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U.S. ENERGY USE: NEW TECHNOLOGIES AND POLICIES IN RESPONSE TO GLOBAL WARMING

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U.S. ENERGY USE: NEW TECHNOLOGIES AND POLICIES IN RESPONSE TO GLOBAL WARMING

Energy use and production accounts for by far the largest portion of emissions of greenhouse gases in the United States and the world. The U.S. Environmental Protection Agency (EPA) has estimated that, worldwide, these activities were responsible for 57% of greenhouse warming in the 1980s.[1] Other activities and their respective contributions as shown in Fig. 1 include agriculture, 14%; land use and modification, 9%; chlorofluorocarbon (CFC) use, 17%; and other (nonenergy) industry, 3%.

Given this importance of energy activities, it is appropriate that efforts to forestall global warming have focused on these activities. Because the United States consumes the largest share of world energy and thus produces the largest share of greenhouse gas emissions, it is the target of many such efforts. A number of U.S. government responses to global warming have been proposed or are now under way. For example, the 101st Congress has seen 11 bills dealing with global warming issues; a research program on climate change has been promised $190 million for 1990; and the United States has signed the Montreal Protocol to control CFCs.

Despite these positive actions, it is important to note that none of the proposed bills has been signed into law; research on environmental issues and energy efficiency has been hindered for the last eight years by spending cuts; and the Montreal Protocol took almost a decade to achieve -- similar international agreements for other greenhouse gas reductions are likely to be more complex and take longer to achieve. Yet the advantages of acting promptly on these and related issues are compelling. In addition to slowing the arrival of global warming, the benefits to be achieved by reducing energy use and using energy more efficiently are many: increased energy security through lower oil imports, a more competitive economy, and a cleaner environment are just a few.

The paper that follows discusses U.S. energy use and related emissions of greenhouse gases. Energy use in each sector is briefly characterized and several new technologies for energy use in that sector are described. Finally, national and state policies that offer potential to reduce energy use are discussed. This discussion is limited by space considerations to only a sampling of the many technologies under development and policy options that have been proposed.

Transportation Sector

Transportation Energy Use. The transportation sector currently accounts for one-fourth of the United States' total fuel use -- about 20 quads per year. Of that, more than half comes from gasoline used to fuel cars and light trucks. The bulk of the rest is from diesel fuel used for heavy trucks and jet fuel used in aviation (see Fig. 2). Activity in this sector contributed 31% of the nation's CO_2 emissions in 1985.[2]

Energy use in this sector has varied historically with the availability of oil. When oil is cheap and plentiful, energy use grows. During the oil price shocks of the seventies, for example, transportation energy use dropped, then rose again as prices fell. The same oil price shocks created the impetus for substantial improvements in energy efficiency that this sector has achieved since the 1970s. Cars sold in 1974 averaged 14.2 miles per gallon, compared with 28.5 miles per gallon in 1988.[3] Some of these improvements were driven by consumer demand for smaller, more efficient cars and some by legislation. The Corporate Average Fuel Economy (CAFE) standards mandated by Congress in 1975 required automakers to make gradual improvements in fleet efficiencies and reach a target of 27.5 mpg by 1985.

However, the eighties brought a decade of declining oil prices that spurred a consumer move back to larger, less efficient cars. Government spending to promote efficiency and develop efficient technologies declined by 50% during the Reagan administration, and the CAFE goal was relaxed to 26 mpg.* As a result, efficiency gains

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*The Bush administration is returning to the goal of 27.5 mpg CAFE for 1990.[4]

have stalled. There were no mileage improvements from 1986 to 1987, and the 1987-1988 gain amounted to only 0.3 mile/gallon.[3]

Transportation Conservation Options. Renewing progress in energy efficiency gains clearly has immediate potential for reducing transportation-related emissions of CO_2. Available technologies could help double automobile fuel economy by 1995 (see Table 1) if sufficient incentive exists. Several studies have shown that the potential reduction in CO_2 emissions with efficiency improvements is large. The U.S. Office of Technology Assessment, for example, calculated that if energy efficiency continued to improve at 1.5%/year and auto use increased by 0.8%/year, CO_2 emissions would be more than one-third lower in 2030 than in 1985.[6] Alternatively, if auto use grows by 2%/year, CO_2 emissions increase by 10%. Bleviss has calculated that achieving an average fuel economy of 45 mpg for light trucks and 60 mpg for automobiles by 2000 (levels already achieved by prototype vehicles) would decrease fuel use and the concomitant CO_2 emissions to almost half of today's levels and, in the process, reduce the chances of another oil crisis by keeping demand for oil below OPEC's production capacity.[7] Brown et al. show that improving fleet efficiency from the current 18 mpg to 50 mpg in 2010 would reduce carbon emissions by 150 million tons, about half of projected levels.[8] Figure 3 shows two estimates of new-car fuel efficiency needed to reduce CO_2 emissions by 50%, as calculated by Argonne National Laboratory researchers.[9]

Because each of these studies makes somewhat different assumptions about the composition of the auto fleet, the improvements that could be achieved, and rates of auto use, it is difficult to compare them directly. However, there appears to be a clear consensus that fuel economy improvements based on available technology could reduce emissions by 50% early in the 21st century. The key, of course, is in giving automakers and consumers sufficient incentives to make such improvements. These incentives are discussed below under transportation policy options.

Technology Options. In addition to improving the efficiency of the current fleet, fuel substitution has been explored by a number of researchers as a way to reduce emissions of greenhouse gases. The primary options available are electricity, natural gas (compressed or liquefied), and methanol. Hydrogen is another option but much less likely to be a commercially viable in the near to medium-term future so it is not discussed here.

Electric vehicles (EVs) being developed now are targeted for the fleet vehicle market (which consists largely of vans that travel short routes and regular schedules) because EVs have power and range limitations that make them less suited for the average consumer. Research under way at Argonne National Laboratory (ANL), however, is addressing these limitations and making significant strides. For example, scientists there have developed a lithium/metal-sulfide battery that can store three times as much energy as a conventional (lead/acid) battery of the same weight. This Li/FeS battery can power a car for about 100 miles before it needs recharging. A similar version of this battery can be recharged 400 times without diminishing performance, and has the potential to power a car or van for 150-200 miles before recharging. Still another Argonne development in the battery field is a new kind of glass that conducts sodium ions with high efficiency. This glass could be used as the electrolyte in a sodium/sulfur battery with the potential to store four to seven times as much energy as a conventional battery.

Prototype natural gas and methanol vehicles are more directly comparable with today's gasoline-fueled vehicles. None of these alternative fuels currently has a significant share of the transportation sector energy use, and market penetration of such new technologies is inevitably slow. Marchetti has shown that the average energy technology takes 30 years to move from a 1% market share to a 50% market share. Clearly, alternative fuels are a longer-term option for reducing CO_2 emissions. Nevertheless, from a policy perspective, it is important to take a critical look at these options now in order to formulate rational research and development priorities.

A study by Deluchi, Johnston, and Sperling that evaluated emissions from alternative fuels is a useful first step toward such priorities. In that study, they estimated emissions of CO_2, CH_4, and N_2O from fuel extraction to end use for each of the alternatives mentioned above (plus hydrogen) and compare these with emissions from gasoline-powered vehicles on an equal-work-provided basis. Emissions of all three gases are reported together as CO_2-equivalent emissions.[10]

Some results from this study are summarized in Table 2. As shown there, two alternative fuel options reduce CO_2 emissions 100% -- electric vehicles charged with electricity from nonfossil power plants (such as hydro or nuclear) and natural gas or methanol produced from biomass. Electric vehicles produce no greenhouse gas emissions themselves, but the power plants that produce the electricity used to charge EV batteries do contribute a significant share of greenhouse gas emissions. Nuclear or hydro plants, which produce no greenhouse gases, could thus be used to power EVs without contributing to global warming. In the case of natural gas or methanol produced from biomass, the CO_2 released when these fuels are burned was removed from the atmosphere by the plants, so there is no net increase in CO_2.

Vehicles running on compressed natural gas release 19% less CO_2-equivalent emissions than their gasoline-powered counterparts. (Although natural gas burns with about half the CO_2 that gasoline does, methane leaks during fuel production make its CO_2-equivalent emissions considerably higher.) Electric vehicles powered from gas-fired power plants contribute 18% less CO_2 equivalents; vehicles using liquefied natural gas, 15% less; and vehicles using methanol from natural gas, 3% less. Supposing that the current power mix were to remain unchanged, EVs would contribute only 1% less CO_2-equivalent emissions. Alternatively, if additional power for EVs were supplied by new coal-fired plants, emissions would be 26% higher. Vehicles fueled by methanol made from coal would release 98% more CO_2-equivalent emissions -- twice as much as a gasoline vehicle. Even if the coal-to-methanol process were made 30% more efficient, emissions would still be 50% higher.

Transportation Policy Options. Of course, policies to encourage development of alternative fuels must consider the findings of these and similar studies. As discussed above, reducing transportation-related greenhouse gas emissions can probably be accomplished most effectively in the near term by increasing U.S. fleet efficiency. One national policy proposed by many to achieve this end is raising the CAFE standards to at least 45 mpg for cars and 35 mpg for light trucks. As Chandler et al. point out, raising the standard for light trucks is particularly important because many people now use these trucks like cars. They account for a growing fraction of gasoline used, but are now required to meet a fuel economy of just 20 mpg.[5]

A second national policy to spur efficiency improvements is a gasoline tax, which could be instituted gradually over several years. Recommended levels vary from 30¢/gallon up to $1 and more. Such a tax would price gasoline closer to its true "social cost" -- i.e., one which incorporates external costs such as air pollution and energy security. The U.S. price of gasoline is substantially lower than that of most other nations, chiefly because other nations tax gasoline much more heavily. For comparison, Fig. 4 shows gasoline prices in a number of widely disparate countries. Higher gas prices would encourage conservation and transportation alternatives, increase U.S. energy security, and (if tax money were recirculated) stimulate the economy. Lower income groups unfairly disadvantaged by such a tax (because they spend a higher proportion of their income on energy) could receive rebates through mechanisms already in place.[5]

State policies, too, have broad potential for curbing greenhouse gas emissions from the transportation sector. In fact, a number of states have recently taken such steps. For example, Vermont recently passed a bill to prohibit the use of CFCs in new automobile air conditioners after 1993.[11] Hawaii, in a similar bill that takes effect in 1991, has banned sales of small quantities of CFCs and requires persons repairing air conditioners (including automobile units) to recover and recycle CFC-containing refrigerants.[11]

Perhaps the most important state role could be in reducing automobile use by providing public transportation incentives. A public shift to light rails, trains, and bicycling -- all more environmentally benign than auto travel -- could be encouraged by vigorous state programs. Increased state funding for mass transit R&D is another policy option to reduce greenhouse gas emissions.

Residential/Commercial Sector

Residential/Commercial Energy Use. The residential/commercial sector uses energy for heating, cooling, lighting, and appliance operation (see Fig. 5). In 1985, residential/commercial energy consumption totaled 16 quads, about 20% of the nation's primary energy use. Of that, natural gas supplied the largest share (44%). Electricity is next in energy share at 32%. Considerably less important are petroleum (16%) and coal (1%). Figure 6 shows sector energy use by fuel. Coal use in this sector has declined steadily since 1960 and petroleum use has declined since 1970. Natural gas use grew rapidly from 1960 to 1970 and has remained at a fairly constant level since then. Electricity, however, has made rapid gains, increasing at an average annual rate of 7.6% from 1960 to 1975. Growth since then has been slower, averaging 2.3% per year.[12]

Overall, energy use in the sector has been almost constant for the last decade, thanks to reductions in energy intensity due to improved equipment efficiencies and consumer behavior changes. Nevertheless, it is expected to rise by some 1% per year in the future, absent any global climate initiatives to check its growth. Fuel combustion in this sector contributes about 15% of the nation's CO_2 emissions. If the sector's share of emissions from electricity production is attributed to it instead of the utility sector, then the sector is actually responsible for about 36% of the nation's CO_2 emissions. These emissions will, of course, rise along with energy use.

Residential/Commercial Technology Options. Continuing the substantial gains in efficiency that were made in this sector over the last 15 years will be more difficult, since the cheapest and easiest gains have already been made. Nevertheless, much research shows that progress can continue to be made, given the proper incentives to encourage market penetration of the most efficient technologies.

For example, recent advances in lighting that are now entering the market include compact fluorescent lamps that fit into standard Edison light sockets, electronic ballasts that are 10% more efficient than conventional ballasts, and high-intensity discharge lamps that are 50% more efficient than fluorescent lights. Sophisticated lighting controls and reflectors are also being developed to more precisely deliver light when and where it is needed.[7] Estimates of potential savings from these innovations range from about 0.1 quad up to 1.5 quads by 2000.[1,5,7]

More-efficient appliances are another route to energy savings in this sector. Refrigerators and freezers account for about 20% of electricity used in the residential sector.[5] Today's new refrigerators use about half the energy they required in the early 1970s, and recently Congress has passed a standard to reduce energy use even more, to 950 kWh annually for refrigerators and 700 kWh for freezers. Researchers say these could be halved again with currently available technology.[7]

One problem with available technology, however, is its dependence on CFCs, which contribute to the greenhouse effect. Much work is being done to find alternative refrigerants, but those available now result in refrigerators that are less efficient than those that use CFCs. Researchers at Argonne are exploring novel alternatives to the vapor-compression cycle: magnetic and chemical heat pump/refrigeration systems. Magnetic heat pumps, for example, make use of the magnetocaloric effect and do not require CFCs. They could potentially operate at higher efficiencies than conventional refrigerators and thus offer significant energy savings.[13]

In addition to refrigerators and freezers, technological improvements in water heaters, clothes dryers, and air conditioners could also lead to energy savings.[1,7] One recent analysis showed that, if air conditioners, furnaces, and water heaters sold after

1992 were as efficient as the best available appliances in 1985, CO_2 emissions in this sector would decrease by 5% by 2000.[6]

Commercial buildings, too, hold many energy-saving opportunities. Dramatic improvements have already been made in new construction -- the average office building built in 1973 had an annual energy bill of $3/ft^2, whereas today's new office buildings have an energy bill of $1.50/ft^2. New standards instituted in California are anticipated to lower costs for buildings there to $1/ft^2.[7] Techniques of thermal storage (storing excess heat during the day for use at night) and improved heating, ventilation, air conditioning, and lighting can all be incorporated in new buildings for the same cost of constructing inefficient buildings because air conditioning and heating systems are smaller, less lighting is needed, and fewer, more-efficient windows replace larger inefficient ones. Rosenfeld estimated that the savings from efficient commercial buildings alone could total 6 quads by 2035, with similar reductions in CO_2 emissions.[14]

Figure 7 shows one attempt to quantify how advances in technology might penetrate the various segments of the residential/commercial market and the outcome in energy savings. Energy savings, of course, can be translated almost directly into savings of CO_2 emissions as well as other greenhouse gases.

Residential/Commercial Policy Options. The new technologies available now, and those under development, will be unable to make the market inroads necessary to rapidly reduce energy use unless the U.S. government adopts policies to encourage such inroads. Some progress has already been made through the national efficiency standards for appliances discussed above. Similar national efficiency standards for lighting should be adopted as well, following the lead of such states as California, Massachusetts, New York, and Florida. These are needed for two reasons. First, consumers are often poorly informed about the merits and paybacks of energy-efficient equipment. Second, as in the case of renters, a property owner may purchase the equipment but pass the operating costs (electric bills) on to tenants. Thus these purchasers have no incentive to choose efficient fixtures, which generally cost more initially but are cheaper to operate and thus save money over the long term.

On the state level, energy-efficiency provisions can be incorporated into building codes, weatherization programs could be expanded, and urban tree planting should be encouraged. Studies have shown that planting shade trees can reduce the energy needed for cooling houses and small commercial buildings. Together with painting surfaces light colors to increase building albedos, such savings could amount to 0.5 quad and 23 million tons of carbon each year.[7]

Industrial Sector

Industrial Energy Use. The industrial sector is the largest end-use energy consuming sector. A total of 22.1 quad accounting for 38% of total end-use energy was consumed in 1985. Recent as well as projected industrial energy use by fuel type is shown in Figure 8. Oil and gas are shown to be the fuels of choice for both the past and predicted future. The principal change seen for the future is a relative increase in electricity use, which would go from about 13% in 1985 to 20% in 2010. This trend away from fossil fuels toward electricity will only have a positive affect on greenhouse gas emissions if nuclear renewable energy sources are utilized to generate the electricity. A breakdown of fuel use for 1985 is shown in Figure 9. Here it is seen that liquids accounted for 35%, gas 32%, coal and electricity both 13%, and 8% for renewables.

The industrial sector is also the most diverse of the economy, encompassing manufacturing, agriculture, construction, and mining. Of these, manufacturing is by far the largest energy user at about 80% of the total. Although the manufacturing sector itself is extremely diverse, its energy use is concentrated in relatively few specific subsectors. The six largest ones, which together accounted for 88% of manufacturing energy use in 1985, are shown in Figure 10. It is from these sectors that we will look for potential energy savings.

Industrial Conservation Options. A a result of the energy price shock of the 1970s, the industrial sector has seen a significant improvement in energy intensity (the energy used to make a ton of product). Savings seen from 1972-1983 are shown in Table 3. Here it is shown that the average reduction in energy intensity weighted across industries was 22%.[15] In looking for future conservation opportunities, it has been estimated that the combined cost-effective energy savings options now available are larger than the total savings thus far achieved since the energy price increases of the 1970s.[16] There are a number of ways in which new technologies can influence industrial energy consumption. In general, they revolve around two basic mechanisms, conservation and substitution which are applied either directly or indirectly to a given industrial process. Thus the four general categories are:

- Direct conservation of fossil fuel or electricity consumption.
- Direct substitution of electricity for fossil fuel use in a production process.
- Indirect conservation of fossil fuel or electricity by changes in use or production of industrial materials.
- Indirect substitution of electricity for fossil fuel use by changes in the use or production of industrial materials.

In a recent study, we reviewed a number of specific technologies which could have a significant impact on industrial energy use, and thus greenhouse gas emissions.[17] Key technologies are summarized in Table 4. All the technologies listed are further described by their level of development as being either established, emerging, or under development. A sample of the technologies from Table 4 will be briefly described.

Electric motor controls are increasingly being used in many industrial applications. The potential for energy savings is significant since 70% of industrial electrical energy use is for motor drive.[16] The most common form of variable speed control is based on semiconductor rectifiers that create a simulated alternating voltage composed of square pulses of modulated time. In recent years there have been significant reductions in the first cost of electronic controls for motors of up to several hundred kilowatts. It has been estimated that an adjustable speed drive typically reduces electricity by 22.5%, making an energy savings of 20%-30% possible in a wide range of applications such as industrial pumps, compressors, blowers, and refrigeration equipment.

Lighting is an important industrial end-use category, containing significant potentials for energy reduction. It has been estimated that 9% of industrial electricity energy use comes from the general lighting and miscellaneous category.[16] Although widely used in industry, fluorescent lighting seldom exists in its most efficient form. Efficient fluorescent lighting, which involves high-reflectance fixtures, electronic ballasts, and high-efficiency bulbs, can reduce electricity requirements by 50% or more compared to standard installations. For area lighting where color rendition is not important, ultra efficient high-pressure sodium lamps can reduce electricity consumption by up to 60% over mercury lamps.

Increasing interest has been shown recently in utilizing aircraft-derivative gas turbines for industrial cogeneration as well as central station electric power generation. The technology is based on generating steam from the gas turbine exhaust and injecting that steam back into the turbine, thus increasing the turbine power output and improving the overall thermal conversion efficiency. When the system is used for industrial cogeneration, only steam not needed for process applications is injected back into the turbine. The two types of systems currently being discussed are the steam-injected gas turbine (STIG) and a variation on this cycle known as the intercooled steam-injected gas turbine (ISTIG) where cooling takes place between two compressor stages.[19] Intercooling decreases the energy used for compression of the turbine inlet gas since the energy required to compress a gas increases with gas temperature. The advantage of these systems is that efficiencies approaching that of combined-cycle systems may be achieved with a simpler, module single-cycle system. A typical system being discussed takes an aircraft gas turbine producing a nominal 33 MW to 52 MW for STIG and 110 MW for ISTIG. Reported net thermal efficiencies range from 42% for an STIG system to 48% from an ISTIG based system.[19]

Industrial Policy Options. The appropriate policies will depend on the current level of technology development. Policies designed to bring a developing technology into the mature range generally center around either additional research and development programs or technology demonstration programs. Industry is generally reluctant to try new technologies if they have not been demonstrated in a similar type of environment. Once a technology is developed, there are a number of direct and indirect mechanisms to encourage adoption by industry. For example, a carbon tax has the advantage of developing a single regulation that can apply to all fossil fuels while letting the marketplace decide on the relative advantage of different fuel options. Such a tax could affect emissions directly by encouraging the use on nonfossil fuels. On the other hand, an investment tax credit for energy conservation equipment or energy efficiency standards on industrial equipment would reduce emissions indirectly by decreasing the demand for energy. Finally, there are multi-effect policies such as those that promote recycling, which not only decrease energy use, and thus greenhouse gas emissions, but also reduce solid waste disposal problems.

Electric Utility Sector

Electric Utility Energy Use. The electric utility sector is the largest primary energy consuming sector in the U.S., accounting for 34% (26 quad) of total energy demand in 1985. Historical as well as projected utility energy use is shown in Figure 11. What can be seen is that, barring a major change in policy, energy use in the sector is expected to be dominated by coal. A breakdown of fuel consumption by energy source for 1985 is shown in Figure 12. Here it is seen that fossil energy accounts for 72% of the total (19 quad), which accounts for 28% of total U.S. fossil energy consumption. The utility sector's importance to greenhouse gas emissions arises from the fact that it is a relatively concentrated industry in terms of large point sources when compared to other energy sectors.

Electric Utility GHG Reduction Potential. Emission reduction from the electric utility sector must come from one or a combination of three areas:

- Substitute a lower carbon-emitting fuel for a higher one, or increase the efficiency of existing fossil units.
- Change the existing utility framework by constructing zero emitting generators.
- Reduce the demand for electricity.

Fuel switching is attractive because in many cases it requires only a modification of current generating systems, not complete rebuilding. Emission reduction potential results from two factors: (1) reduced fuel carbon content -- natural gas has a CO_2 emission factor of approximately 56% that of coal and oil about 70% that of coal; and (2) increased thermal efficiency by up to 35% if advanced combined-cycle units are utilized. Oil and gas combined-cycle units are also attractive because of their relatively short construction time (4 years), as opposed to 8 years for a new coal-fired unit and up to 11 years for a nuclear unit.

Zero carbon emitting generators would involve expanding either nuclear or nonfossil renewables such as hydro, geothermal, or solar. Although research is continuing and advancements are being made in the renewable electric power area, nuclear remains the only option in the near term to replace base load fossil fueled electric power generation plants. Two advances are on the horizon and will be briefly discussed.

The first involves an advancement of current light water reactors (LWR) generally called evolutionary LWRs. These reactors are similar to current reactors but with enhanced safety features and increased operating efficiencies. A principal difference will be that there will be just a few standardized designs as opposed to the current system where each reactor is custom designed from the ground up. Each of the utility sector's importance to greenhouse gas emissions arises from the fact that it is a relatively concentrated industry in terms of large point sources when compared to other energy sectors.

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Another future nuclear option is with the advanced or second generation reactor designs. An example is the integral fast reactor (IFR) currently being developed at Argonne. The IFR differs from other reactor concepts in that it is an entire reactor system which treats the reactor, fuel cycle, and waste systems in a comprehensive manner. In doing so, problems of safety, waste disposal, proliferation, and costs are naturally addressed. The basis of the process is a new type of metal fuel which is submerged in a liquid sodium bath. The design is such that even if all reactor cooling is cut off, the core naturally cools itself down. The metal fuel design is then coupled to on-site reprocessing which recycles the plutonium and other long life radioactive by-products, leaving a waste that decays to that of natural uranium in a few hundred years as compared to several thousand years with conventional reactor waste. On-site reprocessing also prevents unauthorized fuel diversion and eliminates the need to transport radioactive material to or from the site during the reactor's lifetime. Costs are reduced because the inherently safe design and ease of fuel reprocessing provides for simplification and standardization of plant construction and operation. Also, the fact that the reactor is a breeder means that it utilizes fuel about 70 time more efficiently than conventional reactors, thus significantly decreasing fuel costs.

Electric utility demand side options range from utility or state-sponsored energy conservation programs to what is known as demand-side bidding, where an electric utility "buys" new capacity by paying a large user to forego the use of electricity. Demand-side management is widespread in the U.S. An Investor Responsibility Research Center survey in 1987 found that 80% of 123 utilities contacted had implemented formal conservation programs[20]. Two utilities in the Northeast, Central Maine Power Company, and New England Electric System have established demand-side bidding programs to date.

Electric Utility Policy Options. Electric utility policy options vary from demand-side options such as improving state and local energy conservation programs or promoting least-cost planning of interstate power transfers to fiscal incentives such as a carbon based emission tax. A novel approach that is being considered is to provide emission reduction credits for utility sponsored reforestation programs.

U.S. Policy Responses

A number of actions have already be taken at both the federal and state governmental levels to address various aspects of global warming. A summary of current actions is shown in Table 5. At the national level, both the executive and legislative branches have been active. The Committee on Earth Sciences, a U.S. Federal interagency group from the Office of Science and Technology (an executive office of the President) is putting final touches on the U.S. Global Change Research Program for the 1990 fiscal year. The research program's goal is to develop a comprehensive long-term research strategy on global climate. A total budget of $190.5 million has been proposed for FY 1990. The executive branch is also responsible for coordinating international research. Recent actions include signing the Montreal Protocol for the control of CFCs, which are not only a greenhouse gas but are the principal agent in the stratospheric ozone problem. International research includes joint research programs such as the Intergovernmental Panel on Climate Change (IPCC), where the U.S. is chairing a subgroup on responses to climate change, as well as bilateral research efforts which have been established with both the Soviet Union and the Peoples Republic of China.

The U.S. Senate and House of Representatives have together introduced 11 climate related bills into the 101st Congress. The actions recommended by major U. S. congressional bills generally fall into one or more of the following three categories:

- Regulation of the rate of greenhouse gas generation
- Devise mitigative national energy resource policies
- Recommends additional research and development

A listing of the national reduction targets for the principal greenhouse gases that have been proposed in the various bills is shown in Table 6. While a 20% reduction by the year 2000 seems to be the preferred target for CO_2, a total phaseout of CFCs by 2000 is most mentioned.

Actions by state governments have thus far concentrated primarily on various types of energy conservation programs, with 24 states sponsoring utility energy conservation projects. Also, several states have actively promoted the establishment of utility demand side management programs through their public utility commissions. Aggressive action has also been taken on reducing the emission of CFCs in two states by passing their own legislation. The Vermont bill, which has now been signed into law, contains phased-in restrictions on the sale and use of CFCs, as well as a prohibition on the registration of any motor vehicle model year 1993 or later which uses CFCs in its air conditioning unit.

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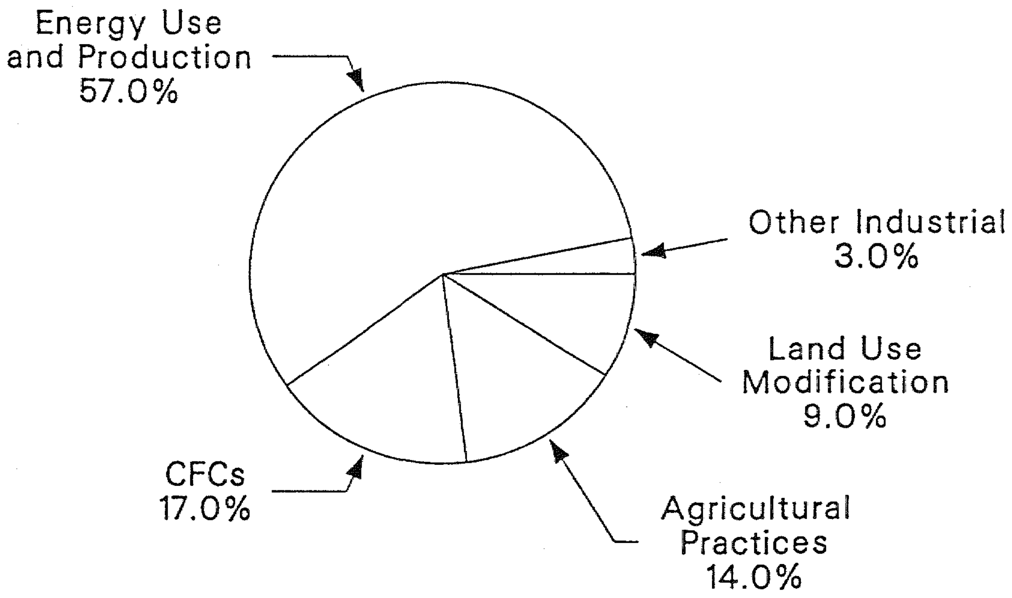

FIGURE 1 Activities Contributing to Global Warming
(Source: Ref. 1)

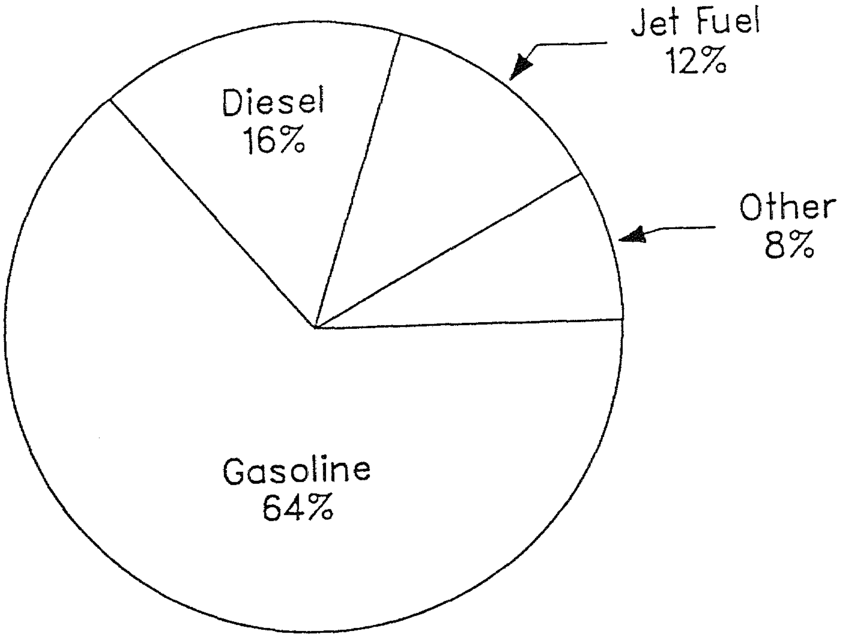

FIGURE 2 Fuel Use in the Transportation Sector

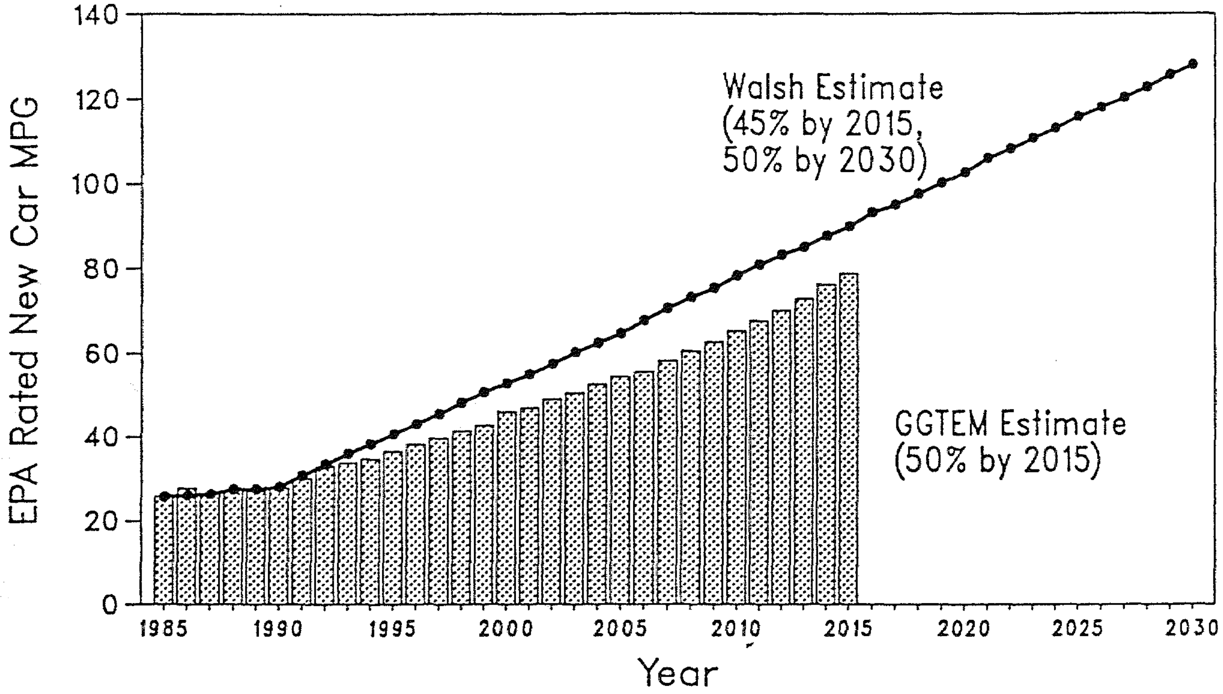

FIGURE 3 Estimates of New Car Fuel Economy Needed to Reduce CO_2 Emissions by 50% (Source: Ref. 9)

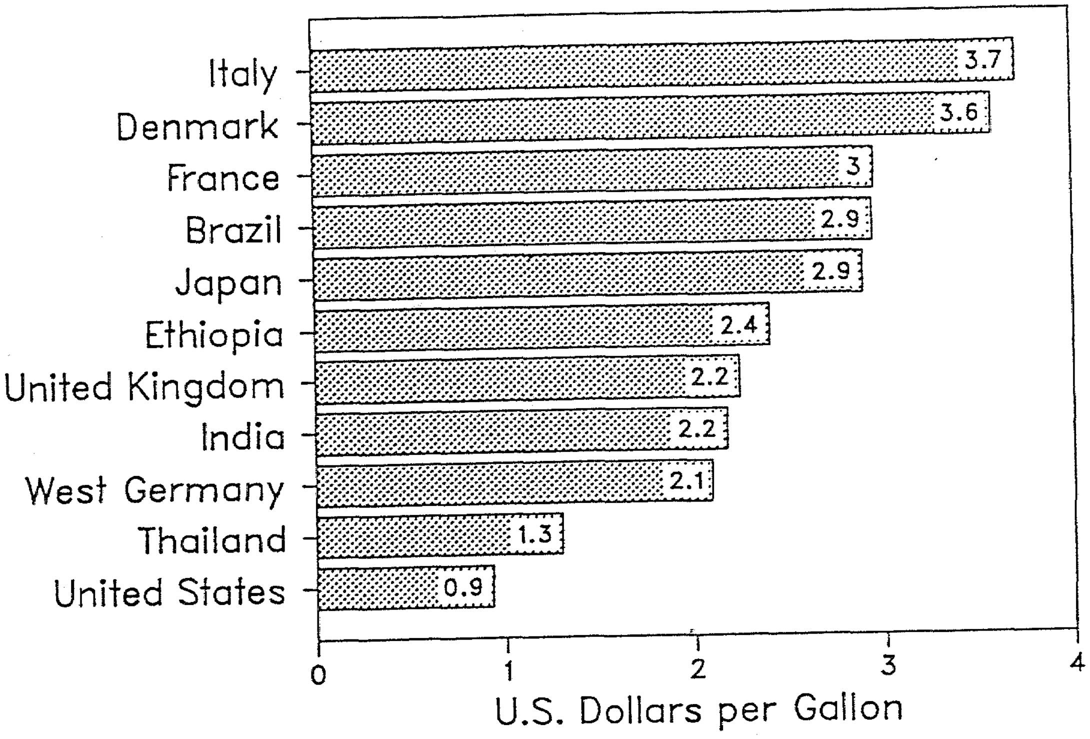

FIGURE 4 Gasoline Prices in Selected Countries, 1987

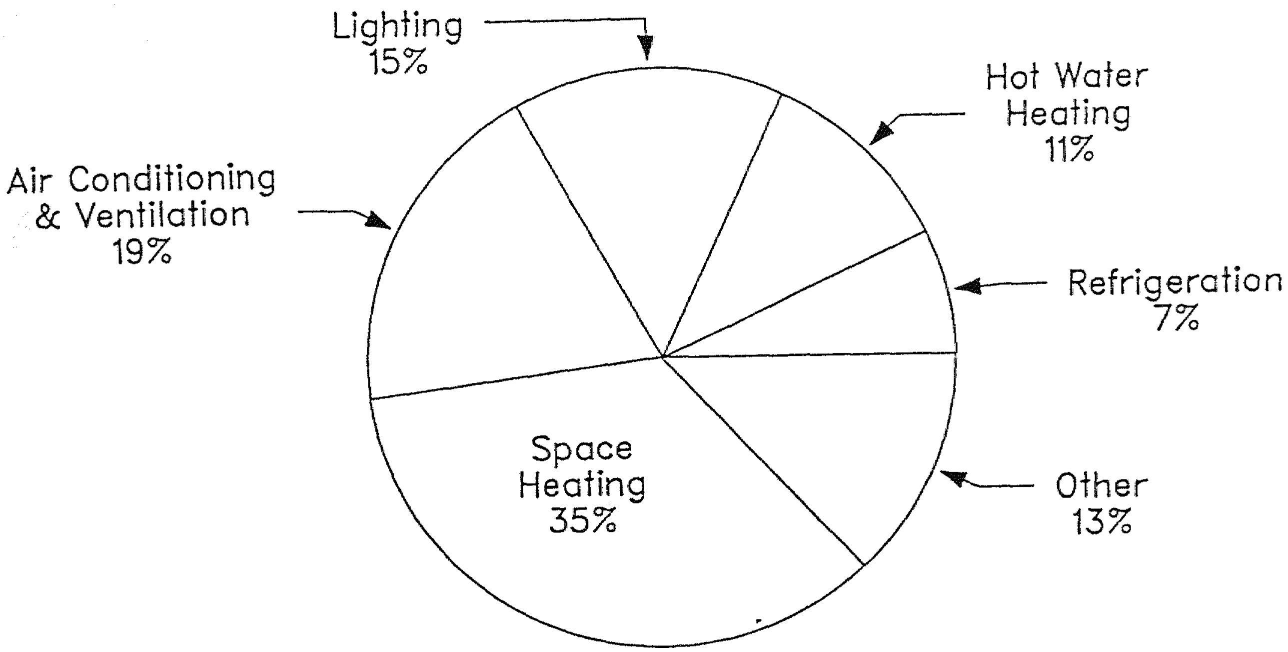

FIGURE 5 Energy Use in the Residential/Commercial Sector

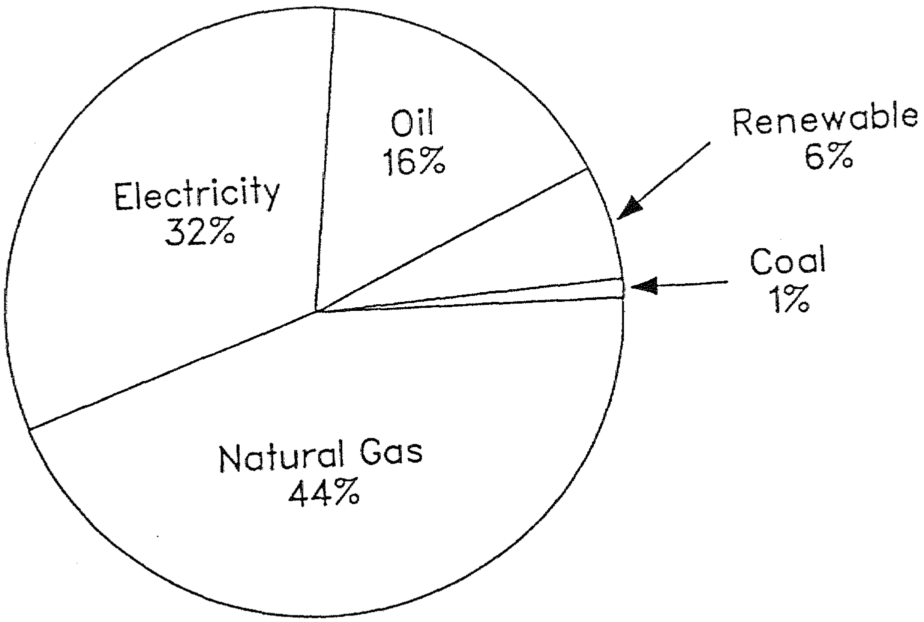

FIGURE 6 Fuel Use in the Residential/Commercial Sector

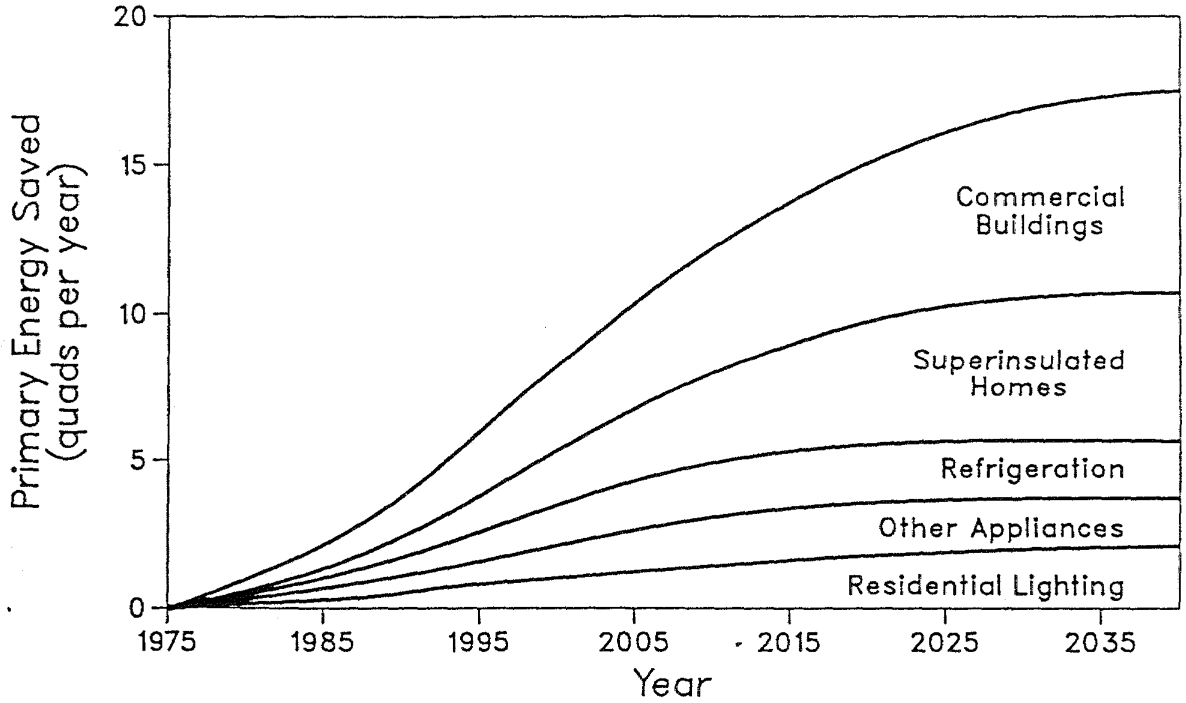

FIGURE 7 Potential Energy Savings in the Residential/Commercial Sector

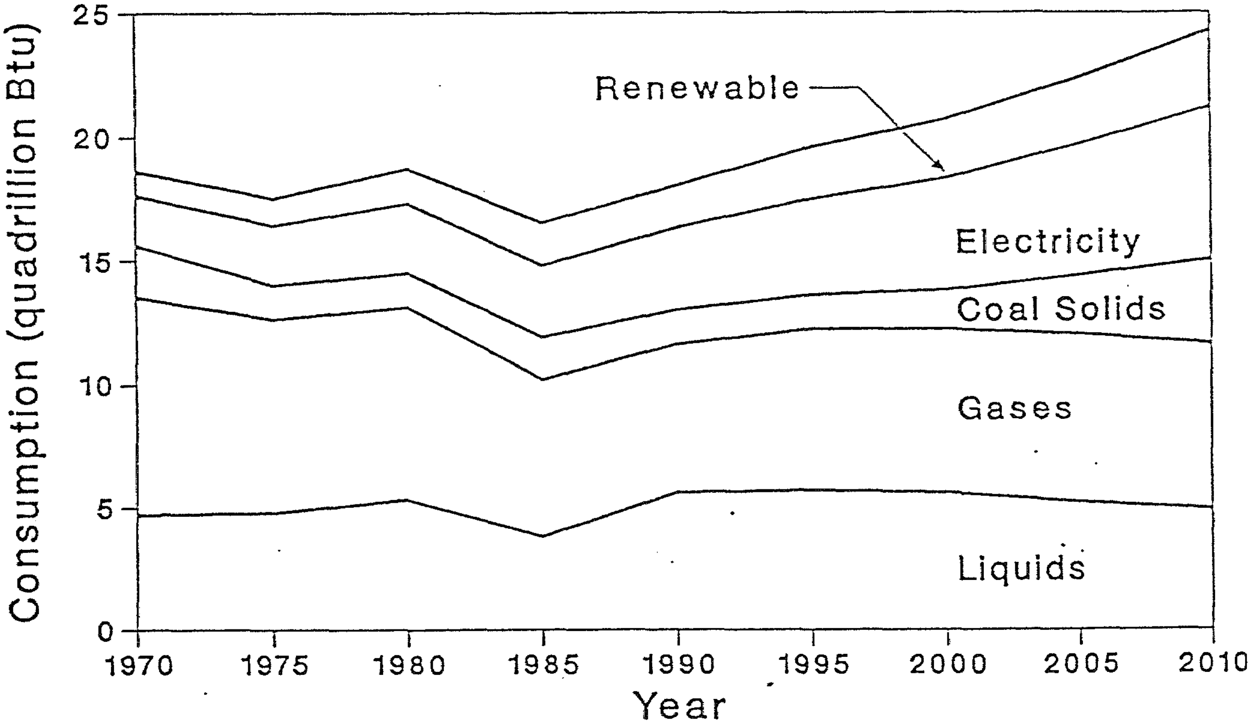

FIGURE 8 Industrial Energy Consumption

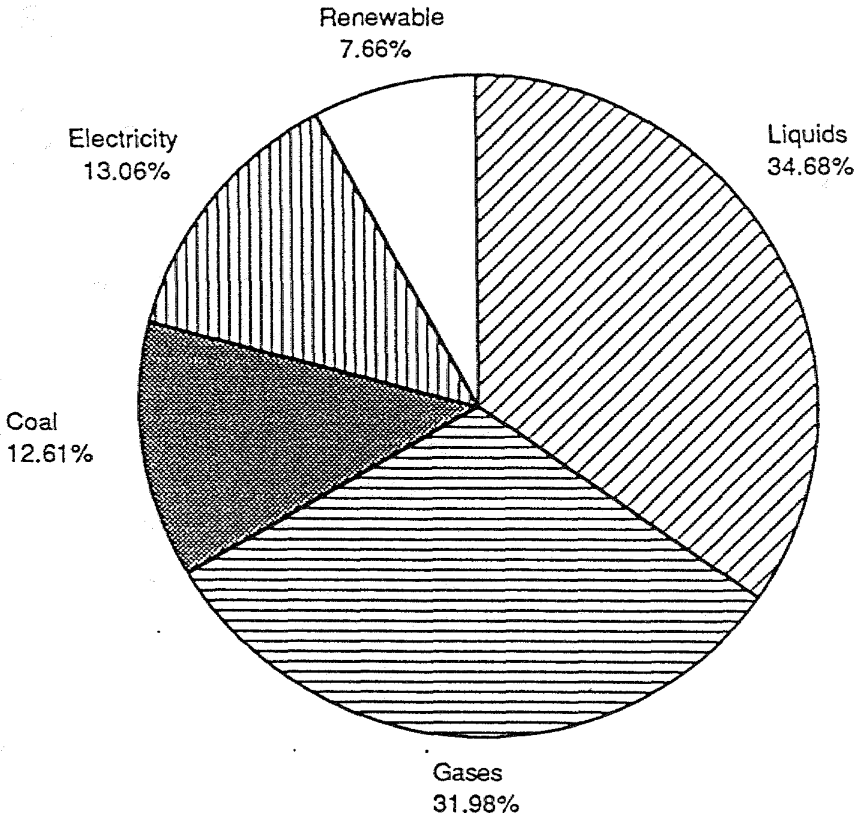

FIGURE 9 1985 Industrial Sector Energy Use

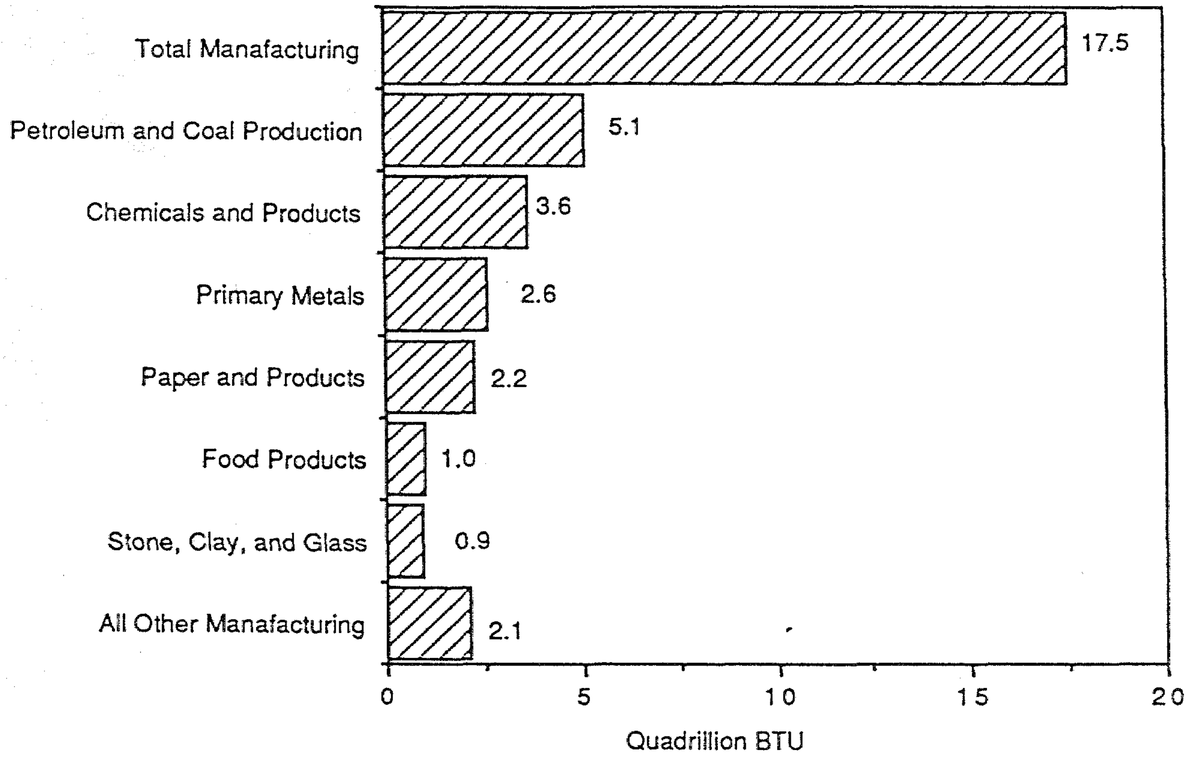

FIGURE 10 Primary Energy Consumption by Selected Manufacturing Industries

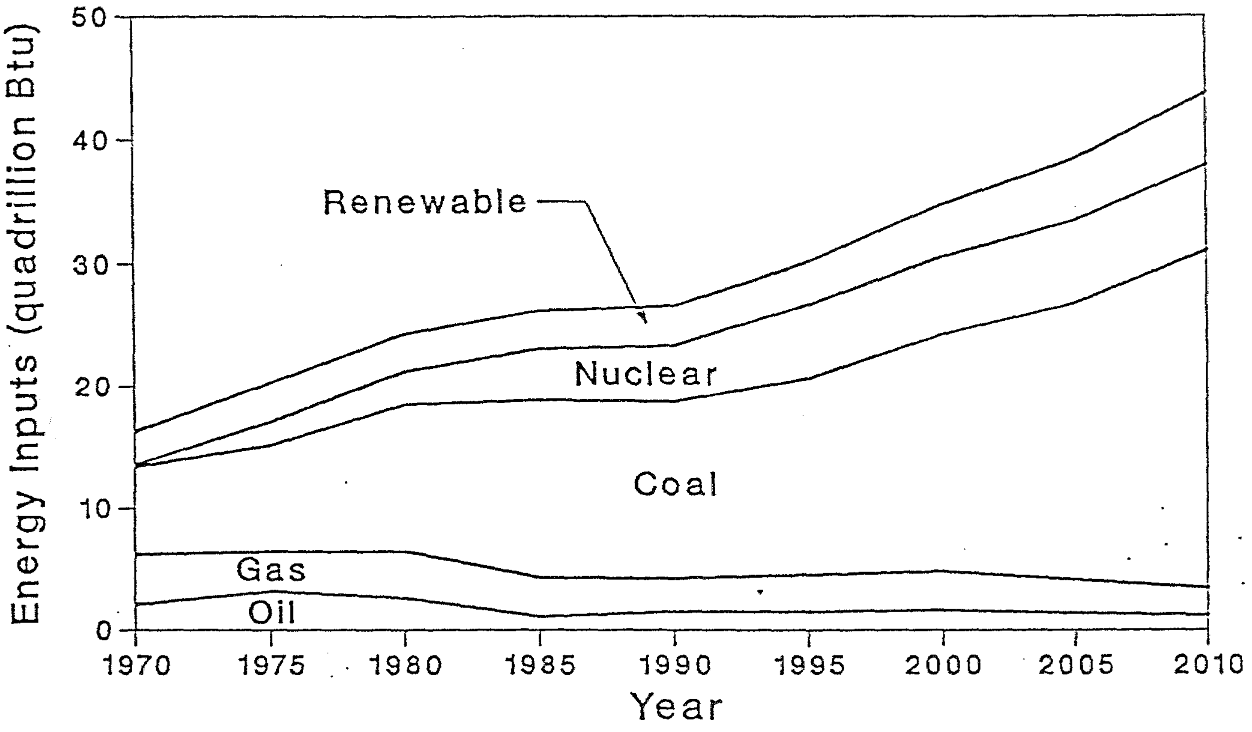

FIGURE 11 U.S. Electric Utility Fuel Inputs

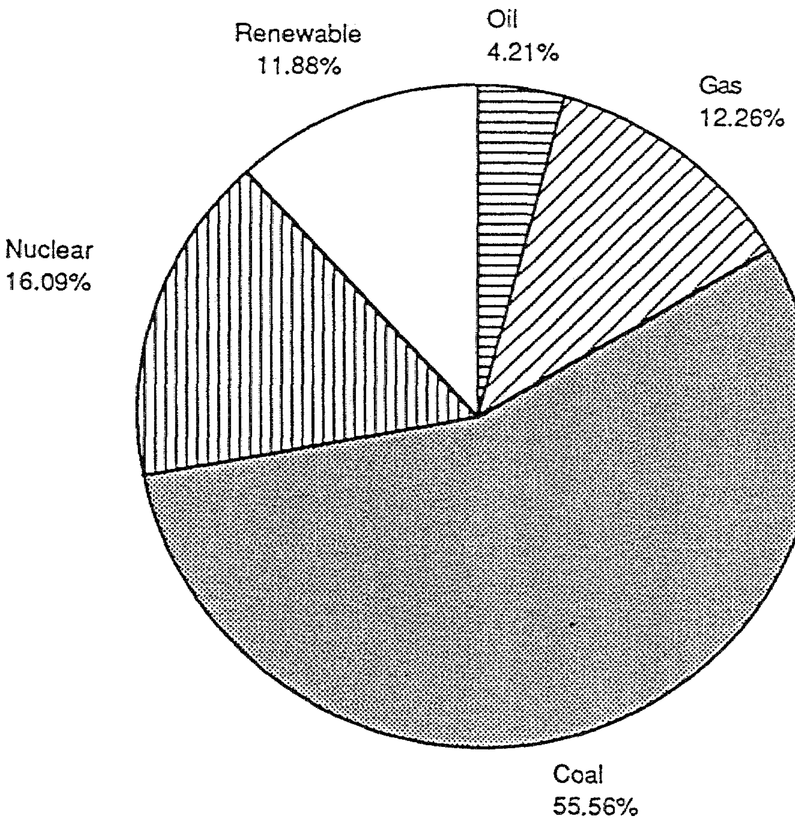

FIGURE 12 Electric Utility Energy Input for 1985

TABLE 1 Potential Gains in Fuel Economy from New Automobile Technologies (Source: Ref. 5)

Technology	Percentage Gain in Fuel Economy by Mid-1990s*
New Engine Designs (e.g., improved shape of combustion chamber)	4
Variable Valve Timing	8
4 Valves Per Cylinder	8
Multi-point Fuel Injection	7
Improved Lubricants and Friction Reducing Materials	4-5
Electronic Transmission Control	3
Continuously Variable Transmission	12
Improved Tires	5
Improved Aerodynamics	5
Efficient Accessories	2

*Note: Gains are not additive.

TABLE 2 Summary of Emissions of Greenhouse Gases from Alternative Vehicular Fuels (Source: Ref. 10)

FUEL/FEEDSTOCK	TOTAL (CO_2-equivalent emissions, GT/yr)	% CHANGE (per mile, rel. to petroleum)
EVs from nonfossil electric	0	-100
CNG/LNG/methanol from biomass	0	-100
CNG from natural gas	1.081	-19
EVs from new natural gas plants	--	-18
LNG from natural gas	1.135	-15
Methanol from natural gas	1.293	-3
EVs from current power mix	--	-1
Gasoline and diesel from crude oil	1.336	--
EVs from new coal plants	--	+26
Methanol from coal, 30% Incr. eff.	2.026	+52
Methanol from coal, baseline	2.639	+98

TABLE 3 Energy Intensity Reduction in the Basic Materials Industries (1972-1983) (Source: Ref. 15)

Industry	% Reduction
Chemicals	31
Steel	18
Aluminum	17
Paper	26
Petroleum refining	10
Average reduction, energy-weighted across industries	21

TABLE 4 Technologies with a Potential Impact on CHG Emissions

	Established	Emerging	Under Development	Impact on Energy Use Patterns	Mechanism of Effect
Generic					
High efficiency Lighting (fluorescent, HPS)	*	*		B	Direct
Energy management systems for factories		*		AB	Direct
Electric motor controls (variable drives)		*		AB	Direct
Fuel/Air controls	*			A	Direct
High Efficiency Motors	*			B	Direct
Pump modifications	*	*		B	Direct
High Temperature Recuperators		*	*	A	Direct
Chemicals, Paper, Food Processes					
Computer Process controls	*		*	AB	Direct
Microwave drying		*	*	D	Direct
Separation based on new membranes, adsorbing surfaces, critical solvents, & freeze concentration		*	*	D	Direct
Ethylene chemistry based on N. Gas feedstocks			*	C	Direct
Waste reduction using closed water systems		*		AB	Direct
New and improved Catalysts for chemical processing	*	*	*	ABC	Direct
Recycling Paper & Plastics (i.e. New Products)		*	*	AB	Indirect
Non-Chlorine bleaching of pulp	*		*	A	Indirect
Continued improvment in strength & formability of plastics & ceramics	*		*	AB	Indirect
Metals Products					
Recycled scrap (e.g. scrap separation technology)		*	*	ABD	Indirect
Ladle Chemistry	*			A	Direct
Thin casting			*	AB	Indirect
Direct rolling and automatic controls	*	*		AB	Direct
Surface treatment with electromagnetic beams		*		D	Direct
Induction or electrical resistance heating	*			D	Direct
Direct and continuous steel making			*	A	Direct
Coal based aluminum smelting			*	B (reverse of D)	Direct
Increased corrosion resistance in products	*		*	AB	Indirect
Gas Turbine					
Black liquor recovery/electric generation with turbines			*	AB	Direct
Advanced turbine systems for cogeneration (STIG & ISTIG)		*	*	B	Direct

A = Improved fuel efficiency, B = Improved electricity efficiency, C = Fuel type switching, D = Electricity for fuel switching

TABLE 5 United States Greenhouse Gas Policy Responses

NATIONAL GOVERNMENT

EXECUTIVE BRANCH

- U.S. Global Change Research Program ($190 million FY 1990)
- Signatory to the Montreal Protocol to Control CFCs
- Participating in International Research (IPCC)
- Bilateral Research Activities

LEGISLATIVE BRANCH

- 11 Climate-Related Bills Submitted to the 101st Congress

STATE GOVERNMENTS

- Enacting Bills to Ban CFCs in Automobile Air Conditioners (2 states)
- Sponsoring Utility Energy Conservation Projects (24 states)
- Developing Utility Demand Side Management Programs

TABLE 6 National Targets and Greenhouse Gases Controlled in Proposed Legislation

	Establishes National CO_2 Emissions Reduction Target	Stipulates Affected CO_2 Sources	Establishes National NO_x Emissions Reductions Target	Stipulates Affected NO_x Sources	Establishes National CFC Target	Stipulates Affected Methane Source
Baucus S. 503					CFC's taxed	
Boschwitz S. 603	20% from 1988 levels by 2000		30% from 1988 levels by 2000			
Chafee S. 491					Phase-out by 7-1-97	
Gore S. 201				Rate limit on stationary sources + vehicle emission standards	Phase-out by 2000	Regulates sewage treatment; flaring and venting prohibited.
Kerry S. 57				Revises NSPS + vehicle efficiency standards		

TABLE 6 (Cont'd)

	Establishes National CO_2 Emissions Reduction Target	Stipulates Affected CO_2 Sources	Establishes National NO_x Emissions Reductions Target	Stipulates Affected NO_x Sources	Establishes National CFC Target	Stipulates Affected Methane Source
Leahy S. 333		Stationary and mobile emissions limits	Stationary and mobile emissions limits		Phase-out by 1-1-95	Stationary emissions limits
Schneider H.R. 1078	20% from 1988 levels by 2000			(Vehicle efficiency standards)	Phase-out Montreal Protocol substances within 5-7 yrs. of enactment.	
Wirth S. 324	20% from 1988 levels by 2000		30% from 1987 levels by 1998.			

[*] S. 251 (Moynihan) and S. 169 (Hollings) does not contain relevant provisions