.— R&D and Environmental Expenditures Steel Industry, United States, 1965-78



SOURCE Off Ice of Technology Assessment from data in table 108

The rate of R&D spending is not uniform among segments of the domestic steel industry. Alloy/specialty mills often allocate a larger proportion of their sales and profits to R&D than do large integrated steel companies (see table 109). Furthermore, integrated steel companies that have diversified are channeling a growing proportion of their R&D funds into nonsteel R&D spending. Using NSF data, apparent nonsteel R&D spending by steel companies increased between 1963 and 1977 from 14 to 32 percent of total R&D spending (table 110). Thus, R&D spending as a percentage of sales for diversified steel companies declined by even more than the data in table 106 indicate. Finally, it appears that nonintegrated steel companies spend much less on

Table 110.—Measure of Diversification of R&D Efforts in Ferrous Companies (dollars in millions)

	Ferrous industry R&D spending	Ferrous product field spending	Apparent nonferrous R&D spending of ferrous companies	
			Dollars	Percent of total
1963	$105	$ 90	$15	14.3
1966	136	104	32	23.5
1967	134	117	17	23.5
1968	134	119	15	11.2
1969	135	125	10	7.4
1970	148	127	21	14.2
1971	142	114	28	19.7
1972	144	137	7	4.9
1973	159	158	1	.6
1974	177	156	21	11.9
1975	211	144	67	31.8
1976	252	163	89	35.3
1977	256	172	84	32.8

SOURCE National Sc!ence Foundation

R&D than the other industry segments, although no published data on spending levels are available to document this.

In addition to significant within-industry R&D spending differences, there are major between-industry differences. Ferrous metals R&D as a percentage of net sales has been lower than that of other basic industries for **15** years or more. Between 1966 and 1977, ferrous metals R&D was only one-sixth to one-half the level of other basic industries like nonferrous metals and chemicals (table 11 l). * Steel industry R&D also ranks very low among a broader range of manufacturing industries—at about 20 percent of the all-manufacturing average, it ranks above only the food, textile, and lumber industries. Similarly, the number of R&D scientists and engineers per 1,000 employees is smaller for steel than for any other industry except for textiles and apparel, about 15 percent of the average for all reported industries (table 112).

Low R&D levels relative to other industries and declining R&D relative to sales can be attributed to a number of economic factors. The pilot and demonstration plant stages of steelmaking research are very expensive compared to R&D in other sectors of the economy, and the steel industry is thus exposed to a much greater degree of risk than are other industries. The decline in the steel industry's share of the domestic market has also increased the market risk of capital-intensive R&D. Related to a declining market share has been a real decline in steel industry investments since about 1965 (ch. 3), which has narrowed the industry's choices among production processes and equipment. And finally, as steel profitability declined professional managers of iron and steel companies have exercised considerable caution with respect to R&D activities. In the case of conglomerates, these managers must allocate R&D funds among various activities: they are undoubtedly influenced by profitability trends in these activities.

Nonindustry R&D.— Steel industry R&D is complemented by only limited efforts else-

'Steel industry sources claim that the record understates actual research efforts, since considerable research is for operational and tax accounting purposes undertaken in production departments and reported as a production expense, See, for instance, Frederick C. Lagenberg, president, American Iron and Steel Institute, "United States Steelmaking Technology-Second to None, " in *Proceedings of the* Steel Industry Economics Seminar, AISI, 1977, p. 43.

The same tax laws also apply to other industries, and therefore similar reporting practices could prevail in other industries although the extent probably varies from industry to industry. Valid conclusions can be made about the comparative standing of steel industrv R&D.

Table 111.— R&D Funds as Percentage of Net Sales in Ferrous Metals, Nonferrous Metals, Chemicals, Petroleum Refining, and Stone, Clay, and Glass Products Industries, United States, 1963-77

Year	Ferrous metals	Nonferrous metals	Chemicals	Petroleum refining	Stone, clay, and glass products
1963 ., ...	0.7	1.1	4.3	1.0	1.6
1966	0.7	0.8	4.4	0.9	1.5
1967	0.8	1.0	4.6	0.8	1.8
1968	0.7	1.0	3.8	0.8	1.6
1969	0.7	1.0	3.9	0.9	1.7
1970	0.7	1.0	3.9	1.0	1.8
1971. , ...	0.7	1.0	3.7	0.9	1.8
1972	0.6	0.9	3.6	0.8	1.7
1973	0.5	0.9	3.5	0.7	1.7
1974. , ...	0.5	1.0	3.5	0.6	1.7
1975	0.6	1.2	3.7	0.7	1.2
1976	0.6	1.2	3.7	0.6	1.2
1977	0.5	1.1	3.6	0.7	1.2
Annual averages					
1966-77, ...	*0.6*	1.0	3.8	0.8	1.5
1968 -72.	0.7	1.0	3.8	0.9	1.7
1973 -77.	0.5	1.1	3.6	0.7	1.4

SOURCE National Science Foundation

Table 112.—Competitive U.S. Trade Performance in Comparison With R&D

	U.S. share of exports, 1962	Company R&D as percentage of sales, 1960	Federal R&D as percentage of sales, 1960	Total R&D as percentage of sales, 1960	‘Scientists and engineers engaged in R&D as a percentage of employment, January 1961
Aircraft	59.52	2.6	19.9	22.5	7.71
Scientific and mechanical measuring equipment	36.52	4.1	7.7	11.8	NA
Drugs	33.09	4.7	0.1	4.8	6.10
Machinery	32.50	2.7	1.6	4.3	1.39
Chemicals, except drugs	27.32	3.4	0.7	4.1	3.65
Electrical equipment	26.75	3.7	7.2	10.9	4.40
Rubber products	23.30	1.4	0.7	2.1	0.95
Motor vehicles and other transport equipment	22.62	2.4	0.7	3.1	1.14
Other instruments	21.62	4.4	2.1	6.5	NA
Petroleum refining	20.59	1.0	0.1	1.1	2.02
Fabricated metal products	19.62	1.0	0.5	1.5	0.51
Nonferrous metals	18.06	0.9	0.2	1.1	0.64
Paper and allied products	15.79	0.7	0.0	0.7	0.47
Lumber, wood products, furniture	12.26	0.5	0.1	0.6	0.03
Textiles and apparel	10.26	0.4	0.2	0.6	0.29
Primary ferrous products	9.14	0.6	0.0	0.6	0.43
Rank correlation with first column		0.84	0.73	0.92	
Linear correlation with first column		0.59	0.84	0.90	

NA = not available

SOURCE D B Keesing, “The Impact of Research and Development and U S Trade, ” *J. Political Economy* 75, 38-48, 1967

where in the private sector and in Government and academic institutions. The industry relies heavily on its supplier industries and companies for technological developments, but for a variety of reasons, including the low level of new steel plant construction in the United States, these supplier companies have been losing their share of the world market and are themselves spending less on R&D. Federal contributions to support steel R&D have also been meager. On average, since 1966, Federal agencies have spent $3 million annually, or 1.9 percent of total steel industry R&D, to support ferrous metals and products R&D (table 108), In fact, Federal support of ferrous metals R&D is lower than for any other category of industrial R&D (table 113). Commenting on this imbalance in Federal R&D, the administration’s major policy statement on the steel industry, the so-called Solomon report, notes:

> Despite the fact that steel is an important basic industry, Federal contributions to the steel industry’s R&D expenditures are low, representing only 1.9 percent of the industry’s R&D spending—compared with 9 percent for the chemical industry, 14 percent for the machinery industry, 47 percent for the electrical equipment industry, and 78 percent for the aircraft industry,[8]

Table 113.—Federal Support of Industrial R&D, 1977

	Federal R&D funds (percent of total R&D)
Ferrous metals and products	1.9
Nonferrous	7.4
Aircraft and missiles	77.8
Electrical equipment and communication	45.5
Motor vehicles	12.5
Chemicals	*9.0*
Instruments	11.1

SOURCE National Science Foundation, R&D in Industry, 1977

Academic institutions also make a limited contribution to steel R&D. The American Iron and Steel Institute (AISI) provides about $1 million annually for university research projects. Federal funding for steel-related R&D at universities may approximate this level, al-

“Solomon Report, 1977.

though no detailed data on university research in ironmaking and steelmaking appear to be available. The relatively low level of academic effort devoted to this area can be inferred, however, from the research interests of metallurgy and materials faculty: in a 1976 survey, thought to be representative of the past decade, less than 3 percent of faculty members listed interests in the areas of iron, steel, or ferrous research.[9] There are larger numbers of academic researchers working on subjects applicable to the steel industry than this figure would suggest, but they may be only indirectly concerned with iron, steel, or ferrous metals research. Low levels of steel research by professors also reflect the poor image steel research has in the academic community. The National Academy of Sciences has identified this low level of academic activity in materials processing as a barrier to progress and innovation:

> Materials-processing technology also suffers from insufficient attention in our engineering colleges. Fewer than 10 percent of the materials faculty (who themselves comprise only a small fraction of the engineering faculty) are experts in materials processing and manufacturing. These fields do not enjoy the status accorded some other academic disciplines, and little current research in the schools is relevant to major developments in materials processing. The near absence in our universities of research in materials-processing and manufacturing technology denies the country a potential source of new ideas and innovation. Furthermore, it means that the universities are not exposing young people to current advances in the field.[10]

It is apparent that steel R&D must be strengthened, and that current R&D must be redirected, for the industry to lower its overall costs, Some of the emphasis on improving labor productivity should be shifted toward attaining substantial raw material and energy savings through technological changes. Capital cost reductions are also necessary. During the late 1960's, U.S. raw materials costs were low and labor costs high compared to European producers.[11] Under such conditions, it was reasonable that considerable U.S. steel R&D effort—mainly innovation in operating efficiency—centered on labor-intensive operations such as rolling. But a heavy emphasis on improvements in labor productivity may no longer be appropriate. The costs of energy, materials, and capital have increased during the past decade to such a degree that they now deserve more prominence in R&D strategies. This inappropriate allocation of steel R&D effort is especially serious in view of the U.S. steel industry's need to modernize. More intensive research into and use of continuous casting and other raw-material-saving innovations would have made this need less pressing. *

Foreign R&D Activities

Foreign steel-related R&D activities differ radically from those in the United States: they have significantly larger budgets; they are conducted with considerable government assistance; and they are often undertaken in multisectoral steel production research institutions,

Foreign steel producers spend more on R&D than those in the United States. The U.S. steel industry's steel-related R&D expenditures have been about 0.5 to 0.6 percent of sales in recent years; in Japan, they are slightly more than 1 percent. Furthermore, Japanese steel-related R&D expenditures

[9] *Metallurgy/Materials Education Yearbook*, American Society for Metals, 1976. This represents 27 of the 936 listed faculty members, 6 of whom were at Canadian schools; the remaining 21 were at 16 U.S. schools. There were 92 schools represented in the survey.

[10] National Academy of Sciences, *Science and Technology—A Five Year Outlook*, Freeman, San Francisco, Calif., 1979, p. 322.

[11] A. K. McAdams ("Big Steel, Invention and Innovation Reconsidered," *Quarterly Journal of Economics*, 91:457-82, August 1967) provides the following data:

costs	*United States*	*ECSC*
Labor, total	40%	20%
Energy, materials, supplies	45	70
Investment and interest	10	5
Miscellaneous	5	5

*It is interesting to note that U.S. Steel Corp. in May of 1977 formed a task force to develop a comprehensive procedure to ensure that potentially attractive new steelmaking processes are effectively evaluated.

have grown gradually but steadily over time (figure 37), even though Japanese steel sales and profits have declined since 1974. In 1974, steel R&D occupied 3 percent of the total number of researchers in Japanese industry, and accounted for 5 percent of total industry R&D spending;[12] in 1973-75, the equivalent figures for U.S. steel R&D were 0.9 and 1.3 percent, respectively.[13] As in the United States, however, steel R&D ranks lower than R&D expenditures in other sectors of the Japanese economy. French and West German steel industry R&D as a percentage of sales is roughly similar to U.S. levels,[14] but there is somewhat more difference in R&D spending per net tonne of raw steel produced; in 1972, the United States spent $1.30, the European Community $1.46, and Japan $2.26 per tonne of steel output.[15]

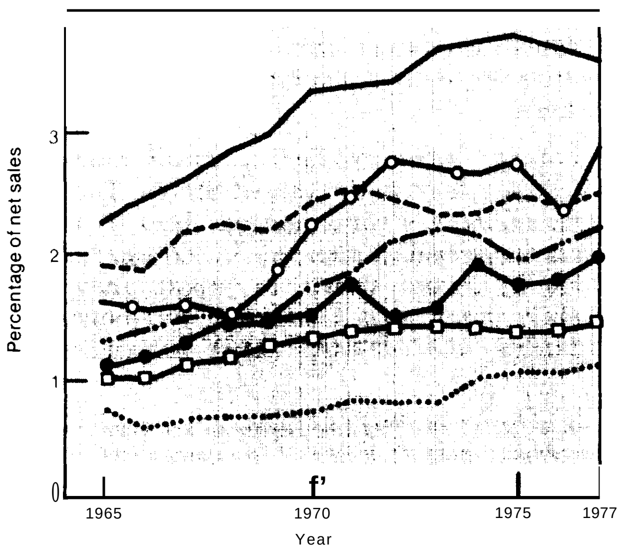
[12] Agency for Industrial Science and Technology, 1977.

[13] National Science Foundation, op. cit.

[14] Hajime Eto, "Relationship Between Basic and Improvement Innovations—Development of Innovation Policy of Japan," presented at IIASA, December 1979.

[15] H. Mueller, "Factors Determining Competitiveness in the World Steel Market," Atlanta Economic Conference, October 1979.

Figure 37.— R&D Expenditures in Japan as Percentage of Net Sales by Sectors



SOURCE Japanese Government 1979

Regional and intersectoral (industry, university, government) steel R&D cooperation is typical in foreign steel-producing countries, but not in the United States. Here, joint R&D efforts by domestic steel producers are inhibited by Federal antitrust policies, but in many other steel-producing countries such cooperative efforts are encouraged. Further, much foreign steel research is undertaken by research institutes jointly supported by industry, university, and government. The Steel Directorate of the Commission of European Communities has a mechanism for regional R&D coordination. It arranges for significant steel-related R&D funding, and the costs are shared among the steel companies and the member countries. At the present time, the annual funding level by the Steel Directorate, alone, is about $36 million. Member country governments supply $20 million of this funding, an amount about four times greater than the U.S. Government's support of steel R&D.

Japan

The Agency for Industrial Science and Technology (AIST) is the part of the Ministry of International Trade and Industry (MITI) that coordinates and influences R&D within Japanese industry. The stated purpose of AIST is the "promotion of R&D of industrial science and technology and diffusion of obtained results."[16] One of the many AIST programs, the national R&D program, deals with large-scale projects that require "a great deal of expense, risks and long-range period."[17]

When initiated in 1973, the policy criteria guiding the selection of projects were that:

- Projects should have a prospect for high social returns by providing technical advances for a wide sector of the economy.
- Projects should be unable to be undertaken by private firms because of "market failure," including an absence of profit motives and high risk.

[16] "Agency for Industrial Science and Technology," MITI, 1978.

[17] "Agency for Industrial Science and Technology, op. cit.

- Projects should use technologies that can be clearly specified: extensive basic research should not be required.
- Projects should be carried out cooperatively by universities, government laboratories, and industry; projects involving only one firm are usually rejected.[18]

One of the major AIST R&D projects has been the nuclear steelmaking program, with the goal of a commercial nuclear steelmaking capability by 2000. A sizable amount (about $54 million) was allocated for the first phase of the program in 1973-79, and project implementation continues on schedule.

Another part of AIST supports R&D activities in private industry. There are four components of this program:

- Subsidies for *R&D:* "The total subsidies granted in (the) past 29 years . . . amounts to approximately 40.2 billion yen ($168 million) for 4,112 programs."
- Tax credits for increased R&D expenditures: "If R&D expenses exceed the largest amount of such expenses of any preceding accounting periods since 1966, 20 percent of such excess amount may be deducted from the corporation tax. The maximum amount deductible is 10 percent of the corporation tax,"
- Low-interest loans: AIST plays an important role in allocating long-term loans through the Japan Development Bank to encourage the use of new technology developed by private enterprises. "The sum of loans furnished in 1976 was approximately 36 billion yen ($150 million) for 38 items."
- A research association for mining and manufacturing technology: "for the promotion of joint research among private companies and the research associations,"[19]

AIST has been conducting technology assessments since 1975; the Japan Industrial Technology Association also helps disseminate technical information by spreading R&D results achieved mainly by AIST laboratories and institutions. In addition, AIST carries out for industry a technological survey that defines R&D themes and describes ongoing R&D activities.

The AIST laboratories and institutes also play a direct R&D role. There are 16 of these, and many, such as the National Research Institute for Pollution and Resources and the Government Industrial Development Laboratory, carry out work of interest to the steel industry. The Industrial Development Laboratory, for example, has a project on high-pressure fluidized reduction of iron ore, as well as one on coal gasification.

The Japanese steel industry, during the period since World War II, has shifted from basic research to very applied R&D. This shift, largely stimulated by demonstrated deficiencies in manufacturing and other technologies, set the stage for Japan's massive industrialization after the war.

> Japanese physicists developed high quality steel in the interwar period. But the Japanese production process of iron and steel was inefficient for mass production, and lack of quality control resulted in big variance of quality which cancelled out the theoretically calculated high quality. The basic innovation founded on great physical discoveries was found useless without suitable production technology.
>
> * * *
>
> A great deal of effort was [therefore] put into automation technology development rather than to improvement in quality of iron and steel itself.[20]

A recent survey of Japanese steel industry personnel, apparently conducted by MITI, found that the most significant changes for the iron and steel industry were expected to be a future de-emphasis on market-driven innovation and resource saving, and an increase in R&D in other fields. The latter would appear to indicate a trend toward diversification. Furthermore, nearly three-quarters of the industry personnel believed

[18] Ibid.
[19] Ibid.

[20] Eto, op. cit.

that there would be incremental innovation within 5 years, and 10 percent believed that there would be an epoch-making innovation in the next 10 years. There are, indeed, indications of a decline in private-sector R&D, which the respondents attributed variously to higher costs, greater risks, declining profits, and a global stagnation in both basic research and technical innovation.

West Germany

The Federal Ministry for Education and Science in West Germany plays a strong coordinating and sponsoring role in the area of industrial research. The attitude of the German steel industry is that basic research should be done in the universities and the development work in the industry. The West German Government apparently accepts this division of labor.

As in Japan, government support for steel-related R&D can also be found in West Germany. Government-funded projects are established and supported on a long-term basis. Four-year projects are normal, with renewal periods ranging from two to four years. Such support creates a large core of people to guide R&D projects to successful outcomes, and German technology in steelmaking and processing normally stays abreast of competition from other countries, This has helped West German steel plant equipment purveyors to capture a fairly large share of business from both developed and developing countries. Several research organizations also draw West German Government support to solve steel industry problems:

- Verein Deutscher Eisenhuttenleute (VDeh)
- Iron Works Slag Research Association (Reinhausen)
- Iron Ore Dressing Study Group (Othfressen)
- Iron and Steel Application Study Group (Dusseldorf) -

The aim of these groups is to find solutions to practical problems encountered by steel plant operators. Government funding is tied to close cooperation between these research organizations, the steel plants, and the senior faculty at the universities and polytechnical schools.

Sweden

The emphasis of Swedish R&D appears to be on the alloy and specialty steels and on the development of major steelmaking innovations that can be exported to foreign steel industries. Swedish research is particularly active in coal-based direct reduction, direct steelmaking processes, and plasma steelmaking.

In addition to significant, though recently declining, private-sector R&D, the government funds a number of research establishments. These include the Swedish Institute for Metals Research and the Royal Institute of Technology, both in Stockholm, and the Foundation for Metallurgical Research (Mefos). Mefos was promoted for the Swedish steel industry by Jernkontoret, the Swedish Iron Makers Association, which is owned collectively by the steel works of the country. Mefos has 65 employees and an annual budget of $3.8 million. About 50 percent of its annual expenditures, outside of contract research, come from the Swedish Government.[21] The foundation operates two full pilot plants, constructed and equipped for a total investment of about $16 million.

R&D and Trade Performance

The export performance of an industry increases with increasing levels of private and government R&D spending, as well as with increasing numbers of scientists and engineers engaged in R&D.[22] The data of tables 112 and 114, as well as more recent trade data, strongly suggest that increasing U.S. steel imports and decreasing participation in world

[21] *Steel Technology Bulletin*, Swedish Trade Office, December 1979,

[22] The causal relation of R&D in determining export performance was shown to be significant in W. H. Branson and H. B. Junz, "Trends in U.S. Trade and Comparative Advantage," *Brookings Papers on Economic Activity*, vol. 2, 1971.

Table 114.—U.S. R&D Intensity and Trade Performance

Description	R&D Intensity[a] (percent)	Trade balance exports-imports, 1976 (millions of dollars)	Description	R&D intensity (percent)	Trade balance exports-imports, 1976 (millions of dollars)
Above-average R&D intensity			Electric transmission equipment	2.30	798.1
Communications equipment. .	15.20	$ 793.7	Motor vehicles.	2.15	– 4,588.6
Aircrafts and parts	12.41	6,748.3	Other electrical equipment	1.95	311.2
Office, computing equipment . .	11.61	1,811.4	Construction, mining	1.90	6,160.4
Optical, medical instruments .	9.44	369.6	Other chemicals	1.76	1,238.5
Drugs and medicines	6.94	743.5	Fabricated metal products.	1.48	1,525.7
Plastic materials	5.62	1,448.0	Rubber and plastics	1.20	– 478.8
Engines and turbines	4.76	1,629.2	Metalworking machinery	1.17	736.4
Agricultural chemicals.	4.63	539.3	Other transport	1.14	72.1
Ordinance (except missiles)	3.64	553.0	Petroleum and coal products. . .	1,11	NA
Professional and scientific instr.	3.17	874.8	Other nonelectric machines .	1,06	3,991.3
Electrical industrial apparatus .	3.00	782.5	Other manufactures	1,02	– 5,137.4
Industrial chemicals.	2.78	2,049.4	Stone, clay, and glass.	0.90	–61 .3
Radio and TV receiving equip.	2.57	– 2,443.4	Nonferrous metals	0.52	– 2,408.9
Average	—	1,223.0	Ferrous **metals . . . .**	0.42	-2,740.4
			Textile mill products, ...	0.28	40.3
Below-average R&D intensity			Food and kindred products	0.21	– 190.0
Farm machinery ., ...	2.34	**696.2**	Average	—	2.0

aMeasures of R&D intensity and trade balance are on product line basis The ratio of applied R&D funds by product field to shipments by product class, averaged between 1968-70

SOURCES Department of Commerce, BIERP Staff Economic Report U S Bureau of the Census

export markets are linked to the domestic steel industry's relatively low levels of R&D spending. A counter example can once again be found in Japanese R&D and the connection between Japanese performance in technology and exports:

> Japan, which has no significant natural resources, runs a positive trade balance. The U. S., which has many natural resources, runs a large deficit. A key difference is in our use of technology. The export accomplishments of Japan in optics, steel, automobiles, and consumer electronics provide obvious examples of what the Japanese can do when they set technological and export goals. In all of these fields they have used their resources more effectively than we . . . We should match it with our best efforts and people. [z]

[z]J. B. Wiesner, The Chronicle of Higher Education. Nov. 13, 1978.

Adoption and Diffusion of New Technology—Case Studies of Six Technologies

Adoption Strategies

Any successful technological innovation has certain benefits associated with it; these may be reductions in the costs of input factors (like raw materials and labor) or improvements in product quality. The changeover to new technology also has the attendant costs of adjustments in employment levels, skill requirements, production quotas, and associated supervisory arrangements. For an innovation to be adopted, obviously, the benefits should outweigh the capital and changeover costs. The adoption decisions made by the management of individual firms collectively determine the rate at which a technological innovation diffuses throughout an industry, and capital investment is a major factor in the firms' adoption decisions. *

*A third variable, labor relations has generally not created any difficulties with the introduction of new steelmaking equipment (see ch. 12).

The issue of capital formation, then, is a crucial one. A company's sources of capital funds may be external, or they may be internal—that is, generated from cash flow. Governments, by their tax policy, influence the cash flow companies have available for reinvestment. If a company has sufficient discretionary funds, it will base its investment decisions on its evaluation of the return on investment from alternate projects, the perceived risk of each project, and the urgency management associates with each project.

The diffusion of major innovations falls into one of three categories: those involving capacity addition, those involving replacement of obsolete facilities, and those involving displacement of functioning facilities.[24] The economic considerations in a decision to adopt a technological innovation are quite similar for capacity expansion and for replacement of obsolete facilities, but they are slightly different for displacement.

When management considers capacity expansion or replacement to be necessary, it is likely to prefer new technology to established technology if the new technology offers either improved product quality (and increased revenue) at little or no increase in cost, or equivalent product quality with at least a modest cost reduction. Both options, however, depend on the prior elimination of technological uncertainties about minimum acceptable performance; even in expansionary periods, the adoption rate of a new technology may remain modest so long as its technical uncertainties outweigh prospective gains. Moreover, if innovations offer advantages in only a limited range of plant sizes or only part of a product range, technological diffusion may be delayed while methods are developed to adapt the technology to the remainder of the size or product range. And finally, a short supply of inputs may delay rapid adoption of technology. Adoption rates would be expected to rise sharply, then, as cumulative practical experience removes uncertainties about acceptable performance and as further technical advances allow the innovation to be applied advantageously to a broad array of products and facility sizes.

The economic criteria for adopting innovations that displace currently functioning facilities are more stringent than for those that add to capacity or replace obsolete facilities. First, an innovative facility that is to replace a functioning facility producing an equivalent product must produce at costs comparable to those of the technology it replaces. If a company has recently undertaken major modernization or expansion programs, any undepreciated investment must be written off, so management is less likely to adopt innovative technology to replace functioning facilities. In evaluating displacements, the changeover costs associated with adjustments in employment levels, skill requirements, production quotas, and associated supervisory arrangements must also be considered. If the displacement of capacity is effected with no increase in capacity, the potential gains may be lower than if capacity can also expand. In such a case, direct displacement is likely to be substantial only if the older facilities have heavier requirements for input factors that are in short supply, or if demands increase for product qualities not attainable by the older facilities.

Six Case Studies of Technological Changes

The six case studies chosen examine major innovations representing different aspects of steel technology, different national origins, and different levels of adoption. Information on the six innovations is summarized in table 115.

Argon-Oxygen Decarburization (AOD) Process

This process is generally considered to be a major process innovation of U.S. origin. It belongs to a class of pressurized-gas stainless steel processes developed during the mid-1950's and early 1960's, and has been in com-

[24] B. Gold, W.S. pierce, and G. Rosseger, "Diffusion of Major Technological Innovations in the U.S. Iron and Steel Manufacturing," The Journal of Industrial Economics, vol. 18, No. 3, July 1970, pp. 218-41.

Table 11 5.—Summary Information on Six OTA Case Studies

Innovation	Type of innovation: Process	Product	Stage of steel making: Ironmaking	Steelmaking	Casting-fabrication	Place of major innovation activity	Level of adoption: World-wide	United States
Argon-oxygen decarburization	X	—	—	x	—	United States	High	Very high
Basic oxygen furnace	X	—	—	x	—	Austria	Very high	Very high
Continuous casting	X	—	—	—	x	West Germany	High	Low
Formcoking	X	—	x	—	—	United States	Very low	Very low
Steel mill waste recycling	X	—	x	—	—	Japan	High	Very low
One-side galvanized steel	—	x	—	—	x	United States	Moderate	High

SOURCE Off Ice of Technology Assessment

mercial production since the late 1960's. Other processes in this class include the basic oxygen furnace (or "oxidation-reduction") process, the vacuum oxygen decarburization (VOD or LD-VAC) process, and the steam, ammonia/oxygen, or Creusot-Loire Uddeholm (CLU) process.

An AOD furnace uses pressurized argon and oxygen to prepare molten alloy steel. The use of argon in combination with oxygen allows decarburization of the melt without excessive oxidation of the chromium, which is quite expensive and has a high affinity for oxygen. In the AOD steelmaking and refining process, less chromium is lost and lower cost chromium charge material can be used,

The AOD process was invented in 1954 by Union Carbide at their Niagara Falls facility. Several years of R&D followed, and Union Carbide began a cooperative AOD development program with Joslyn Stainless Steels in 1960. In conjunction with experiments in the arc furnace, Union Carbide continued to explore the idea of using a separate refining vessel, In 1969, 15 years after AOD's original invention, Joslyn started a 100-percent, full-scale AOD system. The successful demonstration and commercial operation at Joslyn and the aggressive technical marketing effort by Union Carbide spurred the rather rapid adoption of this technology by U.S. alloy/specialty companies.

Computer techniques for optimizing AOD were also developed in the United States and came into use in 1972.[25] This practice has since been widely adopted throughout the world to about the same extent as in the United States.[26] The use of the AOD process is now being extended to the manufacture of other specialty alloys, such as tool-and-die, high-speed, and forging steels. A great many foundries have also installed AOD vessels within the last few years.

Since its first commercial use by a U.S. steel company, the AOD process has been widely adopted throughout the world for the production of stainless steel. Worldwide installed AOD annual capacity increased from 90,700 tomes in 1970[27] to 5,705,000 tonnes by mid-1978.[28] Of this, about 40 percent, or 2,282,000 tonnes, is in the United States,[29] U.S. installation of AOD capacity since 1970 has been almost double that of Western Europe and more than double that of Japan (figure 38); of all major steel-producing countries, only Italy has adopted AOD technology faster than the United States (table 116). The United States is clearly the leader, by far, in installing AOD technology.

U.S. adoption of AOD technology was encouraged by the generally high domestic growth rate for stainless steel consumption. The overseas marketing effort was delayed pending the results in the U.S. domestic market, and this appears to have contributed to differences in the rates of AOD diffusion for the United States and other countries. Also, some plants in Japan and Europe had recently

[25] R. K. Pitler, "Worldwide Technological Developments and Their Adoption by the Steel Industry in the United States," prepared for the General Research Committee of the American Iron and Steel Institute, Apr. 13, 1977.

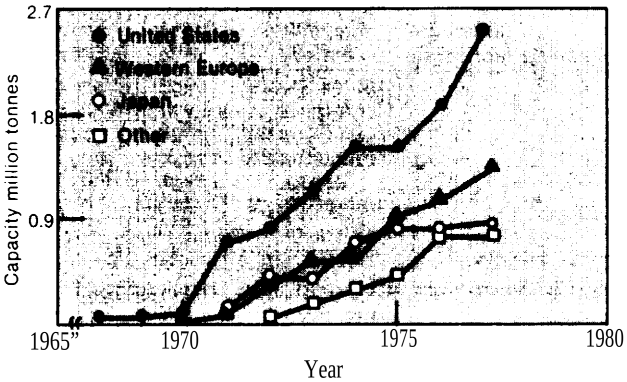
[26] Ibid.

[27] Ibid.

[28] Richard Daily, "Round-Up of AOD Furnaces,' Iron *and* Steelmaker, July 1978, pp. 22-29.

[29] Ibid.

Figure 38.—Installed Argon-Oxygen Decarburization Capacity



SOURCE American Iron and Steel Institute

Table 116.—Adoption of AOD Technology in Various Countries of the World (in tonnes)

Country	1978 installed AOD capacity	1974 production of stainless steel ingot
United States	2,250,000	1,955,000
Japan	762,000	2,037,000
West Germany	454,000	688,000
France	272,000	570,000
Sweden	390,000	519,000
Italy	372,000	311,000
United Kingdom	400,000	224,000
Others	554,000	446,000
Total	5,454,000	6,750,000

SOURCES, Institute for Iron and Steel Studies, INCO World Stainless Steel Statistics, 1976

adopted competing technology. For such plants, a switch to AOD would offer only incremental cost savings, and in addition undepreciated equipment would have to be written off. In some of the LDCs, the availability of industrial gases could be responsible for the delay in adopting AOD technology.

The rapid growth of the AOD process can be attributed to its reduction of raw material costs. The process permits refining almost any initial melt chemistry and achieves high recoveries of almost all elements. High-carbon chromium charge can replace more expensive low-carbon ferrochrome. In addition to chromium, improved recoveries of manganese, molybdenum, nickel, and titanium have been reported. Other savings stem from less overall silicon consumption, lower electric furnace costs because of less power consumption, reduced electrode consumption, and less refractory wear.

AOD operating cost savings range from an estimated $55 to $110 or more per tonne of stainless steel. Even larger savings are typical for the higher chromium and other specialty alloys. Between 20 and 30 percent of these stainless steel savings are attributable to lower energy-related costs. Payback periods ranging from 6 months to 2 years have been estimated. In addition to allowing cost economies, the process also improves product quality: sulfur content is lower, inclusion distribution is improved, temperature and chemical homogenization are better, and final dissolved oxygen, nitrogen, and hydrogen are reduced.

Summary .—The main motivating factors for the rapid adoption of AOD technology are:

- reduced raw materials cost, because of improved yields of alloying elements and the use of lower cost raw materials;
- improved product quality;
- low-cost increases in capacity, because AOD vessels can be retrofitted in existing melt shops; and
- an aggressive technical marketing effort by the process developer, a company in the "supplier" category.

Some of the barriers are:

- the recent installation of competing pneumatic technology in Europe and Japan, which reduced the economic incentive to switch to AOD when it became available;
- the availability of industrial gases, which may have hindered adoption of AOD technology in the LDCs; and
- delays in government approval of licenses in certain countries.

Basic Oxygen Process

The basic oxygen furnace (BOF) has revolutionized steelmaking, and it is generally considered the most significant major process innovation for steelmaking in modern times. Total BOF tonnage has grown faster in Japan and the European Economic Community (EEC) countries than in the United States. About 62 percent of all U.S. steel, 75 percent of West German and French steel, and 80 percent of Japanese steel are made in the BOF,

BOF technology reduces costs and improves productivity. The BOF comprises a vertical, solid-bottom crucible with a vertical water-cooled oxygen lance entering the vessel from above. The vessel can be tilted for charging and tapping. The charge is normally made up of molten pig iron ("hot metal") plus scrap and fluxes, although small quantities of cold pig iron and iron ore may also be charged, The distinguishing feature is that the heat produced by the reaction of oxygen with various constituents of the charge is used without other sources of energy to bring the metal to the desired final conditions of composition and temperature. Occasionally, the heat balance may be altered by the introduction of supplementary fuel to permit melting of above-normal amounts of scrap.

In 1949, experimental results from a small BOF pilot plant in Switzerland showed that it was possible to refine iron by use of oxygen and to remove phosphorus and sulfur by the use of basic linings and fluxes. In addition, a significant proportion of scrap could be added—close to half the weight of the iron in some cases. Scientists at VOEST continued development work on the BOF at Linz, Austria, where the first successful heat was made in October 1949. This development resulted in the first commercial plant, which began operation in 1952 with 32-tonne vessels. Many problems had to be met as growth continued. Some of the improvements were carried out in Austria, and as other nations began to use the BOF, they accelerated the pace of improvements. The BOF has grown from a 30-tonne novelty to the leading steel process in the world, with vessels more than 10 times the original size. To achieve such growth during 20 short years of industrial life is remarkable.

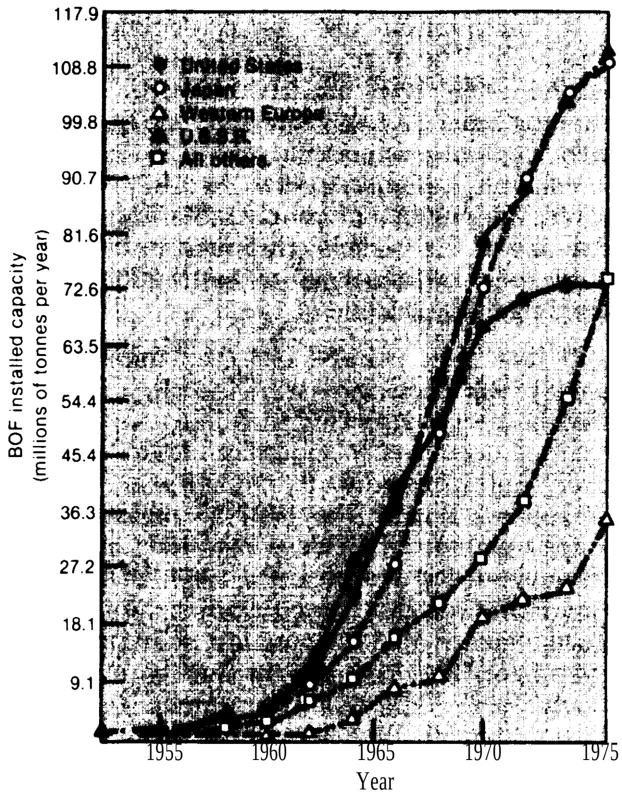
Most of the world's BOF capacity came onstream in the 1963-70 period, and the rate of BOF installation has since declined substantially. The earliest plants were installed in the early and mid-1950's, with vessels ranging from 27 to 45 tonnes; none had a design capacity exceeding the 73 tonnes of Jones and Laughlin's BOF in 1957. Thereafter, the number of yearly installations and the size of the vessels continued to increase, with four installations of over 200 tonnes starting up by the end of 1962.

It has been pointed out that the U.S. industry was more aggressive than Japan or the EEC in introducing this technology as opportunities occurred to increase capacity; however, only limited U.S. capacity expansion took place during the 1952-76 period when large numbers of BOFs were being installed throughout the world. Until **1969,** BOF adoption rates for the United States, Japan, and Europe were in fact roughly similar. Since that time BOF capacity in Europe and particularly in Japan has continued to grow. Despite limited steel industry growth, the U.S. steel industry has had a reasonable growth-rate record for the BOF, largely as BOFs replaced open hearth capacity. Europe and Japan, on the other hand, experienced substantial capacity expansion during the post-war period, and more BOF capacity was put into place in Japan and the EEC countries than in the United States (see figure 39). *

Most of the U.S. companies that have adopted BOF technology are large integrated plants producing carbon and low-alloy steels, and most have hot metal available—a prime requirement for the BOF. U.S. companies can easily purchase BOF technology from other companies and vendors, so it is not necessary for them to support extensive R&D work before installing BOF capacity, nor do they need pilot or demonstration plants, A company can decide on the size of the equipment it needs and purchase it from the vendors, who will

*The higher Japanese and EEC growth rates for the installation of BOFs has contributed to growing exports from these countries to the United States and the rest of the world.

Figure 39.—Growth of BOF Installed Capacity



SOURCE. American Iron and Steel Institute

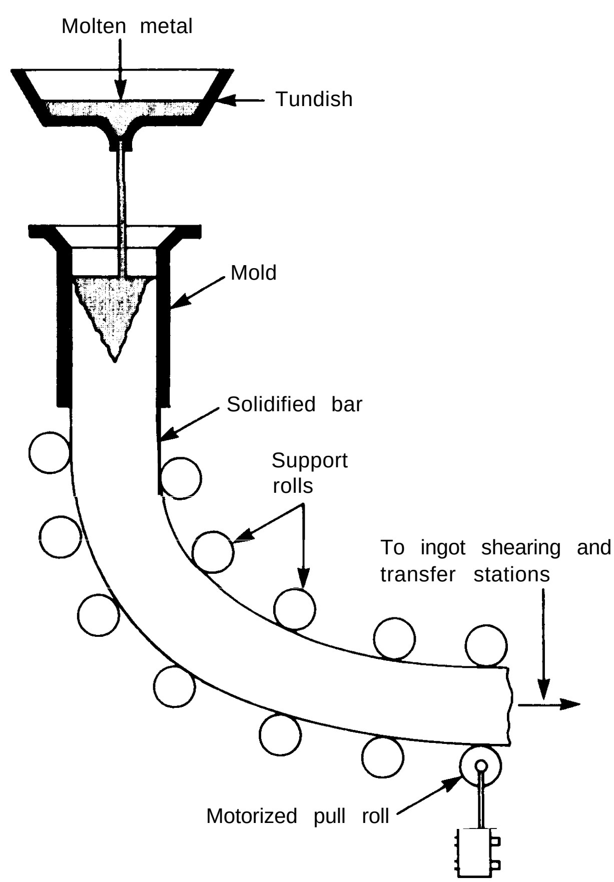
also provide technical and operating know-how. None of the operations in the United States, however, has received any Government assistance in adopting BOF technology, whereas in Europe and Japan a number of companies received help from their governments in securing capital for BOF adoption.

Continuous Casting*

Continuous casting was originally patented in 1865 by Sir Henry Bessemer. However, engineering and equipment problems were not solved and the process was not commercialized until the early 1960's, when significant amounts of steel began to be continuously cast in a number of the world's steel industries. Today, continuous casting is the preferred choice in new steelmaking plants, although there are still some types of steel that have not been converted from the older ingot casting method to continuous casting.

Continuous casting replaces with one operation the separate steps of ingot casting, mold stripping, heating in soaking pits, and primary rolling. In some cases, continuous casting also replaces reheating and rerolling steps (figure 40). The basic feature of all continuous casting machines is their one-step nature: liquid steel is continuously converted into semifinished, solid steel shapes by the use of an open-ended mold. Clearly, continuous casting makes long production runs of a particular product easier and more efficient than ingot casting. The molten steel solidifies

Figure 40.—Continuous Casting Apparatus



SOURCE. *Technology Assessment and Forecast, Ninth Report,* Department of Commerce, March 1979.

*A detailed discussion of continuous casting has been given in *Benefits of Increased Use of Continuous Casting by the U.S. Steel Industry*, OTA technical memorandum, October 1979.

from the outer cooled surfaces inward during the casting process, so that finally a fully solid slab, bloom, or billet is produced. This product can then either be processed in a secondary rolling mill or be shipped as a semifinished steel product.

Energy Savings and Increased Yield.—The continuous casting process saves energy directly, by eliminating energy-intensive steps, and indirectly, by increasing yields. The elimination of intermediate casting steps reduces the consumption of fuels (natural gas, oil, and in-plant byproduct gases) and electricity by approximately 1.1 million Btu / tonne cast. In Japan, where one-half of all steel is continuously cast, the direct energy savings is apparently about 50 percent over traditional ingot casting. Further energy is saved indirectly by the substantial increase in yield from continuous casting, perhaps an additional 2.2 million Btu / tonne.

Increased yield also means that less scrap is generated. End losses, typical with individual ingots, are eliminated, and oxidation losses are reduced because less hot metal is exposed to the air. The simplicity and improved control of continuous casting also improve overall efficiency. All these improvements mean that more shipped steel can be obtained from a given amount of molten steel. When yield increases by 10 percent, an additional tonne of shipped steel is gained for each 10 tonnes of molten steel; continuous casting increases yields by at least 10 to 12 percent, and in some cases by 15 to 20 percent. The raw materials used to produce these "extra" tonnes of steel, including iron ore and coke, have also been saved.

Total direct and indirect energy savings average 3.33 million Btu / tonne continuously cast, which can lead to a significant cost saving. These are average energy savings for many types of steels, but although actual savings may vary considerably the figure is probably conservative. For example, one detailed analysis showed a saving of 6.0 million Btu / tonne for the traditional integrated steelmaking route of blast furnace to basic oxygen furnace, and 2.9 million Btu / tonne for the scrap-fed electric furnace route used by nonintegrated mills. * It is probably safe to say that the total energy savings because of continuous casting are normally equal to about 10 percent of the total energy used to make finished steel products. A comprehensive survey by the North Atlantic Treaty Organization of steel industry experts throughout the world, which considered 41 energy-conserving measures for steelmaking, concluded that continuous casting had the best combination of potential energy conservation and return on investment.[30]

Other Advantages and Benefits.—Continuous casting can also be recommended on the basis of its potential for higher labor productivity, better quality steel product, reduced pollution, lower capital costs, and the increased use of purchased scrap.

Because continuous casting eliminates many of the steps required by ingot casting, all of which require direct labor input, it results in higher labor productivity. The Department of Labor reports that 10 to 15 percent less labor is required in continuous casting than in ingot casting.[31] Productivity growth also results from the increase in yield of shipped steel, from improved working conditions, and from at least 5 hours reduction in production time from the pouring of molten steel to the production of semifinished forms. Advances have recently been made in eliminating time losses that occur when products of different size or composition must be made sequentially.

Most industry experts also report an improvement in the quality of some continuously cast steels, resulting from the reduced number of steps and greater automatic control of the process. There have been steady improvements in the process, particularly in the production of slabs for flat products that require high surface quality.

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*This analysis (by J. E. Elliott, in The Steel Industry and the Energy Crisis, J. Szekely (cd.), Marcel Dekker, N. Y., 1975, pp. 9-33) assumes a 10-percent increase in yield, which is probably conservative.

[30] "The Steel Industry, " NATO/CCMS-47, 1977.

[31] U.S. Department of Labor, Bureau of Labor Statistics Bulletin 1856, 1975, p. 4.

It is generally recognized that continuous casting reduces pollution, as well. It eliminates soaking pits and reheating furnaces, and its lower energy requirements also reduce pollution—hot steel is exposed to the atmosphere for a shorter time than in ingot casting, so there are fewer airborne particulate. Increased yield also means that less primary steelmaking is required for any given level of shipped steel, so less coke is manufactured in integrated plants using blast furnaces; coking is steelmaking's largest source of pollution, particularly for toxic substances.

It is generally agreed that continuous casting reduces capital costs because it eliminates intermediate processing equipment. A study of five new steel technologies by Resources for the Future concluded that continuous casting has the greatest potential for capital cost saving* and recommended the adoption of continuous casting both in new facilities and to displace existing ingot casting capacity.

Finally, continuous casting increases the use of purchased scrap. "Home" scrap (produced in-plant) is normally recycled back to the steelmaking furnaces or the blast furnaces, or both. With higher yields, purchased scrap must replace the lost home scrap in order to maintain liquid-iron-to-scrap ratios. The price of purchased scrap has generally been lower than production costs for hot steel made from new iron units; under such circumstances, increased use of purchased scrap is an advantage.

U.S. and Foreign Rates of Adoption of Continuous Casting.— During the past several years, the Japanese have made frequent reports concerning the continued adoption of continuous casting and its effects in reducing energy consumption and increasing yield in steelmaking operations. Despite these advantages, the United States has fallen behind almost all foreign steel industries in adopting this beneficial technology. Continuous casting has been adopted at a much faster rate in countries like Japan, West Germany, and Italy than in the United States, England, or Canada (figure 41). In 1978, Japan continuously cast 50 percent of all its primary steel and West Germany, 38 percent; in the United States the level was only 15 percent. The Soviet Union has the only major foreign steel industry with a lower level of continuous casting than in the United States (table 117). This is explained by that country's unusual commitment to the open hearth process, which does not readily interface with continuous casting equipment. *

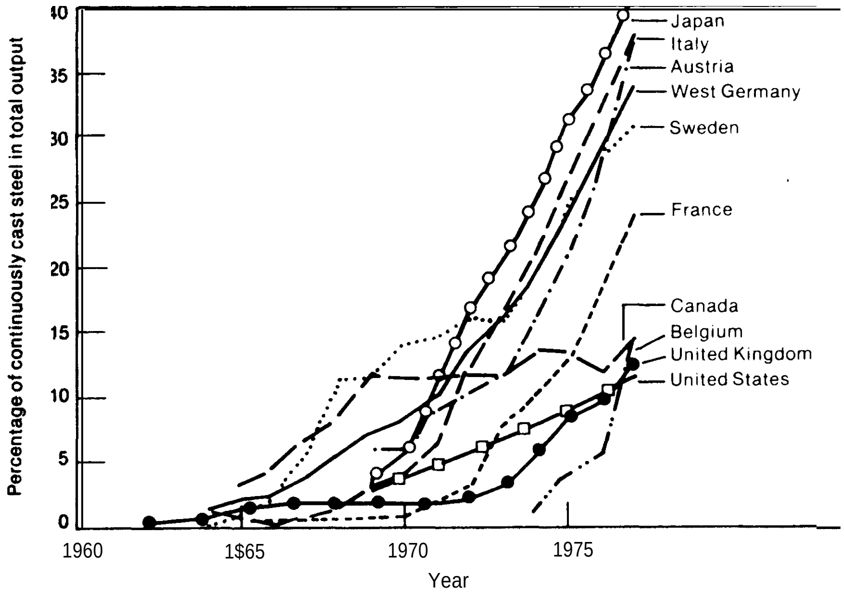
The high rate of adoption of continuous casting by many countries, particularly Japan, is largely explained by the considerable expansion of their steel industries in the late 1960's and early 1970's. The benefits of continuous casting are so compelling that it is the obvious process to choose when new steel plants are constructed, More recent construction of steel plants in Third World nations has also revealed the unequivocal advantages of continuous casting.

Although much of the increased use of continuous casting in the Japanese steel industry has been related to its expansion, in more recent years the Japanese have also pursued a replacement strategy. They will probably meet their goal of 70-percent continuous casting production within a few years. This will be a remarkable achievement, particularly in view of a number of negative factors facing that industry: low rates of capacity utilization, the closing of many older facilities, continued loss of world export markets, and very low profit levels. One reason these adverse factors have not impeded continuous casting adoption is that the Japanese Government and the banking system have channeled suffi-

*The other four technologies were: scrap preheating, direct reduction based on natural gas, coal gasification for direct reduction, and cryogenic shredding of automobilederived scrap. (W. Vaughan et al., "Government Policies and the Adoption of Innovations in the Integrated Iron and Steel Industry, " 1976, Resources for the Future.)

*The energy-intensiveness of the Soviet iron and steel industry is suggested by its 13-percent share of total energy consumption, compared to about 3 percent for the United States. This must be considered a consequence, in part, of its low use of continuous casting.

Figure 41 .—The Diffusion of Continuous Casting



SOURCE Organization for Economic Cooperation and Development International Iron and Steel Institute

Table 117.— Percent Raw Steel Continuously Cast

Country	1969	1975	1977	1978
United States	2 9	9.1	11.8	15.2[a]
Japan.	4.0	31,1	40.8	50.9[b]
Canada	11.8	13,4	14.7	20.2
West Germany	7.3	24.3	34.0	38.0
France.	0.6	12.8	23.6	27.1
Italy	3.1	26.9	37.0	41.3
United Kingdom.	1.8	8.4	12,6	15.5
U.S.S.R.	–	6.9	8.3	–

aAISI has reported that for the first half of 1979 the full Industry usage rate was 161 percent
bA lower value of 46.2 percent has been reported by the International Iron and Steel Institute, presumably this figure is for calendar year 1978 while the 509 percent figure is for Japanese fiscal year 1978 (April 1978. March 1979) and IS indicative of the rapidly Increasing usage

SOURCES AISI, IISI: Japan Steel Information Center, *Iron and Sfeelmaker,* 1978

cient capital at favorable interest rates to the Japanese steel industry.

The most important factor explaining the low rate of U.S. adoption of continuous casting is the low rate of new steel plant construction during the past several decades. A substantial number of small new nonintegrated steel plants using scrap-fed electric furnaces (“minimills’”) process all their steel by continuous casting. This segment of the industry, however, represents onlv about 10 percent of domestic raw steel tonnage. Data-revealing the significant differences in continuous casting use among the three main industry segments and types of plants are given in table 118, Use by integrated steelmaker, just over 9 percent, is far below the nonintegrated carbon steel producers’ use rate of nearly 52 percent. The nonintegrated companies may soon have the capacity to make 80 percent of their steel by continuous casting,

The main issue confronting the domestic steel industry with regard to greater adoption of continuous casting is: Can replacement of existing ingot casting facilities with continuous casting be justified economically? One integrated steel company, McLouth, replaced all its ingot casting with continuous casting, and another, National Steel, has embarked on such a course. By late 1980, National will process 40 percent of its steel in this manner, Recently, CF&I Steel Corp. announced its intention to increase its use of continuous casting from 18 to 100 percent by replacing all of its ingot facilities.

Table 118.—Continuous Casting in Segments of U.S. Steel Industry, 1978

industry segment	Raw steel (1,000 tonnes)	Continuously cast (1,000 tonnes)	Percent continuously cast
Integrated—carbon steel			
Nonelectric furnace	95,048	8,841	9.3
Electric furnace	8,715	2,375	27.2
Integrated—alloy/specialty steels[a]	4,125	680	16.5
Subtotal	107,888	‘-1 1,896	‘11 .0
Non integrated			
Carbon steels	12,274	6,323	51.5
Alloy/specialty steels	4,125	680	16.5
Subtotal	16,399	7,003	‘42.7
Total	124,287	18,899	15.2

aThe total of 9,096 raw steel tonnage and 1,499 continuously cast tonnage was split between Integrated companies producing mostly carbon steels and companies considered as alloy/specialty producers

SOURCE. AISI, Including estimates on amount of steel made by integrated companies in electric furnace shops

A 1990 time frame appears realistic for substantial expansion of domestic continuous casting capacity, considering the large size of the domestic industry, the long leadtimes for construction, the problems of capital availability, and the possible need for Federal assistance, which would require extensive congressional deliberation. There is no simple calculation that can determine unequivocally how much continuous casting the domestic steel industry should use. At best, the feasibility of several possibilities can be examined. It appears that levels of from 25 to 50 percent are feasible and that 50 percent would be necessary to achieve even minimum competitiveness on the international market. The 25-percent level has been suggested in several recent analyses of the steel industry. However, this level reflects nothing more than extrapolation of the past adoption rate for the industry to about 1990.

A 50-percent level of adoption of continuous casting is physically achievable in the United States by 1990; that is, there are no engineering or technological reasons why this level could not be attained. OTA calculations have shown that at this level of adoption the national yield rate could be increased to at least **76** percent. * The 50-percent goal can be supported by the following factors:

- In 1974, when the domestic industry was doing exceptionally well, A.D. Little, on the basis of a survey of industry opinion, concluded that by 1985 there would be 53-percent use of continuous casting.
- The Japanese and U.S. steel industries are similar enough in product mix and size to suggest that if the Japanese can produce 50 percent and probably 70 percent of their steel by continuous casting, then a level of 50 percent for the U.S. industry is technically feasible.
- In a 1979 OTA-conducted survey of steel industry opinion on future technological changes, the respondents projected a U.S. level of 54-percent adoption by 1990 and 74 percent by 2005.
- If appropriate Federal policies were designed to stimulate greater conversion to continuous casting by providing some means of obtaining the necessary capi-

*The yield of 76 percent may appear to be lower, especially relative to that of the Japanese, as noted previously; but we have not assumed any large-scale closing of older U.S. steel plants, which could increase the base yield for the industry at the expense of capacity loss.

tal, then it would be economically feasible to obtain the 50-percent use level (greater details on costs are given below).

One top major steel company executive who has provided much useful information to the OTA assessment has suggested feasible targets of 50 percent for 1987 and 70 percent for **1990.** Similarly, one long-time steel industry analyst on Wall Street has just suggested that "the U.S. could get to 40 percent by 1985 if the money was available. "

Economic Benefits of Adopting Continuous Casting.—The economic justification for replacing existing ingot casting facilities with continuous casting is not examined; summary data are provided in table 119. There are two key areas to be discussed and quantified before proceeding to a calculation of return on investment: the significance of the increase in yield with regard to new steelmaking capacity; and the direct production cost savings provided by continuous casting.

‘Charles Bradford of Merrill, Lynch, Pierce, Fenner and Smith, in an interview in *Steelweek*, Sept. 24, 1979.

With higher yields, a given amount of raw steel will produce more finished steel and less scrap. Both are of significance for steel plant profitability: the first allows capacity expansion at very low capital cost; the second increases reliance on purchased scrap at prices typically lower than the cost of home scrap. But what has not been fully appreciated by some U.S. steel industry and policy analysts is that continuous casting is also an economical way to increase the steelmaking capacity of existing plants. Building major new integrated facilities in the United States appears impossible under existing or projected economic conditions, and new minimills will still represent relatively small tonnages. The substantial increase in yield from raw steel to semifinished steel that continuous casting makes possible means that more steel can be shipped from a given amount of molten steel.

Table 119.—Economic Costs and Benefits of Adopting Continuous Casting (CC)[a]

Percent CC	Incr. in CC tonnage (thousands of tonnes)	Energy 10^{12} Btu	Incr. in yield	Incr. in steel shipped (thousands of tonnes)	Total steel shipments (thousands of tonnes)	New industry yield	CC[b] capital cost ($/tonne)	Total CC capital cost ($ mill.)	Deer cost/ incr. profit[c] ($/tonne)	Total annual benefit ($ mill.)	Return on Investment	Payback period (years)
25	13,424	44.1	0.10	1.342	90.169	0.73	$44	$ 592	$28	$185	0 3 1	3 ?
							44	592	55	222	038	2 7
							66	888	28	185	0.21	4 8
							66	888	55	222	0.25 033	4,0
			012	1,611	90,438	073	44	592	28	192		3.1
							44	592	55	237	0.40	2.5
							66	888	28	192	0.22	4 6
							66	888	55	237	0.27	3.8
							66	888	83	281	0,32	3.2
							88	1,184	83	281	024	4 2
50	44,496	147.2	0.10	4,450	93,277	0.75	44	1,962	28	613	031	3.2
							44	1,962	55	736	0.38 021	2 7
							66	2,944	28	613		4.8
							66	2,944	55	736	0.25	4.0
			012	5,340	94,167	076	44	1,962	28	638	0.33	3.1
								1,962	55	785	0.40	2 5
							66	2,944	28	638	0.22	4.6
								2,944	55	785	0,27	3.7
							66	2,944	83	932	0.32	3.2
							88	3,925	83	932	024	4.2

aBase case 1978 CC usage = 142 percent or 17,648,000 tonnes of 124,287,000 tonnes of raw steel production assumed to remain constant, total domestic shipments = 88,827,000 tonnes, yield = O 715, al I calculations done for replacement of ingot casting in Integrated (blast furnace. based) plants by CC

bThree levels of capital cost for CC have been used $44/tonne is somewhat greater than recent expenditures by National Steel for a major facility; $66/tonne has often been quoted and may be appropriate in those situations where ingot casting facilties to be replaced have not been fully deprecated or where more complex shapes are being cast, $88/tonne IS undoubtedly a high cost estimate but may be realistic for those cases where downstream finishing facilities must be added to take advantage of Increased capacity resulting from a greater yield

cDecreased cost/increased profit (for the increased steel shipped) resultin9 from the hot metal-purchased scrap differential and the normal operating profit

dTotal annual benefit IS calculated on the basis of a $11/tonne combined sav. ings for the additional CC tonnage and the product of the Increase in steel tonnage shipped and the hot metal to scrap savings, the latter IS undoubtedly a crude but conservative estimate of the additional profit resulting from increased yield and capacity. there IS substantial company to company variation in both hot metal production cost and net income per tonne shipped

SOURCE Office of Technology Assessment

In view of the large amount of capacity lost to equipment obsolescence and industry contraction, and the steady increase in domestic steel consumption, an economical way to increase the capacity of existing plants offers considerable benefits, including the avoidance of increased dependence on imports. Past experience, such as in 1974, has shown that import dependence during a period of tight world supply of steel and sharply escalating prices for imports can be a significant inflationary factor in the domestic economy. National security could also be threatened, because it might be difficult to obtain required steel at any price.

Virtually all current analyses point to considerable shortfalls in capital for the domestic steel industry and a growing demand for steel in the years ahead. At the same time, the world supply of steel may be very tight by the mid- to late 1980's because of continued contraction of Western European steel industries, insufficient new capacity in Third World countries to meet their own rapidly increasing demand, and likely insufficient domestic capacity in Soviet bloc nations and the People's Republic of China.[33]

Production Costs, Profits, and Return on Investment.—Although capacity increases from higher yield are a direct benefit of continuous casting, increased yield may have a "hidden" cost that should also be considered: the need to purchase scrap to substitute for that not generated by the continuous casting process. The profit of the additional shipped tonnage is determined by the ratio of the cost of the liquid steel ("hot metal") to that of the purchased scrap; the lower the cost of purchased scrap relative to in-plant costs to produce the liquid steel, the greater the profit from the increase in yield and capacity. This ratio is difficult to determine, but from many discussions with steel industry personnel it has been determined that the cost of hot metal is typically in the range of $132 to $198/tonne; and although the price of scrap varies considerably over time, it has generally been somewhat less than $110/tonne.

Another factor to consider is the normal operating profit that would accrue to the additional steel shipments from the increase in yield; this operating profit is typically $28 to $55/tonne. Because of the wide variations in all cost and profit figures among companies and among plants of any one company, and because of a desire to make conservative estimates of returns on investments, three levels of profits are used —$28, $55, and $82/tonne —for additional steel shipments gained through the greater yield of continuous casting; two levels of yield increase are assumed—lo and 12 percent.

Before proceeding to the return-on-investment calculation, an additional profit factor must be considered: the reduction in production costs for all the steel continuously cast. The decrease in energy consumption is the primary source of these production cost savings: 10 years ago, energy was approximately 10 percent of steelmaking costs; today, it is more than 20 percent. About one-third of the energy saving from continuous casting for the domestic steel industry results from reduced purchases of electricity and fuels, such as natural gas and oil; the other two-thirds is from in-plant energy byproducts that can be put to other productive uses. Because the price of energy and its contribution to the costs of steelmaking appear destined to rise, the future cost-reduction importance of continuous casting will increase. Discussions with industry personnel indicate that the total reduction in production costs resulting from reduced energy use, improved labor productivity, and reduced environmental costs is at least $1 l/tonne cast for a typical plant. For many plants, it would be two to three times greater.

Conclusions.— The results of a complete set of calculations for the return on investment for substitution of continuous casting for ingot casting in existing integrated plants are given in table 119. Three levels of capital

[33] See for example, CIA reports, "World Steel Market—Continued Trouble Ahead," May 1977; "China: The Steel Industry in the 1980's and 1990' s," May 1979; and "The Burgeoning LDC Steel Industry: More Problems for Major Steel Producers,'" July 1979.

costs for the casting equipment have been used: $44, $66, and $88 per annual tonne capacity. These have been chosen on the basis of limited published data and extensive discussions with industry experts. Even with what is believed to be relatively conservative assumptions, the economic rewards of such a substitution are substantial. More than a 20-percent return on investment is likely, although the precise return will be plant specific.

The calculations so far have assumed that raw steel production remains static at the 1978 level. A 2-percent annual increase in domestic shipments from 1978 to 1990 would require additional production of 23.9 million tonnes of steel. Significantly, the attainment of a 50-percent level of continuous casting (on the 1978 capacity base) could supply 5.4 million tonnes of this increase without the need for additional raw steel capacity, and that level of continuous casting would also substantially reduce the amount of additional new steelmaking capacity required to meet the remainder of the increased demand. Hence, total capital needs for the industry would be much lower than for simply adding new steelmaking capacity.

Most integrated domestic steel companies, however, have not used their limited amounts of discretionary capital to install continuous casting capacity. Instead, their investments have been for a variety of other purposes:

- to finance short-range capital projects with payback periods of 1 to 2 years, including technological improvements that minimize capital expenditures as well as implementation times;
- to replace old open hearth furnaces with either basic oxygen or electric steelmaking furnaces, which may give older plants a better return than continuous casting would;
- to make needed repairs or replace worn-out equipment and to comply with regulatory requirements; and
- to diversify out of steelmaking in order to improve profitability or to compensate for the cyclic nature of the steel business.

The industry also cites other reasons for not replacing more ingot casting with continuous casting:

- the difficulty of justifying replacement of operational ingot casting facilities that have not been fully depreciated;
- the costs and difficulties of substantially modifying an operating plant;
- additional capital requirements for downstream facilities to process increased semifinished steel production;
- technical problems with some types of steels and, in some cases, relatively small production runs;
- difficulties in expediting EPA permits and costs of other modifications of facilities EPA may demand before granting construction permits for continuous casting; and
- uncertainties about the degree of competition from imported steel.

Formcoking

Formcoking is a process that makes blast-furnace-grade coke, of uniform size and quality from low-cost, low-quality "noncoking" or steam coals. Formcoke has an advantage over coal-based direct reduction (see ch. 6) because the process generates valuable coke byproducts such as coke oven gas. Formcoke technology has several potential benefits:

- the ability to use less expensive and/or more available domestic feed coals;
- equipment that is less expensive and more flexible than conventional byproduct ovens;
- assurance of high-quality product that can substitute for conventional metallurgical coke;
- lower total production costs than with conventional methods; and
- reduction of pollution in the cokemaking process.

Many formcoking processes have been conceived in the last 40 years, but none of them has yet achieved full commercial operation. Table 120 lists some processes that appear promising in the near future on the basis of technical performance and commercialization status.

A number of steel companies throughout the world have supported the development of formcoke technology. The United States led in the early development, but most of the ongoing development is occurring abroad, particularly in countries that provide significant government support of their domestic steel industries: England, West Germany, the U. S. S. R., and Japan. Eight of the ten leading formcoking processes and a score of less advanced concepts have been developed outside the United States. Only the FMC Corp. has operated a significant commercial plant producing a formcoke that has been successfully tested in blast furnaces.

U.S. companies have spent considerable sums on formcoke development because of inadequate coking capacity. The FMC process will be evaluated on a demonstration-plant level by Inland Steel with assistance from the Department of Energy (DOE). Also supported by DOE, U.S. Steel has been developing a laboratory-scale "clean coke process" with the intention of producing a number of other chemical products, together with coke, from noncoking coals.

At this stage in its development, the most important factors limiting the adoption of formcoke are technical in nature and are concerned with energy use and coke quality. A recent EPA report noted that:

> Although a new process called "formed coke" has been developed that may meet environmental and OSHA standards, this process is not a panacea because of its high energy input and some uncertainties concerning its performance in large-scale blast furnaces.[34]

However, it appears that the FMC process may meet environmental standards.

Interruptions in coke supply have a significant impact on blast furnace performance, so operating companies are rightly concerned about the reliability of this undemonstrated technology. Another important factor is the probably lower quality and quantity of byproducts produced by formcoking processes compared with those produced by conventional byproduct ovens. * In the present period of diminishing energy resources and rising aromatic chemical values, this possibility

[34]Environmental Protection Agency, Analysis of Economic *Affects of* Environmental Regulations on the Integrated *Iron* and *Steel* Industry, vol. I, 1977, pp. 228-29.

*The FMC Formcoke process can yield a byproduct gas with an energy content of only 200 to 250 Btu-scf, compared to the 400 to 500 Btu-scf gas produced by a byproduct coke battery.

Table 120.—Ten Most Promising Formcoke Processes

Process	Developer	Country
FMC formcoke	FMC Corm.	United States
BFL	Bergbau-Forschung and Lurgi Mineralotechnik	West Germany
Consol-BNR process.	Consolidated Coal Co. with Bethlehem Steel, National Steel, Republic Steel, Armco Steel, and C. Itoh and Co.	United States
Sapozhnikov process	The Ukranian Coking Institute	U.S.S.R.
ANCIT process.	Eschweiler-Bergwerks-Verein	West Germany
Sumitomo process.	Sumitomo Metal Industries	Japan
HBN process	Les Houilleres du Bassin du Nord et du Pas-d-Calais	France
ICEM process.	ICEM (Romania)	Romania
Anscoke process ., ...	Broken Hill Proprietary Co., Ltd.	Australia
APCM process	Associated Portland Cement Manufacturers and Simon-Carves, Ltd.	United Kingdom

SOURCE A D Little for Off Ice of Technology Assessment may be a major impediment to adoption of formcoke technology by integated steelmaker. Uncertain capital costs for formcoking processes make comparisons to conventional byproduct ovens difficult. The experiences of the British Steel Co. and Ruhrkohle in West Germany have demonstrated the high cost of trying to develop this new technology. Because of the limited experience in constructing and operating formcoke plants, their costs are not well known and investments in such technology pose a very real technical and economic risk.

In addition to these technical concerns, the abundance of domestic coking coals has given some domestic steelmaker little reason to be interested in developing formcoking processes. U.S. steel companies have far less economic incentive to develop formcoking processes than do steel companies in countries that do not have adequate domestic reserves of coking coal. A recent OTA survey of steel industry technical personnel asked respondents to predict the domestic use of several technological changes in coke manufacture for the years 1990 to 2005. The major changes were improved coke oven design, coal preheating and hot charging, and formcoke. The respondents indicated that the fraction of coke made with these technologies in 1990 would be 41, 32, and 10 percent, respectively. There is some indication that formcoke may not develop quickly, but that modifications of existing technology will affect the industry substantially within the next decade. '5

Steel Mill Waste Recycling

In an average good steel production year, approximately 11.8 million tonnes of high-iron wastes are generated annually. These wastes are found in flue dusts, mill scale, and various in-plant particulate. Historically, most of these wastes have been recycled within the steel mills, particularly in sinter plants. Many of these operations are being curtailed, however, because of environmental considerations related to volatile organic compounds and particulate matter emissions.

Japan is probably the only country in the world where there is a strong emphasis on recycling those in-plant fines; it has been estimated that the Japanese recycle more than 70 percent of their residues. Environmental regulations force Japanese steelmaker to reuse their high-iron dusts. To comply with the regulations, a Japanese steelmaker may use the resources of sister companies or form a joint venture to devise as economical a processing sequence as possible. The solution that evolves is a combination of careful housekeeping with the adaptation of process equipment borrowed from other technologies. The know-how acquired is for sale or license, should other steelmaker be interested in it.

Only in-depth studies can determine whether any of the commercial fines-recycling processes is profitable on its own or is the least expensive way to comply with local environmental regulations. Table 121 summarizes the dust-treatment processes that are presently available in the United States. There are three categories of recycling processes:

High-temperature reduction (dezincing processes). —If inplant fines are brought to about 6000 C under oxidizing conditions, followed by a reducing action at around 1,000° to 1,1000 C, lead volatilizes as PbO in the first stage and zinc volatilizes as metallic vapor in

Table 121. —High-iron Waste-Recycling Processes Commercially Available in the United States

Commercially operated *processes* (all in Japan)
- Kawasaki (1968)
- Sumitomo (1975)
- Ryoho Recycle (Mitsubishi and Toho Zinc Aen) (1975)
- Sotetsu Metals (Waelz process, Germany 1925) (1974)
- Lurgi (SL/RN) (1974, Nippon Kokan)

Other potentially **competing *processes***
- Imperial smelting (United Kingdom)

Agglomeration *processes* at low *or* moderate temperatures
- Berwind —Reclasource (United States)
- Grangcold—A. B. Granges (Sweden)
- Aglomet —Republic Steel (United States)
- MTU— Pelietech (United States)

SOURCE A D Little for Office of Technology Assessment

[15]OTA, Survey of Technical Personnel, 1979.

the second stage. An hour or two at the higher temperature is usually sufficient to volatilize 95 percent of the zinc present. The vaporized zinc and lead can be recovered as contaminated oxides or, by more sophisticated processing, can be recovered as metals. The iron fraction is prereduced to some degree, but it may or may not be recovered for subsequent reuse in steelmaking.

Agglomeration at low *or* moderate temperature (nondezincing).—These processes do not change the chemical characteristics of the recycled materials. A binder, such as cement clinker, calcium carbonate, or polymerized asphalt, is used to provide the physical strength needed during handling and furnace operations. These processes are comparatively cheap, and they produce briquets or pellets containing all the carbon collected in the various fines. The blast furnace is the normal outlet for such products.

Hydrometallurgy. —A number of patents have been granted on wet-mill-waste-recycling processes. Assignees include private domestic interests, the U.S. Government, and foreign interests, A great variety of schemes have been proposed; there is no commercial application of any significance today.

Domestic acceptance of steel mill waste recycling will be predicated on mandatory regulations set forth by EPA and State and local regulators. With its capital so limited, the steel industry is reluctant to invest in these types of processing technology and would prefer that third parties own and operate recycling facilities. Pelletech, Inc., is actively pursuing this approach, as Reclasource and Aglomet did in the past. The foreign process developers are not interested in third-party arrangements.

By far the most important group of companies who may seek to diversify into this business are the slag processors, who presently work along with the steel industry. Most steel plants, with the exception of a few owned by U.S. Steel Corp. and Bethlehem Steel Corp., use a slag processor. Slag processors are secretive about their business because their supplies of raw materials are limited to whatever the steel mills give them and the demand for and prices of their products are limited by the realities of the natural aggregate marketplace in which the crushed slag competes. Some of the scrap processors have the financial resources to process steel dust as well as scrap. Most of the companies are very protective of their positions with the steel industry, and for defensive reasons they may want to tie up steelmaking dusts for future processing, by either themselves or others.

One-Side Galvanized Steel

The most important manufacturing processes for producing one-side galvanized were developed in the late 1960's. Significant quantities of this product have been on the market only during the last 5 years, and the future of one-side galvanized as a major steel product is still far from established. With the exception of one Japanese steel company, all one-side galvanized steel is produced by domestic steelmaker.

One-side galvanized steel differs from other technological innovations examined in these case studies in that it is a product rather than a process. In contrast to the adoption of new process technologies, which are controlled by the producer or a third party, adoption of a new product is determined in the United States by the consumer. Although a producer may offer a new product, it is the potential purchasers who make the decisions that determine the extent of its acceptance in the marketplace. In this case, market concerns about the large quantities of salt used on pavement in this country led to Detroit's interest in a corrosion-resistant, paintable steel. The call went out from domestic car manufacturers to steel producers during the late 1960's for a steel product coated, preferably with zinc, on one side only, and with the following performance characteristics:

- resist rusting on automobile surfaces that are normally exposed to corroding elements, that is, the bottom of the car;
- accept a highly glossed paint coat, free of spangles and other imperfections nor-

really associated with galvanized steel; and
- provide a zinc-free surface so that spot welders can make strong welds and diminish tip fouling.

The steel industry responded quickly to the call for help from Detroit. Existing one-side galvanizing processes were not considered economically feasible for producing the massive tonnages Detroit requires, * and the R&D sections of the major steel firms began a search for new processes. Each major steel producer developed its own innovative and patentable approach to producing one-side galvanized.

The processes can be grouped into four general categories: hot dip, differential hot dip, electrolytic, and a combination of hot dip and electrolytic. According to the most recent estimates, the U.S. steel industry in 1978 produced 181,400 tonnes of one-side galvanized by hot dipping and 317,45o tonnes by electrolytic processes (including hot dip / electrolytic combinations). These quantities were produced by six independent steel companies. A list of these companies, including the only foreign producer of one-side galvanized, is given in table 122.

Steelmaking companies that have successfully adopted one-side galvanized technology share a number of characteristics. These include the following:

- All manufacturers of one-side galvanized are integrated steel producers who produce diversified lines of steel products. One-side galvanized represents but one of their many products.
- They are mature companies. The producers of one-side include some of the oldest steel companies in America. The only foreign producer of one-side, Nippon Steel, is the oldest steelmaking firm in Japan.
- They possess organized R&D programs. Without these programs, the innovative processes for producing one-side could not have been developed as rapidly as they were.
- They possess the capital needed to invest in a new product like one-side without jeopardizing their survival should the market for one-side galvanized disappear.
- They all had close connections with the automotive industry prior to the development of one-side galvanized. The plants in which one-side is produced are located in close proximity to automobile manufacturers.
- They were all producers of galvanized products prior to the development of one-side and had expertise in zinc-coating applications.

The willingness of company management to take a risk on an unestablished product appears to have been the most important characteristic behind the adoption of one-side technology. Even today, the producers of one-side cannot be certain that in **10** years Detroit will accept one-side galvanized as a manufacturing material. In fact, it would appear that the domestic automobile industry is beginning to favor two-side galvanized over one-side because of the increased corrosion protection two-side offers. Interestingly, each of the producers of one-side galvanized also markets Zincrometal, a major competitor of one-side, to minimize the risks associated with Detroit's uncertain attitude towards one-side.

'one steel producer, Sharon Steel Corp., had been manufacturing one-side galvanized for a number of years for sale to the automotive industry on a limited basis. Another steelmaker, U.S. Steel, had developed and pilot tested a one-side process in the late 1950's.

Table 122.-Producers of One-Side Galvanized Steel

Company	Plant location	Process
U.S. producers		
Armco Corp..	Middletown, Ohio	Hot dip
Inland Steel Co.	East Chicago, Ind.	Differential hot dip
National Steel Corp.	Portage, Ind.	Hot dip/electrolytic
Republic Steel Corp.	Cleveland, Ohio	Hot dip
Sharon Steel Corp. .	Sharon, Pa.	Electrolytic
U.S. Steel Corp.	Gary, Ind.	Electrolytic
Foreign producers		
Nippon Steel Corp. .	Japan	Differential hot dip

SOURCE A D Little for Office of Technology Assessment

Unlike process technologies, insufficient capital has not been important in determining which companies adopted one-side galvanized steel as a new product. Two categories of steel companies have not adopted one-side technology: companies like Bethlehem Steel, which backed competing products; and companies like the European steelmaker, which do not feel that the product is worth manufacturing until Detroit firmly decides on the type of steel product it needs.

An enormous disparity exists between the rates at which domestic and foreign steel producers have adopted one-side galvanized technology. Until 2 years ago, only U.S. steel companies offered a one-side product. The reason for this disparity can be traced directly to the U.S. automotive industry, which is the only automotive industry in the world that demands large tonnages of galvanized steel. Foreign steelmaker are only partially dependent on U.S. automakers as customers, and they can afford to wait until Detroit settles its mind before committing capital to new product ventures. Domestic steelmaker, much more vulnerable to the current fancies of the domestic automotive market, could not afford the possibility of losing their biggest customer.

With regard to imported cars, only Japanese carmakers rely chiefly on zinc-plated steel sheets to meet corrosion-resistance requirements, and then only on cars exported to Canada and the United States. This explains why the only producer of one-side galvanized outside of the United States is a Japanese steelmaker. Nippon Steel first began shipping the new product to major automotive manufacturers in Japan and the United States about 1976, and began full-scale marketing of one-side galvanized steel sheets for automobile use in 1978. Although exact production figures are not available, it is safe to say that Nippon's production of one-side galvanized is far less than the combined production of U.S. manufacturers.

Nippon Steel uses a hot dipping method to produce one-side. While passing through a molten zinc bath, one side of the basemetal steel sheet is galvanized thinner than the other side. After galvanizing, the thinner coating is mechanically brushed off in a continuous process in order to completely remove the zinc film and produce a bare steel surface with adequate roughness. The well-controlled roughness of the uncoated side ensures excellent paint finish characteristics.

Conclusions From Case Studies

The slow pace of most domestic adoption of process innovations is primarily a result of the industry's financial problems and limited growth. Both factors have slowed down BOF construction during the past two decades. The relatively slow adoption of continuous casting by the domestic steel industry can be attributed indirectly to the impact of poor financial performance and directly to poor steel industry growth. Construction of continuous casting facilities is best undertaken in a new steel production facility; retrofitting existing facilities with continuous casting is more difficult and more expensive.

The rapid domestic diffusion of AOD technology is attributable to the fact that this technology is used principally by the alloy/specialty steel segment. This segment has had significantly better earnings and far better financial status than the integrated segment. Significant production cost reductions brought about by the AOD process, combined with a rapid increase in the demand for alloy/specialty steels, also contributed to the high adoption rate for this technology. The rapid adoption of one-side galvanized steel was also unique in several ways. Domestic steel industry R&D and innovation have always emphasized product development, which requires far less capital than process innovations. Furthermore, there was a close collaboration between steel producers and the domestic automotive industry, the consumer that represents the single largest market for domestic steel producers.

In addition to limited capital availability, the relatively old age of steel production facilities in the United States compared to those of its principal international competitors has contributed to the slow adoption of process innovations. Obsolete facilities pose technological as well as financial problems for the introduction of innovative technologies within existing plants—the many sequential steps of steelmaking create problems of coordinating old and new facilities. The age of domestic mills thus accounts for lags in introducing continuous casters and is also cited as one of the principal reasons why mill-waste-recycling technology has made relatively modest gains in the United States as compared to Japan.

Another important factor is that many of domestic steel producers are unwilling to adopt innovative technologies unless they have already had large-scale commercial success. Furthermore, domestic steel mills continue to depend on established methods of raw material supply. For instance, the historical availability of excellent coking coal has limited interest in formcoke development, and historically ample scrap supplies have led to only marginal interest in waste recycling. Finally, service industries play a powerful role in creating and developing new technology and providing it to steel companies. It appears that this dependency is unique to U.S. steelmaker; many foreign steel companies do their own design, engineering, construction, and equipment work.

Technology Transfer

There is very little steel technology transfer from domestic steel firms to other countries, and the technologies that are transferred are mostly related to raw material handling rather than steel production. To the extent that domestic steel production technologies are transferred abroad, it is done by domestic equipment manufacturing and engineering firms. Conversely, Japanese, and to a lesser extent West German, steel companies develop and transfer significant amounts of steel production technologies, equipment, and facilities to other countries, including the United States.

From the United States

Earlier in this century, domestic steel companies had a strong role in the transfer of major U.S. steel production technologies to other steel-producing nations. However, the direction of this technology transfer has been reversed since the end of World War II.

Most of the melting, refining, and ingot casting technology presently used by U.S. steel companies had its origin in foreign countries. The only major U.S. process technology that has been quickly adopted by all domestic and foreign steel industries is the AOD process, and this domestic technology was transferred abroad, not by a domestic steel producer, but by a manufacturer of equipment. A large part of domestic steel technology transfer to other countries similarly takes place via domestic equipment manufacturers and engineering firms. In Japan and Europe, it appears that steel firms that create new technologies for their own use are the principal channels for subsequent technology transfer. Tables 123 and 124 summarize the channels of technology transfer to and from the United States as perceived by U.S. steelmaker.

There is some technology transfer from the United States to foreign nations by domestic

Table 123.—Channels of Steel Technology Transfer Between the United States and Japan

Type of channel	Percentage use
Cross-licensing/licensing	20
Engineering/design firms	15
Steel producers	40
Retro engineering	5
Suppliers of manufacturing equipment	10
Technical papers	5
All others	5

aRefers to indirect access to foreign technology; no direct purchase available Information IS used to duplicate technology

SOURCE Survey of U S steel executives by Sterling Hobe Corp for OTA.

Table 124.—Channels of Steel Technology Transfer Between the United States and Other Nations Except Japan

Type of channel	Percentage use
Cross-licensing/licensing	30
Engineering/design firms	30
Steel producer	5
Retro engineering	5
Suppliers of manufacturing equipment	15
Technical papers	2
All others	13

SOURCE Survey of U S steel executives by Sterling Hobe Corp for OTA.

steel mills. However, available data suggest that such transfer is not substantial. Recently, two major domestic firms, U.S. Steel and Bethlehem, have been holding discussions about the export of U.S. steel technology to China, but no sales had been concluded as of 1979.

A major investment for scaling-up an innovative process is often required before its potential applicability and profitability can be fully demonstrated and foreign sales made. This is a large obstacle in the U.S. steel industry, with its low rates of new plant construction and lack of capital for demonstration plants. Government capital assistance may be the only way by which process development can be sustained by the industry.

Experience with the electroslag remelting (ESR) process illustrates the economic constraints that tend to limit domestic technology innovation and transfer. The ESR process was invented in the United States during the 1930's and 1940's and became commercially successful around 1966. This process gained little domestic recognition until a U.S. Air Force agency investigated the special claims a Soviet research laboratory made for ESR. The Air Force awarded a 4-year ESR manufacturing technology development contract for less than $500,000 to Carnegie-Mellon Institute during the early 1960's. The attention that was focused on the ESR process and the prompt dissemination of pertinent information to various segments of the industry resulted in an explosive growth in use of the ESR process. U.S. capacity for ESR steels climbed from 5,442 tonne/yr to more than 163,260 tonnes—close to Soviet capacity levels—between 1965 and 1977. *

Interestingly, neither the original inventor nor the company supporting the work received any benefits from ESR process growth in the United States, because the rights to this technology had been sold prior to its initial commercialization in 1965, The technology is presently owned by the Pullman-Swindell Corp. —an engineering, consulting, and manufacturing conglomerate. Pullman is now in the process of acquiring certain Soviet ESR process rights and licenses for marketing in the United States. Thus, a U.S. investor company will be marketing in the United States the Soviet refinements of a technology originally invented and developed here. However, eventual success of the Soviet ESR technology is far from certain. Thus far, the Soviets have had only modest success in transferring this technology on a worldwide basis, mainly because of their inability to provide proof of the economic viability of the technology.

The domestic steel industry has strongly protested the loans the U.S. Export-Import Bank (Eximbank) provides to foreign competitors to buy domestic steelmaking technology. Many U.S. steelmaker are concerned about the Bank's willingness to finance steel expansion abroad, arguing that low-interest rates are permitting unreasonable investment in unneeded steel capacity, which results in unfairly traded steel exports to the United States. In response to such concerns, the Bank has noted that such loans are needed because they generate U.S. exports and domestic jobs—especially for firms selling technology. According to John L. Moore, president and chairman of Eximbank:

> The net positive economic impact in just the steel products area is over 4,000 man-years of U.S. labor. These employment figures become even more positive when the favorable impact from the related exports of U.S. coal and spare parts are added.[36]

*In 1965. domestic ESR steelmaking capacity was limited to 5,442 tonnes of annual production, all of which was used by one company in the Pittsburgh area, compared to 181,400 tonnes of annual ESR capacity in the Soviet Union.

[36] American Banker, Oct. 22, 1979, p. 2.

Domestic equipment makers have had opposite concerns about Eximbank loans for the construction of steel plants abroad. These companies have asserted that inadequate export financing causes domestic firms to lose sales of technology abroad. The Bank's position has been that lack of price competitiveness, rather than inadequate export financing, has been the principal factor responsible for limiting technology exports. Along these lines, Bank representatives have noted that:

> We found that most of the cases lost were awarded to foreign firms because the American exporter was not competitive in the price offered. In 51 of our recent "lost offers," the U.S. product was priced out of the running. In fewer than 10 percent of the cases did inadequate financing appear to be the reason for losing the bid—and most of those were lost against "foreign aid type" financing.

A distinct handicap for U.S. exporters of technology is the inability of the Bank to finance loans to certain nations undergoing substantial steel industry expansion, including the People's Republic of China and the Soviet Union. Eximbank representatives commented on the resulting decline in U.S. competitiveness in technology exports:

> U.S. firms, however, are constrained from competing in certain key countries of the world, mainly the People's Republic of China and the U. S. S. R., because competitive financing by Eximbank is not yet available to those countries. As a result, the Japanese and the Germans, particularly, have taken advantage of early entries into those countries and have concluded contracts of major proportions to provide technology and equipment, financed by low-interest rate loans . . . Except for the sale of technology to the Russians by one of the three U.S. producers having expertise in making that particular type of steel, the United States has evidently lost out on all the potential equipment and engineering sales . . . [and also on] the longer term benefit of actual experience of building the most modern silicon steel plant anywhere.[38]

[37] Ibid.

[38] "Testimony of D. E. Stingel, Director, U.S. Export-Import Bank, before Senate Subcommittee on International Finance, Nov. 19, 1979.

By Foreign Industries

Unlike the United States, most foreign steel-producing nations, even those with small steel industries such as India or Austria, practice aggressive transfer of their steel technologies. The undisputed leader is Japan.

Japan

Most major Japanese steel companies are engaged in steel technology transfer as well as some design and construction. These companies have well-established ties with West German, British, Austrian, Swedish, and U.S. companies engaged in technology transfer projects through licensing, equipment manufacturing, and joint project efforts. The Japanese steel industry, working in partnership with the Japanese Government, has sold its steel technology on a global basis more successfully than any other country. *

The Japanese, who move technologists to other countries to put their projects in place, are motivated by the need for technology exports to compensate for the loss of steel export markets. They are also aware of the need for access to raw materials. The sacrifices made by individuals engaged in such ventures are well rewarded by the companies they serve and by society in general. Time spent overseas on technology transfer projects is viewed as a service to the country, and the Japanese are proud of their contributions to world technology and to the welfare of their own country.

Commenting on international steel trade, the general manager of Kawasaki Steel's international department has noted that "We realize that we cannot continue to export large amounts of crude steel. Therefore, the industry is putting emphasis on exports of technology, to countries like China, Brazil, and those in Southeast Asia."[39] The assimila-

*The success of this Japanese strategy is shown by the fact that in 1975 their steel industry's technology exports were almost twice as great as imports [a positive balance of 5,800 million yen a year or $24 million at 240: 1). This probably has improved greatly in recent years,

[39] T. Dahlby, "Japan Seeks a Long-Term Strategy for Prosperity," Far Eastern Economic Review, Aug. 25, 1978, p. 45.

tion of designs and technical know-how from different sources has enabled Japanese companies like Nippon Kokan, IHI, Hitachi, Daido Steel, and Mitsubishi to provide the most modern plants to developing countries. The LDCs, in turn, promote the construction of steelworks using the electric furnace process or integrated steelworks employing the BF-BOF process or DR-EAF process, with their technological choices dependent largely on prevailing domestic conditions, such as size of steel demand and existence of natural resources.

There appears to be little concern that Japan is cutting its own throat by selling technology that will strengthen developing countries' production capacities:

> Steelmaker are selling basic technology while improving their own technology for the production of more sophisticated items such as large-diameter steel pipe and higher quality crude steel.

Even so, how long can the Japanese maintain their technological lead? The Kawasaki executive replies that:

> There are no major technological breakthroughs on the horizon for the next 10 to 15 years. Now we are only involved in a fairly sophisticated rounding out process by raising the productivity per worker, but there is a limit.[40]

The search for raw materials and energy has also stimulated Japanese steel companies, in partnership with their government and other companies, to launch an aggressive compensation-trade program based on barter with developing countries. A number of such projects are presently underway in the Middle East, Brazil, Indonesia, and several other developing countries (table 125), and Japan is aggressively pursuing the exchange of steel technology for Mexican oil. In the Japanese steel industry, the guiding philosophy is to beef up divisions handling design and to win contracts in developing countries by offering package deals, including technology licensing, feasibility studies, construction, and engineering advice. By selling the experience gained in building their own highly efficient industry, Japan's major steelmaker are hoping to make up for the export markets they have lost through increased competition and the relatively slow growth of demand in industrialized nations.

Nippon Steel serves as a good example of Japan's commitment to steel technology export.[41] About 10 percent of its sales are technology sales, and the company has promoted the development of steel production in LDCs in particular. It recognizes LDC interest in

Table 125.—Major Japanese Steel Technology Transfer Projects Involving Barter Trade

Abu Dhabi—A Government-Kawasaki Steel ioint venture steel plant; $4 billion.

Qatar— Kobe Steel 20°10, Tokyo Boeki 10°/0, balance local for Midrex DR and mini steel plant; $980 million.

Nigeria— Kyoei Saiko and Nissho-lwai, joint venture DR and ministeel plant; reportedly $440 million.

Saudi-Arabia-Petromar DR plant; ownership: Italy, Marcona 40%, Estel 25%, Japan (Nippon Steel) 25%, United States (Gilmore Steel) 1O°/o; investment, unofficial, $950 million. Project reorganized recently to include Korf Group.

Sudan— Kyoei Seiko joint venture mini steel plant; $250 million.

Tunisia—C. Itoh (Japan), Korf Industries (West German), and Government of Tunisia; Midrex DR plant; investment figures unavailable.

Morocco—Kawasaki Steel 12.5%, Konematsu Goshu 12.5%, balance local; ministeel plant; $200 million.

Iran— DR plant at Bandar Abbas; Japanese participation: C. Itoh, Marubeni, Mitsubishi, Kawasaki Steel. A compensation-trade venture for over $800 million.

Indonesia —Ministeel plant; financial investment by C. Itoh 74%, technology by Kowasaki steel 6%, balance by private Indonesian capital. A compensation-trade venture for approximately $300 million.

Greece—Hellenic Steel; C. Itoh and Co. (Japan) 25°/0 and Estel (Netherlands) 20%; investment unavailable.

Brazil-Siderurgica Brasileira; Nippon Steel 490/.; Japanese investment over $1.8 billion —Usiminas; Nippon Steel 19%; investment unavailable.

SOURCE: Offlce of Technology Assessment

*'Ibid.

[41] U.S. Steel Corp. has recently signed a 3-year contract with Nippon Steel for technical aid. "The contract with Nippon is U.S. Steel's third, and by far the most extensive, call for help from abroad, Although most other domestic steelmaker have been getting help from foreign steel companies for years, Wall Street analysts and industry insiders have long suspected U.S. Steel of harboring a corporate arrogance that led it to ignore foreign technological developments. But the extent of the new contract with Nippon confirms that U.S. Steel is prepared to scour the world for the best steelmaking technology available. " (*Wall Street Journal*, Feb. 14, 1980.)

such matters as the use of domestic resources, the role of a strong steel industry in accelerating the growth of steel-consuming industries, and foreign currency savings. As of early 1979, Nippon Steel's overseas engineering activities had extended to 37 nations, 85 firms, and 285 projects.[42]

Kobe Steel has also accelerated its technology sales efforts. It has improved the quality of its overseas activities, stepped up information exchange, and expanded the scope of its activities from mere product sales to investment, procurement, plant construction, and management and operation guidance. The company employs qualified personnel and gives them language training in special schools or sends them to schools in foreign countries. Moreover, it exchanges personnel with foreign companies and accepts foreign trainees,[43] Kawasaki Steel Corp. 's technology exports in 1978 contributed only 5 percent of the company's business, but it expects to increase them to 10 percent within 5 years.[44]

Japanese steel firms are also increasing their technology trade with China, whose modernization plans offer an obvious market for Japanese exports. Under a long-term trade pact signed early this year by Tokyo and Peking, Japan will export roughly $10 billion worth of plants and construction machinery to China during the next 10 years. The biggest single export project involved is a $3 billion deal for Nippon Steel to build a 5.4-million-tonne/yr steel mill in Shanghai, due for completion in 1980.[45]

West Germany

German steel technology has penetrated both the industrialized and developing countries. Important coke-producing, ironmaking, steelmaking, and metals-working technologies have originated in West Germany and spread to different parts of the world. West German technology transfer methods are as varied as the countries served. Technology sales have traditionally been pursued by West German industry and government in a highly competitive manner, using technologies developed through the active participation of the West German academic and research communities.

The West German Government offers substantial incentives in the form of loan guarantees of up to 90 percent for the export of steel technology and equipment to developing countries. Intergovernmental agreements are actively sought and implemented on a compensation-trade basis. Such barter agreements usually last from 5 to 10 years and have provided for the establishment of entire steel plant complexes in India, Brazil, Iran, Argentina, Venezuela, and Mexico. West German credits extended in India during the past 12 years have exceeded $1.32 billion, to Iran $0.8 billion, to Brazil $1.63 billion.

West German steel plants and equipment construction companies have comprehensive agreements for technical cooperation with Japanese companies engaged in similar ventures. Often such cooperation overlaps with technology agreements with U.S. and British builders of steel-melting and metal-working equipment.

Several West German companies are currently engaged in the export of steel technology. Europe's largest steel group, Thyssen, has a joint venture with Armco Steel in West Germany, and it owns the Thyssen Purofer direct reduction (DR) process, through which it has interests in DR plants in Iran and Venezuela. The Thyssen Group also controls the Dortmund-Horder degassing process, which is used in U.S. and Japanese steel industries.

The United States has received a number of steel-related technologies from West Germany. West German technology entered the United States during the 1960's mostly in the form of licenses, know-how, and personnel exchange. During the 1970's, successful West German corporations established joint ventures, limited partnerships, and even operating companies in the United States for

[42] *Nippon Steel* News, January 1978,
[43] *Kobe Steel* Report, January 1979.
[44] "Kawasaki Steel: Using Technology as a Tool to Bolster Export," Business Week, Jan. 29, 1979, pp. 119-20.
[45] *Steel* Week, Oct. 23, 1978.

timely transfer of steel technologies. The West German company of Laybold-Heraeus opened manufacturing, sales, and service subsidiaries in the United States during the 1960's; it has aggressively pursued the application of vacuum technology to solve a host of steelmaking problems, as well as steel treating and steel protection. In cokemaking and allied coal technology, Koppers Co. in the United States has good access to West German technology through cross-licensing agreements with Lurgi.

Another entrepreneurial West German steel company spreading its technology to the United States is the Korf Industries Group. This firm formed the Midrex Corp. in the United States, and has successfully promoted the Midrex DR process, developed originally by an American company. The Korf Group has successfully promoted minimills in the Untied States based on the use of scrap and DRI. Korf also has projects in Iran, Trinidad, Tunisia, and the U.S.S.R. for the installation of Midrex DR plants with capacities ranging from 227,000 to over 590,000 tonne/yr.

Demag is the leading German builder of complete metallurgical plants and equipment, and it enjoys a worldwide reputation. It has excellent working relationships with U.S. companies, such as Mesta, Wean United, and Blaw-Know, and the technology transferred by Demag is reliable and up-to-date. Demag also cross-licenses and shares its engineering know-how with American builders of rolling mills, forging presses, and other steel plant equipment. International cross-licensing and technology-exchange practices prevailing in metallurgical equipment building make it very difficult to assess the actual monetary values of such technology transfers.

Austria

Austria sits between the East and West in Europe, and receives steel-processing technology from both sides. It often serves as a "window" for Western industries to observe and assess steel technology developments in Eastern European countries, including the U.S.S.R.

The Austrian steel industry originated the BOF steelmaking process and made it available to several of the world's steel industries. This technology was the forerunner of the present-day basic oxygen steelmaking process and of recent variations such as the Q-BOF.

Austria received technology transfer revenues from the United States of about $26 million during 1978. In turn, Austria has received less than $1 million worth of steel-related technology from the United States.

The major Austrian steel technology exporter is Voest-Alpine. This government-owned steel conglomerate is well-known worldwide for its plant design, engineering, and construction expertise. Voest-Alpine has established joint ventures with other European partners in the United States (the Louisiana-Bayou Steel Corp.), Turkey, India, Brazil, Argentina, Colombia, and Iran. Other Voest companies have many technology licensing arrangements with the U. S. S. R., Czechoslovakia, Hungary, South Africa, India, and the United States. Dravo Corp. of Pittsburgh is the principal holder of Voest licenses for steel process technology in the United States. The technology portfolio of Voest-Alpine claims to have more than 1,500 patents related to steel technology.

United Kingdom

There are no barriers to technology transfer between the United States and the United Kingdom. Steel company interests on both sides are engaged in acquisitions and joint ventures for technology transfer and market shares for products. Until about 5 years ago, British engineers and technologists, with advanced technical and industrial skills, had complete freedom to find employment in the United States, so advanced steel technology transfer to the United States occurred largely through the mass movement of highly qualified and experienced engineers. Except through this source, the United States has not received any major steel technology from the United Kingdom during the last two decades.

Many large British companies are engaged in integrated steel technology transfer. Davy Ashmore has recently completed steel technology transfer projects in the United States, Mexico, and Sweden. The company recently acquired complete control of Arthur G. McKee Co. of Cleveland, a well-established design, engineering, consulting, and construction company. This acquisition seems to have strengthened both the technology base of Davy Ashmore and the financial base of Arthur McKee.

Guest, Keen and Nettleford (GKN) has recently increased its engineering and technology transfer activities. The company is well established, with steel technology transfer projects in West Germany and in Australia through its interest in John Lysaght, an integrated steel producer. At present, GKN and John Lysaght are under the umbrella of Australia's biggest company, the Broken Hill Proprietary Co. (BHP). BHP also owns Peabody Coal Co. in the United States, and this ownership includes West German and Japanese interests under the name of Theiss Campier Mitsui Coal Pty Ltd. This arrangement provides all parties involved with good access to the latest British, West German, U. S., and Japanese technologies related to coke, iron, steel, and transportation,

India

Moving away from an emphasis on domestic self-sufficiency, India has emerged during the past 5 years as an exporter of steel, By the end of this century, India plans to export annually 9.1 million to 13.6 million tonnes,

The steel industry in India has made considerable progress in technology and is now self-reliant, Countries in the Middle East, Africa, and Southeast Asia are looking to India for major technical support for the development of metallurgical industries. The Steel Authority of India has established one of the largest consultancy and engineering organizations in Southeast Asia, with more than 1,700 trained engineers and specialists in various disciplines. This agency, named Metallurgical and Engineering Consultants (India) Ltd. (MECON), is rendering services at home and abroad in the development of integrated steel mills, alloy / specialty steel plants, raw materials preparation and agglomeration, sponge iron and DR plants, and other chemical and metallurgical plants. MECON has know-how licensing agreements in the United States, the United Kingdom, West Germany, Czechoslovakia, Sweden, East Germany, and Japan. *

Another Indian consulting organization, M. N. Dastur and Co., has gained a considerable international reputation for its expertise in preparing feasibility and project reports. This company is advising governments and private industries in Venezuela, Brazil, Colombia, Libya, Iran, Saudi Arabia, Nigeria, Yugoslavia, and the developing countries of Southeast Asia. MECON and the Dastur Co. jointly plan and implement metallurgical and chemical industrial plant development with technology that is purchased from overseas services, then "repackaged" and marketed to developing countries. Both organizations compete with similar organizations from industrialized countries for projects in any part of the world.

India has reportedly received steel technology transfer income in excess of $6 million since 1975. Raw technology purchases by India from the United States during the last 5 years reportedly amounted to $14.5 million for 69 agreements. West Germany has 413 collaboration agreements with India in the steel technology sector, 114 of which are joint ventures, with the West German industries holding more than 40 percent equity interest. All these projects have been initiated since 1971.

Summary Comparisons

Technology transfer plays a critical role in determining the technological competitiveness among steel industries. Moreover, as

*Personal discussions of OTA contractor Dr. K. Bhat with Mr. R. Dave, Manager, Bombay Office of M. N. Dastur and Co., Ltd.

steel export markets are lost to expanding indigenous industries, technology sales determine to an increasing degree the economic success of these industries. Nevertheless, there is a dearth of detailed information on steel technology transfer. Summary descriptions of steel technology transfer in the United States, Japan, West Germany, Austria, the United Kingdom, and India are given in table 126. Generally, the nations that are most successful in steel technology transfer have supportive government policies and steel companies that have strong R&D programs and pursue technology transfer as an integral part of their operations.

Table 126.—Features of Technology Transfer in Different Nations

Country	Role of technology transfer in steel industry	Type of technology transferred	Role of Government	Salient aspects of technology transfer
Japan	Integral part of most major steel companies. Supplement to steel experts.	Basic ironmaking and steel making.	Strong—provides planning, advice, financing.	Consists of all soft and hard transfers, including construction and advice.
West Germany	Moderate. German equipment and construction companies active.	Strong in secondary finishing and heat treatments. Direct reduction.	Strong, assists with financing.	Strong and complex associations with foreign design/engineering construction companies.
Austria	Strong in State-owned steel company.	Steel making.	Strong because of ownership of steel industry.	Very aggressive in Third World Western and Eastern sections.
United Kingdom	Slight. Mostly in design/engineering/construction companies.	Basic ironmaking and steel making.	Minimal.	Weak because of declining steel industry.
India	Strong in State-owned industry.	All phases.	Strong because of ownership of steel industry.	Very aggressive in Asian, Middle Eastern, and African LDCs.
United States	Moderate. A number of design/engineering/construction firms are active.	Strongest in raw materials processing and steel products.	Minimal.	Strength lies outside of all but a few large steel companies.

SOURCE Office of Technology Assessment