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PREFACE

The *Industry, Trade, and Technology Review* is a quarterly staff publication of the Office of Industries, U.S. International Trade Commission. The opinions and conclusions it contains are those of the authors and do not necessarily reflect the views of the Commission or of any individual Commissioner. The report is intended to provide analysis of important issues and insights into the global position of U.S. industries, the technological competitiveness of the United States, and implications of trade and policy developments.

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ALTERNATIVE FUELS: CHALLENGES AND OPPORTUNITIES FOR THE U.S. AUTOMOTIVE INDUSTRY

Since the 1960s, concerns about pollution caused by vehicle emissions and increasing U.S. dependence on imported oil have presented challenges and opportunities to the U.S. automobile industry, and to a number of upstream/downstream industries, such as the automotive parts and services industries, the petroleum and petrochemical industries, and certain sectors of U.S. agriculture. U.S. Environmental Protection Agency (EPA) sources estimate that motor vehicles contribute more than 50 percent of all air toxins in the United States annually,[1] and that the current implementation costs of U.S. pollution control measures are equivalent to 2 percent of the U.S. gross national product.[2] In addition, one major foreign automaker estimated that U.S. vehicular traffic accounts for a relatively significant portion, about 3 percent, of total carbon dioxide emissions of the earth annually.[3] These and related environmental concerns have prompted a series of Federal and State Government initiatives to develop and market alternative fuels in lieu of conventional gasoline. This article examines U.S. initiatives to develop alternative-fueled vehicles (AFVs), available technologies, issues of competitiveness, and the economic implications associated with converting conventional (gasoline-powered) vehicles to AFVs.

The U.S. Initiative

U.S. Government initiatives such as the Alternative Motor Fuels Act of 1988 mandated a certain number of AFVs to be used by the U.S. Government, and it provided incentives[4] to U.S. vehicle manufacturers to build AFVs. Subsequently, The Clean Air Act Amendments of 1990 required that, beginning in 1998, clean alternative fuels[5] be introduced in certain geographic regions in the United States that have severe air-quality problems. In addition, the Bush administration's National Energy Strategy (issued on February 20, 1991), which since has been largely endorsed by the Clinton administration, and various bills introduced by the U.S. Congress, encourage the use of alternative fuels through a variety of similar initiatives. These include—(1) additional mandated increases in the number of AFVs used by the U.S. Government, especially in certain urban areas with air-quality problems; (2) tax incentives and credits for producers of alternative fuels, including an efficient distribution system; (3) financial incentives to encourage State and local governments to purchase AFVs; and (4) training and certification for technicians that participate in the conversion of motor vehicles to run on alternative fuels.[6]

California, with the Nation's largest number of registered motor vehicles, has been the U.S. leader in legislating emissions control. For example, the California Air Resources Board (CARB) will require that, by 1998, 2 percent of all vehicles sold in California must produce no emissions, a requirement that currently can be met only by electric vehicles (table 1-1).

This ratio will be increased to 10 percent by the year 2003.[7] Also, pending ongoing cost-effectiveness and feasibility studies by the EPA, additional amendments to the Clean Air Act of 1990 could require that all light-duty vehicles in the U.S. market meet the 1997 California limits by 2003.[8] California standards are designed to measure the nonmethane organic gas (NMOG) content in emissions, which comprises hydrocarbons and oxygenated hydrocarbons (alcohols, aldehydes, ketones, and ethers). It is important to monitor these chemicals because they are frequently added to gasoline by fuel producers to raise octane levels and/or otherwise improve fuel properties. The California pilot program has created four vehicle categories based on NMOG content to help monitor a 10-year phase-in process (1994-2003) of the new emissions requirements (table 1-1). U.S. and foreign

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[1] EPA, *Congressional Quarterly*, Special Report, Jan. 20, 1990.

[2] EPA official, interview by USITC staff, Mar. 1993.

[3] Estimates of Swedish automaker Volvo, "Vehicles and the Environment," *Financial Times*, July 27, 1990, p. 6.

[4] For example, gasoline blended at least 10 percent with ethanol is eligible for a 5.4-cent-per-gallon exemption from Federal motor fuel excise taxes.

[5] According to the Clean Air Act, as amended in 1990, clean alternative fuels include ethanol, methanol, compressed natural gas (CNG), liquified petroleum gas (LPG), commonly known as propane, hydrogen, electricity, and reformulated gasoline, used in clean-fuel vehicles that comply with the emission standards that were established by the act.

[6] U.S. General Accounting Office (GAO), "Alternative Fuels," May 1992, p. 16.

[7] "Filling Up on Alternative Fuels," *Machine Design*, Jan. 8, 1993, p. 64.

[8] EPA official, interview by USITC staff, June 1, 1993.

Table 1-1
California implementation rates according to NMOG standards, model years 1994-2003

Model Year	Vehicle type and NMOG level						NMOG fleet average standard (g/mile)
	Conventional						
	0.39	0.25	TLEV 0.125	LEV 0.075	ULEV 0.04	ZEV 0.0	
1994	10%	80%	10%				0.250
1995		85%	15%				0.231
1996		80%	20%				0.225
1997		73%		25%	2%		0.202
1998		48%		48%	2%	2%	0.157
1999		23%		73%	2%	2%	0.113
2000				96%	2%	2%	0.073
2001				90%	5%	5%	0.070
2002				85%	10%	5%	0.068
2003				75%	15%	10%	0.062

Note.—Vehicle categories established to monitor emissions include Conventional; Transitional Low-Emission Vehicles (TLEV); Low-Emission Vehicles (LEV); Ultra-Low Emission Vehicles (ULEV); and Zero-Emission Vehicles (ZEV).
Source: "Filling Up on Alternative Fuels," *Machine Design*, Jan. 8, 1993, p. 67. and *CARB*.

automakers may produce any combination of vehicles from the four categories, as long as the manufacturer's fleet average[9] meets the NMOG standard for any given year in California.

Despite the technological scramble and the potentially significant costs associated with developing alternative ways to power vehicles, during 1991-93, the legislatures of Massachusetts, New York, and Maine voted to adopt California standards, and additional Northeastern States are expected to follow in the coming years. In recent years, Texas, Louisiana, Oklahoma, and Colorado also adopted legislation that mandates the use of a certain number of AFVs in State-owned government fleets by the mid-1990s. In response to these new State-induced requirements, U.S. automakers have begun to research advanced emission-control technologies, cleaner burning fuels, and the economic feasibility of electric-vehicle models.

Alternative-fuel Technologies

Although research on alternative fuel technologies is ongoing, options can be grouped into two categories: (1) renewable sources such as ethanol derived from corn or sugar cane, hydrogen, geothermal, solar and wind energy, and vegetable oil derivatives (e.g., soybean oil mixed with diesel fuel); and (2) nonrenewable sources such as certain other alcohol fuels (e.g., methanol) and gaseous fuels (e.g., propane and natural gas). Although renewable sources are a means to achieve ultimate energy efficiency, nonrenewable sources currently remain the alternative fuels of choice by major automakers worldwide because of their economic feasibility.

Renewable Sources

During recent years, ethanol has emerged as the most widely accepted alternative fuel for automobiles among renewable supply sources. Although it also can be acquired from nonrenewable sources such as petroleum, ethanol generally is considered a renewable energy source because it is derived principally from renewable sources such as corn and sugar cane. Ethanol production is especially suitable in areas with rich vegetation and a long growing season, such as Brazil. For example, since 1975, Volkswagen has sold over 2 million ethanol-powered vehicles in the Brazilian market, where the feedstock is sugar cane. Ethanol production in the United States relies on corn, which entails a more expensive production process than does sugar cane, partly because of comparatively higher U.S. labor and land costs. Although the required biomass cannot be produced as economically in the United States as in Brazil (production in Brazil is heavily subsidized), General Motors is currently testing 50 ethanol-fueled Chevrolet Luminas in Wisconsin and Illinois, in conjunction with the U.S. Department of Energy.

Hydrogen-powered vehicles are virtually pollution-free, operating on water and emitting mostly water vapor. However, the technical difficulties associated with the production, storage, and distribution of liquid hydrogen make this alternative fuel commercially less viable. To keep hydrogen in a liquid state, it must be stored in an insulated, refrigerated tank at minus 423 degrees Fahrenheit. Liquid hydrogen is also highly explosive when exposed to higher temperatures. Despite these difficulties, the German Government and a Japanese-owned automaker (Mazda) have developed liquid-hydrogen-propelled vehicles.[10] U.S. research on

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[9] Based on vehicle sales.

[10] American Petroleum Institute (API), "New Transportation Fuels," Jan. 7, 1993, p. 6.

the use of liquid hydrogen as an alternative fuel has been limited.

Small-scale hydroelectric, solar, or geothermal energy have emerged as other feasible alternative fuel sources for automobiles. These sources of electricity are widely available natural resources such as water, the sun, and the heat of the inner core of the earth. For example, water is an abundant source of hydroelectric power, and the process of generating electricity from water is a significantly less polluting activity than the process of generating electricity from coal or natural gas. Despite the environmentally friendly properties of these experimental sources, the electric-vehicle technology currently utilized by automakers relies overwhelmingly on traditional, nonrenewable fossil sources such as coal.

Other alternatives such as vegetable oil derivatives also have been considered and tested, mainly in Africa and the Philippines. These have performance characteristics similar to those of diesel fuel. However, vegetable oil derivatives also exhibit negative properties such as high viscosity and flash point, which make starting an engine in low temperatures difficult. Used as a motor-vehicle fuel, vegetable oil causes pollutants and burns with a pungent exhaust odor.[11] In addition, it is considered uneconomical to produce because of the high price of vegetable oil.[12]

Nonrenewable Sources

Alcohol fuels such as methyl alcohol, commonly referred to as methanol, can be made from coal, natural gas, heavy oil, wood, and from methane derived from municipal waste. Methanol has been advanced by certain U.S. automotive industry representatives to be the most feasible alternative fuel, primarily because there are sufficient reserves of natural gas and coal in the United States. Methanol is also preferred because of its cleaner combustibility compared with that of ethanol-enhanced gasoline. In addition, it is reasonably priced and suitable for today's liquid-fuel distribution and storage systems. Critics of methanol as an alternative fuel argue that it is toxic; delivers half the driving range of conventional gasoline; produces ozone-creating formaldehyde emissions; corrodes rubber and steel; and causes starting problems in cold weather.[13]

Gaseous fuels such as liquified petroleum gas (LPG), commonly called propane, and compressed natural gas (CNG) have also been considered as alternative fuels by automakers worldwide. LPG is a mixture of gaseous hydrocarbons that are converted to a liquid state by pressure and/or reduced temperatures during either the processing of natural gas or the refining of crude oil. LPG provides a high-octane fuel, but vehicles using this fuel generally have a reduced driving range, and cargo space is compromised because relatively large on-board canisters are required to store the necessary amounts of fast-burning LPG.

Although the data available concerning the pollution effects of LPG-fueled vehicles are not conclusive, U.S. industry sources state that LPG tends to produce lower levels of hydrocarbons than gasoline, and CARB has reported that LPG has a lower ground-level-ozone-forming potential.[14] CNG also has a lower NMOG content than gasoline and is reported to be a high-performance, high-octane, and relatively clean-burning fuel. Further, natural gas is widely available in the United States and costs somewhat less than the petroleum required to produce conventional gasoline. However, CNG produces higher levels of nitrous oxide, a lower atmosphere ozone-forming pollutant.[15] In addition, CNG consists mainly of methane, a potent green-house gas. Because of these adverse properties of CNG, it is essential to minimize its leakage and ensure its complete combustion.[16]

The cleanest form of alternative fuel, electricity, is generated from nonrenewable fossil sources such as coal, although fossil-fuel electric power plants continue to produce a variety of emissions such as hydrocarbons, nitrous oxides, and sulfur dioxide.[17] In addition, developmental and marketing restraints such as higher production and usage costs and limited driving range, have proven to be significant obstacles to electric-powered vehicles (EPVs). First-generation EPVs are compelled to use lead-acid, nickel-cadmium, and nickel-iron batteries, all of which are currently available. Sodium-sulphur batteries, which offer greater driving range, will likely be developed and marketed in a few years. After the year 2000, EPVs may utilize lithium batteries that provide a driving range comparable to that of gasoline-powered vehicles (in excess of 300 miles). To augment their own research, the U.S. Big Three automakers (General Motors, Ford, and Chrysler), along with the Electric Power Research Institute and the U.S. Department of Energy, formed the U.S. Advanced Battery Consortium in 1991 to improve battery technology. Funds for this initiative are expected to total $260 million over a 4-year period.[18]

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[11] "Filling Up," p. 69.

[12] For example, in 1992, the price of crude, bulk vegetable oil exceeded $400 per metric ton, or about $2 per gallon, according to U.S. Department of Agriculture data.

[13] API, p. 3

[14] Ozone, which is a common chemical in the upper atmosphere of the earth, protects the biosphere from ultraviolet radiation. However, in the lower atmosphere, it is a principal constituent of smog and can irritate the lungs.

[15] GAO, p. 9.

[16] "Filling Up," p. 68.

[17] GAO, p. 5.

[18] "Detroit Charged Up About EVs," *Machine Design*, Jan.8, 1993, p. 80.

Marketing and Distribution Issues

Distribution networks are yet to be developed and/or approved nationwide for the marketing of alternative fuels. However, in 1991, the California Public Utilities Commission approved a pilot program to create a comprehensive distribution system for CNG, including the installation of refueling stations at oil-company-owned service stations for public access; conversion incentives to consumers of up to $1,250 per vehicle; marketing programs to demonstrate the benefits of CNG-powered vehicles; and the development of maintenance and technical support systems.[19] In addition, the California Energy Commission developed an "Infrastructure Master Plan" in 1992 to bring EPVs to the market. This development program calls for the standardization of re-charging connectors and equipment; the installation of charge stations at public parking lots, airports, and shopping malls; and an EPV readiness plan by the City of Los Angeles that includes wiring in new residential homes that is suitable for the re-charging of EPVs.[20]

Competitiveness Issues

During 1988-91, Brazil led all countries worldwide in the number of operational AFVs with 4.2 million units (almost exclusively ethanol-powered); followed by Japan with 1.5 million (all were LPG-powered); Italy with 1.3 million (1.1 million units LPG-powered and the rest CNG-propelled); and the Netherlands with about 1.1 million (mostly LPG-powered). During this period, the United States recorded the fifth-highest number of operational AFVs (330,000 LPG-powered and 30,000 ethanol-propelled). However, AFVs combine for only 0.2 percent of the total U.S. vehicle fleet, ranking the United States as 11th worldwide with respect to the overall incorporation of these vehicles (figure 1-1).

National governments (e.g., especially the Governments of Brazil, Canada, and New Zealand) have intervened in the marketplace to stimulate the development of AFVs through legislation, subsidies, tax exemptions, and other means.[21] For example, in the mid-1970s, the Government of Brazil used fuel

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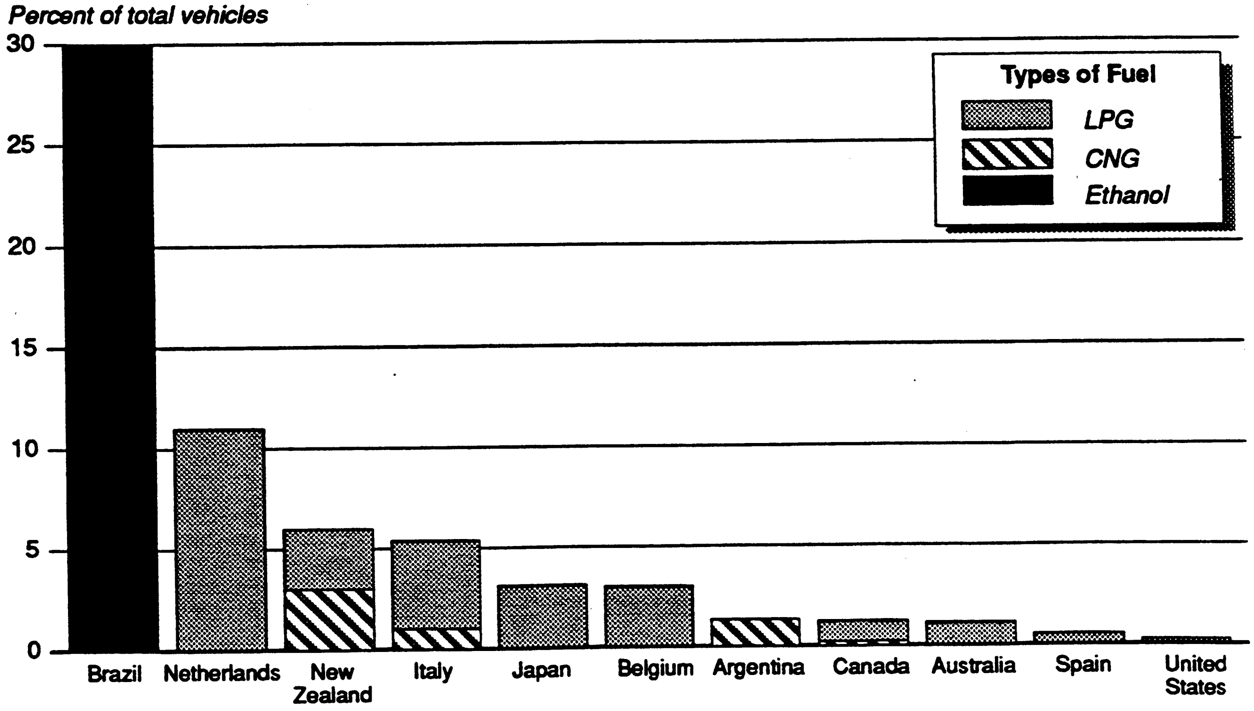
[19] California Energy Commission, "Fuels," Dec. 1991, p. 18.

[20] "What If Electric Vehicles Don't Sell," *Automotive Industries*, Apr.1993, p. 35.

[21] GAO, p. 3.

Figure 1-1
Alternative-fueled vehicles as a percentage of total number of vehicles, by country and fuel type, 1988-91



Source: U.S. Department of Energy.

subsidies, price controls, and loans to persuade Brazil's automotive industry to exploit alternative fuel technologies such as ethanol. It also provided incentives in the form of reduced vehicle taxes to consumers that purchased ethanol-powered vehicles. In addition, heavy dependence on imported oil and a depressed sugar market spurred the Brazilian Government to begin a centralized program involving the conversion of domestic sugar cane into ethanol for use as a motor-vehicle fuel. Brazil's annual production of ethanol was projected to be about 5 billion gallons in 1990, or about six times U.S. production.[22] However, in recent years, Brazilian production of ethanol has declined because of structural inefficiencies in the Brazilian economy. Partly because of its continued high consumption of ethanol, Brazil currently imports some of its needs.

European firms have long been supported by government incentives in Italy, the Netherlands, Belgium, and Spain to develop and test mostly LPG-fueled vehicles, and to a lesser degree, CNG-propelled vehicles. In addition, German luxury automakers Mercedes and BMW have developed electric vehicles. Mercedes built an electric rendition of its 190E model that uses sodium-nickel chloride batteries. Industry sources indicate that battery packs can be recharged in 12 hours and are largely maintenance free. The BMW electric prototype models (E1 and E2) use sodium-sulphur batteries that provide a longer driving range (161 miles) compared with that of the electric version of the Mercedes 190E (93 miles).[23] Other large-scale European EPV development programs have been initiated by the PSA Group[24] and Renault of France, Volkswagen of Germany, and Fiat of Italy.

In Japan, Nissan has emerged as one of the leaders in electric-vehicle testing. Its prototype, the Future Electric Vehicle (FEV) is slightly smaller than the Nissan Sentra. The FEV uses nickel-cadmium batteries that can be re-charged in 8 hours through an onboard unit that accepts standard household power. Nissan is currently working on other prototypes such as the EV-2 and a so-called Cedric/Gloria conversion. The EV-2 uses nickel-iron batteries and the Cedric is powered by lead-acid batteries. In addition to Nissan's efforts, most Japanese automakers have various EPV development programs under way.[25]

As discussed, the United States has not been a global leader in the development of operational AFVs during 1988-91. However, since the mid-1980s, U.S. automakers have been in the forefront of global research and development efforts with respect to EPVs. The GM prototype, known as Impact, represents one of the U.S. industry's best attempts at an EPV that can be mass marketed. Mainly because of its aluminum body construction, the Impact weighs only 2,200 pounds (including an 870-pound battery system), which is about 600 pounds less than the weight of a comparably sized conventional automobile. Its top speed is 100 miles per hour (mph), and it is capable of accelerating from 0 to 60 mph in 8 seconds. Remaining obstacles to bringing this model to the market include the limited driving range of the vehicle (currently 120 miles with one charge under ideal driving conditions), and the relatively short life-cycle (20,000 miles) and high price tag of its battery ($1,500).[26]

Other U.S. automakers also developed EPV prototypes during the early 1990s. Ford's leading experimental model is a two-seat minivan, called the Ecostar, that uses sodium-sulfur batteries. The automaker has plans to distribute 80 units of the Ecostar for testing purposes to clients such as Detroit Edison. These customers will work with Ford to develop comprehensive vehicle service and maintenance programs. Chrysler's TEVan is powered by more expensive nickel-iron batteries ($6,000 each), which provide 50 percent more power than lead-acid cells and last the longest of any batteries tested in EPVs. The TEVan will be sold primarily to fleet buyers at a price in excess of $100,000 per unit.[27] Despite these advances, and because none of the U.S. automakers has appeared ready to unilaterally cross the threshold that separates development from volume production, discussions among the U.S. Big Three automakers have recently shifted towards the possible joint development and production of an EPV.[28]

Economic Implications

State Government officials in California have determined that the impact on the global automotive industry of converting to AFVs is significant both in terms of costs and benefits (table 1-2). U.S. industry sources are concerned primarily with costs and estimate that the Clean Air Act of 1990, when fully implemented, will add from $500 to $1,000 to the production cost of an automobile in the United States incurred either as a result of more advanced emission-control technologies or from the conversion to alternative fuels. For example, EPA officials estimate that the conversion cost of a CNG-fueled vehicle is about $900 higher than that of a gasoline-propelled vehicle.[29] Some of these costs will

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[22] EPA, "Analysis of the Economic and Environmental Effects of Ethanol as an Alternative Fuel," Apr. 1990, p. 27.

[23] "Paving the Way for Electric Cars," *Machine Design*, Jan. 8, 1993, p. 78.

[24] The PSA Group includes French automakers Peugeot and Citroen.

[25] "Update on Automaker Electric Vehicle Projects," *Automotive News*, June 7, 1993, p. 9i.

[26] "Is America Ready for the Gasless Carriage?" *Business Week*, Apr. 8, 1992, p. 58.

[27] "This is Not Your Grandfather's Electric," *Machine Design*, Jan. 8, 1993, p. 76.

[28] "Big Three Accelerate EV Development Programs", *Ward's Engine and Vehicle Technology Update*, May 1, 1993, p. 5.

[29] "Filling up," p. 69.

Table 1-2
Projected costs and benefits[30] of converting gasoline-powered vehicles to AFVs

Fuel	Estimated price per/gallon in the year 2000	Conversion cost per car to meet standards	Cost to equip a fuel station	Net annual cost/benefit: LEV vs. conventional
	Dollars	*Dollars*	*(x$1,000)*	*(@$1.45/gal.)*
Gasoline	1.35-1.45	70-170	50-70	[1]30
CNG	.84	1,000-1,200	250	-55
LPG	.98	600-700	40-75	-88
Methanol	1.44-1.49	200-440	50-70	50
Ethanol	2.33	200-440	50-70	405
Electricity	.59	1,350	(2)	-135

[1] Reformulated vs. conventional gasoline.
[2] Charged at garage.
Source: CARB.

likely be passed on to the consumer in the form of higher manufacturer's retail prices, and some will be absorbed by the auto producers. However, consumers might benefit (depending on the type of AFV used) in the form of lower operation and maintenance costs because the unit cost of LPG and CNG compares favorably with that of conventional gasoline. In addition, EPVs are likely to require less maintenance than gasoline-powered vehicles. U.S. automobile manufacturers likely will absorb part of the higher production costs in the form of lower profit margins and may experience sluggish sales owing to higher retail prices. In addition, U.S. automakers may face reduced export competitiveness in foreign markets because of higher priced U.S. automobiles, especially in countries where pollution-abatement technologies are not required.

In contrast to cost concerns raised by automakers, U.S. automotive parts suppliers are likely to benefit from the increasing use of AFVs. Although certain small engine parts, exhaust system, and emission control manufacturers may find it difficult to make the transition to produce the parts required by AFVs, the demand for new technologies is likely to spur additional opportunities for well-established U.S. parts makers.

The petroleum and petrochemical industries are not likely to be major beneficiaries in the movement toward AFVs. However, opportunities for these industries do exist in the areas of reformulated gasoline, oxygenated gasoline, and shale and tar sands exploration. Yet petroleum industry sources caution that, California standards notwithstanding, alternative fuels will constitute only about 3 percent of the U.S. market by the year 2010.[31] Despite concerted efforts by the U.S. Government and the U.S. Big Three automakers to develop alternative fuels, the U.S. petroleum industry likely will retain the auto industry as its most important customer in the foreseeable future. Petroleum industry sources point out that, to date, no alternative fuel has seriously challenged the viability of oil as a source of transportation fuel. They argue that conventional gasoline is easy to transport, powerful in small quantities, inexpensive, and abundant.[32]

Outlook

As discussed, coordinated efforts between national governments and major industries have been typically the catalysts for action in the development of AFVs worldwide. In response to such efforts undertaken by global competitors and in an attempt to be responsive to environmental interest groups, the Clinton administration and the U.S. Big Three automakers have established a task force in February 1993 to facilitate private-sector development of "clean cars" that create little or no pollution. This task force was organized under the Federal Coordinating Council for Science, Engineering, and Technology, which estlabished six interagency groups to address high-priority technology issues. One of these six groups will focus on advanced manufacturing technology and is responsible for the "clean car" initiative. The "clean car" subgroup is composed of representatives from the U.S. Departments of Commerce, Energy, Defense, and Transportation, as well as the EPA, the National Aeronautics and Space Administration, and the National Science Foundation.[33] Participants are currently considering ways to fund and develop a "hyperclean" vehicle that can attain a gas mileage of 60 to 90 miles per gallon.[34] A final agreement between the parties, which is expected to include a $1 billion research package, will likely be crafted by yearend 1993. A key part of this agreement will be a cooperative effort between the U.S. Big Three

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[30] EPA, "Analysis," table 4, p. 10.

[31] Estimates provided by the Argonne National Laboratory as cited by the API in an update on "New Transportation Fuels," Jan. 7, 1993, p. 6.

[32] Ibid., p. 7.

[33] U.S. Department of Commerce, "The Clean Car Initiative,"Apr. 2, 1993.

[34] "U.S. Makes 'Decent Proposal,'" *Automotive News*, May 10, 1993, p. 1.

automakers and Federal research laboratories, especially those that are managed by the U.S. Department of Energy.

The global quest for AFVs is likely to intensify by the turn of the century. The U.S. automotive industry remains competitive with its Japanese and European counterparts in the research and development of AFVs. U.S. emissions-control legislation and technology set the international standards in the reduction of vehicle pollutants during the 1980s, and the United States is likely to retain this advantage during the 1990s. However, the debate among representatives of U.S. industry and the U.S. Government continues regarding the development of a uniformly accepted AFV. In the United States, methanol and CNG are beginning to emerge as preferred energy sources among nonrenewable alternative fuels, primarily because of abundant U.S. supplies of coal and natural gas. In addition, U.S. automakers, such as GM, and U.S. parts manufacturers, such as Allied Signal, participate in, and sometimes lead, the global pursuit for an operational AFV that uses renewable energy sources such as solar electricity.

The complexities and challenges associated with the task of developing an AFV that can be mass marketed are significant. The future AFVs will need to cater to the business interests of the automotive, petroleum, petrochemical, and related upstream/downstream industries. It will need to address concerns about the environment; and it will have to be the type of vehicle that can be efficiently produced and distributed. At the same time, it must remain price-competitive, be successful in the marketplace, and not compromise vehicle performance.■

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PACE OF FLAT GLASS INDUSTRY GLOBALIZATION AND PROSPECTS FOR MORE INTENSE COMPETITION

The trend toward industry globalization has continued in recent years in flat glass,[1] a material primarily used in windows, doors, and mirrors in the construction and automotive markets. French, Japanese, British, and U.S. firms have continued their expansion of worldwide networks of production facilities through investment in existing or new facilities (table 2-1). Joint-venture arrangements have afforded such producers an excellent means of market entry at reduced risk, combining their capital and technical expertise with the established distribution channels and market knowledge of local partners.

Globalization Factors

Globalization of the flat glass industry is promoted primarily by five factors:

- Heightened global perspective of producers;
- High transportation costs;
- Difficult adoption of float technology;
- Access to countries formerly closed to foreign investment; and
- Globalization of the automotive industry.

Heightened global perspective of producers and high transportation costs have been common factors behind the recent growth of foreign investment in global flat-glass facilities. The influence of the other factors has varied by region (figure 2-1).

Heightened Global Perspective of Producers

Producers increasingly see that national markets for flat glass can no longer be viewed in isolation but must be seen as part of a global market.[2] This heightened global awareness has encouraged firms to seek foreign-market opportunities. The resultant expansion in international competition for markets has reinforced firms' global focus. At least one U.S. producer believes that globalization is a necessary defensive measure to remain competitive in the flat-glass industry. Firms that fail to compete globally will be dominated by foreign competitors that have increased in size and strength by expanding into foreign markets.[3]

High Transportation Costs

When flat glass producers look beyond their national boundaries, they often find that high transportation costs[4] encourage the servicing of foreign markets through the establishment of foreign production facilities rather than through trade. In those cases where a firm's shipped goods are too expensive to be competitive in a foreign market, an investment in local production facilities may be the only practical means for market entry. Flat glass is expensive to ship because it is relatively heavy, low in value, and fragile. Land transportation costs can add roughly 10 percent to total shipment costs per 500 miles shipped;[5] water and air transportation added 7.4 percent to the value of U.S. imports of flat glass in 1992.

Difficult Adoption of Float Technology[6]

The patent-restricted availability,[7] high cost, and complexity of state-of-the-art production technology in the flat glass industry continue to allow a limited number of companies to expand their worldwide

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[1] The flat glass industry encompasses flat glass and the following products fabricated from flat glass: tempered glass, laminated glass, mirrors, insulating units, and miscellaneous products such as desk tops, curved display windows, and partition glass.

[2] "In Business Think Globally," *American Glass Review*, Dec. 1991, p. 12.

[3] U.S. industry representative, interview by U.S. International Trade Commission (USITC) staff, July 1992.

[4] Posthearing brief of Guardian Industries Corp. to the USITC in *Potential Impact on the U.S. Economy and Selected Industries of the North American Free-Trade Agreement*, (investigation No. 332-337), Nov. 24, 1992, p. 5.

[5] U.S. industry representative, interview by USITC staff, July 1992, and prehearing brief on behalf of Vidrio Plano de Mexico, S.A., Vitro Flotado, S.A., and Sentinel Holdings, Inc., to the USITC in *President's List of Articles Which May be Designated or Modified as Eligible Articles for Purposes of the U.S. Generalized System of Preferences*, (investigation Nos. TA-503(a)-18 and 332-279), Sept. 22, 1989, p. 12.

[6] In the float process of flat glass production, molten glass is fed as a continuous ribbon from the melting furnace onto a bath of molten tin where the glass is fire polished by controlled temperatures. It offers quality and cost advantages over the production methods it replaced.

[7] The float process was developed and patented in the 1950s by Pilkington Brothers, Ltd. (Pilkington), of the United Kingdom. Pilkington has licensed the use of its process throughout the world.

Table 2-1
Flat glass and certain flat glass products: Foreign investment in selected glassmaking facilities, by region and country, 1990-1993

Region and country	Year	Nature of investment
North America:		
United States	1992	Asahi Glass (Asahi) of Japan acquired AFG Industries, Inc. (AFG), one of the top five U.S. producers of flat glass.
	1992	Vitro, S.A. (Vitro), a Mexican producer of flat glass, purchased ACI America, a U.S. firm with fabrication, distribution, retail, and installation operations in the southern part of the United States.
	1991	Central Glass of Japan opened a joint venture with Ford Motor Co. to produce automotive-glass in Tennessee.
Canada	1992	Asahi gained control of AFG's Canadian facilities through the acquisition of AFG.
	1990	Asahi subsidiary opened a float-glass plant in Quebec.
Mexico	1992	Vitro[1] opened its third float-glass plant.
South America:		
Venezuela	1991	Guardian Industries Corp. (Guardian) of the United States opened a float-glass plant in Venezuela, a joint venture with local companies.
Europe:		
Eastern Europe:		
Czech Republic	1991	Asahi subsidiary purchased a minority share and then control of Czech flat-glass operations.
Hungary	1991	Guardian opened a joint venture with a local firm to produce float glass.
Poland	1992	Pilkington Brothers, Ltd. (Pilkington), of the United Kingdom purchased distribution facilities.
	1991	Pilkington was selected over Asahi for a float-glass joint venture with a Polish firm.
Western Europe:		
Belgium	1992	Asahi subsidiary began construction of a laminated-windshield plant in Fleurus scheduled for completion in 1994.
	1991	Asahi subsidiary acquired controlling interest in an automotive-glass operation from its Italian partner and built a laminated-glass plant in Athus.
Germany	1991	Asahi subsidiary purchased glass fabrication facilities in former East German territory.
	1991	Pilkington acquired an automotive-glass producer in former East German territory.
Luxembourg	1991	Guardian announced plans to construct an automotive-glass plant expected to be operational by the end of 1993.
Spain	1992	Guardian began construction of a float-glass plant expected to be operational by the end of 1993.
Portugal	1991	La Compagnie de Saint Gobain (Saint Gobain) of France acquired Portuguese Government's glass plant through its Spanish subsidiary.
United Kingdom	1990	Saint Gobain acquired fabrication facilities from South African firm.
Asia:		
China	1993	Asahi, PPG Industries, Inc. (PPG), two Chinese partners, and a Japanese trading company entered into a joint venture to build a float-glass plant in Dalian that should be operational in early 1995.
	1992	Asahi acquired half of the PPG holdings in China, joining PPG and Pilkington as the only foreign firms with investments in Chinese flat-glass facilities.
India	1993	Asahi announced a joint venture with the Tata Group, a local conglomerate, to build a float-glass plant that is expected to open by late 1994.
	1992	Guardian opened India's first float-glass plant, following a relaxation of India's restrictions on foreign investment in 1991.

See footnote at end of table.

Table 2-1
Flat glass and certain flat glass products: Foreign investment in selected glassmaking facilities, by region and country, 1990-1993

Region and country	Year	Nature of investment
Asia:—Continued		
Thailand	1992	Guardian opened a float-glass plant in 1992, a joint venture with a local firm, Siam Cement Co.

[1] Pilkington Brothers, Ltd. (Pilkington), of the United Kingdom holds a minority interest in the Mexican flat-glass operations of Vitro, S.A.

Source: Compiled by the staff of the U.S. International Trade Commission from telephone interviews with U.S. industry representatives and various articles appearing in *American Glass Review, Ceramic Industry, Glass Digest, Glass Industry,* and *Glass Magazine*; and industry submissions to the Commission in various statutory investigations.

Figure 2-1
Flat glass and certain flat glass products: Globalization factors, by region

Factor	Region North America	 South America	 Eastern Europe	 Western Europe	 Asia
Heightened global perspective of producers	X	X	X	X	X
Transportation costs	X	X	X	X	X
Adoption of float technology		X	X		X
Access to countries formerly closed to foreign investment			X		X
Globalization of the automotive industry	X			X	

Source: Compiled by the staff of the U.S. International Trade Commission based on interviews with U.S. industry representatives; various articles appearing in *American Glass Review, Ceramic Industry, Glass Digest, Glass Industry,* and *Glass Magazine*; and industry submissions to the Commission in various statutory investigations.

holdings and influence. Flat glass typically is produced by the float process, which affords quality and cost advantages over other production methods. However, firms in many countries lack the necessary capital (in excess of $100 million for a float plant)[8] and technical expertise to shift to the float process. This inability has created opportunities for foreign (including U.S.) firms with adequate financial resources and float-process experience to enter markets by establishing their own plants or entering joint ventures with local producers. The technological experience of Pilkington Brothers, Ltd. (Pilkington), of the United Kingdom, coupled with aggressive defense of its patent rights, made it the early leader in this global expansion. Asahi Glass (Asahi) of Japan, Guardian Industries Corp. (Guardian) of the United States, La Compagnie de Saint Gobain (Saint Gobain) of France, and PPG Industries, Inc. (PPG) of the United States have also parlayed experience with float technology to their advantage in foreign investments.

Access to Countries Formerly Closed to Foreign Investment

The transfer of float technology has been a significant factor in investment in several markets recently opened to foreign investment, such as India and Eastern Europe. The lack of float glass facilities and the fact of a large market potential in these countries have made them attractive markets for investments by major global producers. Eastern Europe offers investors greater short-term potential, with per capita income and glass consumption levels closer to those of Western countries. Although income and glass consumption levels are relatively low in India, even modest improvement in per capita income could generate considerable glass demand because of the size of its population (16 percent of the world total in 1991).

In other countries recently opened to investment, such as China and Thailand, however, float-technology transfer was not a significant investment issue. Both China and Thailand already had float facilities. U.S. and Japanese investment in these Asian-Pacific

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[8] Posthearing brief of Guardian Industries Corp. to the USITC in investigation No. 332-337, Nov. 24, 1992, p. 10.

countries was encouraged by regional demand, which is the fastest growing in the world at 5 percent a year.[9]

In South America, on the other hand, additional investment in the region is unlikely despite recent efforts to liberalize business and trade conditions. The South American countries that have sufficient population and per capita income to sustain float facilities—Argentina, Brazil, and Venezuela—have already acquired such operations. Smaller and less developed countries cannot sustain such industries on the basis of their internal markets, and transportation costs prevent them from becoming export platforms to other markets.

Globalization of the Automotive Industry

Globalization of the automotive and flat glass industries are increasingly intertwined; automotive applications are the second-largest market for the industry, representing about one-quarter of all sales. Automotive and automotive-glass producers—particularly Japanese firms—are drawn to North America and Western Europe because they are major centers for automotive production and consumption. In both the United States and the European Community (EC), limits on automotive imports encouraged the Japanese automotive industry to build local automotive assembly operations, which were then followed by Japanese investment in automotive-glass fabrication facilities. The last of three Japanese flat-glass producers to invest in U.S. automotive-glass facilities, Central Glass (Central), opened a joint venture with Ford Motor Co. in 1991 to produce automotive glass in Tennessee. Asahi has wholly owned U.S. facilities, and Nippon Sheet Glass (Nippon) has equity investments in such facilities. Moreover, the latter two Japanese firms subsequently secured U.S. sources of raw flat glass for their fabrication operations by purchasing shares of major U.S. flat glass producers.[10] Japanese, British, and U.S. flat-glass producers have also have invested in Canadian and Mexican automotive-glass fabrication facilities. Guardian and Pilkington also made recent investments in EC fabrication facilities.

Outlook

Globalization of the flat glass industry is expected to continue throughout the 1990s, but the pace will fall, and reasons for investment may change. Although heightened global perspective and high transportation costs are expected to remain significant factors, the other elements will likely diminish in importance. Adoption of the float process has limited future potential to promote globalization, since roughly 75 percent of all countries known to produce flat glass already have float facilities, and many of the remaining countries may be too small to support such facilities. Globalization of the automotive industry is expected to continue to be a factor in the short term, but the number of countries that can sustain an automotive industry is also limited. Countries formerly inaccessible to investment, such as China, those in Eastern Europe, and India, will remain attractive as expanding markets. But their potentially uncertain business climates will likely force potential investors to evaluate the success of recently established local operations before proceeding with additional new flat glass investments. In addition, future investment may not always remain expansive in nature, as corporate strategies are re-evaluated. For example, Ford's recent announcement that it will close its last plant in Canada early in 1994 suggests such a re-evaluation,[11] as the company shifts its non-U.S. automotive-glass fabrication operations from Canada to Mexico.

Based on assessments of the dominant float-glass segment of the U.S. flat glass market by domestic producers, the continued globalization of the flat glass industry could have important competitive implications for U.S. producers, including excess capacity, downward pressure on prices, increased competition within markets, reduced revenues, and reduced profits. There is currently overcapacity in the global flat glass market.[12] The continuing addition of float-glass facilities is especially serious inasmuch as float-glass plants have limited ability to slow production rates and generally must operate continuously for the 10-year life of the glass-melting furnace in order to be economically viable. These conditions may add to excess supply, which is accompanied by downward pressure on prices in float glass.[13] Since price differentials as low as 2 percent are enough to influence sales of float glass,[14] price pressure likely would increase competition in markets and could generate significant market-share changes. Moreover, downward pressure on prices may result in reduced revenues and profits for U.S. producers of float glass.[15]■

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[9] "PPG Asahi to Build Chinese Glass Plant," *Glass Digest*, Jan. 15, 1993, p. 26.

[10] Asahi Glass acquired AFG Industries, Inc., in 1992. Nippon Sheet Glass purchased a 20-percent share of Libby-Owens-Ford Co. from Pilkington Brothers, Ltd., of the United Kingdom in 1989.

[11] *Glass Industry*, Mar. 1993, p. 6.

[12] "Belt Tightening Pays Off at PPG, but More To Be Done Says Sami," *American Glass Review*, June 1992, p. 12.

[13] Prehearing brief of PPG Industries, Inc., to the USITC in investigation No. 332-337, Nov. 9, 1992, p. 9.

[14] Hearing transcript, USITC investigation No. 332-337, Nov. 18, 1992, p. 522.

[15] Posthearing brief of Guardian Industries Corp. to the USITC in investigation No. 332-337, Nov. 24, 1992, p. 16.

HISTORIC TECHNOLOGY-TRANSFER PACT WITH FEDERAL LABS AND TEXTILE-SECTOR COMPETITIVENESS

A cooperative research and development (R&D) agreement recently reached between the U.S. Department of Energy (DOE) and the domestic textile sector is designed to revitalize the industry through the transfer of government-developed technology. The accord links the textile sector with well-known DOE R&D laboratories in a joint effort to apply the strengths of the laboratories to the industry's technological needs.[1] The joint effort between DOE and the textile sector marks the first major initiative under legislation passed in 1980[2] to facilitate the transfer of government technology to an entire industrial complex. Proposed research in the initial 6-month period is expected to total $30 million, with DOE and the industry each providing roughly half the cost of the program. The agreement not only advances the Clinton administration's initiative of focusing government R&D on technologies that help enhance U.S. industrial performance, but also helps sustain operations of DOE labs as Federal budget cutbacks decrease demand for their traditional defense and space-related projects.

The American Textile Partnership (AMTEX),[3] an organization formed to represent the industry in this endeavor, includes the vertically integrated manufacturing chain of fibers, textiles, and apparel. These industries collectively are the largest employer in U.S. manufacturing, directly generating 1.8 million jobs across the nation. The DOE/AMTEX program is predicted to save 350,000 jobs over the next 5 years and to create 200,000 additional ones in the textile sector in the succeeding 5-year period.[4] Capital investment by the sector in the past decade has led to significant improvements in productivity. However, increased imports from low wage-cost sources has eroded U.S. producers' share of the domestic textile and apparel markets and contributed to a decline in the sector workforce. This article first highlights these trends and then discusses proposed R&D projects under the DOE/AMTEX program aimed at resolving specific industry shortfalls. It concludes with some views of the expected impact of the program.

Research Partnership To Augment Industry's Recent Investments

In contrast to their smokestack image, the U.S. manmade fiber and textile mill industries have become technically sophisticated, less labor-intensive, and more competitive in world markets. Workers in the U.S. apparel industry are among the most productive per labor hour in the world.

Capital expenditures by U.S. manmade fiber producers averaged about $500 million annually during 1980-87, and then increased steadily to $900 million in 1991. As a result, productivity gains of 143 percent exceeded the U.S. industry average, as shown in figure 3-1. Value added per production worker hour for the industry was $79.25 for 1991. In contrast to the gains recorded by the manmade fiber industry, productivity gains in textiles and apparel were below that for all manufacturing. Nevertheless, capital expenditures by the U.S. textile mill industry, of about $2 billion annually since 1980, have significantly increased productivity. The value added per production worker hour has risen by 85 percent, to $25.24 in 1991. For U.S. apparel manufacturers, capital investment has averaged $750 million annually since 1980 and production worker output nearly doubled to $22.40 per hour.

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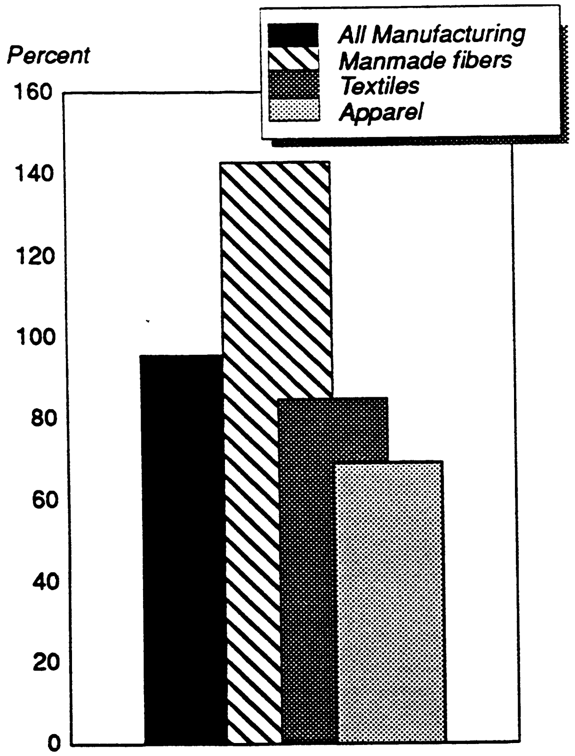
[1] The participating DOE labs are: Argonne National Laboratory, Argonne, IL; Brookhaven National Laboratory, Upton, NY; Lawrence Berkeley National Laboratory, Berkeley, CA; Lawrence Livermore National Laboratory, Livermore, CA; Los Alamos National Laboratory, Los Alamos, NM; Oak Ridge National Laboratory, Oak Ridge, TN; Pacific Northwest National Laboratory, Richland, WA; Sandia National Laboratory, Albuquerque, NM.

[2] The Stevenson-Wylder Technology Innovation Act of 1980 (15 U.S.C. 3701-3714) authorizes DOE to work with U.S. industry to ensure that DOE capabilities are accessible to meet industrial needs.

[3] AMTEX encompasses all stages of textile production and distribution, from raw materials to retail sales, and also machinery manufacturers. AMTEX also includes the four leading textile research universities—North Carolina State, Raleigh, NC; Auburn, Auburn, AL; Clemson, Clemson, SC; and the Georgia Institute of Technology, Atlanta, GA; and four nonprofit, industry-supported research organizations—the Institute of Textile Technology, Charlottesville, VA; the Textile/Clothing Technology Center (TC^2), Raleigh NC; Cotton Inc., New York, NY; and The Textile Research Institute, Princeton, NJ. The universities are also united in a research and education consortium called the National Textile Center, which is partly funded by the U.S. Department of Commerce.

[4] Hazel R. O'Leary, secretary, U.S. Department of Energy, as cited in press release, "U.S. Department of Energy/Textile Industry Sign Historic Multimillion-Dollar Research Agreement," Mar. 15, 1993.

Figure 3-1
Labor productivity: Changes for selected industry sectors, 1980 to 1991



Source: Compiled from U.S. Department of Commerce, Annual Survey of Manufactures, 1981 and 1991.

Despite improved productivity, the rapid buildup of textile and apparel production in developing countries for export, set against a backdrop of slow growth in U.S. consumption of these products, has contributed to a decline in jobs in the U.S. textile sector and to a deterioration in its trade balance. Employment has fallen by about 400,000 workers since 1980, also reflecting the growing use of labor-saving technology, especially in textile mills. Over the same period, imports have substantially expanded their share of the U.S. market for apparel, to 46 percent in 1992, and for textiles, to about 8 percent. Because the U.S. textile industry relies heavily on demand by the domestic apparel market, the increase in import penetration of apparel has had a directly adverse effect on U.S. textile mills. Thus, whereas the U.S. textile industry has improved its competitiveness, its dependence on the apparel industry accentuates the need for the DOE/AMTEX program to benefit the entire textile-manufacturing chain.

Initial Proposed Projects To Target Diverse Issues

AMTEX has identified five areas where technology is likely to have the greatest potential to improve the textile industry's competitive position, while reducing waste and costs of compliance with environmental regulations:

- Analysis, simulation, and computer integration (quick response);
- Improved materials and processes;
- Environmental quality and waste minimization;
- Energy efficiency; and
- Apparel automation.

R&D priorities and projects under each area will be determined by industry needs. Work on the projects will be done at one or more of the eight participating DOE national laboratories, at the industry research organizations' facilities, at the textile universities, or at industry sites according to the technology requirements of each project and the unique equipment and expertise of each location. Personnel from the labs, research organizations, universities, and industry will also be assigned to work wherever their talents can be most effectively used.

Analysis, Simulation, and Computer Integration

The textile complex, including retailing, loses an estimated $25 billion a year in markdowns, stockouts, and inventory-carrying costs. These losses are attributable to a lack of understanding of how the various industry sectors interact and service their customers and to the absence of an information system linking the supply chain from fiber manufacturer to retailer. The industry has already begun to address this deficiency through a Quick Response (QR) program that uses computers to quicken the flow of goods, services, and information between segments of the industry chain, linking apparel producers with textile suppliers and retailers. The goal of QR is to develop a "demand-activated" manufacturing stream, reducing turnaround times and inventory costs.[5]

AMTEX proposes to use DOE research on computer-aided logistical support, originally conducted for the U.S. Department of Defense, in a multiphase project called the Textile Industry Information Architecture (TIA). When fully implemented, the TIA would allow for each of the 26,000 firms in the industry to access information from other firms through a common data infrastructure. This could, for

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[5] For further information on QR see "'Quick Response' Applications of Technology Enable U.S. Apparel Companies to Improve Competitiveness," *USITC Industry, Trade, and Technology Review*, Oct. 1992, p. 8.

example, allow a supplier to have access to inventory or consumption information of its customer so that shipments of new supplies could be shipped at the optimal time. The TIA also would contain a simulation model similar to military flight simulators to aid industry decision makers through demonstrations and "what if" processes to facilitate making strategic decisions, such as capital investment, and product creation. TIA would further assist business operations with tools such as electronic catalogs and price lists and provide the capability to negotiate purchases through electronic media. AMTEX anticipates including the computer and communications industries in designing and implementing the infrastructure needed to realize this electronic marketplace.

Improved Materials and Processes

During the past several years, use of electronic technologies and computer controls has vastly changed the equipment and methods used in production processes of the textile sector and has promoted the creation of new products, such as patterned tufted carpet and friction-spun yarn. R&D projects under AMTEX will focus on further reducing costs by improving production processes and maximizing use of technology, such as waterless dyeing, intelligent processing sensors, and expert control systems.[6] Given the expertise of DOE labs in sensors and machine-vision technology, an initial research proposal focuses on developing automation techniques for the inspection of textiles. Automated inspection would allow for inspection closer to or within the production process to facilitate quicker detection and elimination of defects, greatly reducing second-quality goods and costs. Product-quality improvements also derive from a more consistent and reliable inspection process. Other benefits of automated inspection are establishment of a rapid and reproducible method for grading quality of textiles, decreased waste, reduced or eliminated end-of-line inspections, and facilitated just-in-time delivery. At least one major textile mill has already established a program through which electronic data are transmitted from the fabric inspection process to customers, allowing them to avoid duplicating the inspection process before cutting the fabric rolls. Moreover, automated inspection will reduce costs and improve productivity because inspectors account for a substantial share of the workforce of a textile mill and are among the highest paid workers.

Environmental Quality and Waste Minimization

Although developing and purchasing equipment to meet air- and water-quality standards has been costly for the textile sector, in some instances it has led to faster, more automated production. For example, efforts to comply with cotton dust standards for textile mills has resulted in the automation of almost the entire yarn-spinning process. AMTEX intends to use the extensive experience of the DOE labs with emission-technology applications to facilitate more cost-effective compliance with environmental regulations by the textile industry. Proposed projects relating to the environment and waste reduction are—

- Evaluation of textile waste water and determination of the most cost-effective technologies to remove heavy metals from this water to reduce costs of waste treatment and disposal;
- Examination of technologies for gas treatment and identification of process changes that can recycle and minimize wastes; and
- Determination of physical and chemical properties of apparel fabric waste to develop technology to convert this waste into energy for use in high-energy-consuming operations, such as the dyeing and drying processes, to reduce energy costs and minimize wastes that must be disposed of in landfills.

Energy Efficiency

High energy requirements associated with fiber and textile production result in fuel and electrical energy costs of $2.5 billion yearly. Energy costs for manmade fiber manufacturers and textile mills were 7.6 and 7.4 percent, respectively, of value added by manufacture, compared with 4.2 percent for all manufacturing. AMTEX will tap the expertise of DOE labs in energy metering and analysis to determine how energy is being consumed; DOE experience in use of byproducts and waste heat to reduce overall energy costs; and DOE advanced technologies to augment ongoing research in alternative methods of drying (such as infrared and microwave) and ultrasonically aided dyeing.

For example, motor-driven equipment accounts for 80 percent of the electricity consumed annually in textile mills, and every 1 percent of increased motor efficiency saves about $10 million for the industry. A proposed system to more efficiently control motor current is expected to achieve several times this savings. AMTEX has also proposed projects to reduce energy required for process heating,[7] improve efficiency of water use, and assess the feasibility of zero-discharge plants.

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[6] The development of new production equipment and specific products is the responsibility of the commercial sector and not an objective of the AMTEX program.

[7] Process heating includes heat to dye, rinse, and dry textiles.

Apparel Automation

A growing number of U.S. apparel producers are adopting QR technologies and new production methods in an effort to gain a competitive edge in the marketplace, particularly relative to imports. Adoption of the AMTEX-envisioned TIA portends significant advantages in cost and response strategy for the U.S. apparel industry, particularly because it would facilitate establishing an industrywide QR system, with mutually compatible computer hardware and software used by all firms. To further and more directly reduce production costs, the domestic industry foresees using DOE technology and experience to assist in developing more efficient or entirely new apparel production methods.

One proposal is to develop sensors and control methods needed for cutting and sewing processes in garment assembly that could automatically adjust feed and thread tension to accommodate changes in fabric characteristics, reducing sewing defects and eliminating costly defective garments. The sensors would need to evaluate fabrics for characteristics, such as softness, firmness, elasticity, fineness, and resilience, without damaging the goods. Another challenge is to develop sensors with the capability to determine sharpness of cutting blades, eliminate fabric fusing during cutting, aid in following pattern lines, and otherwise complement existing skills of fabric cutters. A related initiative is designed to analyze the physics of high-speed cutting and develop refined cutting techniques, achieve more consistent quality of cut parts to reduce sewing time, economize on plant space needed for large cutting tables, improve materials handling by having cutting take place closer to sewing work stations, provide better fabric utilization, and reduce waste. AMTEX also envisions a feasibility study of three-dimensional sewing automation to examine machinery and processes needed to automate the garment assembly process.

A project indirectly aimed at enhancing production efficiency is development of a garment-fingerprint tag and a tag reader to uniquely identify and track a garment from fabrication to recycling. The laboratories would draw on the technology used by the DOE Office of Arms Control and Nonproliferation for identifying missiles in developing this tag to better maintain inventory records, facilitate fiber identification for recycling, and reduce counterfeiting of popular U.S. brand-name apparel by foreign firms.

Expected Impact of AMTEX Program

Initial AMTEX research projects are expected to be underway by September 1993. In mid-June 1993, AMTEX had submitted to DOE the initial projects for which it sought approval and funding. Inasmuch as priorities and project selection are based on industry priorities, these should help ensure that the R&D focuses on basic industry needs and that any "spinoffs" are promptly transferred to the industry. One industry official stated that entering into the DOE/AMTEX agreement is "the single most important step for our industry ever in its history, because for the first time, we're able to draw on new resources to bring to bear on our needs, and we've been able to position ourselves as a high technology, integrated industry."[8] The industry's incentive to maximize adoption of new technology is based on both the sustained erosion of its market share and anticipation of potential changes in the global trade environment. Adoption of the North American Free Trade Agreement and the elimination of U.S. quotas on textile and apparel imports as currently proposed in the Uruguay Round of multilateral trade negotiations would create even more intense competition. In a broader perspective, the DOE/AMTEX program is expected to serve as a model for comparable liaisons between government and other industries, and further industrial applications of the expansive expertise of the government research facilities and the global competitiveness of U.S. industry.

Others are more skeptical of the potential impact of the program. Firms that have worked with National Aeronautical and Space Administration labs on similar technology assistance and transfer programs have indicated that in many instances dealing with the bureaucratic structure of the government labs takes too much time.[9] The immediacy with which private industry is accustomed to, and often of necessity must, resolve its problems is incompatible with the past problem-solving strategy of the labs. Their tradition has been "performance at any cost," and not the commercial perspective of cheaper and faster.[10] On the other hand, some critics believe that the textile and apparel industries are moving too slow and spending too little on adopting currently available new technology and processes.[11] They imply that these industries have tunnel vision and lack the imagination to adopt new technologies.

As with most innovative programs, only time will tell what impact the DOE/AMTEX program will have. Two circumstances need to occur for the program to be a success: the research must yield cost-effective technologies and processes, and the industry must invest in them.■

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[8] Peter Butenhoff, president and chief operating officer, Textile/Clothing Technology Center, *Bobbin*, May 1993, p. 2.

[9] Conversation by USITC staff with apparel industry official, June 16, 1993, Washington, DC.

[10] Kay Adams, director of technology transfer, Los Alamos National Laboratory, in "The Fight over the Weapons Labs," *Business Week*, June 7, 1993, p. 104.

[11] Sprinkle, Hooper, and Mix, "U.S. Textiles is Slow Implementing Info Systems", *Textile World*, Jan. 1992, pp. 81-2.

NEW TECHNOLOGIES TO INCREASE INDUSTRIAL USES FOR CORN PRODUCTS

Animal feeds—both for export and domestic use—have traditionally represented the primary use for U.S. corn. Other corn-product markets, however, have been developing and increasing in recent years. These include the markets for the products and byproducts of the corn wet milling industry,[1] including starches; sweeteners (e.g., corn syrup or glucose syrup, dried glucose syrup, dextrose, maltodextrin, high-fructose corn syrup (HFCS), corn syrup solids, and crystalline fructose); fuel alcohol; corn oil; and animal feed products (corn gluten feed and meal, corn germ meal, and condensed fermented corn extractives).

In addition to the products mentioned above, a number of new and potentially important industrial products are emerging from the corn wet milling industry. Most of the new and emerging uses of corn are extensions of current technology. Some have been given a new thrust by legislation, such as the Clean Air Act or the Marine Plastic Pollution Act. Others have been encouraged by health considerations, such as the desirability of reducing the intake of dietary fats. Others, such as the biotechnology-spawned varieties of corn, have been developed with an eye to improving yields (by making varieties more resistant to diseases and/or pests and better adapted to a certain area) or minimizing costs (such as minimizing processing by eliminating the need to modify starches). As a group, these products potentially will contribute to increased demand for U.S. corn, raise industry profit margins, and provide more environmentally-sound products.

According to the U.S. Department of Agriculture, the commercialization of farm-based industrial products has the potential to increase market-driven demand for agricultural materials, thus improving farm income.[2] This article provides an overview of farm-based industrial products emerging from new corn-based technologies.

U.S. Production and Consumption of Corn

The United States is the largest producer and exporter of corn in the world, exporting about 15 percent of its corn supply. In 1992, U.S. exports of corn were valued at $4.9 billion[3]. U.S. corn production for the 1992 growing season (1992/93) was 240.8 million metric tons (mt), and for the 1993 growing season (1993/94) the U.S. Department of Agriculture forecast it at approximately 214.6 million mt[4], or about 45 percent of world production.

The use of corn for food, alcohol, and other industrial (FAI) uses has more than doubled over the last decade, increasing from 18.1 million mt in 1981/82[5] to 37.5 million mt in 1992/93 (figure 4-1). Use of corn for either export or domestic use as livestock feed also rose during this period, from 107.8 million mt to 132.1 million mt, but at a much lower rate. As a result of this rapid growth in demand, FAI uses of corn accounted for 22 percent of total corn disappearance in 1992/93, up from 14 percent in 1981/82.

In 1992/93, the use of corn for sweeteners, starch, and fuel alcohol (ethanol) was equivalent to 32.2 million mt, or 13 percent of corn production and 86 percent of all FAI uses (figure 4-2). The two largest industrial uses for corn are in the production of HFCS and in production of fuel-grade ethanol. Use of corn for production of HFCS, which has virtually replaced sugar as a caloric sweetener in soft drinks, rose from 4.2 million mt in 1981/82 to 10.3 million mt in 1991/92. Use of corn for production in ethanol has risen from 0.9 million mt to 10.3 million mt during the same period. Ethanol, which is made virtually entirely from corn in the United States, has been used primarily as a gasoline extender, especially in the Midwest.[6] Both HFCS and fuel ethanol have benefited from U.S. Government assistance programs.[7]

Other FAI uses for corn have also been increasing, as shown in figure 4-3, although the 23-percent annual rate of growth in use for fuel alcohol was the most dramatic during 1981/82-1992/93. The third principal

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[1] Corn is processed by both the dry and the wet milling industries. This article deals with corn wet milling.

[2] U.S. Department of Agriculture, *Agricultural Outlook*, June 1993, pp. 29-31.

[3] All types of corn, including corn seed; from official data of the U.S. Department of Commerce.

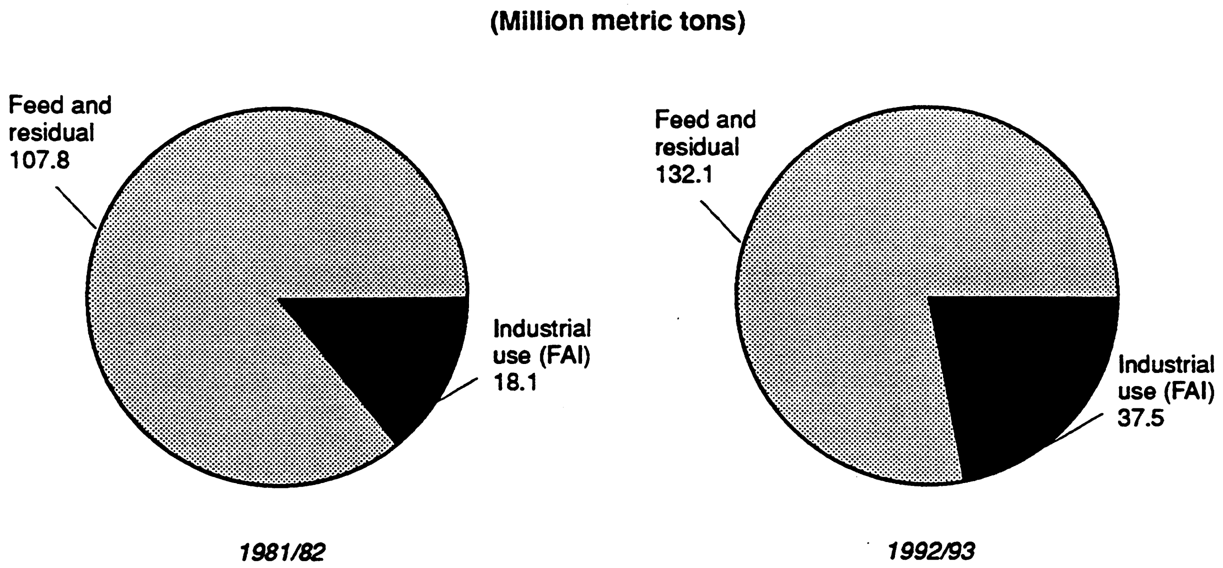
[4] Or 8.45 billion bushels.

[5] The split year refers to the corn marketing year beginning September 1.

[6] Norman Rask, Kevin Rask, and Jill Tiefenthaler, "Ethanol Policy in the Clean Air-Free Trade Era," *Choices*, first quarter 1993, pp. 18-21.

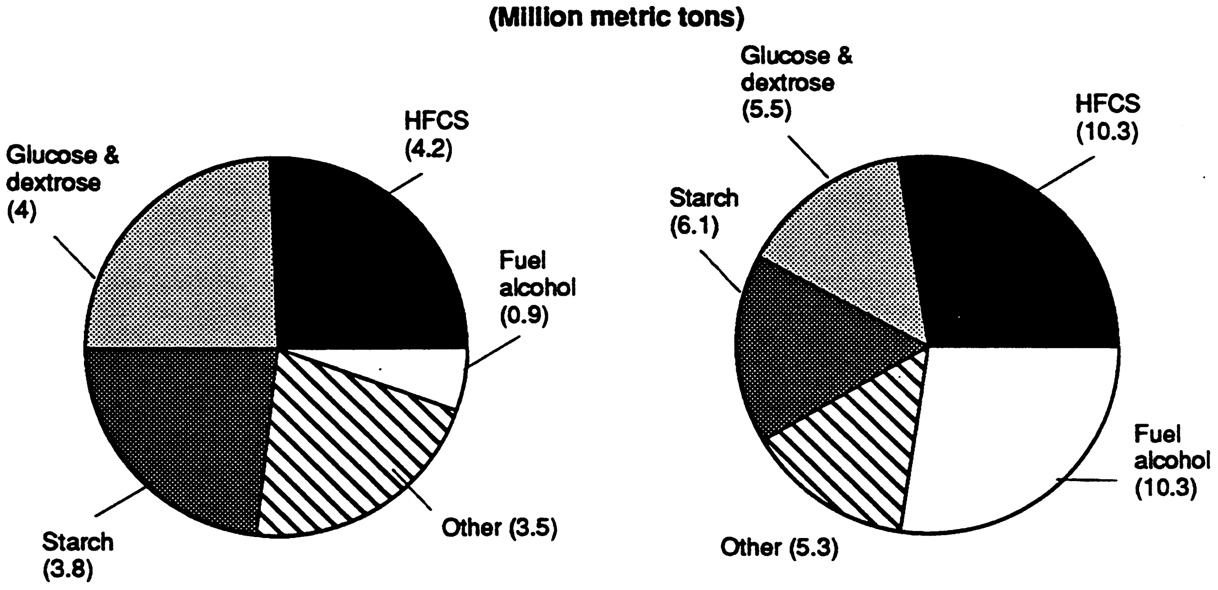
[7] The success of HFCS is closely tied to the U.S. sugar program, which tends to raise the prices of sugar and sugar-containing products to levels above what the prices would be in the absence of the program, making sugar substitutes more attractive. Ethanol-blended gasoline currently receives a 5.4-cent-per-gallon excise tax exemption for 10-percent ethanol blends.

Figure 4-1
Corn: U.S. domestic use, crop years 1981/82 and 1992/93[1]



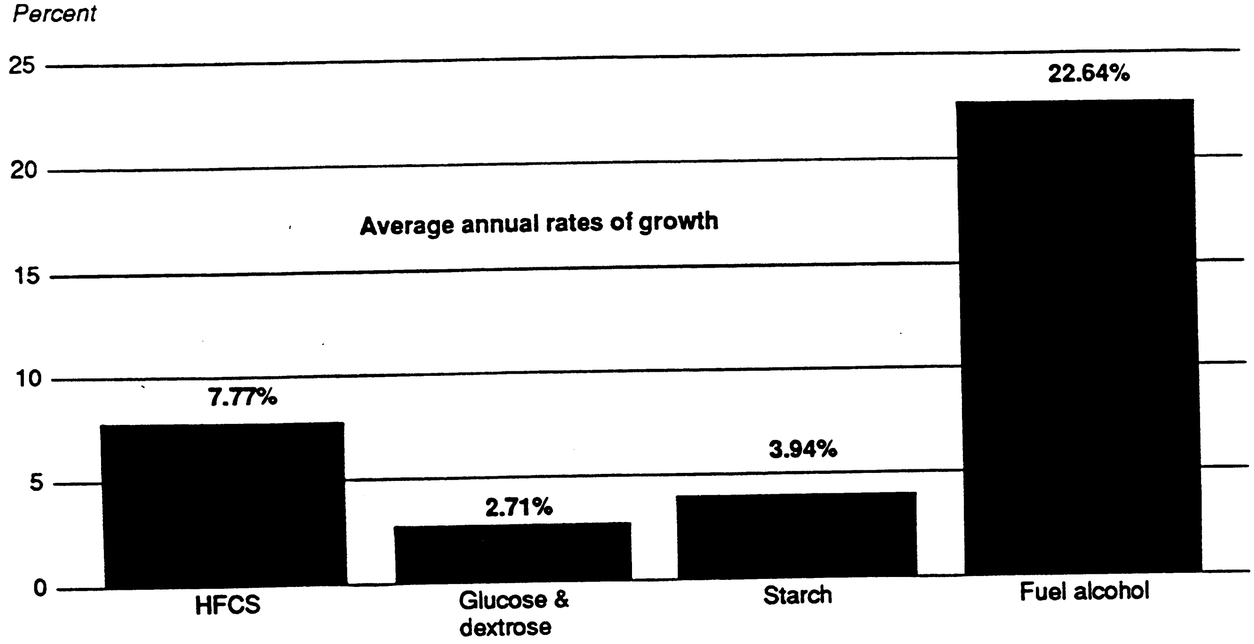
[1] Crop year begins September 1.
Source: U.S. Department of Agriculture (FAI for 1992/93 is estimated by USITC staff).

Figure 4-2
Corn: U.S. industrial uses, marketing years 1981/82 and 1992/93[1]



[1] Crop year begins September 1.
Source: U.S. Department of Agriculture.

Figure 4-3
Corn industrial uses: Growth rates, 1981-1993



Source: U.S. Department of Agriculture.

use of corn is for the production of starch, which is used as a production input—either directly or in modified forms—by the food, feed, plastics, and pharmaceuticals industries, among many others.

The U.S. corn wet milling industry consumed about 12 percent of all corn produced in the United States (28 million mt) in 1992/93. This industry ships over 19 million mt of products annually. Additionally, the ethanol industry ships about 3.4 million kiloliters annually. The industry exported close to 8 million mt of corn products. Corn wet milling is an important source of income to corn producers in the United States. Based on the latest available data from the Census of Agriculture, U.S. farms gained a total of $1.6 billion from all corn-refining activities.

New and Growing Industrial Areas for Corn Products

Table 4-1 summarizes some of the current and potential new uses for the products and byproducts of the corn wet milling industry. As shown in this table, most of these new technologies are expansions of those currently used in the production of a number of corn-based products.

New technologies in the corn wet milling industry have led to the development of products such as "mutant corn," corn that has been altered through biotechnology to produce starches for specific applications that do not need to be modified. These starches require much less processing and can result in lower production costs, less waste or byproducts, and a more "natural" public image. For example, food labels could read "natural cornstarch" instead of "modified cornstarch." Other new products include cationic starches, which hold the potential for reducing waste in the production of paper from recycled material, thus lowering costs and minimizing environmental impacts.

Emerging corn-based industrial technologies have also been successful in developing fully biodegradable polymers containing cornstarch.[8] These are being applied to the production of environmentally sounder plastic containers, packing materials, and eating utensils, among other applications. Additionally, a manufacturing process using corn-based materials for the production of lysine has the potential for replacing a large percentage of imported lysine with domestic product.[9] Additional products include antibiotics that use corn wet milling byproducts as an input to the fermentation production process.

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[8] Encouraged by legislation pertaining to U.S. Navy at-sea disposal techniques.

[9] Lysine is a basic amino acid essential in human and animal nutrition.

Table 4-1
Current and potential uses for corn based products

Corn-based Products	Current Uses	Emerging New Uses
Starches	Modified starches Additives to polyethylene Foam Packing material[1] Biopolymer plastics[2] Super Slurper[3] Encapsulation[4]	Mutant corn[5] Dietetic foods Cationic starches[6] Biodegradable plastics Road de-icer[7]
Fuel ethanol	Gasoline extender Octane booster	Fuel oxygenation
Sweeteners	Corn syrup Glucose High fructose corn syrup Crystalline fructose Dextrose Maltodextrin	Production of lysine from dextrose
Wet-milling byproducts (steepwater)	Antibiotics	New antibioctics

[1] Especially packing foam "peanuts".

[2] Biopolymer plastics involve lactic acid and the fermentation of starch. One of their uses is for the manufacture of degradable plastic containers.

[3] Super Slurper can absorb several hundred times its weight in water without dissolving. One use of this product is to minimize irrigation and natural precipitation evaporation loss by plowing it into the ground, especially in areas where water is dear and/or rain scarce.

[4] Encapsulation is a means of preserving pharmaceutical products and chemicals by coating them.

[5] Genetic manipulation of the corn plant which would permit growing corn yielding starch requiring either much less modification or no modification.

[6] Cationic starches bond to the much shorter fibers used in the manufacture of recycled paper, thus increasing the quality and reducing waste.

[7] A major ingredient in road de-icer would be starch fermented to acetic acid.

Starch-based Products

Mutant Corn

The cornstarch industry—a $5.4 billion industry in 1992—has been financing research in corn biotechnology. Active research programs are now being conducted into new methods to alter the genetic makeup of corn to produce starches that have the characteristics of starch derivatives. Varieties of "mutant corn" are being developed that provide starches with specific properties or in a form that needs no further modification. These custom-grown starches have the potential to reduce processing costs on the part of starch-using industries.[10] Because there are many competing sources of starch, such as potatoes, sago, cassava, wheat, and rice, these custom-grown starches should provide the corn wet-milling industry greater flexibility in meeting this competition.

Dietetic Foods

Cornstarch-derived products may be utilized to replace fats and oils in many food applications, including ice cream, salad dressings, and bread spreads. These starch-derived products mimic the lubricity or slippery feel of fats and oils, but do not add fat to the diet. Examples of such starches include hydroxypropyl waxy maize starches. These may be partially hydrolyzed to varying degrees to allow the use of higher solids without excessive viscosity development.[11] Cyclodextrins made from corn are the basis for a new process to separate cholesterol from eggs. This process is presently under review by the Food and Drug Administration.

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[10] Examples of starch-using industries are paper, food, adhesives, and pharmaceuticals.

[11] Donald Harris, "Fat Replacers from Starch," *1992 Scientific Conference*, Corn Refiners Association, Sept. 1992, Oak Brook, Il.

Cationic Starches

Another example of one of the new uses to which corn starch may be applied is cationic starches. The corn wet-milling industry has developed starches which have special application to the production of recycled paper.

The manufacture of recycled paper involves the use of materials with much shorter fiber lengths than those used in non-recycled papers. Heretofore, starches could only be used to provide for the adhesion of these fibers, and as a coating on the recycled paper. Cationic starches, on the other hand, can actually chemically bond the fibers together. The process increases the manufacturing efficiency and the quality of the paper. Another substantial benefit is that the effluent stream is sharply reduced, i.e., there is less waste when cationic starches are utilized.

Biodegradable Plastics

Certain provisions of the Marine Plastic Pollution Act of 1987[12] require the U.S. Navy to cease disposing of nonbiodegradable plastics at sea by the end of 1993. This act has provided the impetus for researchers from academia, industry, and government to develop plastics based on natural materials that will biodegrade in the sea to harmless components.[13] Corn is playing an important role in this research.

The goal of the plastics industry has been to produce materials that are durable, long-lasting, and resistant to environmental factors. In 1992, the plastic component of municipal waste was over 7 percent by weight and about 18 percent by volume, with less than 1 percent of plastics being recycled.[14] One solution to the solid waste disposal of plastics is degradable plastics. The most common approach to producing these plastics is to mix starch with a polymer.

According to the chemical industry, corn is becoming a major plastic feedstock. Corn-derived chemicals, used in plastics, are growing at a 36-percent annual rate, from 11 billion pounds in 1991 to 19 billion in 1996; cornstarch enjoys 20-percent yearly growth. Cornstarch can be used as a filler or a polymer and cornstarch additives are already popular in compostable bags, polystyrene foam, and high-density polyethylene bottles. In addition, acetone and butanol, two resin intermediates, will be made from corn by the mid-1990s.[15] According to the chemical industry, a variety of technologies used to produce biodegradable plastics with cornstarch is "going forward on all fronts," and advances have resulted in a strong, heat-sealable, waterproof but degradable plastic bag.[16] One disadvantage of corn-product-based plastics is their cost; at present such products may be at least 25 percent more expensive to produce than petroleum-based plastics.

Research work at Iowa State University at Ames has shown that it is possible to cross-link cornstarch and zein—a nonnutritive protein found in corn—to produce a new degradable plastic, which, reportedly, is stronger and less water-sensitive than combinations of cornstarch and polyethylene and polystyrene plastics.[17]

Clean Air Act: Mandates for Use of Oxygenator

As noted earlier (figure 4-3), the use of ethanol has increased by close to 23 percent over the last decade. First used as a fuel extender[18], ethanol received its first significant market opportunity in the 1980s, when the U.S. Government mandated the elimination of lead from fuel. Lead was used as an octane additive in automotive fuels[19]; since ethanol may also serve as an octane enhancer, it was used as a replacement additive. Nevertheless, owing to the availability of ready substitutes, such as methy-tert-butyl ether, preferred by petroleum refiners, ethanol played a minor role as an octane enhancer. Further, ethanol is a higher cost additive.[20] Thus, the use of ethanol has been increasing at a decreasing rate.

Ethanol may also serve as an oxygenator in automotive fuels, i.e., in fuels that serve to alleviate air pollution. The U.S. demand for oxygenated fuels may grow rapidly owing to clean air standards and the Clean Air Act of 1990 (CAA),[21] which mandates pollution controls. Although, for the next 3 years, the market potential for fuel ethanol in the winter oxygenated fuels program is strong[22], changes in the Environmental Protection Agency (EPA) regulations may curtail long-term prospects for the fuel ethanol market. These uncertainties in the EPA, congressional, and other government regulations that will emerge subsequent to the CAA have had a negative impact on

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[12] Public Law 100-200, Dec. 29, 1987.

[13] *1992 Yearbook of Agriculture*, pg. 149.

[14] U.S. Department of Agriculture, "New Crops, New Users, New Markets," *1992 Yearbook on Agriculture*, p. 148.

[15] *Chemical World*, Apr. 17, 1993.

[16] *Chemical Marketing Reporter*, July 13, 1990.

[17] Ibid.

[18] As a fuel extender, ethanol is blended with gasoline to increase the availability of fuel.

[19] The octane rating of fuel relates to its antiknock qualities.

[20] However, the cost of producing ethanol, presently about $1.24 per gallon, is forecast to drop to $1.17-1.19 per gallon by 1996, and $1.09-1.15 per gallon by 2001; C. Matthew Rendleman and Neil Hohmann, "The Impact of Production Innovations in the Fuel Ethanol Industry," Agribusiness, vol 9 (1993) No. 3, pp. 217-221.

[21] Ibid.

[22] Especially in pollution nonattainment areas and in those cities and States whose legislation exceeds the requirements of the CAA.

the U.S. market, and many ethanol plant expansion programs have been put on hold.[23]

Since ethanol is primarily made from corn in the United States, the future uses to which ethanol will be put by the transportation industry will have a major impact on U.S. corn producers and wet millers. The corn industry states that the use of ethanol in the CAA gasoline program could boost ethanol production to 2 billion gallons, up from 900 million gallons in 1991 and 1 billion gallons in 1992, as well as adding 20 cents to the value of a bushel of corn, or a potential of about $19 million additional dollars in revenue to the corn producers of the United States.

The uncertainty over the long-term use of ethanol as a fuel oxygenator continues due to the current prohibition of all additives to automotive fuel unless granted a waiver by the EPA. On January 25, 1993, the Office of Management and Budget (OMB) canceled all proposed regulations not yet published in the *Federal Register*, including the use of ethanol under the CAA. However, EPA countered by letting stand a series of actions by the Bush administration, including a proposal to use ethanol in reformulated gasolines.[24]

Animal Feed Additive

Another important area for corn-based technology involves the production of lysine, an animal feed additive. Lysine, an amino acid, is used by the poultry and hog industries to improve animal nutrition. It is almost entirely imported by the United States from Japan[25]. By using a coproduct of corn wet milling, dextrose, Archer Daniels Midland, Inc. (ADM) has reportedly developed a process to produce lysine. This domestic product can potentially replace U.S. imports, and by ADM estimates, supply 60-65 percent of the world need for lysine.[26]

Corn Byproducts

An important byproduct of the corn wet milling process is corn steep liquor, or steepwater, which is used in the production of antibiotics. Antibiotics are produced in nearly all developed countries and in many developing countries, and compose an important sector of the pharmaceuticals industry. The demand for steepwater stays strong owing to the ever-present need for new antibiotics.

Industry Outlook

Until recently, the growth in the corn wet milling industry came from large-scale developments such as HFCS and ethanol. The Corn Refiners Association indicates that the industry sees a different evolution in the future.[27] Market growth is expected to come from smaller scale, higher value developments, such as the use of cationic starches in the paper-recycling industry or the development of additional degradable plastics using cornstarch as an ingredient. The future of ethanol is still uncertain in the United States, due to legislative and regulatory questions (see related article in this issue on alternative fuels).

Overall, corn refiners export the products from about 27 percent of the corn they process. The corn-refining industry estimates that, when value-added exports are combined with the value of imports replaced by domestic value-added corn products, its contribution to a positive trade balance can be estimated at $5 billion.[28] The more important corn-based export products in 1992 were corn gluten feed, accounting for nearly 60 percent of U.S. exports of corn byproducts, and corn oil and corn oil-cake (20 percent). Starch exports accounted for 4 percent of U.S. exports of products made from corn; residues from starch manufacture accounted for another 6 percent. The total value of starch, dextrins, modified starch, and starch manufacture residue exports in 1992 was $1.4 billion.[29]

In the future the competition in the area of corn wet milling will be international. European companies are already marketing biodegradable products throughout the world. The Japanese Ministry of Industry and Trade has invested millions in the development of biodegradable plastics.[30] The development of new, more environmentally sound plastics is driven by economics. At present there is more economic motivation for "green technology" in Japan and Western Europe than there is in the United States. However, owing to the multinational nature of the plastics industry, there is a ready exchange of technology across national boundaries.■

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[23] Remarks by Bruce W. Heine for the Renewable Fuels Association, Sept. 9, 1992, as published in the *1992 Scientific Conference*, Corn Refiners Association, Sept. 1992, Oak Brook, Ill.

[24] Chemical Marketing Reporter, Feb. 8, 1993.

[25] Imports of lysine from Japan were about $75 million in 1992.

[26] *Corn Annual*, op. cit.

[27] USITC staff conversion with official of the Corn Refiners Association, Feb. 1993.

[28] *Corn Annual*, 1993.

[29] *Corn Annual*, 1993.

[30] *Plastics World*, Mar. 1993.

ADVANCED STRUCTURAL CERAMICS: TECHNICAL AND ECONOMIC CHALLENGES

During the last several decades, advanced structural ceramics (ASC)[1] have gained a modest market share in structural applications, such as wear parts, cutting tools, and bearings, that have long been dominated by metal components. Producers of ASC anticipate the increasing use of ceramic products over the next decade in nontraditional markets, such as heat engines, heat exchangers, and bioceramics.[2] These markets are driven by the need to find industrial materials that can tolerate high-temperature, corrosive environments and by concerns for the weight reduction and increased energy efficiency of aircraft and automotive engines. Such improvements can decrease fuel costs and meet fuel economy and emissions standards. Future success in expanding traditional advanced ceramic markets and developing nontraditional markets depends on increasing the quality and reliability of these products, improving the cost/benefit ratio of ceramic components compared with metallic counterparts, and overcoming end-user reluctance to substitute ceramic parts for metal parts. This article will examine (1) current and potential applications for advanced structural ceramics and (2) industry attempts to overcome obstacles to increased adoption of structural ceramic components.

The most common advanced ceramic materials and some of their industrial uses are shown in figure 5-1. Table 5-1 includes some of the principal properties of the most common advanced monolithic ceramics in use today. Monolithic ceramics contain one of these materials while ceramic composites contain fibers that are added to the monolithic material to improve toughness. Parts made of advanced ceramics typically have superior high-temperature strength, higher hardness, lower density, and lower thermal conductivity than conventional metal parts, resulting in greater product durability and more efficient system operation. For example, one ASC producer claims that its ceramic composite wear part used in mineral-processing equipment will last up to 50 times longer than the metal part it replaces.

The U.S. market for ASC products was nearly $500 million in 1992, with three principal markets—wear parts, cutting tools, and bearings— collectively accounting for about 65 percent of domestic ASC parts consumption. The United States and Japan currently dominate global ASC production, with each nation accounting for nearly 25 percent of global production.

ASC products account for only 5 percent of total market share in current applications. But substantial growth of more than 10 percent per annum is expected in response to greater overall demand by end-use industries for light-weight, energy-saving components.[3] Figure 5-2 shows a chronology of past introductions of advanced ceramic materials and an estimate for possible future applications in ASC products. U.S. demand for all ASC products is projected to rise to $2-3 billion by the year 2000 (figure 5-3). Principal applications and application requirements of ASC materials are shown in figure 5-4.

By far, the largest potential markets for ASC parts are those related to automotive engines, which, apart from rare and expensive ceramic turbochargers, currently have virtually no advanced ceramic parts. The advantages of such ceramic parts for automotive engines include increased fuel efficiency due to the ability of advanced ceramics to tolerate high engine operating temperatures; reduced friction, weight, and inertia; and reduction or elimination of cooling systems. The major obstacles to adoption of ASC parts in automotive applications remain the much higher cost of these parts compared with that of metal parts and the resistance of automotive manufacturers to replacing proven metal parts with ASC parts, which are relatively untested in gasoline engine applications. In addition, U.S. automakers require multiple sources of supply, which may affect the proprietary nature of research. Silicon nitride turbocharger rotors are currently the most popular engine application for advanced ceramics. These rotors are much more widely used in Japanese automobiles than in U.S. automobiles because of the use of turbochargers to boost engine horsepower in smaller cylinder Japanese cars. Other potential automotive ceramic components include valves, valve spring retainers, push rod tips, fuel injectors and fuel-injector components, valve lifters, and valve seats.[4]

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[1] Advanced ceramics exhibit mechanical, electronic, chemical, optical, and high-temperature properties that are superior to those of traditional ceramics. Advanced structural ceramics differ from traditional ceramic goods in that they are made from extremely pure, microscopic powders that are consolidated at high temperatures to yield a dense, durable structure for use in load-bearing or structural applications.

[2] USITC interviews with industry officials, June 1993.

[3] Market forecasts are provided by Thomas Abraham, senior industry analyst and editor, *High Tech Ceramics News,* Business Communications Co., Inc., Norwalk, CT.

[4] R. Nathan Katz, "Advanced Ceramics Overview and Outlook," p. 37. Article appears in *Advanced Materials: Outlook and Information Requirements*. Proceedings of a Bureau of Mines conference, Nov. 7-8, 1989, Arlington, VA.

Figure 5-1
Current industrial uses of ASC

Type	Description
Wear parts	A wide variety of products in which long wear, high temperatures, and a high degree of chemical corrosion are generated, particularly in the oil industry (e.g., seals, valves and valve components), and the machine tool industry (e.g., nozzles, wear pads, extrusion dies, high-temperature fasteners, grinding wheels, and liners). Ceramic wear parts are also being increasingly used as mechanical seals in automobiles and appliances, due to their longer durability.
Cutting tools	As a result of their superior thermal and hardness properties, ceramics of silicon nitride and zirconia can be used at much higher machining speeds than are tolerated by cemented carbides, which are typically used as inserts for metal turning and milling operations. It is estimated that ceramic cutting tools are capable of increasing metal-cutting processing times by 200-300 percent. In addition, ceramic tools are less prone to interfacial adhesion with the workpiece they come in contact with than are metal tools.
Bearings	Ceramic bearings are replacing steel and carbide as rolling elements because they have the ability to operate for a moderate length of time with little or no lubrication and offer high speed and acceleration capability. It is estimated that ceramic or ceramic hybrid roller bearings can increase wear life of equipment by 10-fold when compared to traditional steel bearings. Military applications such as ceramic missile bearings may spawn commercial products such as instrumentation bearings, hydraulic, and pneumatic activator systems, and ceramic coatings for use in gas bearings.
Ceramic coatings	Coatings have been developed to protect or lubricate ceramics and ceramic-metal composites (cermets) operating in hostile environments that cause excessive friction and wear of machinery. Coatings of titanium nitride, titanium carbide, and alumina are used to extend the life of tungsten carbide cutting tools by a factor of 2 to 5. Zirconia coatings are being tested as a thermal barrier in diesel engines to prevent the wear of metal pistons and cylinders and have also been used in turbine engines to allow increased combustion temperatures of several hundred degrees F. without increasing the temperature of the metal components in the engine.

Source: U.S. Office of Technology Assessment, *Advanced Materials By Design*, New Structural Materials Technologies, 1988, p. 52-53.

In the United States, one company, Carborundum Co., already mass produces silicon carbide water pump seals, which are sold to Volkswagen AG. In general, however, U.S. automakers are less confident than foreign automakers that a major market for advanced ceramics for use in automobiles will develop, and they are currently less committed to using these products in their automobiles.

Although advanced ceramic materials are not currently used in aircraft engines, the ability of these materials to operate at high temperatures with greater strength than metal alloys promises increased demand. Industry experts forecast that by the year 2010, 20 to 30 percent of the weight of an aircraft engine may be made up of ceramic parts. If this forecast proves accurate, the use of advanced ceramics could reduce the weight of an aircraft engine by 25 percent, with subsequent reduction in fuel consumption of 5 percent. For a typical airliner, this may reduce lifetime operating costs by nearly $18 million, yielding a cost savings of 3.7 percent per passenger mile.[5] Potential ASC aerospace applications include the use of ceramic composites in compressor and fan blades and in nonrotating engines parts.

Initiatives to Reduce Obstacles Facing Advanced Ceramics

There are essentially three challenges that must be met to enable ASC parts to achieve broader market access: (1) reducing technical obstacles that affect the performance and reliability of ceramic materials in many critical applications; (2) minimizing higher costs associated with both individual ASC parts and with required system redesigns; and (3) improving end-user acceptance of ceramic parts.

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[5] "Advances in Composites for Aircraft Engines," *Ceramic Industry Magazine*, Apr. 1993, p. 75.

Table 5-1
Properties and end-uses of selected advanced ceramic materials compared to tool steel[1]

Material	Flexural strength	Hardness (Vickers)	Fracture toughness	Maximum use temperature	Young's modulus[4]	End uses
	MPa[2]	*GPa[3]*	*MPa m^1/2*	*Degrees centigrade*	*GPa*	
Alumina	310	17	4	1,200	310	Wear parts, cutting tools
Silicon carbide	690	22.4	4	2,000	450	Wear parts, cutting tools, heat exchangers
Silicon nitride	925	15.9	5.5	1,400	315	Wear parts, automotive engine applications
Zirconia	1,440	12.8	8.5	800	220	Cutting tools, wear parts, experimental heat engines
Tool steel	5,500	10	98	700	210	Cutting tools, wear parts

[1] A comparison of material in this table, must note that while metals, such as tool, steel, often exhibit higher strength characteristics than advanced ceramics at normal operating temperatures, their strength characteristics fall considerably, compared to ceramics, at relatively high operating temperatures.

[2] Mega (1,000) pascals. A pascal is a metric measurement of force. One pound per square inch (psi) = 6.894 pascals.

[3] Giga (million) pascals.

[4] Young's Modulus defines the ratio between stress and strain and is an indicator of the elasticity of a material.

Source: Saint-Gobain/Norton Industrial Ceramics Corp.

Research and development efforts to improve the quality and lower the cost of advanced ceramics is divided among private industry and government funding. According to the U.S. Department of Commerce, the U.S. advanced ceramics industry spent nearly $190 million on research and development in 1992 while government-funded research and development (principally by the Department of Energy and the Department of Defense) totaled nearly $20 million in 1992.[6] Nearly 75 percent of total funding on research and development is composed of spending on ceramics processing, which includes ASC fabrication and powder synthesis.

Initiatives to Reduce Technical Obstacles

The principal technical disadvantage ASC parts face is their low ductility, which makes these materials inherently brittle and sensitive to small flaws, such as cracks and voids. Flaws as small as 10 to 20 micrometers can reduce the strength of a ceramic structure to a few percent of its theoretical strength, resulting in failure under excessive loads.[7] Critical flaws in ASC parts that are too small to be detected by conventional analytical techniques are often difficult to eliminate. Ceramic parts are less tolerant of flaws than metal parts because flaws are far more likely to spread in a ceramic part.

Ceramic producers have generally dealt with the problem of the inherent brittleness of ceramic materials by designing ASC products to be tougher and stronger, making them more tolerant of flaws and more resistant to fracture. Some of the more commonly used methods to improve toughness and strength are summarized in figure 5-5. Other methods used to improve product quality include improving the quality of ceramic powders and improving the testing of finished products.

Improving Ceramic Materials

Because the ASC parts industries rely on ceramic powders as their raw material, the quality of powders is probably the greatest factor influencing the structure and performance of the final product. Generally, the finer and purer the powder, the stronger the finished product. Most commercial ceramic powders are made

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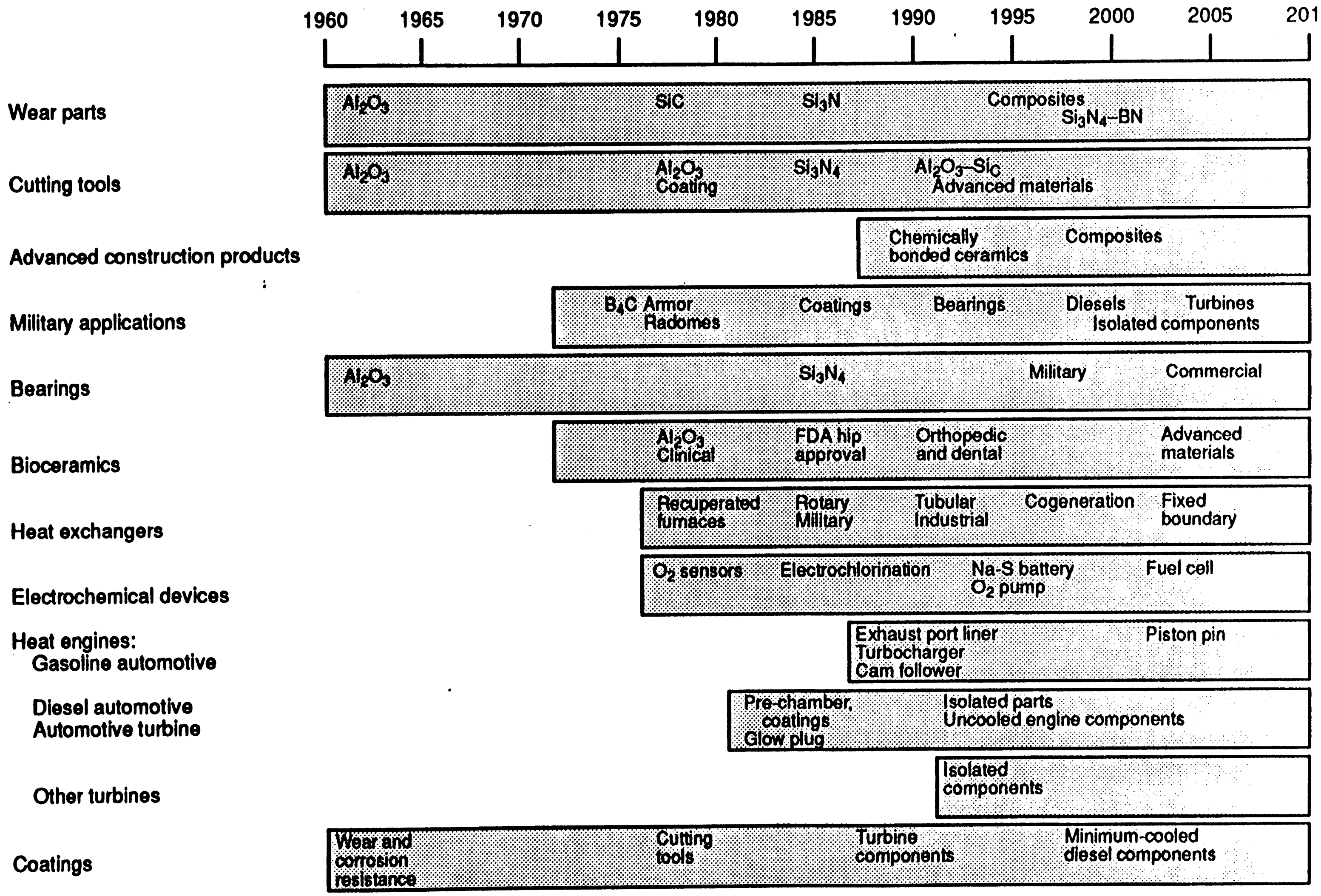
[6] Government-funded research has been driven by efforts to find high-strength, high-temperature, corrosion-resistant materials for increased energy efficiency and military applications. U.S. Department of Commerce, *Critical Technology Assessment of the U.S. Advanced Ceramics Industry*, forthcoming summer 1993.

[7] U.S. Office of Technology Assessment, *Advanced Materials: By Design*, New Structural Materials Technologies, 1988, p. 38.

Figure 5-2
Estimated scenario for implementation of ceramic comonents in structural application categories



Source: David W. Richardson, "Design, Processing Development, and Manufacturing Requirements of Ceramics and Ceramic Matrix Composites," contractor report prepared for the Office of Technology Assessment and industry contacts.

Figure 5-3
Estimated size of current and projected U.S. markets for ASC (in million dollars)

Item	1992	2000
Wear parts	150	540
Cutting tool inserts	100	300
Bearings	75	300
Bioceramics	20	60
Heat Exchangers	20	100
Automotive/heat engine	50	920
Aerospace, defense	80	450

Source: Various sources from 1993 including U.S. Department of Commerce publications and private industry estimates.

Figure 5-4
Various current and potential applications of ASC and application requirements

Industry	Application	Application requirements
Machine tool	Cutting tools Bearings Wire drawing dies	Wear and corrosion resistance, minimum lubrication requirements
Petrochemical	Seals Valves Pump impellers Heat exchanges	Energy-efficient heat regeneration
Automotive	Turbocharger rotors Push rod tips Rocker arms Cylinder liners	Light-weight, high-temperature, corrosion wear-resistance
Defense	Gun liners Ceramic armor	Light-weight, strength, corrosion, and high-temperature resistance

Figure 5-5
Methods to improve ceramic toughness and strength

Change in microstructure
Microstructure design of a single material through alteration of grain size and shape, or the production of ceramic matrix composites. In composites, ceramic particulates such as whiskers and fibers are introduced to reduce fractures. Advantages offered by ceramic composites over monolithic ceramics include increased strength and reliability, improved wear resistance, high thermal shock resistance, and excellent chemical resistance.

Transformation toughening
Toughening zirconium oxide by the addition of stabilizing oxides has great potential for increased use in low-temperature applications (e.g., hot-metal scissors) or where impact resistance is required. Aluminum oxide has also been transformation-toughened for use in woven preforms, mats, and papers.

Hot-Isostatic Pressing (HIP)
Simultaneously applies high temperatures and pressures to eliminate flaws in silicon carbide, silicon nitride, and zirconia to produce a microstructure that is more fine grained and uniform. This procedure permits parts to achieve maximum strength and density and allows complex net shapes to be produced. Although still at an early stage in commercial development, HIP is being used in a number of high-performance ceramic prototypes such as gas turbine blades and rotors, turbocharger rotors, and various engineering components. Due to the high costs of the process, applications are presently limited to low-volume, high value-added products.

Source: U.S. Office of Technology Assessment, *Advanced Materials By Design*, New Structural Materials Technologies, 1988, p. 39-44.

with an average diameter of 1 micron although powders for use in advanced ceramics are as small as 0.1 micron in size. Research efforts by manufacturers are devoted to making ceramic powders that are purer, more consistent from batch to batch, and which sinter more easily. Unfortunately, current technologies to improve the quality and reliability of ceramic powders are also expensive, thereby limiting their use.

One technology being developed to produce high-quality ceramic powders at low cost is the sol-gel process, which relies on the natural forces of synthetic chemistry rather than on the mechanical skills of the powder processor to produce a more consistent product. The process creates high-purity powders by altering powder characteristics at the molecular level to produce precise particle sizes and to eliminate further grinding or finishing operations. Sol-gel technology is already being used in applications where extremely high purity is required.

Other technologies for improving ceramic powder quality and consistency include rapid solidification, laser processing, and spray pyrolysis. These technologies are currently in an early stage of development and will not be commercially available for a number of years.

Nondestructive Testing

Nondestructive testing, which determines properties of a structural material without altering the material, has long been used for flaw detection in ceramic materials and will play a critical role in development of high-quality advanced ceramics. Testing equipment is being developed that will be able to detect flaws in complex shaped parts, but in a cost-effective manner.

In addition to the design of testing equipment, the design of testing standards to determine performance and reliability is an important component in any attempt to increase the market share of ASC parts. Many end users are hesitant to adopt ASC parts that do not have a long record of reliability as documented by independent testing. The American Society for Testing and Materials (ASTM) is currently taking preliminary steps to develop methods that can predict and improve the strength and durability of these materials. One of the most important properties for determining the service life of advanced materials is "creep behavior," also called porosity. A number of methods are currently being studied that seek to predict creep behavior. Other research efforts are being made to develop accurate and cost-effective tests to measure tensile strength and high-temperature performance.[8]

According to the ASC industry, these efforts to improve product quality have succeeded in largely eliminating brittleness as a factor adversely influencing the use of advanced ceramics in structural applications. As a result, ASC producers feel the quality and performance of ASC parts are now beginning to compare favorably with metal parts and are actively attempting to convince end users of this fact.[9]

Initiatives to Reduce Costs

Many in the industry argue that to compete effectively against metal parts, ASC parts must cost no more than metal parts and must provide comparable quality and

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[8] Laurel M. Sheppard, "Innovative Processing of Advanced Ceramics," *American Ceramic Society Bulletin*, Apr. 1993, p. 54.

[9] USITC interviews with industry officials, June 1993.

reliability.[10] In specialized applications where the unique properties of ASC materials are desired, these materials may successfully sell at somewhat of a premium when compared to prices of metal parts. At present, the average ASC part costs two to four times more than a comparable metallic component.

According to industry officials, the largest single factor contributing to high production costs for ASC parts is lack of sales volume. Because there are, thus far, no large consumer markets for these items, production runs tend to be small, and average unit costs are higher than for competing metal products. Only by increasing sales volume and achieving the economies of scale that derive from high-volume production will the widespread implementation of newer cost-saving technologies, such as near-net-shape processing, be justified, thereby enabling prices to fall to the level of metal parts. In addition to attempting to encourage the development of a large consumer markets through contacts with the automotive and aerospace industries, ASC producers have also concentrated research and development efforts on technologies to reduce raw material and processing costs.

Because raw materials, principally powders, account for nearly 40 percent of total manufacturing costs, lowering these costs is important. The Ceramic Technology for Advanced Heat Engines Project, a joint research effort undertaken by private industry and the U.S. Department of Energy, was initiated in 1983 to attempt to reduce the cost of high-quality silicon nitride powders from their current cost of nearly $20 per pound to a cost of less than $10 per pound. In addition, the project hopes to produce silicon nitride powders that are suitable for forming into components for heat-engine applications. Dow Chemical Co. has been selected as subcontractor to produce high-quality silicon nitride powder.[11]

Since nearly 30 percent of manufacturing costs are accounted for by finishing and machining operations required to form a part to its final shape and by nondestructive testing of the part, reduction or elimination of expensive machining and finishing operations is also critical. Labor costs currently account for nearly 30 percent of production costs, with 85 percent of these occurring at the finishing stage. Near-net-shape processing[12] is one of the operations that holds the most promise for reducing finishing costs because firms often use an injection-molding forming process to meet manufacturing requirements of high volume and cost effectiveness. By increasing the total yield and volume of ceramic parts produced, near-net-shape processing reduces average unit costs.[13] In Japan, where injection-molding techniques have been used to produce ceramic turbocharger rotors since the mid-1980s, reject rates for parts produced using injection-molding have declined significantly, although they are still above reject rates for metal components.[14] The use of near-net-shape processing would allow many firms in the industry to achieve economies of scale and would allow more firms to exceed break-even production levels. However, the increased use of near-net-shape processing techniques is only cost-effective when production runs are fairly large and the type of products produced are fairly uniform.

Initiatives to Improve End-user Acceptance

Despite significant improvements in the product quality and reliability of ceramics, the continued perception of most designers is that ceramic parts are not adequate for most structural uses because of the potential for sudden failure. Furthermore, end users have had a long and successful experience with metal parts and are reluctant to use advanced ceramic materials because the performance data on these materials are not as well developed. To overcome the perception that ceramics are not viable materials, advanced ceramic companies have developed close working relationships with end users to demonstrate the effectiveness of ASC parts in specific applications. Joint-venture arrangements that allow manufacturers to confer with design engineers of the end-user company are one example of such relationships. Government programs also help bring end-user companies and their suppliers together for a specific purpose, such as the design of a more efficient gas turbine engine.

Another strategy for gaining end-user acceptance is to focus adoption efforts on areas where sudden failure would not cause catastrophic consequences. Advanced ceramic valves are demonstrating their cost-effectiveness in diesel engines where high heat and rough working environments have caused engines to need frequent overhauls to repair metal valves, which wear more quickly. Although still too expensive for cost-conscious automotive manufacturers, ASC producers have been able to demonstrate their strength and toughness in diesel valve applications. As another example, an advanced ceramic manufacturer is developing turbine blades for auxiliary power units for

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[10] Sujit Das and T. Randall Curlee, "The Cost of Silicon Nitride Powder and the Economic Viability of Advanced Ceramics," *American Ceramic Society Bulletin*, July 1992, p. 1110.

[11] Susan G. Winslow, "Development of a Cost Effective Silicon Nitride Powder," *American Ceramic Society Bulletin*, Apr. 1993, p. 102.

[12] Near-net-shape processing describes any forming process that produces a final product that requires little or no machining.

[13] Sujit Das and T. Randall Curlee, "The Cost of Silicon Nitride Powder and the Economic Viability of Advanced Ceramics," *American Ceramic Society Bulletin*, July 1992,, p. 1109.

[14] John Mack, "Advanced Ceramics Processing: Cracking the Edge," *Materials Edge*, Aug. 1991, p. 24.

aircraft.[15] By establishing a successful record in these applications, opportunities for adoption of other parts for heat engines could materialize.

Implications for U.S. Competitiveness

The ability to compete in the international market for advanced ceramics has enormous competitive implications for the United States. According to a U.S. Department of Energy survey of global ceramics experts, the U.S. gross national product (GNP) could expand by $11 billion in the year 2000 if the United States were to become the world leading ceramics producer.[16] On the other hand, GNP could decline by $26 billion if foreign manufacturers were to dominate the market.[17]

The United States and Japan currently lead in the manufacture of advanced ceramics, with each nation accounting for nearly one-quarter of total world advanced ceramics production of $15.3 billion in 1991.[18] Advanced ceramics use in the United States tends, thus far, to be concentrated in specialized applications in the wear part and cutting tool industries while Japanese strength in ASC markets has been built on its experience in designing advanced ceramic components for the automotive market, in which Japan leads the United States. In Japan, advanced ceramics are widely used in automotive engines as turbocharger rotors due to the heat-generating characteristics of turbochargers and the greater popularity of turbocharged automobiles in Japan. On the other hand, the United States is believed to lead Japan in the development of ASC parts for other industrial applications and in the production of ceramic-matrix composites.

Although the U.S. ASC industry has overcome many of the technical problems that have prevented greater market access for ASC products, the problems of low-volume production, relative high cost, and end-user resistance to newer, nontraditional applications for these products will take longer to overcome. In these areas, government support of both research and development funding through the Advanced Materials and Processing Program (AMPP) and projects such as the High Speed Civil Transport Program, which will serve to build volume, may greatly hasten the commercialization of these products.■

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[15] Auxiliary power units are integral gas turbine engines that supply power to aircraft when they are on the ground.

[16] Dana Gardner, "Making Ceramics Work For You," *Design News*, Mar. 26, 1990, p. 95.

[17] *Ibid.*

[18] *Advanced Materials*, Annual Report of the U.S. Bureau of Mines, table 8, prepared by William J. McDonough and Robert D. Brown, Jr., p. 29, 1991.

EMERGENCY SHELTERS: A POTENTIAL MARKET FOR PREFABRICATED BUILDINGS

Every year natural and manmade disasters around the world leave countless people without homes, schools, and hospitals. Relief organizations provide the initial support for rebuilding such communities. Minimal construction requirements, near-term availability, and superior performance compared to other types of emergency shelters make prefabricated buildings a logical component of relief.[1] The often unexpected and varied nature of major disasters characterize the market for prefabricated buildings in emergency situations with an immediacy and diversity of demand. Consequently, U.S. producers seeking to enter the emergency shelter market have found that having production facilities close to the location of the disaster or crisis can be a significant competitive advantage. Establishing a foreign production facility lowers the transportation cost for a prefabricated building and simplifies the process of adhering to local building codes. High transportation costs and local building codes have limited international trade in prefabricated buildings.

This article provides a brief background of the international prefabricated building industry, followed by discussions of the traditional uses of these products. Next it outlines recent disasters and the nature of the relief shelters needed in the wake of such disasters. It also gives specific examples of the structures used by relief organizations. The article concludes with an analysis of the potential of the emergency shelter market and the ability of U.S. producers to take advantage of these opportunities.

The International Prefabricated Building Industry

The major world producers of prefabricated buildings are the United States, members of the European Community (EC), Japan, members of the European Free-Trade Association (EFTA),[2] and Canada. These producers have comparable methods of manufacturing: materials are cut to architectural specifications and then sent to a production line. Distinguishing characteristics of the buildings produced by these different producers are primarily a function of cultural preferences.

The production of prefabricated buildings is becoming increasingly automated. However, the industry remains relatively low-tech because production does not require highly sophisticated or particularly costly equipment. High transportation costs and local building codes generally limit the market for prefabricated buildings to a radius of 300 miles from the production plant.

The U.S. prefabricated building industry consisted of an estimated 1,200 producers in 1992; employment totaled roughly 70,000. U.S. producers' shipments of prefabricated buildings were an estimated $8 billion in 1992. The U.S. industry places a strong emphasis on providing a variety of models to consumers. Computer-aided-design technology allows manufacturers to quickly modify floor plans. The EC, Japanese, EFTA, and Canadian prefabricated building industries are also well established. Since markets are characterized by high transportation costs and local building codes, producers in each of these countries tend to concentrate on their domestic markets. Individually, producers in these countries have their own strengths and weaknesses. EC firms are subject to the various local building codes of each EC-member country, although the EC is working towards a marketwide code. Japanese manufacturers, which are usually subsidiaries of major corporations with close linkages to the banking industry, produce very cost-efficient buildings made from metal or precast concrete. Swedish manufacturers are known for producing highly insulated wood structures, using very automated equipment and well-trained production workers. Canadian wood prefabricated building producers have an important cost advantage because they have favorable access to abundant sources of lumber at relatively low prices.

The international emergency housing market is open to foreign producers. The governments of most of the agencies purchasing prefabricated buildings used for emergency shelter have signed the General Agreement on Tariff and Trade (GATT) Government Procurement

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[1] Prefabricated buildings are used for such purposes as single-family dwellings, low-level apartment buildings, schools, mobile homes, and mobile offices. There are three different classes of prefabricated buildings: completely assembled modular buildings, partially assembled panelized sections (roof, walls, floors), and precut unassembled packages. Most of the construction of a prefabricated building takes place in a manufacturing facility as opposed to at a building site. Mobile homes, also known in the industry as manufactured homes, are always shipped in modular form. Mobil homes for the U.S. market are built to U.S. Department of Housing and Urban Development guidelines and are permanently attached to a chassis that can serve as a foundation.

[2] European Free-Trade Association members include Austria, Finland, Iceland, Liechtenstein, Norway, Sweden, and Switzerland.

Code.[3] The code seeks to ensure that government procurement practices do not serve to protect aid-originating country producers or suppliers from international competition. Signatories are required to allow suppliers from other signatories to compete for government contracts on conditions no less favorable than those accorded to domestic suppliers.[4] As of late 1992, the code had 13 signatories.[5]

Traditional Uses of Prefabricated Buildings

Prefabricated buildings have traditionally been used for every type of housing and commercial application, usually in a nonemergency setting. The prefabricated building method provides a faster return on investment, owing to shorter construction time and increased control over inventory and methods of production. Prefabricated buildings are used for such purposes as single family dwellings, low-rise apartment buildings, and mobil homes. Mobile modular offices serve as bank branches, schools, storage sheds, and grocery stores. Prefabricated structures have also been fitted with specialized equipment and used as mobile hospitals, infirmaries, and post offices.

Emergency Needs and Shelters Used by Relief Organizations

Civil wars have caused the most sustained and wide-spread dislocation of people in recent years (table 6-1). In contrast, natural disasters are sudden and often unexpected, but the effects are usually temporary. In the past 2 years alone, over 7 million people have been affected by civil wars in Africa and Eastern Europe, while natural disasters in the form of volcanoes, hurricanes, floods, and earth earthquakes, affected over 1 million people around the world.

Relief organizations purchase emergency shelters for disaster victims. Prefabricated buildings are more substantial than other types of emergency shelter such as tents and plastic sheeting, and they require more time, effort, and expense to put in place than alternative forms of shelter. Thus, prefabricated buildings are more likely to be used in emergencies of longer duration (such as civil wars) than in briefer emergencies (natural disasters).

Within the U.S. Government, the Federal Emergency Management Agency (FEMA) and the Agency for International Development (AID) are responsible for domestic and international relief efforts. The United Nations (UN) and the Red Cross are transnational emergency relief organizations that provide shelter in emergency situations.

FEMA is authorized to provide disaster assistance to an area once the President has approved a request from the governor of the affected State. Almost all of the assistance provided by FEMA is monetary. A team of technical advisors assesses the damage and a FEMA field office disburses financial assistance. FEMA keeps an inventory of 2,500 mobile homes purchased under Federal procurement policies.[6] The homes provide temporary housing for disaster victims and can be trucked to a disaster area within hours. Mobile homes are relocatable, easy to transport, and come fully equipped.[7] In some cases, FEMA mobile homes are purchased by or donated to the people who move into them.[8] As part of its response to Hurricane Andrew, which destroyed or damaged over 3 million buildings in South Florida in August of 1992, FEMA purchased an additional 3,500 mobile homes. This was the first addition to the FEMA inventory since 1984. In response to the Mississippi flood of 1993, FEMA immediately sent 100 mobile homes. More homes will be sent once FEMA has determined the number of people that cannot either find alternative shelter or rebuild.

The emergency housing facilities provided at the State and local level are primarily existing structures such as schools, meeting halls, churches, and armories. Because schools are numerous and publicly funded, they play a significant role in both providing emergency shelter and creating demand for prefabricated buildings. Modular relocatable classrooms, which are cost-efficient and movable, are particularly suited to the reconstruction or expansion of a school damaged or destroyed by a disaster. A

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[3] U.S. International Trade Commission (USITC), *The Year in Trade, Operation of the Trade Agreement Program, 1991*, USITC publication 2554 (Aug. 1992), p.44.

[4] The code also established common procedures aimed at improving transparency by settling disputes and providing information on both proposed government purchases and the opening and awarding of bids by signatories agencies.

[5] The signatories are Austria, Canada, the EC, Finland, Hong Kong, Israel, Japan, Norway, Singapore, Sweden, Switzerland, United Kingdom, and the United States.

[6] Federal purchases are governed by the Office of Federal Procurement Policy, Federal acquisition regulations, the General Services Administration procurement policies, and Federal property management regulations.

[7] FEMA reinforces its mobile homes so they can be reused. Additional FEMA specifications include a wooden belt rail that is wrapped around the outside of the house; plywood flooring, as opposed to particle board; and a stronger chassis and running gear (wheels and axles).

[8] Miami officials involved in rebuilding efforts have questioned the safety of prefabricated buildings, particularly mobile homes. Housing and Urban Development homes, which are supposed to be built to withstand winds of up to 110 miles an hour, were severely wind damaged. Acres of housing developments that used such prefabricated components as roofs, walls, and flooring were ruined because of improper installation.

Table 6-1
Major disasters, location, number of people affected, and date

Major disasters	Location	Number of people affected	Date
Civil War	Somalia	2,500,000	1993
Civil War	Bosnia, Croatia	2,000,000	1993
Civil War	Liberia	1,200,000	1993
Floods	United States (Mississippi River)	30,000	1993
Volcano	Philippines	950,000	1992
Hurricane	United States, The Bahamas	100,000	1992
Flood	Vietnam	68,000	1992
Flash floods	Afghanistan (Hindu Kush mountains)	30,000	1992
Tsunami	Nicaragua	14,000	1992
Earth quake	Egypt	10,000	1992

Source: UN Department of Humanitarian Affairs, International Red Cross, and *Washington Post.*

traditional block-constructed classroom costs between $75,000 to $80,000. A relocatable classroom costs between $50,000 to $55,000.[9]

The AID Office of Foreign Disaster Assistance (OFDA) oversees international disaster relief efforts.[10] OFDA normally uses existing structures or plastic sheeting for emergency shelter. Prefabricated buildings are not used because they are expensive to ship, difficult to distribute, and need an established building site. In equatorial climates, prefabricated buildings must be cooled, and electricity is usually not available for fans or air conditioning.

The UN emergency relief efforts are coordinated by the High Commission for Refugees (UNHCR), the UN Disaster Relief Coordination Office (UNDRO), and UN peace-keeping forces. The UNHCR provides protection and emergency relief to large groups of people for whom individual refugee status would be impractical because of the urgency of their needs.[11] For example, during the 1980s, the UN refugee camp in Bangladesh sheltered as many as 2 million people at a time. The UNHCR uses prefabricated buildings primarily for storage and health care. Storage facilities are made of metal and are shipped to the refugee camps in precut unassembled packages. Health care facilities are typically mobile modular units that have had hospital equipment installed. The UNHCR resists using prefabricated buildings for housing because such "permanent" housing for refugees is only provided after the refugees have been permanently relocated.

Bilateral relief efforts for refugees are often coordinated through the UNHCR. For example, Germany is providing shelter for 20,000 refugees in Croatia and Bosnia-Hercegovina. The operation was funded by the Arbeitsstab Humaenetare Hilfe (Office of Humanitarian Assistance). Construction is being overseen by the German Agency for Technical Cooperation (GTZ), in close coordination with UNHCR and the Croatian Government. Three different housing projects are being planned: the shipment of roughly 100 modified railway cars from the eastern part of Germany; the repair/winterization of existing structures for 12,000 persons; and the construction of new homes for 8,000 people. The Netherlands provided an additional 176 prefabricated structures for the project. The combined value of the aid provided by the Dutch and German Governments to refugees from the former Yugoslavia was an estimated $50 million in 1992.[12] The emergency relief provided by UNDRO usually consists of tents, blankets, food, and water.[13] However, in Bosnia it provided building materials, including a modest amount of prefabricated components.

The UN peace-keeping missions use prefabricated buildings to house soldiers in areas where existing structures are unsuitable or nonexistent. These camps

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[9] School populations are known for their erratic growth. A modular relocatable classroom can follow a "population bubble" through the school system.

[10] OFDA is authorized to provide emergency relief once the affected country's U.S. ambassador has declared that additional funds are needed.

[11] A refugee is any person who cannot return to a country of nationality because of political, religious, or ethnic persecution. These people are not protected by the country they are in. The UN breaks down the number of refugees by region: Southwest Asia and the Middle East, 7 million; Africa, 5.9 million; Europe, 1.3 million; Latin America and the Caribbean, 1.2 million; North America, 982,000; Asia, 516,000; and Oceania, 110,000.

[12] The Danish Red Cross build a prefabricated resettlement camp for 1,400 people.

[13] The main UNDRO functions are to mobilize and co-ordinate disaster relief assistance and promote activities related to disaster mitigation.

are constructed in the production facilities of companies that are usually based in the aid-originating country. A Canadian company with offices in the United States won a contract for the construction of prefabricated camps for the UN peace-keeping forces in Iraq. The camps were built in the company's Saudi Arabian production facilities. The market potential for supplying housing to UN forces is significant when compared with other disaster/crisis relief needs. For example, the UN peace-keeping force in Cambodia numbers 22,000 and has a budget of $1.9 billion.

Foreign Market Potential

The potential of the emergency shelter market for U.S. producers of prefabricated buildings is reflected by existing participation in foreign markets, certain structural limitations of prefabricated buildings, and proximity of global competitors to disaster sites. Illustrations of current efforts by U.S. producers to take advantage of foreign market opportunities are noted.

The current level of U.S. participation in the emergency shelter market can be estimated by the amount of U.S. exports of prefabricated buildings to countries that have been subjected to an emergency situation (table 6-2). Exports to Saudi Arabia surged in 1991 and 1992 to meet the demand for shelters for Gulf War armed forces, prisoners of war, and refugees.

Lack of housing has prevented soldiers of the former Soviet Union from leaving Eastern Europe. Building Exporter, a division of the Homebuilders Institute (US), has received a grant from the U.S. Government to establish office space in Moscow, Kiev, and St. Petersburg. These offices will help U.S. producers set up prefabricated building operations throughout the former Soviet Union. American companies starting production facilities will most likely use local materials and labor, but import specialized components (e.g., energy-efficient windows and thermostats), machinery and equipment, and engineering and design services. A significant portion of the money for new housing will be provided by various aid organizations. U.S. exports of prefabricated buildings to the former Soviet Union were $19 million in 1992, up from no trade the previous year.

The largest market for U.S. emergency housing in 1991 was Israel, which imported such products to alleviate the housing shortage caused by an influx of immigrants from Russia and Ethiopia. U.S. exports to Israel of prefabricated buildings peaked at $53 million in 1991, compared with only $2 million in 1990. The bulk of U.S. exports to Israel consisted of metal-framed, four-story apartment buildings and single-family units.

Participation in the emergency shelter market by U.S. and foreign producers of prefabricated buildings is limited by certain structural characteristics. These characteristics include high transportation costs as compared with those of local manufacturers, and high construction costs relative to other types of emergency shelters such as tents and existing structures that have been repaired with plastic sheeting. If the disaster occurs in a warm climate where building materials are readily available and relatively inexpensive (for example, adobe, stucco, or concrete block), and where there is a large labor pool, these factors accentuate the relatively unfavorable aspects of prefabricated buildings. A natural, short-term disaster may further limit the competitive opportunity for prefabricated units because the demand is so immediate.

Local production facilities enable a foreign company to lower its transportation costs. These facilities are normally built near such traditional markets for prefabricated buildings as the Middle East or Europe. However, establishing foreign production facilities can create other problems. Certain U.S. firms currently in the emergency shelter market have found that sovereign governments often dictate the terms of such agreements, making it difficult to return profits to the United States. In addition, companies may have problems obtaining standard production inputs, such as builders' hardware and lumber.

Firms that have chosen to avoid the problems of operating foreign subsidiaries tend to focus on providing buildings that can be built quickly in the United States and then shipped abroad, compensating for the higher transportation costs by achieving lower construction costs. For example, one U.S. producer of prefabricated structures has attempted to expand into foreign markets by successfully bidding on a U.S. State Department contract for an embassy.[14] Building an embassy in a foreign country generally takes 72 months. Constructing a prefabricated embassy in the United States and then shipping and assembling it abroad can be done in as few as 10 months. In situations where establishing a timely U.S. presence in a foreign country is important, those with a newly elected democratic government, timely construction may more than compensate for high transportation costs.

Although all major producers of prefabricated buildings are potential competitors in the emergency shelter market, U.S. industry sources indicate that Italy, Germany, and Canada are the most active in this market. German and Italian producers benefit from their proximity and traditional economic ties to the former Yugoslavia. Domestically made prefabricated buildings are often included in bilateral Canadian relief efforts.

The market potential of prefabricated buildings in emergency situations has been limited by high transportation costs and long delivery times to

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[14] U.S.I.T.C. Staff interview, June 24, 1993.

Table 6-2
U.S. exports of prefabricated buildings to the former Soviet Union, Israel, and Saudi Arabia, 1990-92

Partner	1990	1991	1992
	Value *(1,000 dollars)*		
Saudi Arabia	1,370	13,937	20,129
Former Soviet Union	0	0	19,258
Israel	2,228	53,105	9,061

Source: Compiled from official statistics of the U.S. Department of Commerce.

emergency sites. These factors often result in underutilization of prefabricated buildings to assist disaster victims. Prefabricated buildings are the only type of emergency structures that can be used as hospitals or as efficient transportable housing in extremely cold climates. Industry sources indicate that market potential would improve if relief organizations had—

- A response plan for disasters that outlined under what situations prefabricated buildings would be required;
- A staging/storage area for emergency relief supplies; and
- A commitment to a certain amount of prepurchasing of prefabricated buildings.

A response plan, staging area, and prepurchasing would substantially cut the delivery times of prefabricated buildings to emergency sites. The repeated use of prefabricated buildings would also allow relief organizations to standardize methods for installation.■

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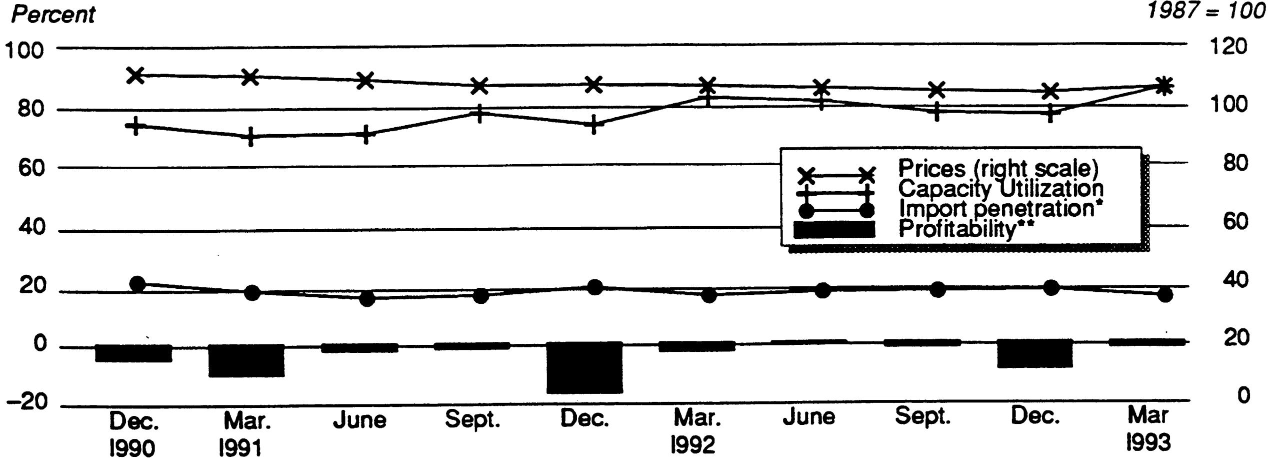
APPENDIX A
KEY PERFORMANCE INDICATORS OF SELECTED INDUSTRIES

STEEL

Figure A-1
Steel mill products, all grades: Selected industry conditions



*Import share of apparent supply.
**Operating income as a percent of sales for companies representing about 65 percent of production.
Source: American Iron and Steel Institute, U.S. Bureau of Labor Statistics.

- After steadily declining throughout 1992, aggregate price trends reversed direction in the first quarter of 1993. Strong ordering activity has resulted in backlogs at many domestic mills. As mills have responded to the increased volume, capacity utilization for raw-steel-making facilities has improved by almost 10 percentage points.
- Import penetration for the first quarter of 1993 fell to 15.3 percent from the 1992 average of 18 percent. The decline in import penetration reflected both the decline in imports associated with preliminary dumping and countervailing duties on flat-rolled products announced in January by the U.S. Department of Commerce and a moderate resurgence in domestic shipments. Imports were particularly low in February 1993, rebounding somewhat in March.
- Increased prices, capacity utilization, and shipments contributed to improved profitability. Despite this improvement, the industry sustained operating losses of $124 million. Additional price increases on certain steel products, announced during the first quarter, may be sufficient to move the industry into profitability in the second quarter of 1993.

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[1] Based on financial data reported to the American Iron and Steel Institute by producers accounting for approximately 65 percent of domestic shipments.

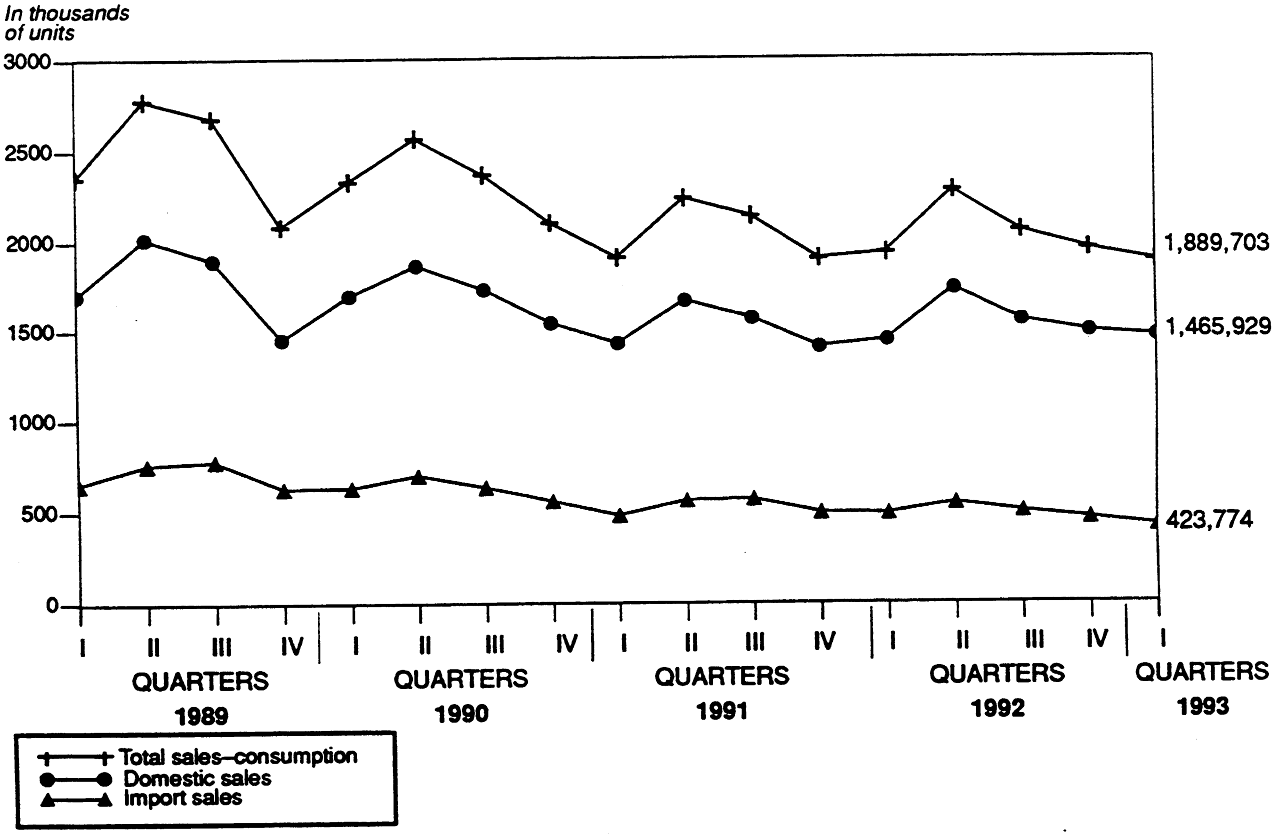
Table A-1
Steel mill products, all grades

Item	*March 1993*	*Percentage change, March 1993 from December 1992*[1]	*January March 1993*	*Percentage change, Jan.-Mar. 1993 from Jan.-Mar. 1992*[1]
Producers' shipments *(1,000 short tons)*	7,886	11.1	21,770	6.5
Imports *(1,000 short tons)*	1,380	7.2	3,753	-8.4
Exports *(1,000 short tons)*	359	0.7	1,049	-8.5
Apparent supply *(1,000 short tons)*	8,907	10.9	24,475	4.6
Ratio of imports to apparent supply *(percent)*	15.5	-0.5	15.3	2.2

[1] Based on unrounded numbers.
[2] Percentage point change.
Note.—Because of rounding, figures may not add to the totals shown.
Source: American Iron and Steel Institute.

AUTOMOBILES

Figure A-2
U.S. sales of new passenger automobiles



Note:—Domestic sales include all automobiles assembled in Canada and imported into the United States under the United States–Canadian automotive agreement; these same units are not included in import sales.

Source: *Automotive News;* prepared by the Office of Industries.

Table A-2
U.S. sales of new automobiles, domestic and imported, and share of U.S. market accounted for by sales of total imports and Japanese imports, by specifed periods, Jan. 1992–Mar. 1992

Item	Jan.-Mar. 1993	Percentage change— Jan.-Mar. 1993 from Oct.-Dec. 1992	Percentage change— Jan.-Mar. 1993 from Jan.-Mar. 1992
U.S. sales of domestic autos (1,000 units)[1]	1,466	-1.6	-1.6
U.S. sales of imported autos (1,000 units)[2]	424	-8.6	-13.8
Total U.S. sales (1,000 units)[1,2]	1,890	-3.2	-2.3
Ratio of U.S. sales of imported autos to total U.S. sales (percent)[1,2]	22.4	-5.5	-11.8
U.S. sales of Japanese imports as a share of the total U.S. market (percent)[1,2]	15.9	-9.7	-14.1

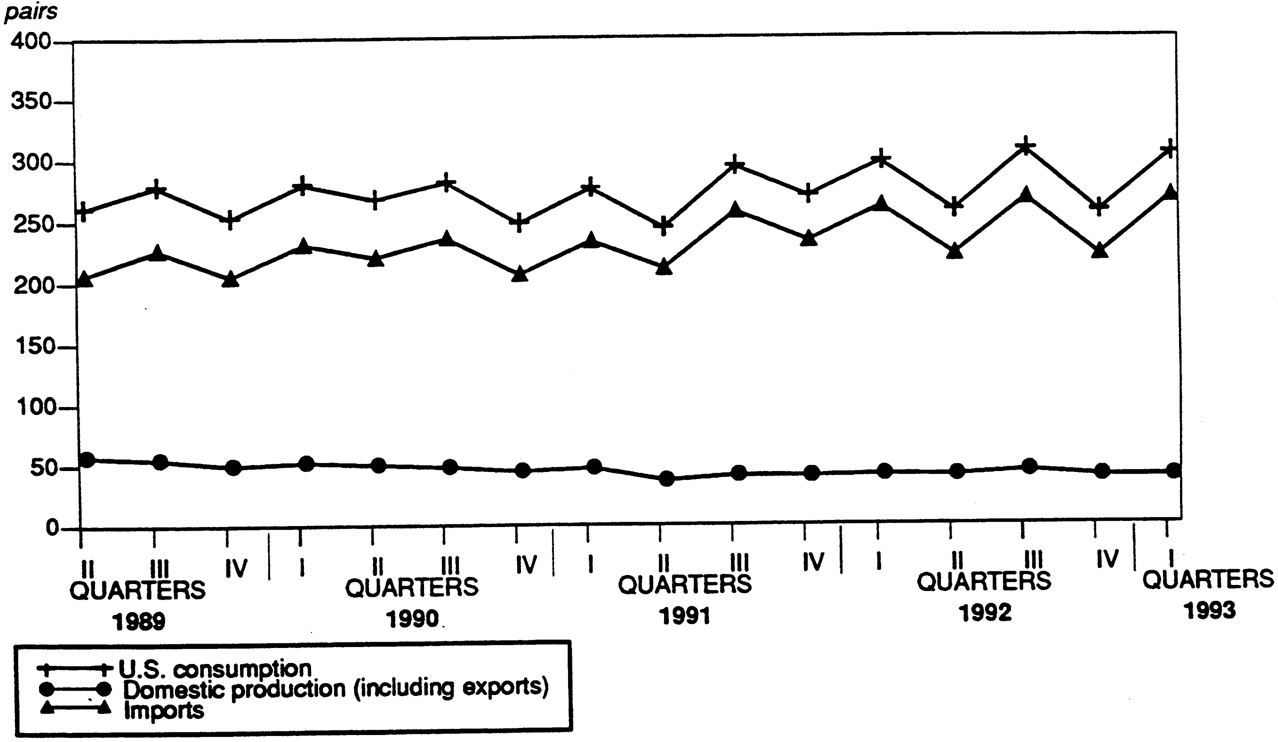
[1] Domestic automobile sales include U.S.-, Canadian-, and Mexican-built automobiles sold in the United States.

[2] Does not include automobiles imported from Canada and Mexico.

Source: Compiled from data obtained from *Automotive News*.

FOOTWEAR

Figure A-3
Nonrubber footwear: U.S. consumption, by quarters, 1989-1993



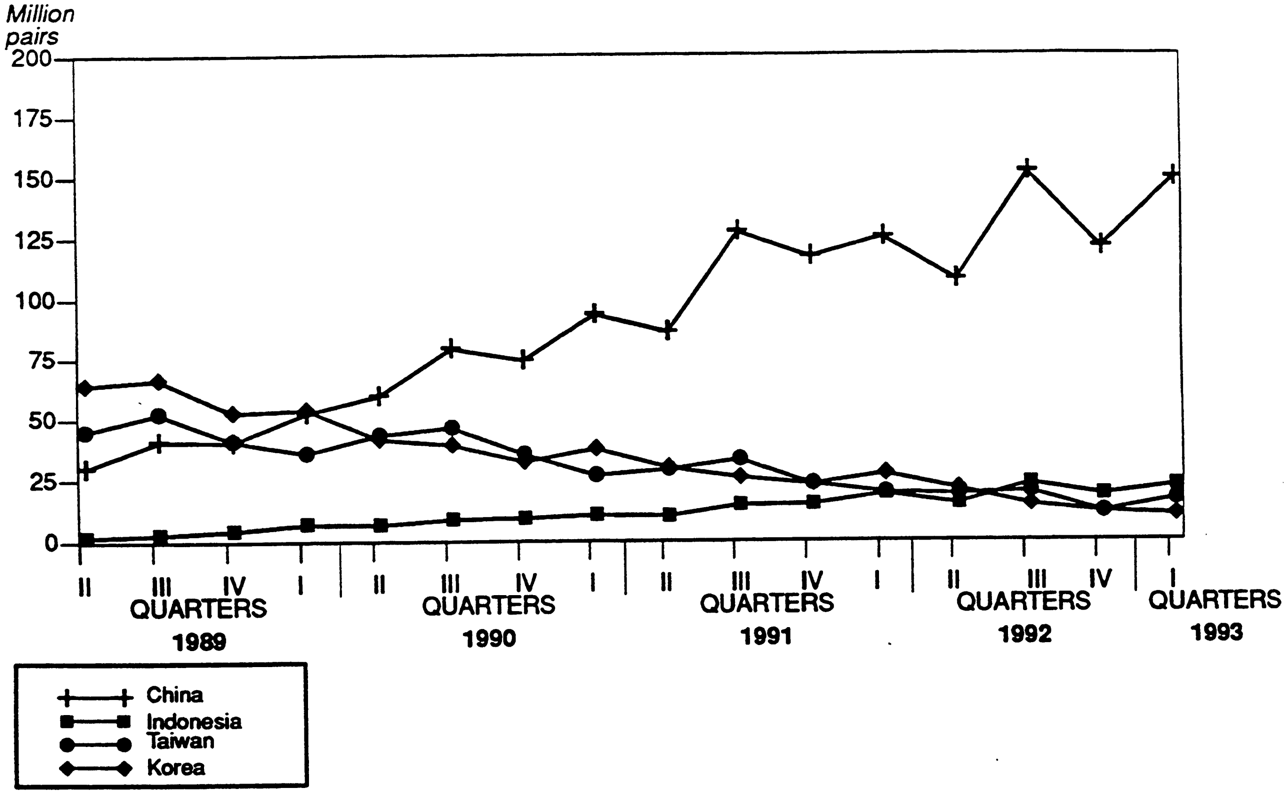
Source: Compiled from official statistics of the U.S. Department of Commerce.

Table A-3
Nonrubber footwear: U.S. consumption, by quarters, 1989-1993
(Million pairs)

Period	Imports	Production	Consumption
1989			
II	207.1	57.7	261.2
III	228.0	55.4	279.8
IV	206.4	50.5	253.7
1990			
I	232.2	53.0	281.1
II	221.3	51.0	268.7
III	236.8	49.0	282.3
IV	207.2	45.3	248.5
1991			
I	233.8	47.7	277.0
II	211.9	37.4	244.5
III	257.7	41.5	294.6
IV	233.8	40.9	270.4
1992			
I	261.5	42.0	298.2
II	222.5	41.7	258.6
III	268.1	44.4	307.2
IV	222.1	40.7	257.6
1993			
I	269.2	40.2	304.6

Source: Compiled from official statistics of the U.S. Department of Commerce.

Figure A-4
Nonrubber footwear: U.S. imports, by selected sources, by quarters, 1989-1993



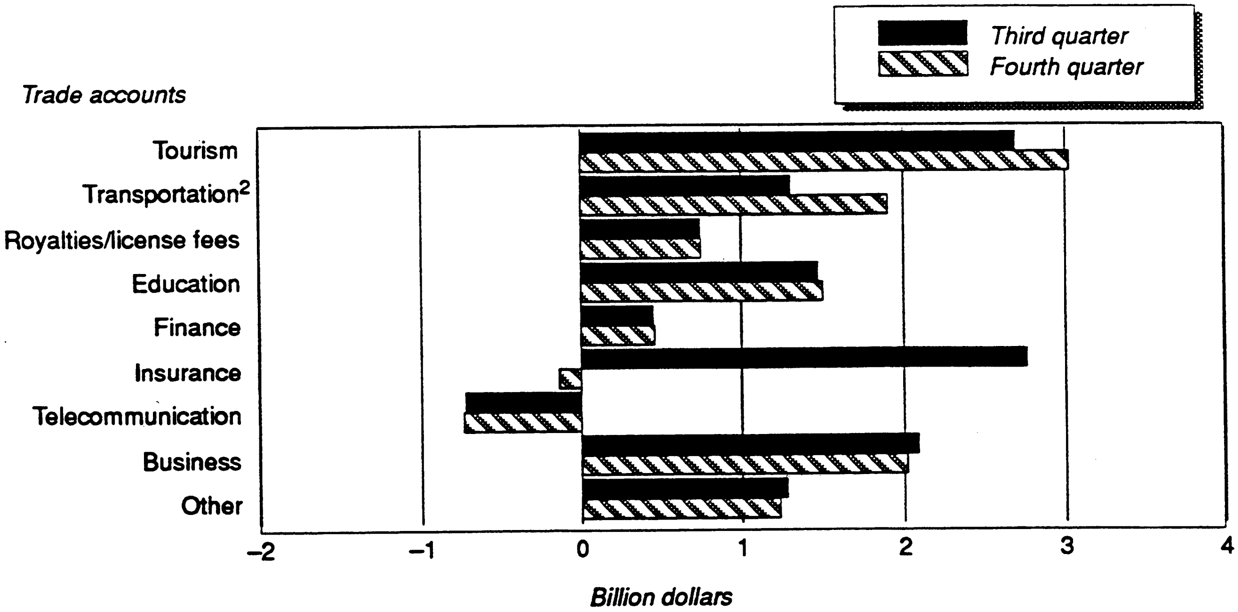
Source: Compiled from official statistics of the U.S. Department of Commerce.

Table A-4
U.S. imports of nonrubber footwear from selected suppliers, by quarters, 1989-1993
(Million pairs)

Period	*China*	*Indonesia*	*Taiwan*	*Korea*
1989				
II	30.3	2.2	45.3	64.5
III	41.3	3.2	52.8	67.0
IV	41.0	4.8	41.4	53.3
1990				
I	53.0	7.3	36.4	54.5
II	60.2	7.0	43.9	42.1
III	79.7	9.2	46.9	39.8
IV	74.4	9.6	35.9	32.7
1991				
I	93.6	10.8	27.1	38.0
II	86.3	10.4	29.5	30.2
III	127.5	14.8	33.5	26.2
IV	117.2	15.0	23.5	23.4
1992				
I	125.3	19.3	19.8	27.5
II	107.7	15.2	19.1	21.3
III	152.0	23.5	20.2	14.8
IV	121.0	18.8	11.8	11.7
1993				
I	149.3	22.3	16.9	10.5

Source: Compiled from official statistics of the U.S. Department of Commerce.

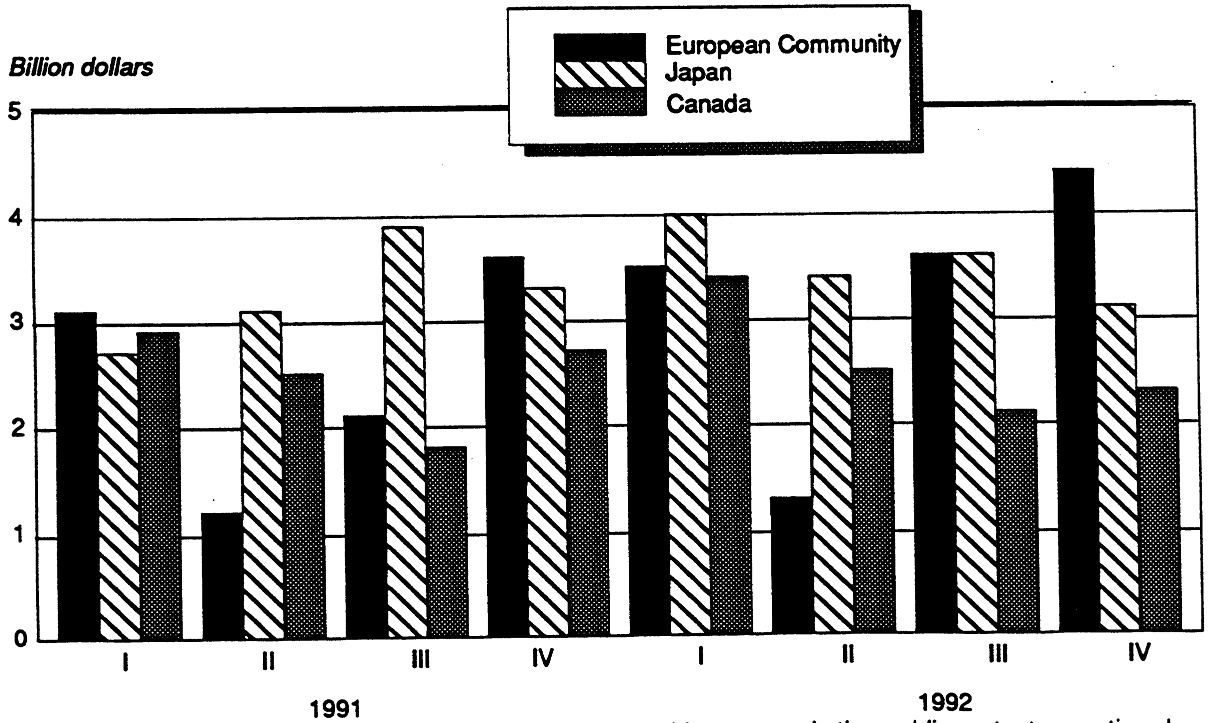
Figure A-5
Balances on U.S. service trade accounts,[1] third and fourth quarters, 1992



[1] Figures reflect trade among unaffiliated firms only.
[2] Includes port fees.

Source: Bureau of Economic Analysis, *Survey of Current Business.*

Figure A-6
Surpluses on cross-border U.S. service transactions with select trading partners,[1] by quarter



[1] Figures reflect private sector transactions only; military shipments and other public sector transactions have been excluded.

Source: Bureau of Economic Analysis, *Survey of Current Business.*