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Summary of Presentations at the Workshop on

Energy Efficiency and Structural Change: Implications for the Greenhouse Problem

Oakland, CA, May 1–3, 1988

August 1988

APPLIED SCIENCE DIVISION

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SUMMARY OF PRESENTATIONS AT THE WORKSHOP ON

ENERGY EFFICIENCY AND STRUCTURAL CHANGE: IMPLICATIONS FOR THE GREENHOUSE PROBLEM

May 1-3, 1988

Oakland, CA

Sponsored by

U.S. Environmental Protection Agency

Lawrence Berkeley Laboratory

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PREFACE

The "Workshop on Energy Efficiency and Structural Change: Implications for the Greenhouse Problem" was part of a major study of global climate change and options for mitigating such change being conducted by the U.S. Environmental Protection Agency (EPA). It was one of four workshops sponsored by EPA on various topics important to analysis of the greenhouse problem. The purpose of this workshop, which was organized and co-sponsored by Lawrence Berkeley Laboratory, was to provide a forum for experts from a variety of backgrounds to share information and ideas about the long-run prospects for energy efficiency and the effect on energy demand of structural economic and demographic changes.

The information presented and discussed at the workshop is being used by the EPA in refining scenarios of long-range energy consumption and the climatic implications of different levels of energy use, and in its examination of the impact of policy options that might be available to the global community to limit emissions of atmospheric gases that contribute to global climate change. EPA has been requested to provide this analysis by the U.S. Congress.

The workshop had some 45 participants from the U.S. and abroad, including individuals from the academic, corporate, and government sectors. The addresses of all participants, including those whose presentations are summarized herein, are included at the end of this report. The summaries in this report were edited by Stephen Meyers of Lawrence Berkeley Laboratory based on materials provided by the presenters.

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EXECUTIVE SUMMARY OF PRESENTATIONS

The Greenhouse Problem and EPA's Program

Dennis Tirpak, U.S. Environmental Protection Agency

The "greenhouse effect" is based on the accumulation in the atmosphere of gases that form a thermal blanket by trapping infrared radiation given off by the earth. Atmospheric concentration of the key greenhouse gases — carbon dioxide (CO_2), nitrous oxide (N_2O), methane, nitrogen oxides (NO_x), carbon monoxide, and chloroflourocarbons (CFCs) — have increased considerably in recent decades, leading to predictions of global warming and other climatic changes.

EPA's global climate change program stems from a congressional request in which EPA was asked to conduct two studies. The first will examine the health and environmental effects of climate change, examining the potential impacts on agriculture, forests, wetlands, human health, rivers, lakes, and estuaries as well as other ecosystems and societal impacts. The second study is examining the policy options that, if implemented, would stabilize current levels of greenhouse gas concentrations. A major goal of this study is to provide information on the relative effectiveness of options that may be needed to stabilize the atmosphere. Key tasks that are being carried out for the "Stabilization Report" include identifying emissions sources; forecasting changes in emissions; developing models to link emission scenarios to atmospheric concentrations and global temperatures; and identifying strategies for reducing effects.

End-Use Oriented Projections of Energy Demand in Industrialized Countries

Irving Mintzer, World Resources Institute

The industrialized countries part of the Global Energy End Use Model being used by the EPA in its analysis of global climate change projects fuel demand in 2030 for the major industrialized countries. In each of the major end-use sectors, fuel demand is the product of energy intensity and activity level. For the residential sector, future fuel demand is a function of population, fuel use per square meter of living area, and living area per capita. The future intensity depends on a non-price efficiency improvement factor, GNP growth, income elasticity, the growth rate of prices, and the price elasticity of demand.

For the transportation sector, fuel demand for each mode (cars, rail, air) is a function of the stock, the level of use, and energy intensity. For energy intensity there is a non-price efficiency improvement factor. For the industrial sector, fuel demand is projected for five sub-sectors: iron and steel, non-ferrous metals, chemicals, pulp and paper, and stone, clay, and glass. Fuel demand in each is a function of population, kg of product per capita, and fuel use per kg, which depends on a non-price efficiency improvement factor, GNP growth, income elasticity, the growth rate of real prices, and the price elasticity of demand.

An End-Use Approach to Development of Long-Term Energy Demand Scenarios for Developing Countries

Jayant Sathaye, Lawrence Berkeley Laboratory

For the developing countries part of the Global Energy End Use Model being used by the EPA in its analysis of global climate change, we have used an end-use approach to formulate three scenarios of energy demand in the year 2025 in five regions: Asia, China, Africa, Latin America and the Middle East. The three scenarios are called the Rapidly Changing World (RCW), the Slowly Changing World (SCW), and the Low Emissions World (LEW); the last one is the same as RCW except that strong policies aimed at increasing energy efficiency are implemented, with resulting decrease in energy demand.

Total energy demand is separated into that for industry, residential, commercial or services, agriculture and transportation. For households and transportation, use of electricity and fuels is divided among various end-uses. We establish measures of energy intensity (energy consumption per unit of activity) for each sector, and assess the changes in sectoral structure that will influence energy intensity. We use current patterns of energy use at different levels of income to select future activity levels that are consistent with the projected income in each region.

Total delivered energy for all LDCs increases from 1.9 billion TOE in 1985 to 4.0 billion TOE in the SCW case, and 5.4 billion TOE in the RCW case by 2025. Policies designed to improve the efficiency of energy use in the LEW case reduce energy consumption to 4.2 billion TOE. Delivered energy increases at 1.8%, 2.5% and 1.9% annually in the three scenarios.

Energy Scenarios and Greenhouse Gas Emissions: Introduction to the EPA Scenarios

Daniel Lashof, U.S. Environmental Protection Agency

The Atmosperic Stabilization Framework being used by EPA in its analysis of global climate change allows systematic assessments of the implications of various technological and economic choices and assumptions. It has separate emissions forecasting modules related to energy, industry, agriculture, and land-use. The Energy Module uses two models to forecast global energy supply and demand. One is a global equilibrium model that has nine major types of supply and three end-use sectors in OECD countries (one in other countries). It covers nine geopolitical regions over the period 1985-2100. The other estimates demand (up to 2025) based on consumption of specific energy services and technical efficiency.

The key scenario assumptions are oil price, efficiency improvements, and energy technology trends. Preliminary results assuming low oil prices show that by 2050, global primary energy use is nearly three times the 1985 level in the Low Efficiency Improvement scenario, but the High Efficiency Improvement scenario has energy use only slightly more than the 2025 level. Global energy consumption in the High Price, High Efficiency Improvement scenario in 2050 is just over half of consumption in the Low Price, Low Efficiency Improvement scenario.

Along with the energy scenarios, there are also three different scenarios for deforestation. The amount of average global warming realized between 2000 and 2100 ranges from about 1 °C in the High Prices, High Efficiency, High Non-Fossil, and Reforestation

scenario to about 3 °C in the Low Prices, Low Efficiency, Low Non-Fossil, and Moderate Deforestation scenario.

Energy Efficiency and Structural Change in the Industrialized Countries
Robert Williams, Princeton University

Taking into account the structural shift toward less energy-intensive activity and the prospects for more efficient use of energy, it is possible to achieve a 50% reduction in per capita energy use in the industrialized countries by 2020, even with a doubling in per capita GDP. The shift from goods to services production in the industrialized countries is well-known, but there is also a marked trend away from basic materials processing towards more fabrication and finishing activities. As a result, the industrialized countries seem to be reaching saturation or even decline in per capita consumption for a wide range of materials. This is due in part to more efficient materials use and use of more modern materials, especially plastics. The latter require more energy per ton to produce, but the substitution of these usually results in a significant reduction in overall energy requirements because of their much smaller weight. Another factor is the shift of consumer preference toward "value-added-intensive" goods and services (electronics, computers).

There exists considerable technical potential for improving end-use energy efficiency, but the innovations that achieve the most success in the market are those that improve several attributes of a product or process simultaneously. Most consumers are not so interested in energy efficiency *per se,* so it must be incorporated into the process of technological innovation in ways that make the products broadly appealing. For example, with energy-saving electronic variable-speed drives for motors, maintenance costs are lower, equipment lifetime is longer, higher-speed operation is possible, and there is often better quality control of the product. In the industrial sector, energy efficiency should be part of the modernization that will be required to retain competitiveness. Although much will happen through market forces alone, realizing the energy efficiency potential will require public sector involvement.

Energy Use in Transportation: 2000 and Beyond
Albert Sobey, General Motors Corporation

The evolution in industry and commerce from major industrial complexes to high technology and niche companies will change how we will live and use our transportation systems for both people and goods. The reductions in scale of manufacturing processes made possible by new manufacturing process controls and information systems will allow plants to be located almost anywhere. Freight movement will become more diverse, and time sensitive. While this favors trucking, new technology, like "car-less" piggyback and logistics controls, will enable the railroads to compete more effectively.

The automobile will provide most urban transportation, as public transit is at a disadvantage in our low density cities, but families will have cars for different purposes. The technical feasibility of a half-width personal vehicle, which can provide up to 150 mpg without compromising comfort or acceleration performance, has been confirmed by GM. They should be very attractive to the commuter, but their effective use will require coordination with local traffic officials.

We expect people to continue to respond to two budgets: time spent in travel, averaging 60 to 80 minutes a day, and a financial budget which averages 10 to 12% of disposable income. The major transportation problem facing our cities is congestion, though the time budget implies that people will change residences or jobs when travel time becomes excessive. Use of computers to work at home will increase but not be significant in the near future.

With respect to fuel efficiency, we may be close to the economic limits with available technology. Use of exotic materials to reduce vehicle weight will probably increase the price of the car more than the cost of the fuel saved at today's prices. The internal combustion engine is approaching its inherent efficiency limit. While fuel cells appear technically feasible, new knowledge will be required to reduce their costs and replace the platinum catalysts. This could be available by 2020, if we continue to work the problem.

Energy Efficiency Prospects for Light Vehicles

Deborah Bleviss, International Institue for Energy Conservation

There has been considerable improvement in light vehicle fuel economy, but the technology revolution of the past decade in materials and electronics has only begun to be applied to vehicles. Applying these innovations to improve the efficiencies of engines and transmissions, reduce vehicle weight, improve aerodynamic drag, reduce tire rolling resistance, improve accessory efficiency, and reduce braking energy loss can substantially increase the fuel economy of light vehicles. The fuel efficient prototypes that have been developed by car manufacturers in recent years mostly have fuel economies in excess of 60 miles per gallon. Moreover, these prototypes generally do not incorporate the most advanced of the technological innovations now being investigated. The prototype development has shown that innovations can render an efficient vehicle without giving up performance, comfort, safety, low emissions, and cost.

While the technological potential for fuel economy is quite bright, the likelihood that these technologies will be introduced expeditiously is small. Today's low oil prices discourage interest in fuel efficiency from consumers and manufacturers alike. If energy efficiency technologies are to be introduced expeditiously across all model lines, national governments will have to develop policies to promote the transition. Such policies will need to accomplish three tasks: speed the research, development, and demonstration of fuel efficient technologies; provide incentives to manufacturers to introduce such technologies into commercialization on a wide scale; and provide incentives to consumers to purchase highly fuel efficient vehicles. Accelerated introduction of fuel economy technologies can have a substantial impact on future oil use and carbon dioxide emissions.

Aerospace Transport in the 21st Century

William M. Wallace, Boeing Commercial Airplane Company

Aerospace transport in the 21st Century will depend heavily on new technology and the cost of investing in it, fuel costs, and environmental constraints. The development of the jet turbine has driven the enormous growth of air travel for the past 30 years. Now, however, it appears that further improvements will show decreasing returns. The major new developments on the horizon appear to cost more and not less. For example, the SST would improve speed dramatically, but at a cost premium. It may be possible to get

supersonic speeds at a small cost premium if some hoped-for technical improvements prove out, but any significant real increase in the price of fuel could doom the commercial viability of an SST.

The SST is perhaps the ultimate in foreseeable speed within the earth's atmosphere because of the distances. For outer space travel, the distances involved require much higher speeds. If any serious space travel or development is to take place, costs must come down dramatically. Such a decrease probably requires big increases in the specific impulse of rocket fuels.

End-use Efficiency and NOx Emissions in Aviation
Michael Kavanaugh, Consulting Economist

In the context of global NOx emissions, aircraft emissions are small, but since they are above cloud level, they may reside in the troposphere longer than emissions from surface sources and contribute more to the chemistry of the atmosphere than their size indicates. Improvements in the energy efficiency of jet aircraft, which increased by over 40% between 1974 and 1985, result in lower emissions. Improvements have included: more fuel efficient engines (less fuel is needed to produce a pound of thrust); increases in aircraft structural efficiency (lighter airframes carry more seats); improved lift/drag performance; improved routing to increase fleet utilization; altering networks to reduce seasonality and improve fleet utillization; and pricing strategies that stabilize load factors.

Recent analysis of future prospects for jet aircraft suggests that (1) average emissions per unit of fuel burned will decline as new engines and new airframes enter the fleet; (2) emissions of NOx from aircraft will continue to grow because the use of new engines and airframes cannot offset increases in air travel; (3) NOx emissions in 2025 may be 1.7 to 2.8 times 1980 emissions; (4) future emissions from sub-sonic jet aircraft will be at higher altitudes. These may have a higher probability of reaching the stratosphere and entering into reactions that, in the end, deplete stratospheric ozone.

Trends in Home Appliances in Europe
G.P. Abbate, Industrie Zanussi

Average annual consumption of new refrigerator/freezers and freezers from in Italy dropped 12-13% between 1977 and 1987. Future improvements are expected to average 30-33% for all three types of technologies, and will be induced by better thermal insulation and improvements in the refrigeration system. For clothes-washers, the average new system in 1987 is using 24% less than in 1977. The innovative Jet System clothes-washer uses 30% less electricity than same-size conventional machines. Efficiency is expected to continue to increase with improvements in the water heating system (including heat-recovery from other kitchen appliances), better insulation, and improved motor efficiency. Similar improvements will apply to dishwashers, which currently have low saturation in homes. Changes are expected that will reduce the quantity of water to be heated, and, as with clothes-washers, bring recovery of heat from other kitchen appliances to pre-heat the water. These measures should provide overall savings of 8-9% of the total electricity requirements.

Energy Efficiency in Residential Appliances

Isaac Turiel, Lawrence Berkeley Laboratory

The energy efficiency of home appliances in the U.S. has increased substantially since the early 1970s, but there is considerable potential for cost-effective modifications that can improve efficiency further. Since 1972, the average annual energy consumption of new units of the most popular type of refrigerator has declined from 2000 kWh to 1050 kWh. The NAECA standard recently passed into law will bring annual consumption down to a maximum of 950 kWh. Design options for further improving the energy efficiency of refrigerators include foam insulation in doors, use of a high-efficiency compressor, fan and fan motor improvement, improved foam insulation, adaptive defrost, evacuated insulation panels, variable speed compressors, and mixed refrigerants. Application of the first six of these options would reduce consumption down to around 525 kWh, and a 600 kWh level could be achieved without additional use of CFCs.

Methods to improve the energy efficiency of water heaters involve reducing standby losses and improving recovery efficiency. For a gas water heater, use of intermittent ignition plus a power burner increases the energy factor up to about 70%, while a pulsed combustion/condensing water heater would have an efficiency of about 83%. The latter technology is still in the experimental stage, but is promising.

The minimum efficiency standards due to become effective in 1990 for a number of home appliances will remove from the market the least efficient models sold today. The potential to increase efficiency further, relying on design options that are well understood, is considerable. The extent to which energy-efficient options are incorporated into future appliances will depend in part on the marketing advantage that appliance manufacturers believe they will yield.

Trends in HVAC Equipment Efficiency

Gerald C. Groff, Solar Energy Research Institute

During the last decade, continuing improvements have been made in the average efficiency of heating, air conditioning and water heating products for residential and commercial buildings. These improvements have been driven by increased public consciousness with regard to energy costs, the introduction of state and federal standards for energy efficiency, and by the advent of a significant market opportunity (and competition) for energy-efficient products.

The new federal minimum efficiency standards, the demonstrated market opportunities that have developed for energy-efficient HVAC equipment, and advances in technology that permit design and manufacture of such equipment, all lead to the conclusion that prospects are very bright for substantial further improvements in building equipment and systems. In combination with advances in the energy-conserving design of new buildings (and the rehabilitation of existing buildings), such equipment can provide the opportunity to significantly reduce energy use for space heating, cooling and water heating. Improved systems and equipment can also provide new functions and contribute to the creation of much higher quality indoor environments for working and living.

Advances in technology that are expected to play a significant role in achieving these goals include: advanced window designs with insulation effectiveness equal to solid walls, advanced insulation (e.g., compact vacuum insulation) for appliances and buildings; variable-capacity equipment that will maintain high operating efficiency at partial-load

conditions; and advanced system and control designs to insure that the maximum operating efficiency of the installed equipment is achieved and preserved.

Energy Efficiency Prospects in Lighting
R. R. Verderber, Lawrence Berkeley Laboratory

The new, more efficient technologies that have been developed in the past ten years are now penetrating the market place and should impact lighting techniques in the next ten to twenty years. Further improvements, based upon current research that has demonstrated viability, will lead to still greater efficiency. Fluorescent lamp efficacy can be roughly doubled, and use of electrodeless compact flourescent lamps in today's incandescent sockets will more than double the efficacy given by current efficient technology, as well as give longer lamp life. The efficacy of HID lamps can also be improved by 50%. In addition, controls will provide a means to dynamically control lighting power demands for building operators as well as the utilities.

With adoption of the potential technological innovations, projected U.S. energy consumption for lighting would be only 55% of today's level even with a three-fold increase in floor space. A requirement for the realization of this projection is expansion or at least continuation of the current research efforts by the government. New lighting innovations that are based upon different technologies not currently practiced by the lighting industry have been catalyzed by government research efforts. The major lighting manufacturers have continuously reduced their investments in future lighting innovations to low levels that would delay the future implementation of innovations without public activities and endeavors by small entrepreneurs.

Energy Efficiency in Buildings: Progress and Potential; and
Arthur Rosenfeld, Lawrence Berkeley Laboratory

Dramatic improvements have occurred over the past 15 years in the average energy efficiency of U.S. buildings. For a large set of all-electric office buildings for which data were compiled by LBL, the average measured energy use was 19 kWh/ft^2-yr. Ten of the most efficient new buildings use less than 14 kWh/ft^2-yr, and the best-performing building, in Tokyo, Japan, uses about 3.5 kWh/ft^2-yr. When changes equivalent to these "best-practice" commercial buildings capture the entire new-construction market and eventually replace existing stock, we will be saving primary energy equivalent to about 90 power plants. In residences, our analysis of several hundred single-family houses shows that good passive solar design, insulation, and low-infiltration construction practices can reduce space heating loads to roughly half the heating requirements of typical new U.S. homes.

Looking at energy efficiency as a demand-side energy resource rests on the underlying idea that demand for energy as a *commodity* is secondary to the demand for energy *services*. If improvements in energy efficiency provide the same end-use service at a lower level of energy consumption, then they can be considered as much a part of the future resource mix as new energy supply. The technical potential for conservation as a demand-side resource can be determined using a "supply curve of saved energy," which ranks efficiency measures in terms of their cost-effectiveness in order to compare the energy savings with energy supply options. Use of this methodology for the state of

Michigan has shown that 29% of the present residential electricity demand could be saved at a cost of conserved energy less than 3.3 ¢/kWh, which is the operating cost of existing coal power plants.

Urban Trees and Light-Colored Surfaces for Reducing Cooling Energy Consumption

Arthur Rosenfeld, Lawrence Berkeley Laboratory

Developed urban areas create summer heat islands with typical daily average temperatures 3 to 5 °C hotter than the rural areas surrounding them. These significantly increase air conditioning loads. Planting trees in urban areas can reduce summer heat islands and cooling energy use in buildings through shading, evapotranspiration, and wind shielding at only about 1% of the cost of avoided power plants and air-conditioning equipment. Using light-colored paints and surfacing the asphalt of streets and parking lots with lighter-color sand are also cheap and effective in reducing heat islands and summer air conditioning electricity use.

Our analysis shows that the direct effect of planting three trees per house, along with increasing building albedo for 50% of the 51 million air conditioned houses in the U.S., can result in roughly 15% air conditioning energy savings, or 0.17 quad equivalent. The corresponding direct savings for small commercial buildings is about 0.05 quad. As for indirect savings, our preliminary results from simulating the effect changes in the amount of urban vegetation and the magnitude of urban albedo have on urban microclimates suggest a total savings of 0.23 quad of residential energy use and 0.10 quad for commercial buildings. The cost of conserved energy of the urban trees and light-colored cities strategy, 0.1 - 1.0¢/kWh, is much cheaper than other conservation measures.

Efficiency and Structural Change in Industry in Europe

Michael Brand, Institute for Systems Technology and Innovation Research

From 1973 to 1979 the final energy use in industry for 10 countries of the European Community dropped by 4.2%, despite growth in industrial output of 16%. While intersectoral structural changes had an effect, increased energy efficiency was responsible for most of the reduction. Based on the 1973-85 period, we estimate the long term effect of structural change on energy use at -0.5%/year. This estimate includes intersectoral as well as intrasectoral structural changes. Further in the future, the effect will increase because of the modernization of Spain, Portugal, Greece, and Ireland.

The long term potential for rational energy use and efficiency improvements in industry includes recycling of used and energy-intensive material as secondary raw materials; reduction of material requirements by improved construction and design and longer lifetimes; process improvements like reducing waste heat by heat insulation, heat exchangers, and better control, and reducing energy use by addition of catalysts, enzymes, and higher turbulence; and process substitution by membrane technologies and absorption extraction, by substitution of solvents with low evaporation energy needs, and use of biotechnological rather than thermal processes. There are also long-term tendencies to increased energy demand, mainly electricity, but the prospects for increase are probably an order of magnitude smaller than the potential for energy savings.

Structural Change in Industry Over the Long Run

Alan M. Strout, Massuchusetts Institute of Technology

In considering long-run trends in the world's production of industrial goods, one must look at population and GDP growth, political and social factors, and industrial shares of GDP. All of these have some degree of uncertainty. For GDP, country growth rates have tended to rise, often after many discouraging years of development efforts, reach a peak at some middle level of income, and then gradually decline as countries became richer. Such longer-run changes as the transformation of agriculture and the relative increases first of manufacturing and then of services are well-documented. Political factors such as the alignment of international power and changing power realignments within a country may have an effect on patterns of industrial production.

For almost all of the common bulk commodities, per capita consumption increases at a constantly declining rate as incomes rise. The analysis suggests that consumption will reach an absolute upper limit at some time in the future. Consumption of the more energy-intensive materials appears to have fallen even more dramatically in the richer countries than one would have predicted. Another factor affecting global industry is that as countries get richer, their desire to export manufactures seems to far outpace their desire to import them. Thus, international trade balances may only be achieved by more structural change than so far observed in favor of agricultural and service exports and away from manufacturing exports, or by serious price reductions in order to bring desired exports in line with desired imports.

Industrial Processes in the Long Run

Charles Berg, Northeastern University

In every instance where we use energy, we do so to cause a specific, desired change in a material body. At each stage of production we use energy to inscribe information on matter. The key to economic efficiency in any production process is to inscribe the desired information upon the object rapidly, directly, and accurately. It is better to inscribe the information in one step rather than two if it can be done without sacrificing speed or accuracy. Accuracy is important because the need to compensate for information that has been transcribed incorrectly is often at the root of production costs that are unnecessary in principle.

In a production system the medium of transmission of information is the flux of power one directs upon the object. One is concerned with establishing effective coupling between the transmitter, the medium of transmission, and the receiver. One wants to use the power flux to excite certain responses in the material, while not exciting others. For it is the effect of the interactions on other bodies (the atmospere, the earth, the oceans) in which almost all environmental concerns arise. Electricity is a stream of power capable of carrying a large flux of information with minimal loss or error, and it can be converted to other forms of electromagnetic power with little loss of information. It thus offers far greater opportunities in production technology than obtain in the family of techniques based upon directing a flux of heat upon the object. Another avenue that appears to offer important opportunities to impress information on matter with relatively high speed, control, and precision is the use of biological phenomena in production.

Long-Term Energy Demand: Production or Pleasure?

Lee Schipper, Lawrence Berkeley Laboratory

In the development phase of most economies, energy use for producing goods dominates the picture, but in the wealthy countries, energy use for comfort, entertainment, and mobility is now the driving force in energy demand, and a major source of uncertainty in energy demand forecasts. Energy prices and the level of incomes affect personal energy use choices, but at a high level of affluence where the basic "needs" as related to energy are satisfied, changes in the utilization of the stock become more important than changes in the level of ownership. Consumer choices as to how to use their homes and cars, and where to spend their time when away from home, will play an increasingly important role in the determination of overall energy use.

Decline in family size will place upward pressure on energy use in homes and in travel. Perhaps most important is the disposition of free time, which has increased in most countries. During the past several decades, out-of-home leisure has increased, while increased work-force participation decreased occupancy of homes further. This reduced home energy use somewhat, but increased transportation. Various factors could cause people to stay home more in the future, though there is also much potential for increased travel. The growing numbers of older people may be more active and mobile. However people chose to spend their increasing free time, they will indirectly make energy choices when they choose whether to stay home (or in the "neighborhood") or move around. This growing freedom to choose makes forecasting uncertain, and requires more sensitivity to issues of lifestyle.

Perspective on Long-Run Energy Demand Projections

W.R. Finger, Exxon Company, U.S.A.

Making a projection of world energy use 50 to 100 years in the future is a totally subjective exercise. It is especially difficult to project technological innovations: If we thought about the view of 1988 in 1888, we would not have several major technologies in our inventory. The sensitivity in using energy conservation measures conceived of today is that their impact is rapidly utilized. If the conservation technology known today is implemented in the first turnover of stock, there is no specific addition beyond that time. One way to get around this dilemma would be to estimate an environmentally acceptable level of energy use in 2030, assume a ratable change in use between 1985 and 2030, and estimate the level of conservation implementation necessary to accomplish the change. At that point, a comparison of available conservation measures with the estimated level of conservation need for the next several years should provide some insight into whether or not this factor alone is adequate.

Energy Policies for Averting Global Warming: The Importance of Energy Efficiency

David B. Goldstein, Natural Resources Defense Council

There is an immense technical potential for reducing energy use more cheaply than producing new energy supplies, both in the U.S. and in the rest of the world. The energy savings, ranging from 50% to 80% and more of current energy consumption, could allow

the current trends of increasing carbon dioxide emissions from fossil fuels to be reversed. These gains are not just theoretical; actual recorded energy performance has been much more encouraging than anyone dared to believe fifteen years ago. The track record in California shows a steady 2% per year decline in the ratio of electricity demand to gross state product since the state began to move toward least-cost electricity planning in 1974.

An important policy lesson illustrated by past forecasting experience is the danger of model-dependent thinking. In 1970s-vintage energy studies, the models by their structure attributed virtually all energy savings to price elasticities. In fact, elements not within the model, such as the Federal miles-per-gallon standards and state building and appliance standards, led to significant unpredicted reductions in energy use. The danger with a focus on single-point forecast models is that the policymaker is inclined to ask the question, "Are we in trouble with global climate change or not?" rather than asking what I believe is the more relevant question, "What policy actions do we have to take to make sure that we do not get in trouble?" Conservation policies that require high efficiency in new additions to the stock of energy-consuming devices can reduce the level of uncertainty inherent in the forecast.

Motor Vehicles and Global Air Pollution
Michael Walsh, Consultant

Motor vehicles account for more of the world's air pollution than any other human activity. They are responsible for virtually all of the carbon monoxide and lead in the air of cities, and a major portion of the NOx, VOC's, fine particles and toxic chemicals. As the major consumer of oil in the world, vehicles also emit substantial amounts of carbon dioxide and other gases which contribute to global warming. Due to expanded CFC use in vehicle air conditioners, vehicles also play a significant role in the stratospheric ozone depletion.

Although emissions from cars have been substantially reduced from uncontrolled states, further reductions could be achieved by tightening tailpipe standards (especially on trucks, buses, heavy duty engines, and diesel-powered vehicles) and by expanding the areas of the world in which stringent standards apply. Mandatory fuel efficiency standards throughout the world would slow the growth in carbon dioxide emissions. Inspection and maintenance programs are also important. However, continued growth in the number of vehicles and their use is undercutting the overall benefits of the technological gains that have been achieved. The global vehicle population has climbed from under 50 million just one generation ago to more than 350 million. By the year 2000, it is projected to exceed 500 million. Unless this growth is constrained, global pollution will continue to increase, many areas which currently have relatively clean environments will deteriorate, and the few areas which have made progress will see some of these gains erode.

Policy Options on Energy Efficiency and Global Warming: A Congressional Perspective
Leonard Weiss, U.S. Senate Committee on Governmental Affairs

Between 1974 and 1981, Congress established several complementary programs to foster energy efficiency. The initial motivation was strategic concerns related to

petroleum consumption, but other benefits of increased efficiency soon became apparent: Improved industrial competitiveness through lower production costs and products with lower life-cycle costs; the saving of capital for investment; the creation of international markets for advanced equipment designed to conserve energy such as cogeneration systems, advanced engines, and heat pumps; and environmental benefits such as decreased air and water pollution, decreased nuclear waste, and decreased greenhouse gases. Despite these benefits, federal spending for conservation R&D has dropped 75% from FY 1979 to FY 1988.

There is, at present, no discernible consensus among U.S. policy makers on the scientific facts regarding global warming, the potential for damage from such warming, or the appropriate policy to follow if we unambiguously detect a warming signal with definite long-term dire consequences. In the meantime, the multiple benefits from increased energy efficiency provide a rationale for some policy decisions that will benefit the mitigation of any global warming phenomenon. Ultimately, any proposed restructuring of energy use in America will have to be dealt with through the same process that will be needed to deal with challenges to our international economic competitive position -- through a partnership involving government, industry, and the general public to achieve consensus on goals.

The Greenhouse Problem and EPA's Program

Dennis Tirpak
Office of Policy Analysis
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The Greenhouse Problem

The "greenhouse effect" is based on the accumulation in the atmosphere of gases that form a thermal blanket by trapping infrared radiation given off by the earth. Atmospheric concentration of the key greenhouse gases — carbon dioxide (CO_2), nitrous oxide (N_2O), methane, nitrogen oxides (NO_x), carbon monoxide, and chloroflourocarbons (CFCs) — have increased considerably in recent decades, leading to predictions of global warming and other climatic changes.

The major sources of CO_2 are fossil fuel combustion (73-83%) and deforestation (15-25%). Although CO_2 emissions from fossil fuels have begun to level off in the U.S. and Western Europe, emissions have continued to increase in other regions. CO_2 emissions from deforestation have also increased.

Sources of N_2O include natural land emissions (approximately 42%), fossil fuel combustion (20%), fertilizer use (11%), and biomass burning (10%). Methane originates from rice production (26%), wetlands (22%), biomass burning (16%), domestic animals (15%), and fossil fuel production (14%). Emissions of NO_x stem mainly from fossil fuel combustion (43%) and biomass burning (25%). Carbon monoxide originates from fossil fuel combustion (37%), tropical deforestation (31%), and agricultural burning (22%). The production of non-aerosol CFCs has continued to increase, although the production of aerosol CFCs has decreased with recent bans. (The above percentages are approximate values. In many cases, the estimates of emissions from particular sources may vary by a factor of two.)

Increased atmospheric concentration of these gases has been generally correlated with the observed rise of 0.5-0.7 °C in the mean global temperature over the past century. The anticipated temperature rise of 1.5-4.5 °C over the next 100 years is equivalent to the temperature increase that has taken place over the last 18,000 years.

EPA's Global Climate Change Program

EPA's current global climate change program stems from a congressional request in which EPA was asked to conduct two studies. The first will examine the health and environmental effects of climate change. It will develop climate change scenarios and study the potential impacts on agriculture, forests, wetlands, human health, rivers, lakes, and estuaries as well as other ecosystems and societal impacts.

The second study, to which this workshop will contribute, will produce a Stabilization Report that will examine the policy options that, if implemented, would stabilize current levels of greenhouse gas concentrations. Goals of this study include:

- Developing an analytical framework within which different strategies to stabilize the atmosphere can be evaluated;
- Providing information on the relative effectiveness of options that may be needed to stabilize the atmosphere; and

- Providing a framework to guide further research.

In meeting these goals, there are a number of social, economic, and physical uncertainties that influence the ability to forecast emission patterns. Social and economic uncertainties include GNP growth rate, structural economic change, technological efficiency improvement rate, reliance on fossil fuels, rice paddy cultivation rate, cattle populations, anhydrous ammonia use rate, and compliance with the stratospheric ozone protocol. Physical uncertainties include ocean CO_2 uptake, climate-ocean circulation feedback, climate-ocean biology feedback, climate-terrestrial ecosystem feedbacks, methane-hydrate releases, emissions coefficients, tropospheric ozone increases, global CO_2 fertilization, and unknown carbon sinks. It is hoped that report results will stimulate policy-relevant research to assist in the resolution of these uncertainties.

Key tasks that are being carried out for the Stabilization Report include:

- Identifying emissions sources;
- Forecasting changes in emissions;
- Developing models to link emission scenarios to atmospheric concentrations and global temperatures; and
- Identifying strategies for reducing effects.

EPA's Atmospheric Stabilization Framework consists of six modules (see Figure 1). Four emissions modules (energy, industry, agriculture, land-use) estimate trace gas emissions and determine the impact of assumptions and policies on emissions levels. Two concentration/determination modules determine the impact of emissions on the atmospheric concentrations of the greenhouse gases. The Framework will be evaluated in the context of this and three other workshops. The other workshops will focus on the relationship between global climate change and agriculture, LDC energy supply and demand, and electricity production.

Atmospheric Stabilization Framework Flow Diagram

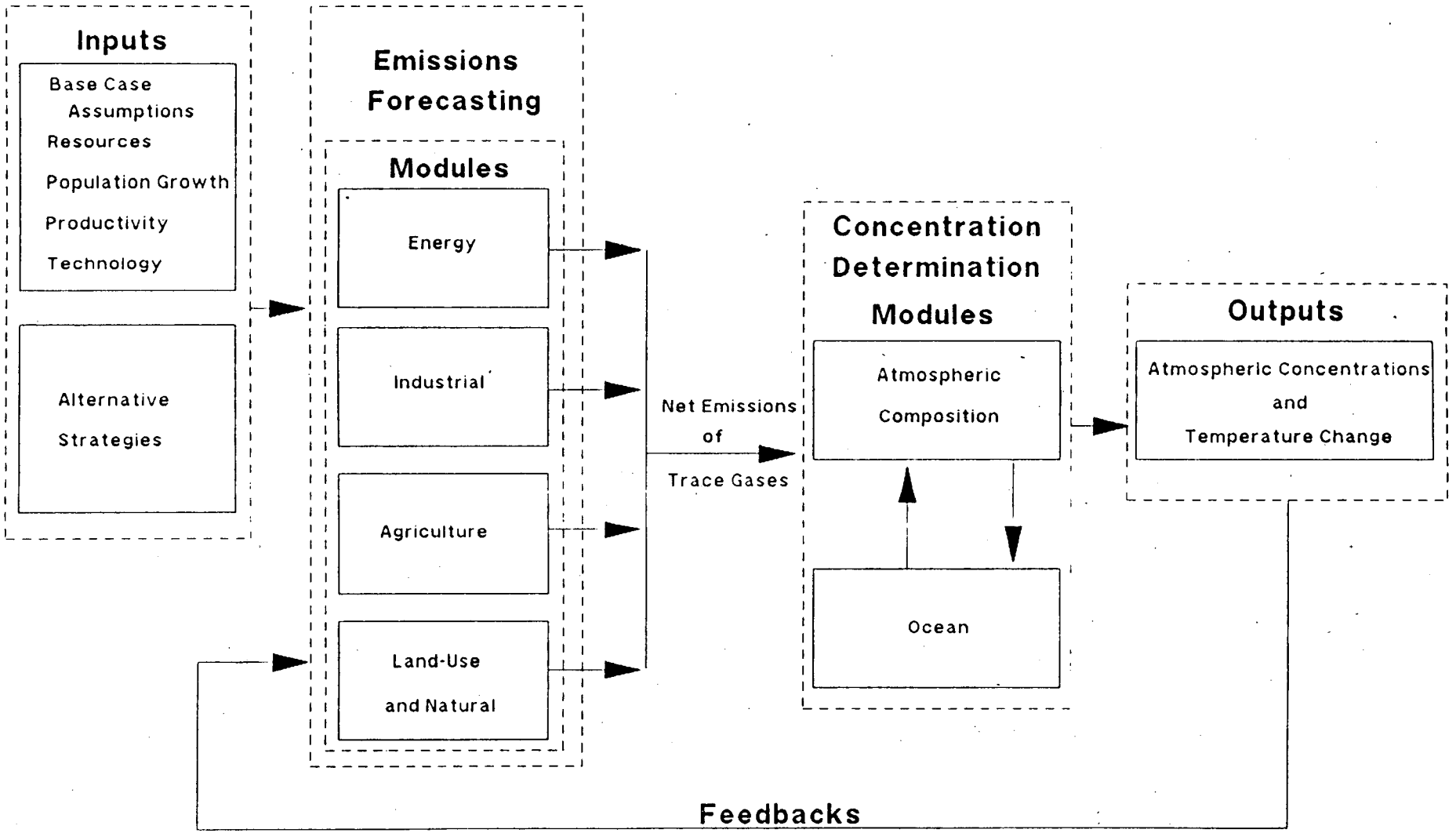


Figure 1

End-Use Oriented Projections of Energy Demand in Industrialized Countries

Irving Mintzer
Senior Associate, World Resources Institute

The industrialized countries part of the Global Energy End Use Model (GEEM) being used by the EPA in its analysis of global climate change projects fuel demand in 2030 for the major industrialized countries. In each of the major end-use sectors, fuel demand is the product of energy intensity and activity level.

For the residential sector, future fuel demand is equal to: (Population) times (Fuel use per square meter of living area) times (m^2 per capita). The future intensity (fuel use/m^2) depends on a non-price efficiency improvement factor, GNP growth and the income elasticity of demand, and the growth rate of real prices and the price elasticity of demand.

For the transportation sector, fuel demand for each mode (cars, rail, air) is equal to: (Stock) times (Level of use) times (Energy intensity). The future stock depends on GNP growth and the income elasticity of demand, while the level of use is affected by fuel price and the price elasticity of demand. For energy intensity there is a non-price efficiency improvement factor.

For the industrial sector, fuel demand is projected for five sub-sectors: iron and steel, non-ferrous metals, chemicals, pulp and paper, and stone, clay, and glass. Fuel demand in each sub-sector is equal to: (Population) times (kg of product per capita) times (Fuel use per kg). Product consumption depends on a saturation factor, while fuel use intensity depends on a non-price efficiency improvement factor, GNP growth and the income elasticity of demand, and the growth rate of real prices and the price elasticity of demand.

Improvements in end-use efficiency between 1985 and 2025 under different assumptions are shown in Table 1 for the USA.

Table 1
Assumed Improvements in End-Use Efficiency Between 1985 and 2025

	High Efficiency		Low Efficiency	
	Low Price	High Price	Low Price	High Price
Cars (mpg)	23>54	23>78	23>42	23>61
Other vehicles (%/year)	0.5	0.7	0.3	0.7
Industry (%/year)	1.0	1.2	0.3	0.6
Residential (%/year)				
Electricity	0.8	2.2	0.5	0.9
Other fuels	0.5	1.2	0.3	0.5

An End-Use Approach to Development of Long-Term Energy Demand Scenarios for Developing Countries

Jayant Sathaye
Staff Scientist, International Energy Studies Group
Lawrence Berkeley Laboratory

The International Energy Studies Group has been responsible for the developing countries part of the Global Energy End Use Model (GEEM) being used by the EPA in its analysis of global climate change. Using an end-use approach, we have developed three scenarios of energy demand in the year 2025 in five developing regions: Asia, China, Africa, Latin America and the Middle East. The three scenarios are called the Rapidly Changing World (RCW), the Slowly Changing World (SCW), and the Low Emissions World (LEW); the latter is the same as RCW except that strong policies aimed at increasing energy efficiency are implemented.

The Scenarios

In the *Rapidly Changing World,* the world economy grows at 3-4%/year, with somewhat higher rates in many developing regions. In this case, technological progress leads to higher economic growth, which drives energy demand upward. This progress, along with higher energy prices resulting from increased energy demand, also provides new ways of using energy more efficiently. However, economic growth also brings the means for using energy for increased mobility and comfort. This may drive total energy use up faster than economic growth for a considerable length of time. Parts of all regions in the developing world that have not entered this phase already will likely pass into it by the year 2025. Thus the RCW scenario shows significant increases in motorization and comfort and service levels in homes and buildings.

In the *Slowly Changing World,* world economic growth is slow and energy demand growth is sluggish. Energy prices do not rise significantly over present levels. Technological progress, although slower than in the RCW case, tends to reduce energy intensities, but the low price of energy retards any serious efforts to increase efficiency. Slower economic growth restrains the opportunities for people in developing countries to improve their comfort and mobility, and even the rate of increase in urbanization and electrification is restrained. Population growth is somewhat higher than in the RCW case, due to the lower economic growth.

In the *Low Emissions World,* we have estimated the impact of policies that would accelerate energy efficiency increases and other means that could restrain energy demand without restraining economic growth. We do this by applying realistic conservation measures to the RCW case. By the year 2025, these measures would reduce energy intensities significantly over their values in the RCW case (see Figure 1, which shows automobile fuel efficiency in the different scenarios). Where appropriate we also reduce levels of energy-intensive activities somewhat for the LEW scenario.

End-Use Methodology

Total energy demand is separated into that for industry, residential, commercial or services, agriculture and transportation. Sectoral activity levels are chosen to be consistent with the levels of income obtained from the exogenous economic growth rates. We establish measures of energy intensity (energy consumption per unit of activity) for each

sector, and assess the changes in sectoral structure that will influence its energy intensity. We examined current patterns of energy use (output of raw materials, automobile and truck use, appliance ownership, etc.) at different levels of income to select future activity levels for regions that are consistent with the income levels these regions are projected to reach.

Sectoral demand is broken up into electricity and fuel demand. For households and transportation, use of each is divided among various end-uses (cooking, water heating, lighting, and different appliances for households, various vehicles for transportation). We estimate ownership/activity levels and energy use per end-use (or per unit of activity), multiplying these two elements to obtain total energy use for each end use. For industry, we break industrial energy use into electricity and non-electricity components, and form the ratio of each to total product. For the appropriate regions, refining, chemical feedstocks, and any other energy processing industries are counted separately and their energy demands included in the final accounting of primary energy. For the services sector, we estimated fuel and electricity use from country data that separate that sector from residential usage. For agricultural energy use, we made rough estimates of fuel and electricity use and formed intensities.

Results

Total delivered energy for all LDCs increases from 1.9 billion TOE in 1985 to 4.0 billion TOE in the SCW case, and 5.4 billion TOE in the RCW case by 2025. Policies designed to improve the efficiency of energy use in the LEW case reduce energy consumption to 4.2 billion TOE. Delivered energy increases at 1.8%, 2.5% and 1.9% annually in the three scenarios.

The use of electricity and modern fuels increases in each scenario, but that of biomass declines in RCW and LEW. The growth rate of electricity use is much faster than that for modern fuels. Annual electricity-use growth ranges from 2.4% in Latin America to 3.5% in Asia in the SCW case, and from 4.3% to 5.2% in the RCW case. Total LDC primary energy use, which was 2.4 billion TOE in 1985, reaches 5.4, 7.7, and 5.7 billion TOE in the three scenarios, respectively. Most of this demand is in Asia and China (see Figure 2).

Biomass use varies significantly across scenarios. In the SCW, more people use biomass in 2025 than today as the penetration of modern fuels does not compensate for population growth. In the RCW, biomass consumption declines at 1%/yr because of increased end-use efficiency and substitution by modern fuels. Improvements in the efficiency of biomass use drive its use for all LDCs down by 1.2%/yr in the LEW case.

The increased energy efficiency we expect to occur under a scenario of rapid technological progress reduces growth in energy use. But more careful application of efficient energy use, which could be encouraged by policies, could reduce energy demand in the Rapidly Changing World by more than 20%. The end-uses that we judged most receptive to strategies for greater efficiency were household appliances, automobiles, and the uses of electricity in commercial buildings. In other sectors, particularly the industrial sector, policies that directly affect energy use may be less important than policies that promote new approaches to materials use.

Figure 1

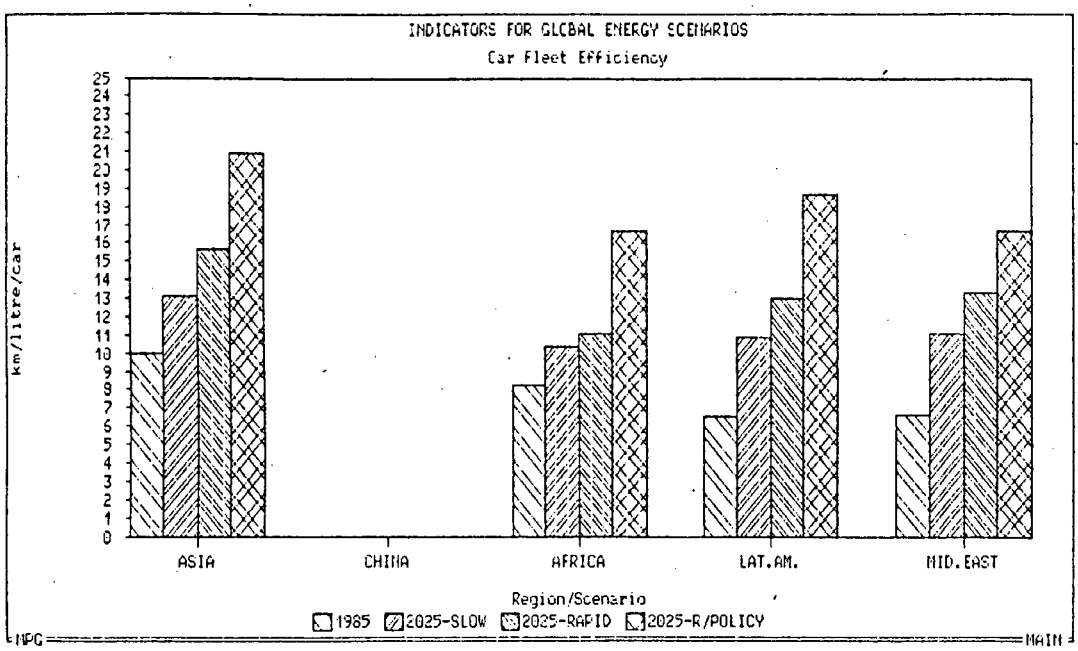
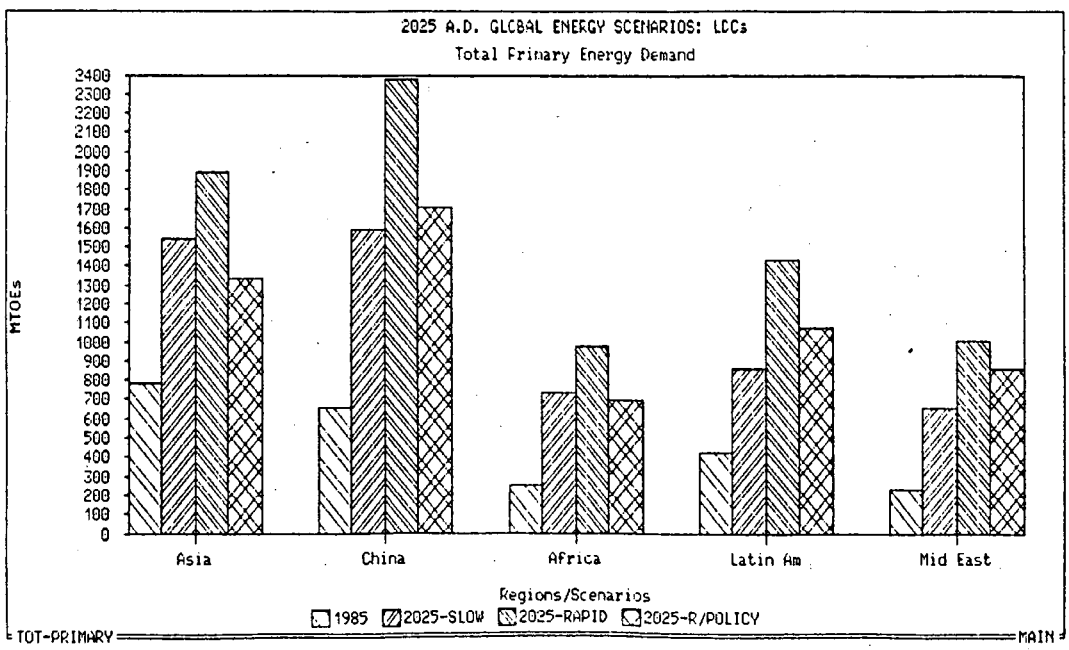


Figure 2



Energy Scenarios and Greenhouse Gas Emissions: Introduction to the EPA Scenarios

Daniel Lashof
Office of Policy Analysis
U.S. Environmental Protection Agency

The Energy Forecasting Module

The Atmosperic Stabilization Framework being used by EPA in its analysis of global climate change has separate emissions forecasting modules related to energy, industry, agriculture, and land-use. The Energy Module uses two models to forecast global energy supply and demand: the Global Energy Forecasting Model (GEFM) developed by Edmonds and Reilly for the EIA and modified by ICF Incorporated, and the Global Energy End Use Model (GEEM), which is under development by World Resources Institute and Lawrence Berkeley Laboratory. Energy Module assumptions are based on world population estimates, GNP growth rates, new combustion technologies, efficiency improvements, fossil energy supply, and advances in renewable resource technologies. Combustion emission coefficients for specific technologies were developed by Radian Corporation for this study.

The two energy models provide alternative approaches to forecasting consumption patterns. The modified GEFM is a global equilibrium model that has nine major types of supply and three end-use sectors in OECD countries (one in other countries). It covers nine geopolitical regions over the period 1985-2100. The GEEM is described in the presentations by Mintzer and Sathaye. It estimates demand (up to 2030) based on consumption of specific energy services and technical efficiency. Since the end-use model does not project supply, the GEFM will be used to project fuel mix and supply prices in all cases.

Scenarios

The Atmosperic Stabilization Framework is not intended to predict the future, but rather to allow systematic assessments of the implications of various technological and economic choices and assumptions. While the absolute level of global warming depends on a large number of variables that cannot be specified with any confidence, the relative impact of specific assumptions and policy options is much more robust. Thus we do not ask: How warm will the earth be in 2100? Rather we consider, for example, how important technical change in rice production could be in comparison to more efficient automobiles, in terms of the rate of global climate change during the next century.

The key scenario assumptions are oil price ($42/bbl by 2030 in the low case, $73/bbl in the high case), efficiency improvements (low and high), and energy technology trends (low and high non-fossil development). Preliminary results assuming low oil prices show a near-doubling of global primary energy use between 1985 and 2025 in the Low Efficiency Improvement scenario, with a much smaller increase in the High Efficiency Improvement scenario (see Figure 1). By 2050, global primary energy use is nearly three times the 1985 level in the Low Efficiency Improvement scenario, but the High Efficiency Improvement scenario has energy use only slightly more than the 2025 level.

The difference between the Low Price, Low Efficiency Improvement scenario and the High Price, High Efficiency Improvement scenario is great (see Table 1). Global energy

consumption by 2050 in the latter is just over half of consumption in the former. (Both assume low non-fossil development.)

Table 1
Primary Energy Use in 2050 by Region
(Exajoules)

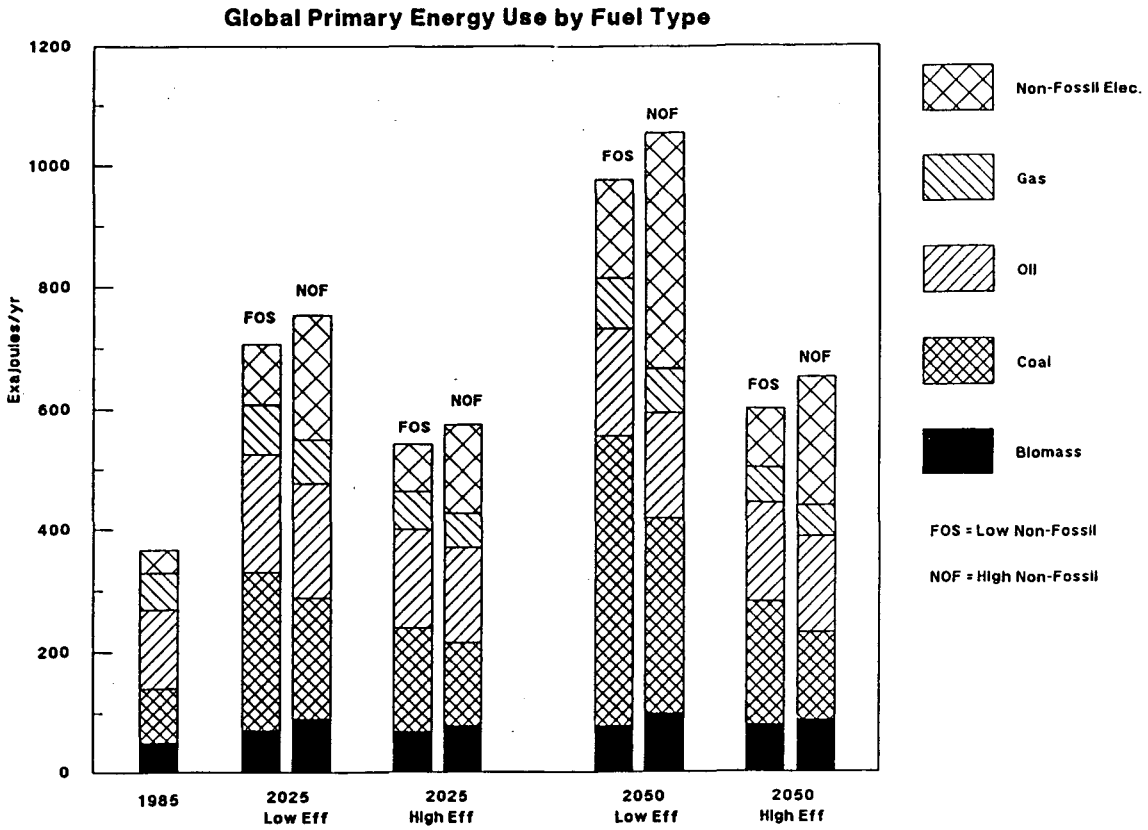
	Low Prices/Low Eff	High Prices/High Eff
Developing	380	175
USA	150	90
Rest of OECD	185	110
USSR/CPE	200	100
Total	915	475

Along with the energy scenarios, there are also three different scenarios for deforestation. These include: moderate and steady increase from the current level; rapid increase until 2050, followed by a steep decline due to forest depletion; and high reforestation, in which carbon release declines until 2020 and forests become a sink for 0.5 Pg/year of carbon by 2025.

Global CO_2 emissions in 2050 range from around 5 Pg of carbon in the High Prices, High Efficiency, High Non-Fossil, and Reforestation scenario to about 18 Pg of carbon in the Low Prices, Low Efficiency, Low Non-Fossil, and Moderate Deforestation scenario. In the latter, annual emissions decline between 1985 and 2025, and then remain roughly constant. In the former, annual emissions increase steadily after 2000.

The effect of the different assumptions on realized global warming is great (see Figure 2). The amount of warming realized between 2000 and 2100 ranges from about 1 °C in the High Prices, High Efficiency, High Non-Fossil, and Reforestation scenario to about 3 °C in the Low Prices, Low Efficiency, Low Non-Fossil, and Moderate Deforestation scenario.

Figure 1



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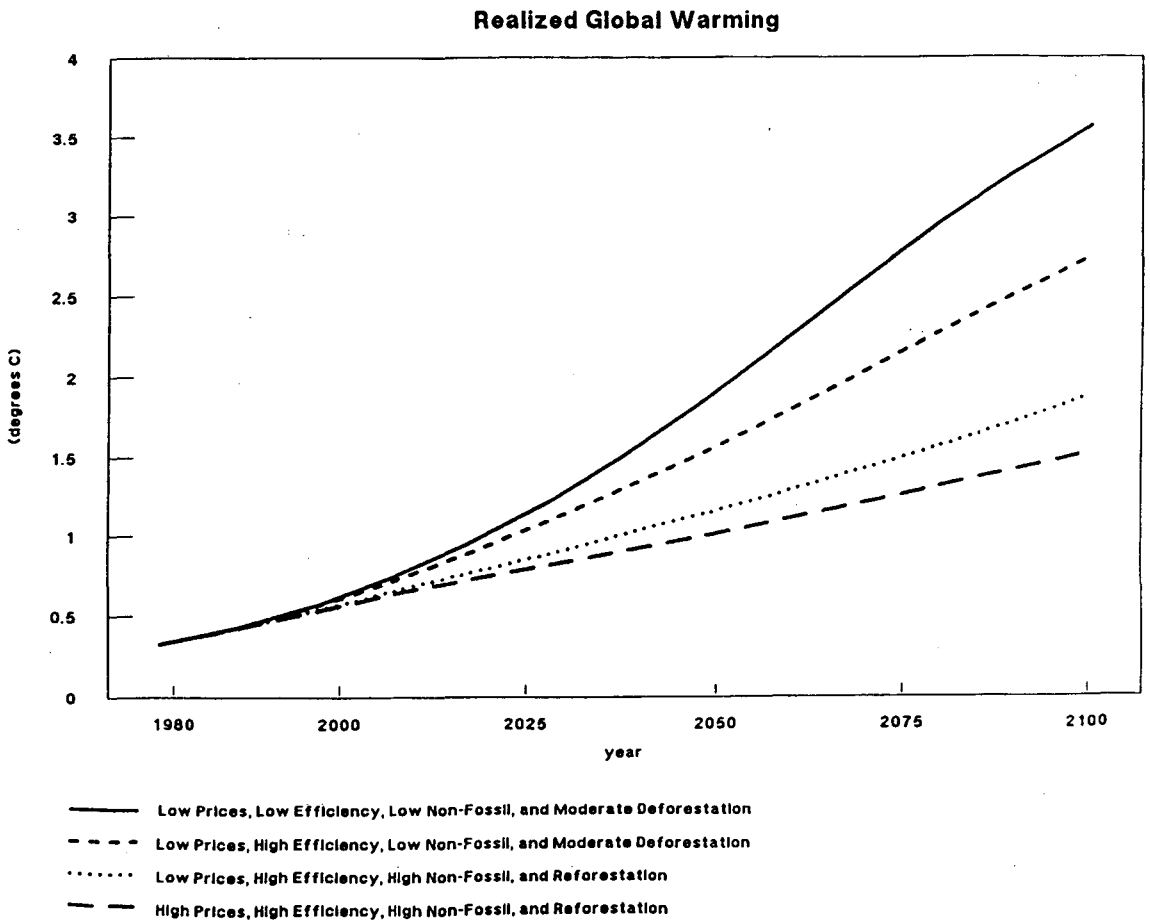

Energy Efficiency and Structural Change in the Industrialized Countries

Robert Williams
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Princeton University

Most global energy studies done in the past 10 years project a doubling or tripling of global energy use over the next 50 years. These studies envision considerable expansion of fossil fuel use and nuclear power. There is considerable evidence that conventional forecasts considerably overstate energy demand even in a "business-as-usual" case. In the analysis that I and my colleagues have done,[1] we have looked at the prospects for more efficient use of energy, and have also examined what we believe is an important structural shift taking place in the industrialized countries toward much less energy-intensive economic activity. We conclude that the economic goals of both industrialized and developing countries can probably be met over the next several decades without increasing global energy use very much, thus avoiding overdependence on the most troublesome supply sources. Our scenario involves a 50% reduction in per capita energy use in the industrialized countries by 2020, with about a doubling in per capita GDP.

Structural Change

The shift from goods to services production in the industrialized countries is well-known. Much of the reduction in energy use is due to structural change within the industrial sector, which in the U.S. accounts for about 40% of total energy use. Almost 60% of U.S. manufacturing energy use goes to basic materials processing, which accounts for a relatively small share of value added. We see an important transition taking place away from this activity towards more fabrication and finishing activities, which are much less energy-intensive (see Figure 1).

The movement away from basic materials processing has already accounted for much of the reduction in overall U.S. energy intensity that has occured over the past 15 years. It is reflected in the fact that the industrialized countries seem to be reaching saturation or even decline in per capita consumption for a wide range of materials, even modern ones like aluminum and plastics (see Figure 2). With metals, U.S. demand in 1985 was less than the early 1970s average in nearly all cases. There is a shift to more modern materials, which require more energy per ton to produce, but the substitution of these usually results in a significant reduction in overall energy requirements because of the much smaller weight of the modern materials. In refrigerators, for example, displacement of steel, aluminum, and glass with plastics resulted in 33% energy savings in 1977.

The trends to more efficient materials use and use of more modern materials are not new. What is more recent is a shift of consumer preference toward "value-added-intensive" goods and services (electronics, computers). With plastics, there is a shift away from cheap "commodity plastics" toward specialized plastics with higher prices. These trends have much more to do with affluence than with energy price.

Energy-Saving Technologies

Bringing about a 50% reduction in per capita energy use requires some kind of public sector intervention in the market. Much will happen through market forces alone, but not to the extent needed. The challenge is to make energy efficiency a design criterion of

the innovation process. It is important to be aware that those new technologies that make it in the market improve several attributes of a product or process simultaneously. Most consumers are not so interested in energy efficiency *per se,* so it must be incorporated into the process of technological innovation in ways that make the products broadly appealing. Recent improvements in compact flourescent bulbs are an example of this.

In the industrial sector, energy efficiency should be part of the modernization that will be required to retain competitiveness. In Sweden, modernization of the steel industry resulted in a 25% decline in energy use per tonne between 1976 and 1983. New technologies can lead to much greater improvement in energy efficiency, but the primary incentive for their introduction is to provide non-energy benefits (e.g., use of powdered ores directly and steam coal rather than more costly coke).

Multiple benefits are also being seen in other areas. Super-insulated homes have very low energy requirements, but also obviate the need for a central heating system and provide more comfortable indoor conditions. In addition, a higher level of quality control in construction and the economies of factory construction can be realized through the use of partial pre-fabrication techniques.

Another example is with energy-saving electronic variable-speed drives for motors. Maintenance costs are lower, equipment lifetime is longer, higher-speed operation is possible, and there is often better quality control of the product.

Low-Energy Scenario for the U.S.

The purpose of our scenario development, which is based on an end-use approach, is to show what could happen if opportunities for energy efficiency are emphasized in planning. For the industrial sector, our scenario has output growing slightly slower than aggregate GDP. With the ongoing structural shift in industry, basic materials use increases with population through 2020, while fabrication and finishing increases about three-fold. Industrial energy intensity declines by about 50% from 1980 to 2020. The rate of decline is somewhat less than occured in the 1973-84 period. The implicit income elasticity for the industrial sector (relative to aggregate GDP) is about 0.5, much less than is used in most top-down models.

Total industrial energy use declines by about 25%, but there is a considerable shift to electricity. This is also seen in looking at the economy as a whole. Growth in electricity's share is important to bringing about an energy-efficient future, as it facilitates the process of technical innovation.

1. J. Goldemberg, T. Johansson, A.K.N. Reddy, R. Williams (1988). *Energy for a Sustainable World.* World Resources Institute, Washington, D.C.

Figure 1

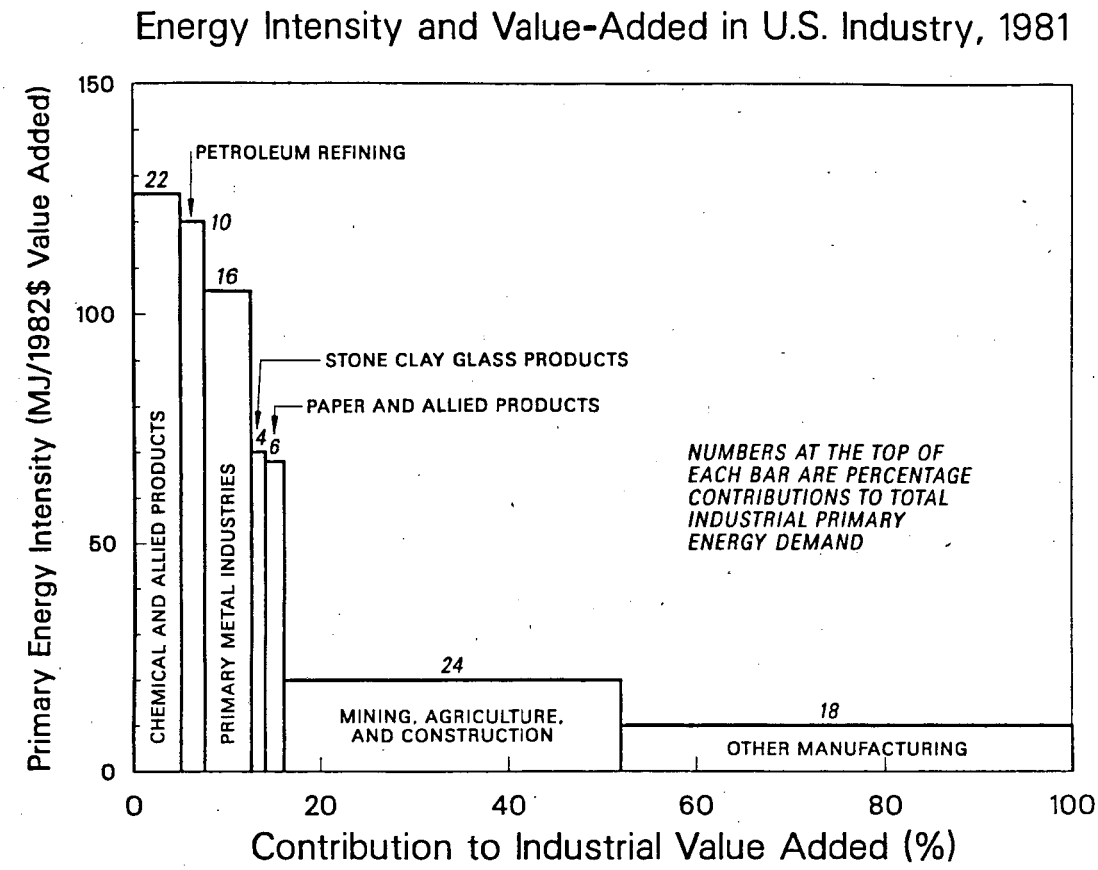
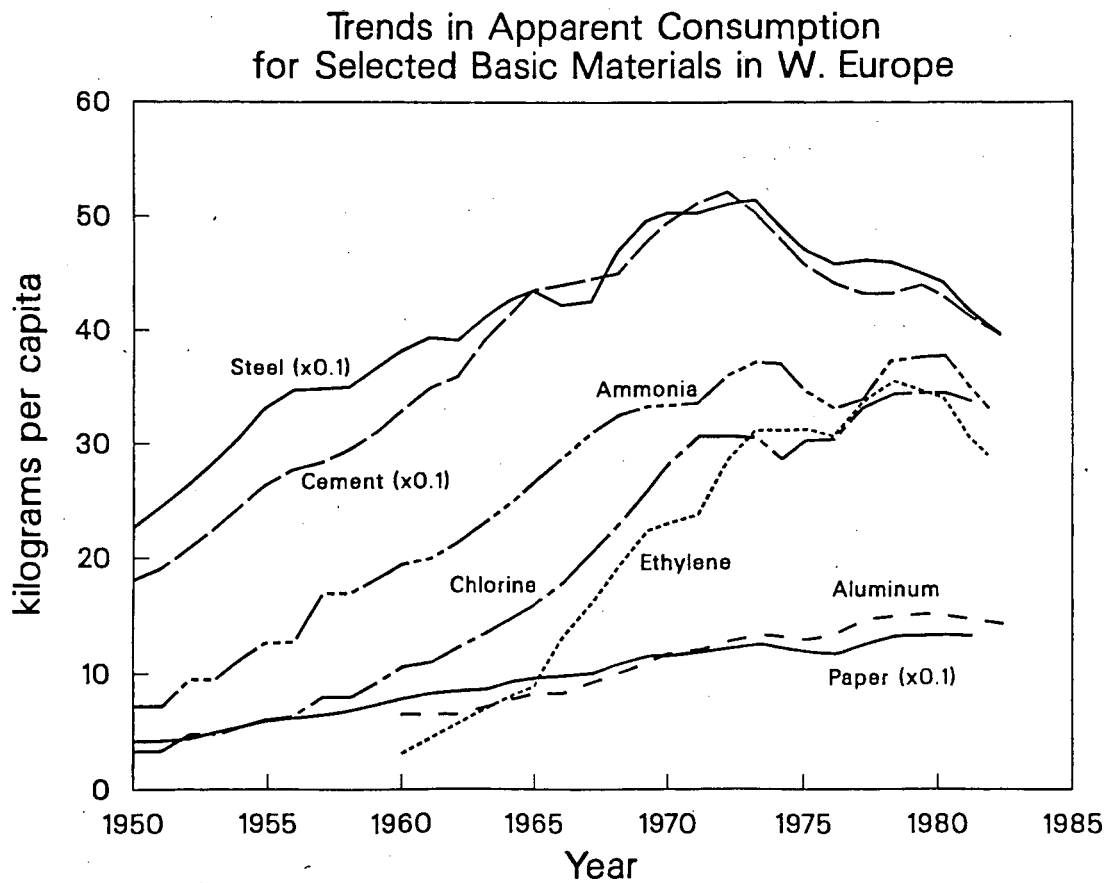


Figure 2



Energy Use in Transportation: 2000 and Beyond

Albert J. Sobey
Senior Director, Energy & Advanced Products Economics
General Motors Corporation

Improvements in technology may change several factors that will determine how energy use in transportation may evolve in the future. The evolution of technology in industry and commerce from major industrial complexes to high technology and niche companies will change how we live, and how we will use our transportation systems for both people and goods.

The evolution of technology can be divided into four phases, or revolutions:

The first	The use of artificial power to produce more, lower cost goods, than was possible with human labor.
The second	The use of mechanical transportation to move people and goods rapidly within cities, and between cities and countries.
The third	The use of the telephone and radio to link people, nearly instantaneously, across distance.
The fourth	The use of computers to increase our ability to evaluate, regulate and control processes, and thus reduce the need for human intervention.

Each of these phases has contributed to improvements in our quality of life, and with time has lead to reductions in the use of energy, either by improving the efficiency, redicing the energy content of the goods we purchase, or reducing the need for transportation.

The reductions in scale of manufacturing processes made posible by new manufacturing process controls and information systems will lead to major changes in the manufacturing industry. Plants can be located anywhere, even in places which are not yet cities. We are approaching the point where mega-industries will not need mega-cities.

Freight movement will become more diverse, and time sensitive. While this favors trucking, new technology, like "car-less" piggyback and logistics controls, will enable the railroads to compete more effectively. The "car-less" piggyback systems being used by GM reduce the fuel consumption to 20% of a truck, or half of conventional rail, but require no new technology.

The automobile will provide most urban transportation, although there will be more choices. Families will have cars for different purposes. We expect people to continue to respond to two budgets: time spent in travel, averaging 60 to 80 minutes a day, and a financial budget which averages 10 to 12% of disposable income. The major transportation problem facing our cities is congestion, which is neither efficient or pleasant. It is possible that the congestion problem is self limiting. The time budget implies that people will change residences or jobs when travel time becomes excessive. More than 10% of the population relocates every year.

There are several possible ways to reduce energy consumption in personal transportation. Public transit is at a disadvantage in our low density cities, and its benefits in

terms of energy saving probably peak at less than twice present ridership.

The technical feasibility of a half-width personal vehicle, called the "lean machine", has been confirmed by GM. It can provide up to 150 mpg without compromising comfort or acceleration performance. They should be very attractive to the commuter, but their effective use will require coordination with local traffic officials.

Use of computers to work at home will increase but not be significant in the near future. Electronic information systems will help locate new destinations, and speed traffic flow on arterial streets. They may not only reduce time and fuel consumption, but will improve safety and provide significant reduction in air pollution.

The vehicle technology is evolving. Prior to 1973 fuel efficiency improved at 1-2% per year (in gallons/mile), a rate which should continue. We may be close to the economic limits with available technology. The internal combustion engine is approaching the inherent efficiency limit defined by Carnot 150 years ago. Use of exotic materials to reduce weight will probably increase the price of the car more than the cost of the fuel saved at today's prices.

There is one hypothetical electrochemical powerplant which bypasses Carnot's limit: the fuel cell. It generates electrical power, heat and water or carbon dioxide (if the fuel is a hydrocarbon or alcohol). While fuel cells appear technically feasible, new knowledge will be required to reduce their costs and replace the platinum catalysts. This could be available by 2020, if we continue to work the problem.

Alternative fuels like methanol are popular, and may provide the solution to energy availability. Data provided by several major chemical companies implies that an adequate return on investment can be obtained from the construction of a series of large processing facilities when the retail price of gasoline approaches $1.50 per gallon. It is unlikely that many plants will be built because OPEC could "whipsaw" the oil prices, and natural gas, the best feedstock, is cheaper in other nations that do not have a market for their gas.

We do not expect alternative fuels for transportation to be a significant factor in the U.S. much before 2020, although they should be in use earlier in oil-poor developing nations, many of which have large natural gas resources. This would not only provide those nations with some independence from OPEC, but benefit the U.S. and the rest of the world by helping to cap oil prices.

Energy Efficiency Prospects for Light Vehicles

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In considering reducing the rate of increase of CO_2 emissions so as to mitigate the global warming effect, light vehicles (which include automobiles and light trucks) cannot be ignored. Their numbers are expected to rise sharply by the end of the century; automobiles alone are projected to increase from 310 million worldwide to 480 million. Most of this increase will occur outside the U.S., and a large fraction of the increase will occur in developing countries. Nevertheless, at least through the beginning of the next century, industrialized world policies will dominate in determining the nature of the cars that will be on the road. For while automobiles will be on the rise in the developing world, they will be either imported from industrialized countries, assembled from knock-down kits manufacturerd in industrialized countries, or designed based upon retired models developed in industrialized countries.

While some alternative light vehicle fuels (e.g. compressed natural gas, hydrogen) promise to reduce or even eliminate carbon dioxide emissions, substantial problems at present in offering comparable amenities (e.g. range limitations, safety problems) as today's cars mean these fuels are unlikely to be in widespread use by the turn of the century. If efforts are to be made now to control the rate of increase in carbon dioxide emissions, the only option is to increase the energy efficiency of light vehicles.

Fortunately, this is a technically viable option. The technology revolution of the past decade in materials and electronics has only begun to be applied to vehicles. Applying the innovations born of that revolution to improve the efficiencies of engines and transmissions, reduce vehicle weight, improve aerodynamic drag, reduce tire rolling resistance, improve accessory efficiency, and reduce braking energy loss can substantially increase the fuel economy of light vehicles. Work is presently ongoing in all of these areas — disproportionately outside of the U.S. — and under an aggressive development program, many of these innovations could be brought into production by the turn of the century.

The potential offered by new technologies can be seen in the fuel efficient prototypes that have been developed in recent years (see Table 1). Most of these were developed by European light vehicle manufacturers, often with partial funding from their national governments. With few exceptions, these prototype vehicles enjoy fuel economies in excess of 60 miles per gallon (mpg). Moreover, these prototypes generally do not incorporate the most advanced of the technological innovations presently being investigated. Hence, the potential for fuel economy improvements is likely to be even higher than demonstrated by the existing prototypes (see Table 2).

The prototype development that has occurred in recent years has demonstrated more than the efficiency potential wrought by the materials and electronics revolution. It has also shown that these innovations can render an efficient vehicle without giving up other consumer amenities, namely performance, comfort, safety, low emissions, and cost. The Volvo LCP 2000 was designed with this in mind; minimum criteria were established in each of these areas. As a result, the vehicle — which enjoys a fuel economy of 63 mpg city/81 highway — can accelerate from 0 to 60 miles per hour in 11 seconds (the average for the 1986 American fleet was 13.1 seconds), can hold 4-5 persons, has a higher

crashworthiness than is required in the U.S. for production automobiles, has an emissions level close to those required in the U.S. today, and is estimated by its engineers to be able to be produced at a cost comparable to today's cars of equivalent size.

While the technological potential for fuel economy is quite bright, the likelihood that these technologies will be introduced expeditiously is small. Today's low oil prices discourage interest in fuel efficiency from consumers and manufacturers alike. Competitive pressures may speed the introduction of some of these innovations in an effort to gain more market share (primarily in Japan and Europe), but if this occurs, the technologies will probably be concentrated in the smaller car lines where carmakers know their buyers are more interested in fuel economy. Hence, if energy efficiency technologies are to be introduced expeditiously across all model lines, national governments will have to develop policies to promote the transition. Such policies will need to accomplish three tasks: speed the research, development, and demonstration of fuel efficient technologies; provide incentives to manufacturers to introduce such technologies into commercialization on a wide scale; and provide incentives to consumers to purchase highly fuel efficient vehicles.

The introduction of fuel economy technologies can have a substantial impact on the oil required to power the light vehicles of tomorrow. Rather than having oil use attributable to such vehicles rise above 1985 levels, as is presently projected, oil use could potentially drop below current levels (see Figure 1). Not only would such a drop be important, in and of itself, for reducing the rate of carbon dioxide emissions worldwide, but it could also affect the decision as to which type of alternative fuel is selected for the post-petroleum era.

If only a modest improvement in light vehicle fleet fuel economy is achieved by the end of the century, the chances for another oil crisis occurring by then will be quite high. Such a crisis is likely to spur an accelerated conversion to an alternative fuel. In the short term, the most likely fuel to be selected will probably be methanol from natural gas; its costs are relatively low and its liquid form renders its adaptation to existing vehicle designs relatively effortless. However, methanol from natural gas produces roughly the same amount of carbon dioxide per unit energy as gasoline. Hence, no net reduction in the rate of increase of carbon dioxide emissions is likely to result. Moreover, many believe that methanol from natural gas is only a transitional strategy because U.S. reserves of this fuel are limited. Once the U.S. becomes dependent on natural gas reserves in strategically undesirable regions (e.g. the Middle East and the Soviet Union), pressures are likely to increase to produce methanol from this country's abundant coal reserves. Unfortunately, methanol from coal releases about twice the amount of carbon dioxide per unit of energy as gasoline.

On the other hand, if levels of light vehicle energy efficiency are sufficiently high, the drive to convert to an alternative fuel will not be nearly as great. As shown in Figure 1, if the average light vehicle fuel economy reaches 45 mpg for all light trucks and 60 mpg for all automobiles by the turn of the century, the resulting energy savings is likely to keep demand for OPEC oil below 80 percent of its production capacity. By buying time until conversion is required to an alternative fuel, the transition to a more benign fuel such as hydrogen is all the more likely.

Table 1

High Fuel Economy Prototype Vehicles

Company	General Motors	British Leyland	Volkswagen	Volkswagen	Volvo	Renault	Renault	Peugeot	Peugeot	Ford	Toyota
Model	TPC (gasoline)	ECV-3 (gasoline)	Auto 2000 (diesel)	VW-E80 (diesel)	LCP 2000 (diesel)	EVE+ (diesel)	VESTA2 (gasoline)	VERA+ (diesel)	ECO 2000 (gasoline)	--- (diesel)	AXV (diesel)
Number of passengers	2	4-5	4-5	4	2-4	4-5	2-4	4-5	4	4-5	4-5
Aerodynamic Drag Coefficient	.31	.24-.25	.25	.35	.25-.28	.225	.186	.22	.21	.40	.26
Curb Weight (lb)	1040	1460	1716	1540	1555	1880	1047	1740	990	1875	1430-target
Maximum Power (hp)	38	72	53	51	52,88	50	27	50	28	40	56
Fuel Economy (mpg)	61 city 74 hwy	41 city 52 hwy	63 city 71 hwy	74 city 99 hwy	63 city 81 hwy	63 city 81 hwy	78 city 107 hwy	55 city 87 hwy	70 city 77 city	57 city 92 hwy	89 city 110 hwy
Innovative Features	Aluminum body and engine.	High use of aluminum and plastics.	DI with plastic and aluminum parts, fly-wheel stop-start.	Modified DI 3-cyl. Polo, flywheel stop-start, supercharger.	Hi magnesium use; 2 DI engines developed, 1 heat insulated.	Supercharged DI with stop-start.	High use of light material.	DI engine, high use of light material.	2-cylinder engine, high use of light material.	DI engine.	Weight is 15% plastic, 6% aluminum, has CVT & DI engine.
Development Status	Prototype complete, no production plans.	Prototype complete.	Prototype complete.	Ongoing re-search, pos-sibility of production.	Prototype complete, adaptable to production.	Prototype complete.	Program completed.	Ongoing development.	Ongoing development.	Research.	Ongoing development.

Table 2

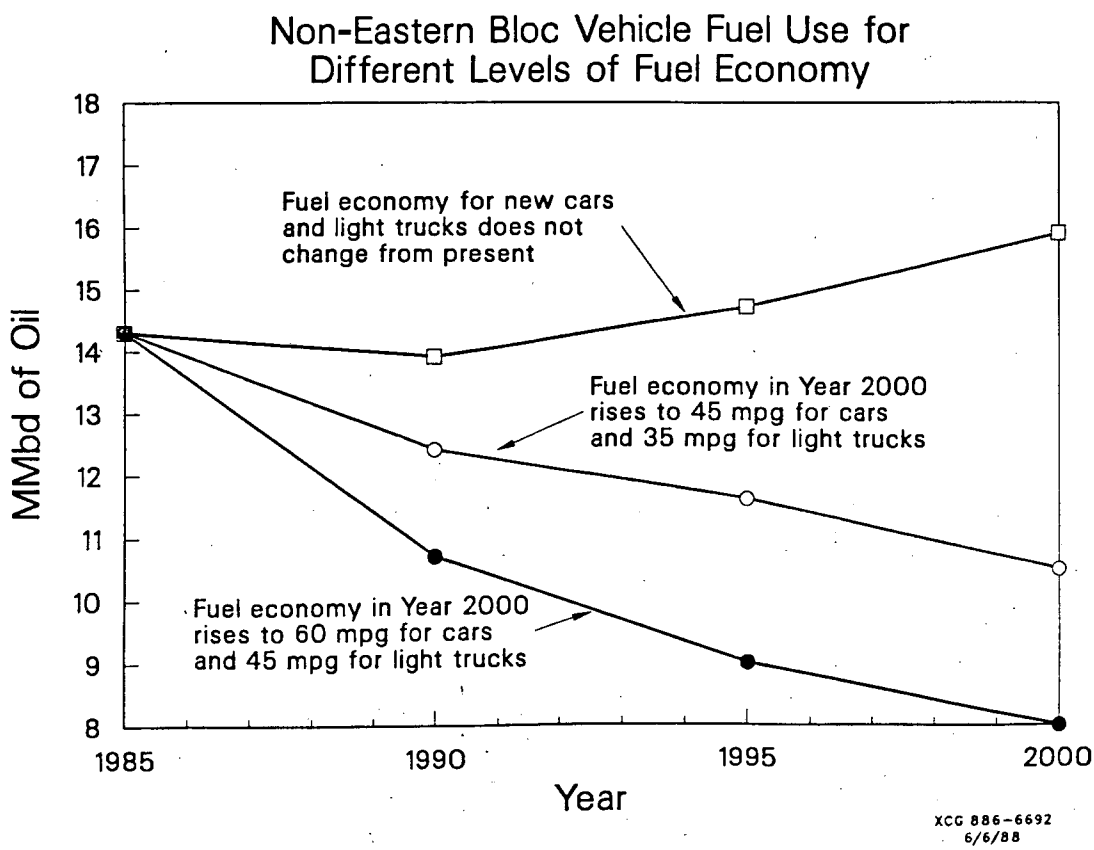
Technologies for Automobile Fuel Economy Improvements

Technology	Percent Gain in Fuel Economy 1995	2010
Weight Reduction	5-10	10-20
Improved Aerodynamics	2-3	3-4
Efficient Tires/Lubricants	1-2	2-3
Improved Spark Ignition Engines	5-8	10-15
Direct Injection Strat. Charge	0-10	10-20
Automatic, Lock-Up Torque Conv.	5	5
Continuously Variable Transmission	3-6	10-15
Engine Idle-Off	0-5	5-10
Improved Accessories	1-2	2-3

Source: U.S. Congress Office of Technology Assessment

Note: Improvements are not additive.

Figure 1



Aerospace Transport in the 21st Century

William M. Wallace
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Aerospace transport in the 21st Century will depend heavily on three things: (1) new technology and the cost of investing in it, (2) fuel costs, and (3) environmental constraints.

Better technology accounts for most real economic growth and has since the Stone Age. The pace picked up when technology was reinforced by the systematic study of science under the scientific method late in the Middle Ages, culminating in the industrial revolution.

If a new technology is to induce growth, it must cut costs and improve utility at the same time. In the early stages of a new technology, both tend to occur; costs come down on an improving good or service. Growth is dynamic. At some point, however, it begins to cost more, not less, to get improvements. Dynamic growth then ceases and a more mature rate of about that of the general economy sets in.

New modes of transport have often led the way, paced by such developments as railroads, steamships, motor vehicles, and commercial airplanes. In the latter case, the jet turbine proved to be the crucial development; it has driven the enormous growth of air travel for the past 30 years. Directly and indirectly the industry now accounts for as much as 20% of the GNP according to some admittedly rough estimates.

Now, however, it appears that further improvements will show decreasing returns. The major new developments now on the horizon appear to cost more and not less. For example, the SST would improve speed dramatically, but at a cost premium. Studies by NASA estimated that the cost per seat-mile for various SST jets would be higher than that of sub-sonic jets in the year 2000 (see Figure 1). By way of contrast, the first jets not only flew much faster but at much lower seat-mile cost.

It may be possible to get supersonic speeds at a small cost premium if some hoped-for technical improvements prove out. Any significant real increase in the price of fuel, however, could well doom the commercial viability of an SST. Its introduction would then depend on government or some other form of cross-subsidy. Only if fuel prices fall below today's level would the higher seat-mile productivity of the SST offset its higher rate of fuel consumption.

The investment hurdle rate is another important constraint. Most hurdle rates reflect the prevailing rate of risk-free interest (long-term Treasury bonds for example) plus some investment risk premium. At current interest rates (which many forecasters expect to persist over the long term) very few major new investments look promising—including the SST. Indeed, the airlines are motivated to retain equipment in flight service long past the original design life.

Longer Term Prospects

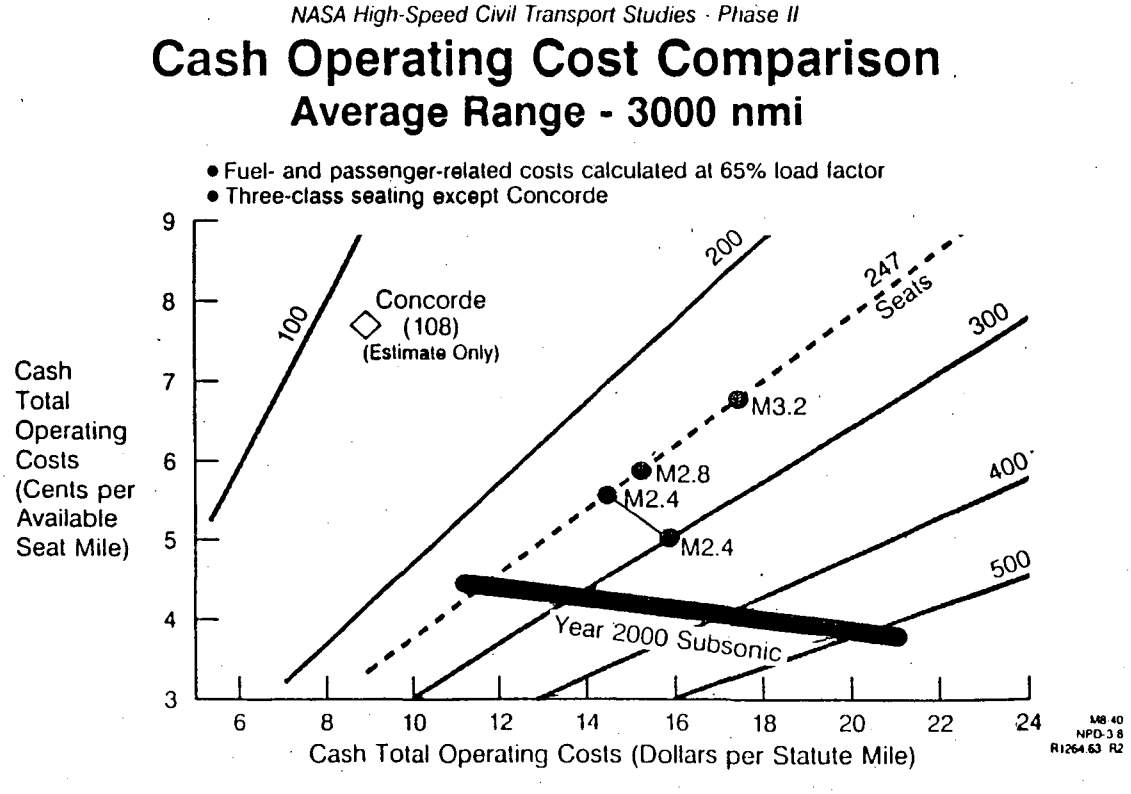
The SST is perhaps the ultimate in foreseeable speed within the earth's atmosphere because of the distances. A mach 6 hypersonic vehicle, for example, would cruise but 2 or 3 minutes at mach 6 on a Los Angeles to Sydney, Australia flight. For the rest of the flight, the vehicle would be either in acceleration or deceleration, the limits set by passenger comfort. Mach 2.5 seems to be the upper practical limit.

Outer space is a different matter: The distances involved require much higher speeds. But clearly today's rockets are far too expensive to use for anything but early exploration. If any serious space travel or development is to take place, costs must come down dramatically. Such a decrease probably requires big increases in the specific impulse (ISP) of rocket fuels. Some possibilities are already on the horizon. New high energy density materials offer the prospect of a four-fold increase by the year 2000. That would help, but not result in any really dramatic developments.

Fusion, however, would increase the specific impulse by a factor of about one million, perhaps as early as 2010, but more likely closer to 2050. Antimatter promises an even more dramatic rise in ISP over today's rockets, by a factor of 100 million. Some estimates envision antimatter propulsion as early as 2020, but a more conservative estimate is 2100. With such energy boosts, intersteller travel becomes a practical matter to contemplate. Acceleration at one gravity (earth-like comfort) for one year would yield a velocity at close to the speed of light by year's end.

Estimates of such new technology are, of course, entirely conjectural at this juncture. But in the absence of such advances, the 200-year old trend of rapid development in transportation pacing economic growth may be nearing an end.

Figure 1



End-use Efficiency and NOx Emissions in Aviation

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NOx is an ambient air pollutant, a tropospheric ozone precursor, and a contributor to acid rain. It is involved in catalytic cycles which destroy stratospheric ozone, and it influences the oxidizing power of the troposphere and the lifetimes of many gases.

In the context of global NOx emissions, aircraft emissions are small. (Logan[1] estimates that 165 teragrams of NOx are emitted annually from all sources, while aircraft emissions are about 2 teragrams.) Since aircraft emissions are above cloud level, they may reside in the free troposphere longer than emissions from surface sources and contribute more to the chemistry of the atmosphere than their size indicates.

The considerable research performed in the 1970's, which estimated NOx emissions of 1.2 to 2.8 teragrams in 1990 from commercial jet aircraft, continues to provide the reference estimates of NOx emissions at altitude.[2] There have been significant changes in aircraft design and airline economics since the 1970's, and the prior research needs updating. This work also elaborates upon previous estimates of NOx emissions.[3]

The emission coefficient expresses the amount of gas released per unit of fuel burned. Engines burn fuel under varying conditions of temperature and pressure. Thus, not only are there different coefficients for different engines, but also for the same engine when flown at different altitudes. Coefficients for specific engines or types of engines are given by the International Civil Aviation Organization,[4] and the EPA.[5] For this analysis weighted-average coefficients for the global fleet of jet aircraft flying at cruise altitude were constructed.

The leading sources of global data on jet fuel use omit estimates of use in Eastern European countries, the USSR, and China, and they do not report use by user or type of jet for any region. As a remedy, data from other sources are combined with United Nations data to arrive at estimates of fuel use by user and type of plane. Even so, a hard estimate of global military jet fuel use is wanting. Commercial jets burn about 70% of all jet fuel; military jets burn about 24%, with business and turbo-props the remainder. These estimates can serve as a first approximation.

Forecasts of flight profiles are uncertain because wind and weather are highly variable, but design, air corridor capacity limits, and deregulation work to raise flight profiles. As newer, higher-flying aircraft enter the fleet and increase their share of fuel consumption, the global fleet, on average, is likely to fly higher. Increases in jet travel may crowd the principal air corridors and force flights higher. Moroever, there is advantage to higher flights since the reduced air pressure at higher altitudes implies the same amount of thrust will result in increased velocity. Deregulation appears to be lengthening flight stages for jets because turboprop commuter craft are used on stage lengths less than 200 miles. Short flights log less time at high altitudes than long flights. As aircraft fly higher, downward pressure is placed on emission coefficients; but a 10% increase in altitude does not translate into proportional decrease in coefficients.[6] A limit is reached at about 35,000 feet.

Two forecasts of global jet fuel use to 2025 are used. The low estimate of 2.2% per year is derived from a global economic model; the high estimate of 3.6% per year is based on independent estimates of the rate of growth of passenger travel and jet fuel use.[7,8] Roughly 100 million metric tons of jet fuel were burnt in 1980, with about 65% of it

burnt in the western industrialized economies.

Gains in productivity and energy efficiency allow growth in jet miles flown to be supported by a smaller increase in jet fuel use. Between 1974 and 1985 the energy efficiency of jets increased by over 40% (Figure 1). Jet aircraft improvements include: more fuel efficient engines (less fuel is needed to produce a pound of thrust); increases in aircraft structural efficiency (lighter airframes carry more seats); improved lift/drag performance; improved routing to increase fleet utilization; altering networks to reduce seasonality and improve fleet utillization; and pricing strategies that stabilize load factors.

The principal results of this analysis are: (1) average emission coefficients decline as new engines and new airframes enter the fleet; (2) emissions of NOx from aircraft continue to grow because the use of new engines and airframes cannot offset increases in air travel; (3) emissions in 2025 may be 1.7 to 2.8 times 1980 emissions; (4) future emissions from sub-sonic jet aircraft will be at higher altitudes; (5) 70% of emissions are emitted between 20 and 60 degrees north latitude, with most of that emitted in the USA, Europe, and USSR.

Figure 2 illustrates how NOx emissions at the 34-38,000 ft altitude may well increase greatly between 1990 and 2025. Emissions at higher altitude may have a higher probability of reaching the stratosphere and entering into complex reactions that, in the end, deplete stratospheric ozone. Accordingly, higher flying craft may bring lower emissions for a given level of fuel use, but a higher probability of emissions entering the stratosphere.

References

1. J.A. Logan, "Nitrogen oxides in the troposphere: global and regional budgets". *J. Geophys. Res. 88,* 10785-10807, (1983).

2. D.J. Wuebbles, M.C. MacCracken and F.M. Luther, *A Proposed Reference Set of Scenarios for Radiatively Active Atmospheric Constituents,* Lawrence Livermore National Laboratory, 1984.

3. M. Kavanaugh, "Estimates of future CO, N20, and NOx emissions from energy combustion", *Atmospheric Environment (21) 3,* (1987).

4. ICAO, *Emissions Data Bank,* Committee on Aircraft Engine Emissions, Background Information Paper #29, Montreal, 1980.

5. U.S. Environmental Protection Agency, *Compilation of Emission Factors.* Washington, D.C. 1984.

6. J.C. Bobick, *Global Aircraft Emissions Forecasting Model: Documentation and Users' Manual.* Analytical Technology Applications Corporation, Mountain View 1983.

7. U .S. Federal Aviation Administration, *FAA Aviation Forecasts Fiscal Years 1988-1999.* Department of Transportation, Federal Aviation Administration, 1988.

8. *Aviation Week and Space Technology,* November 9, 1987.

Figure 1

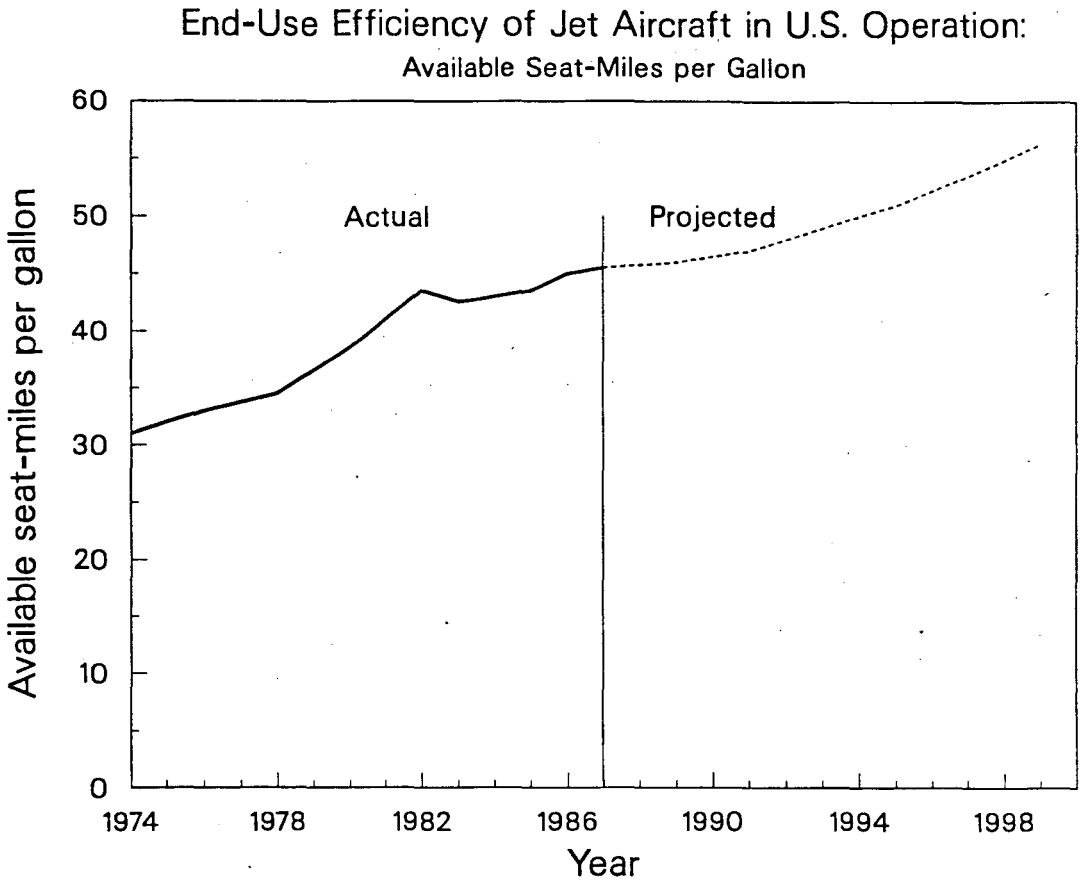
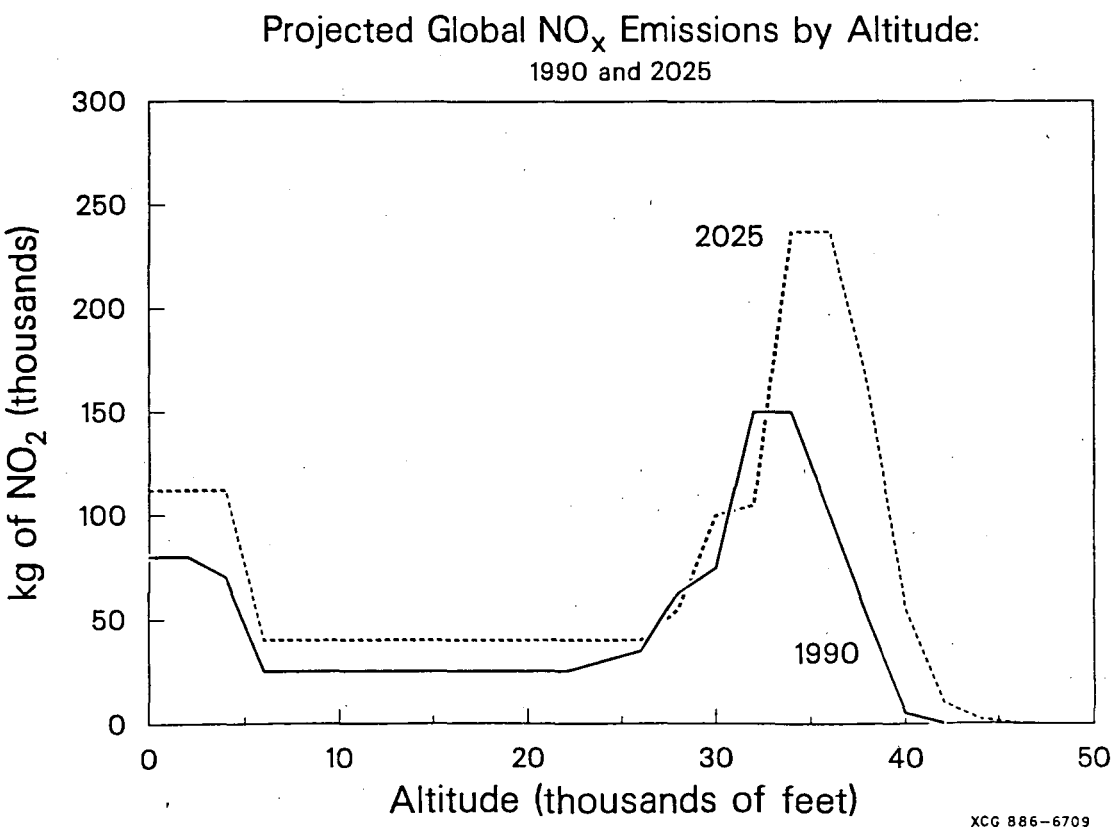


Figure 2



Trends in Home Appliances in Europe

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The Italian Market

Electrolux-Zanussi accounts for about 25% of the market for home appliances in Western Europe. In evaluating the evolution of the market, we look at appliance saturation and energy consumption. Table 1 shows the market saturation in Italy as of December, 1986, the estimated specific consumption of the stock in use and of new appliances, and the share of each appliance in total electricity consumption for appliances.

Looking ahead to 1998, the appliances that we expect to grow the most in saturation are those that have low saturation today: clothes dryers, dishwashers, freezers, and microwave ovens, which have only recently come on the scene in Italy. We expect that "combis" (refrigerator-freezers) will continue to grow, while the market for simple refrigerators will decline.

Table 1
Electric Appliances in Italy

	Saturation %, 12/86	Specific Consumption* 1987 Stock	1987 New	% of 1987 Elec Use
Clothes-washer	89.8	2.2	1.9	30
Clothes-dryer	0.5	3.0	3.0	..
Dish-washer	13.0	2.3	1.9	5
Refrigerator	39.0	1.1	1.0	14
Refrig/Freezer	59.5	1.6	1.5	30
Freezer	22.2	1.4	1.3	10
Elec Oven	37.8	2.2	2.0	7
Elec Range	0.9	2.0	2.0	..
Mixed Range	39.6	2.0	2.0	3
Microwave oven	0.8	1.2	1.2	..

* kWh per cycle for dryers and washers, per day for cooling devices, and per hour for cooking devices.

In terms of energy consumption, we expect that the stock in 1998 will have a specific consumption (electricity use per cycle, hour, or day) about the same as today's new appliances. The increase in efficiency will be more than offset by growth in the stock, however. We forecast a growth in total electricity consumption for home appliances of 17% between 1987 and 1998.

Future Prospects for Appliance Energy Efficiency

Average annual consumption of new **refrigerators and "combis"** has dropped 17% and 12% respectively between 1977 and 1987. This is particularly significant given the already low electricity intensity of the average Italian refrigerator. Freezers too have

improved by about 13% in the same period.

Future improvements are expected to average 30-33% for all three types of technologies, and will be induced by the following improvements:

- *Better thermal insulation.* This is expected to come either (i) from an increase in the thickness of the insulating foam, or (ii) through the substitution of different insulating material. In the first case, overall consumption is expected to drop 15-20%. In the second, savings will depend on the type of material used (lower conductivity polyurethane, porous materials, or fiberglass), and will range between 7% and 30%.
- *Improvements in the refrigeration system.* These imply reducing energy losses in either the thermal exchange at the condenser and at the evaporator (expected savings 5-8%), or in the compression process (expected savings 5-6%), or in the on-off regulation (expected savings 5-10%).

Considerable improvements were made over the last ten years in the efficiency of **clothes-washers.** The average new system in 1987 is using 24% less than in 1977, and most progress was done just in the last year through the introduction of the innovative Jet System technology, a clothes-washer using 30% less electricity than same-size conventional machines. Still, efficiency is expected to continue to increase as the following improvements will be applied:

- *Improvements in the heating system.* Traditional washers use 78% of the energy for heating the water, while this share is 62% in the case of the Jet System. Reductions in washing temperature and in the quantity of water to be heated, as well as efficiency improvement of the heating elements and heat-recovery from other kitchen appliances, are expected to provide a total reduction in energy use for heating of around 12% in the case of the traditional washer, and 10% in the case of the Jet System type.
- *Better insulation.* Thermal losses cover 10% of the energy needed by a traditional washer, and 17% of a Jet System machine. An estimated 20% reduction in these losses could be obtained by properly insulating the tub.
- *Improved motor efficiency.* The use of more efficient motors is expected to lower their demand by around 15%.

Overall, electricity intensity should decline around 13% for both types of machines, but total savings will very much depend on the market shares of the two models. The Jet System is expected to cover one-third of the stock in the next ten years.

Considerable efficiency improvements in the 1977-1987 period have already reduced unit consumption of **dish-washers** by around 30%. Further reductions are expected for the coming years from:

- *Improvements in the heating system.* The manufacturers expect the introduction of "saving cycles", of low-temperature detergents, and of ultrasonic systems to lower the water temperature in the machines. Other changes are expected that will reduce the quantity of water to be heated, and, as with clothes-washers, bring recovery of heat from other kitchen appliances to pre-heat the water. These measures should provide overall savings of 8-9% of the total electricity requirements.
- *Better insulation of the water tub.* This is expected to lower specific use by 3%. Thermal losses constitute in fact 15% of total requirements, and could be improved by 20%.

-- *Motor efficiency improvements.* The efficiency of motors in use today varies between 60% and 70%, and could be optimized by another 10%, providing an additional 1.5% savings.

Expected savings from efficiency of dish-washing machines is not as large as for clothes-washers. However, the relatively low level of saturation reached in Italy indicates that many machines will be introduced in the market in the coming years. Any improvement in the efficiency of this appliance will have then a rapid influence on the sectors' electricity demand.

It is difficult to predict which of the efficiency improvements described above will be adopted without policy incentives. The example of the introduction of the new *Jet System* for clothes-washers indicates that efficiency might improve considerably as a result of technological improvements that are not uniquely driven by energy-savings motivations. Overall, it is interesting to note that the improvements listed above could lower the consumption of electricity for these three end-uses by about 16% in the next ten years. Since these covered in 1986 more than 41% of total electricity use in Italian households, we can roughly estimate that improvements in refrigeration and washing technologies only can provide 7% electricity savings by 1998. Similar improvements should be expected in other end-uses as well, particularly water heaters and cooking devices.

Energy Efficiency in Residential Appliances

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Home appliances such as refrigerators, freezers, cooking appliances, water heaters, dishwashers, and clotheswashers and dryers account for over half of residential electricity use in the U.S. and a smaller share of residential natural gas use. The energy efficiency of these devices has increased considerably since the early 1970s, but there is considerable potential for cost-effective modifications that can improve efficiency further.

Refrigerators and Freezers

Refrigerators and freezers account for an estimated 20% of U.S. residential electricity use. Since 1972, the average annual energy consumption of new units of the most popular type of refrigerator (18 cu. ft., automatic defrost, top mount refrigerator/freezer) has declined from 2000 kWh to 1050 kWh. For freezers (upright, manual defrost), consumption of an average model has fallen from 1300 kWh to about 800 kWh. These improvements have resulted from such design options as the use of foam insulation instead of fiberglass, improved gaskets, and more efficient compressors and fan motors. The NAECA standard recently passed into law by the U.S. Congress will bring annual consumption (for average-sized models) down to a maximum of 950 kWh for new refrigerators and 700 kWh for freezers when it becomes effective in 1990. (The estimated average electricity use for all refrigerators in use in 1988 is about 1250 kWh.)

Three-fourths of the electricity used by a typical refrigerator meeting the NAECA standard is accounted for by the compressor. Fans, anti-sweat heaters, and defrost heaters share roughly equally in the remaining 25% of consumption. Design options for improving the energy efficiency of refrigerators include foam insulation in doors, use of a high-efficiency compressor, fan and fan motor improvement, improved foam insulation, evacuated insulation panels, variable speed compressors, and mixed refrigerants. The effect of some of these options on electricity use are shown in Figure 1 (the options are cumulative). Application of all of the options shown would reduce annual consumption down to around 525 kWh. The last option shown is use of evacuated panels, which have very high insulation value.

Our analysis indicates that a 600 kWh level could be achieved without additional use of CFCs. Potential CFC substitutes for refrigerant include R-22 and HFC-134a, while substitutes for insulation include HCFC-123 and HCFC-141b. Use of CFC substitutes would increase electricity use of the baseline refrigerator by 8-9%.

Water Heaters

The energy efficiency (energy factor) of new electric and gas water heaters has increased from around 80% and 47% respectively in 1972 to about 83% and 50% in recent years. The NAECA standard will bring the minimum energy factor of new water heaters up to 89% and 54%, respectively.

Methods to improve the energy efficiency of water heaters involve reducing standby losses (jacket and flue) and improving recovery efficiency. Design options include jacket insulation, heat traps, automatic ignition with a flue damper, increased flue baffling with

forced draft, multiple flues, a submerged combustion chamber, use of pulsed combustion, and use of heat pump technology. For a gas water heater (40 gallon capacity), use of intermittent ignition plus a power burner increases the energy factor up to about 70%, while a pulsed combustion/condensing water heater would have an efficiency of about 83% (Figure 2). The latter technology is still in the experimental stage, but is promising. Use of a heat pump in an electric water heater would increase efficiency greatly, but costs at this time are high.

Conclusion

The minimum efficiency standards due to become effective in 1990 for a number of home appliances will remove from the market the least efficient models sold today. The potential to increase efficiency further, relying on design options that are well understood, is considerable. The extent to which energy-efficient options are incorporated into future appliances will depend in part on the marketing advantage that appliance manufacturers believe they will yield.

Figure 1. Energy Use of a Top-Mounted Auto Defrost Refrigerator-Freezer
For Various Design Options (Adjusted Volume = 20.8 cu.ft.)

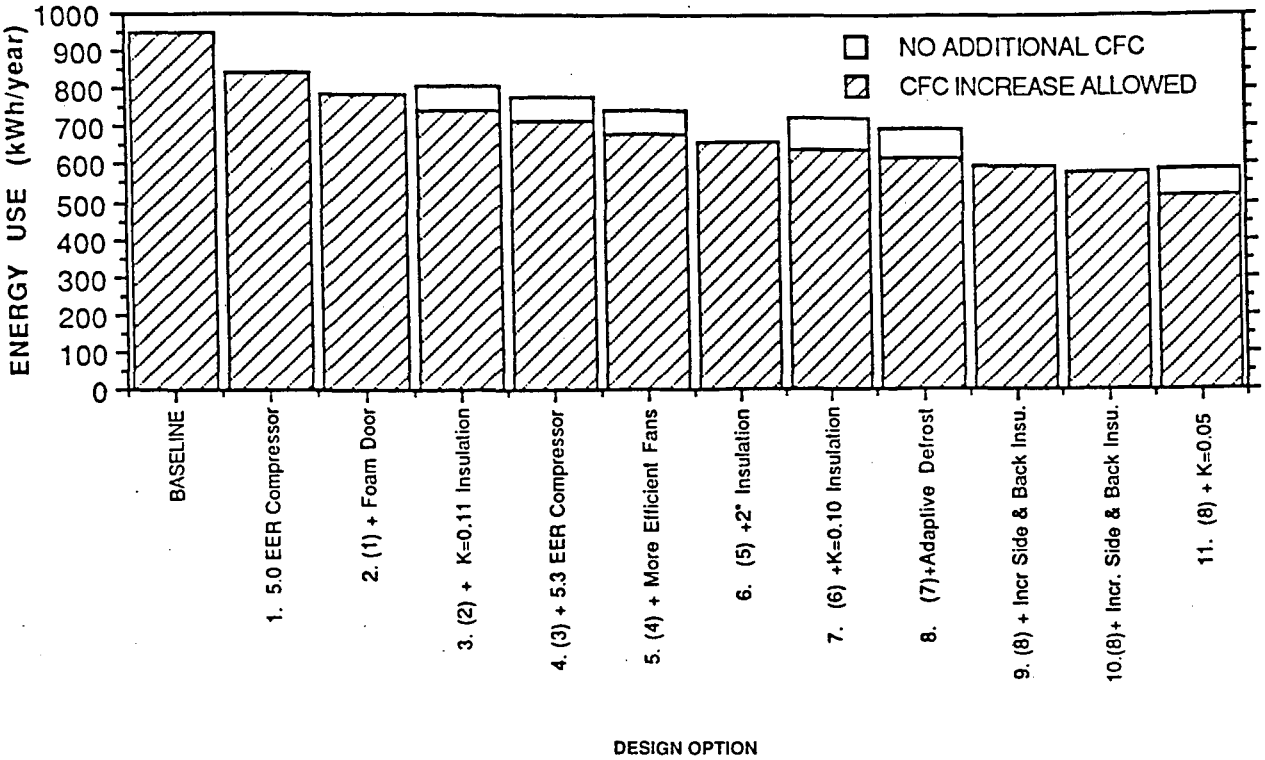
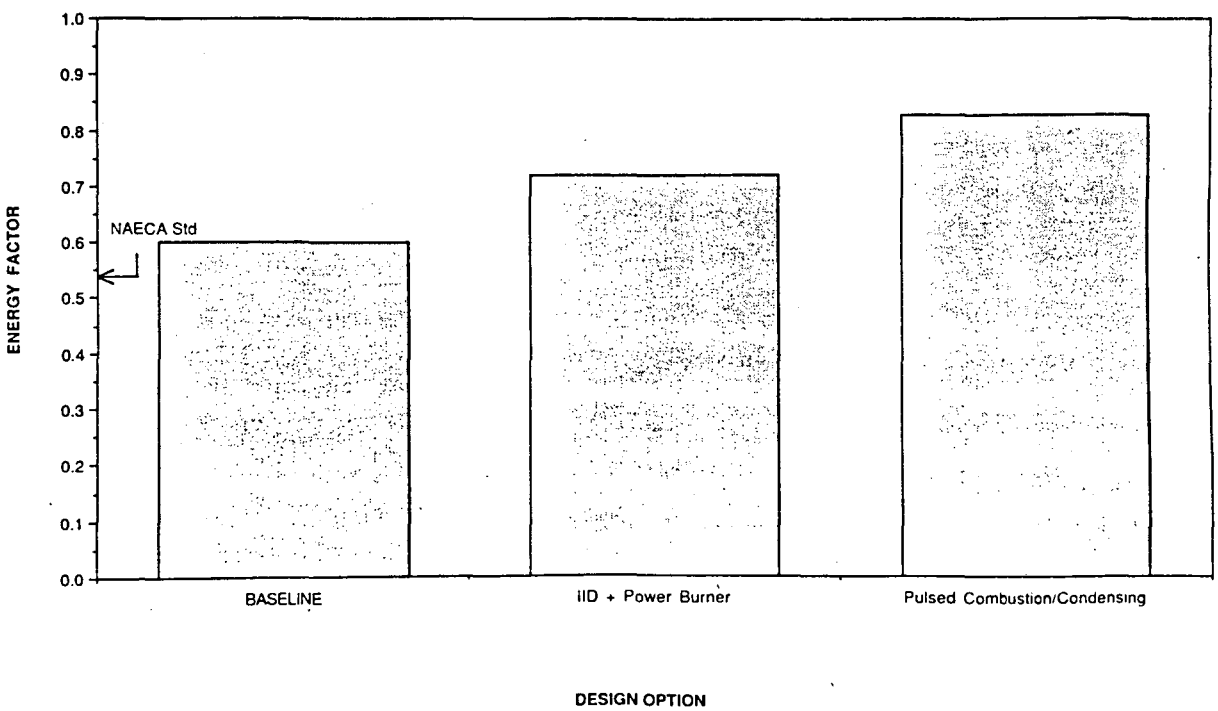


Figure 2

ENERGY FACTOR FOR DESIGN OPTIONS OF

GAS FIRED WATER HEATERS (40 Gallons Capacity)



Trends in HVAC Equipment Efficiency

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Solar Energy Research Institute

Energy use in the residential and commercial sector accounts for more than 35% of U.S. energy consumption, despite more than a decade of public consciousness for energy conservation and continually-rising energy bills for home and building owners. Equipment used to provide heating, ventilating and cooling (HVAC), and water heating consumes more than two-thirds of this energy. This raises several key questions concerning the impact of this equipment on our energy future:

- What advances are being made in HVAC equipment design and technology?
- At what rate are such advances entering the market?
- What forces have precipitated this change?
- What impact has energy conservation had on equipment design?
- What is the impact of improved equipment efficiency on building energy conservation? and,
- What are the prospects for further advances in space conditioning technology?

First, with respect to the impact of improved equipment efficiency on building energy consumption: Building loads (conduction, lighting, solar, equipment) translate to HVAC system and equipment loads. Equipment loads translate to on-site power demand and energy consumption. Equipment energy consumption is a direct function of equipment efficiency, and energy consumption translates directly to energy cost. For example: If building loads are reduced by 30% through energy conserving design strategies, equipment energy consumption may be reduced proportionately. A 30% reduction in building load may be amplified to a 44% reduction in building energy consumption with a 20% improvement in equipment efficiency, or an additional 7% for each 10% increase in efficiency (see Figure 1).

During the last decade, continuing improvements have been made in the shipment-weighted average efficiency of heating, air conditioning and water heating products for residential and commercial buildings. These improvements have been driven by increased public consciousness with regard to energy costs, the introduction of state and federal standards for energy efficiency, and by the advent of a significant market opportunity (and competition) for energy-efficient products.

Since 1976, efficiency of residential air conditioners has increased by 20%, or nearly 2% per year. In 1976, less than 30% of residential gas-fired, warm-air furnaces sold were above 65% average fuel utilization efficiency (AFUE), and none were above 71% AFUE. In 1987, only 10% of the furnaces sold were below 65%, and 52% of the furnaces sold were above 71% AFUE. Shipment-weighted average efficiency increased more than 8% in this period.

The acceptance of heat pumps has grown substantially during this period, as well. Heat pumps represent a particularly important energy conservation strategy where electricity is the fuel of choice for heating. Residential heat pump sales have grown from less

than 500,000 units in 1977 to nearly 1 million units in 1987. In some regions of the country where both heating and cooling are required, heat pumps are installed in nearly all new homes. Efficiency of these products has increased at approximately the same rate as for air conditioners.

The increasing trend in HVAC efficiency is significant -- but it is not enough to meet new standards for minimum efficiency such as the National Appliance Energy Conservation Act (NAECA) standard, which was signed into law in January, 1987. This standard requires that all air conditioners sold meet minimum efficiency requirements of 10.0 SEER (split-systems) and 9.7 SEER (single-package) by 1992 and 1993, respectively. As noted in Figure 2, the current trend in efficiency improvement would carry the average shipped efficiency to 10.0 SEER by 1992. To permit all units sold to reach this efficiency will require a monumental industry effort. And this effort is made further challenging by the prospect that use of CFC refrigerants may be constrained. Actually, such constraints are more likely to affect the efficiency of larger air conditioning machines used in office and other commercial buildings. Standards are also being developed to promote efficiency improvement in equipment for these larger buildings. The most noteworthy efforts are the ASHRAE Standard 90.1 and a parallel standard being adopted by the U.S. Department of Energy that will be mandatory for all federal buildings.

One of the more significant advances in these two standards is the inclusion, for the first time, of minimum efficiency requirements for partial-load efficiency. Since most HVAC equipment operates most of the time at partial-loads, and consumes the majority of its annual energy use at these partial-loads, such standards are important.

These new minimum efficiency standards, the demonstrated market opportunities that have developed for energy-efficient HVAC equipment, and advances in technology that permit design and manufacture of such equipment, all lead to the conclusion that prospects are very bright for substantial further improvements in building equipment and systems. In combination with advances in the energy-conserving design of new buildings (and the rehabilitation of existing buildings), such equipment can provide the opportunity to significantly reduce energy use for space heating, cooling and water heating. Improved systems and equipment can also provide new functions and contribute to the creation of much higher quality indoor environments for working and living.

Advances in technology that are expected to play a significant role in achieving these goals include:

- Advanced window designs with insulation effectiveness equal to solid walls and permitting greater utilization of winter sun;
- Advanced insulation (e.g., compact vacuum insulation) that will provide a high value insulation for appliances and buildings;
- Variable-capacity equipment that will maintain high operating efficiency at partial-load conditions;
- Advanced desiccant cooling systems that provide more comfortable, and more energy-efficient air conditioning and removal of moisture;
- Combined-function equipment designs that integrate space heating, water heating, and cooling functions to achieve greater system efficiencies; and
- Advanced system and control designs to insure that the maximum operating efficiency of the installed equipment is achieved and preserved.

Figure 1

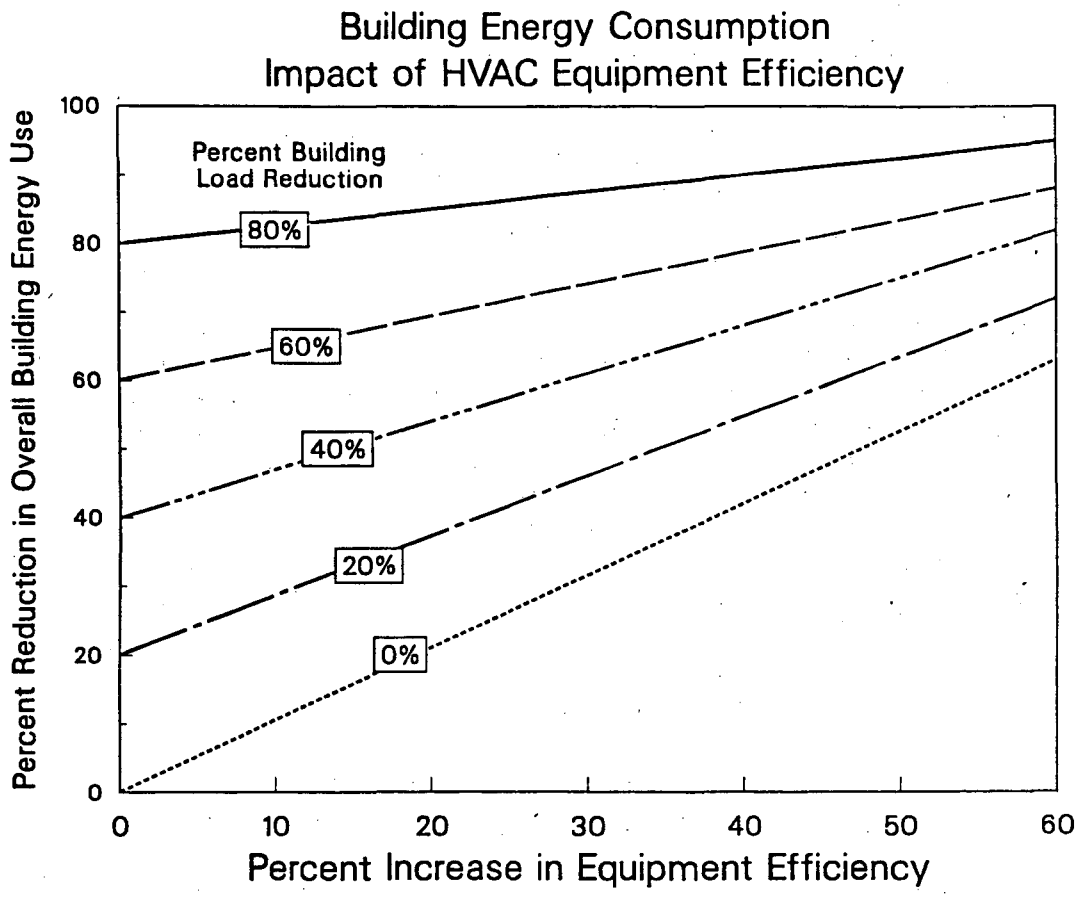
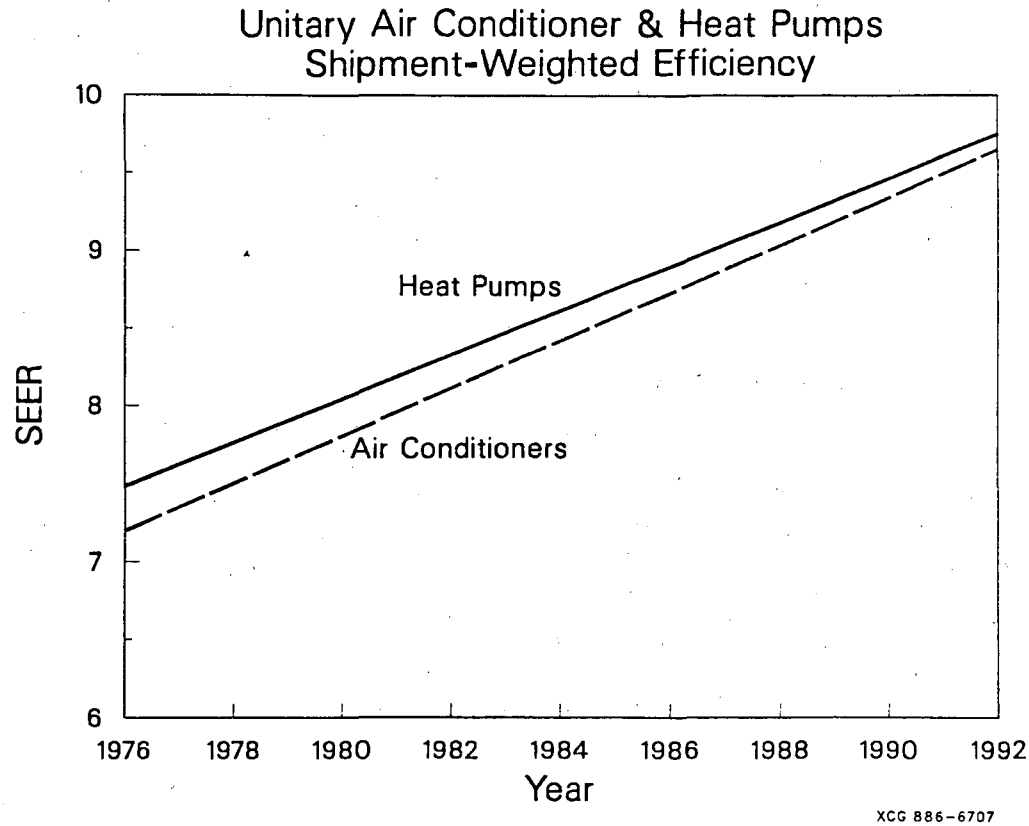


Figure 2



Energy Efficiency Prospects in Lighting

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In 1976 the estimated annual energy use for lighting in the U.S. was about 420 billion kWh (BkWh), 25% of the total electric energy supplied and 5% of total energy consumption.[1] Flourescents accounted for an estimated 51% of the total energy consumption, while incandescents accounted for 37% (see Table 1). Considering the growth of illuminated floor space, coupled with implemented conservation strategies, today lighting probably consumes between 430 and 450 BkWh. The electric load for illumination is particularly important since it contributes a disproportionally large amount during peak demand hours (about 30 to 40%). Thus, the power demand for lighting significantly influences the present and future requirements for electrical generating capacity.

Table 1
Lighting Energy Usage in 1976

	Incandescent		Flourescent		HID	
	BkWh	%	BkWh	%	BkWh	%
Residential	85	53	10	5	5	10
Commercial	50	31	140	64	10	20
Industrial	20	12	50	23	20	40
Street, outdoor					14	28
Other	6	4	17	8		
Total	161	100	217	100	50	100

Since 1976 the main cause of lower energy consumption for lighting has been reduction in illumination levels. Most of the new products installed in the past 12 years at best improved efficiency slightly, but primarily reduced power by decreasing light levels. The rather large reductions in the recommended light levels in the last few years likely precludes further reductions in the future.

Lighting Equipment Performance

Table 2 lists the performance of lighting equipment in 1976, the present and projected in the future. The performance cited for the present is for the new efficient technologies that are just becoming more available in the marketplace, including the one-inch diameter fluorescent lamp operated at high frequency, the high frequency electronic ballast, the compact fluorescent lamp for Edison sockets, and fluorescent fixtures with specular reflectors and controls and dimming standard core-coil ballasts.

The future improvements are based upon current research that has demonstrated viability. The fluorescent lamp can be made more efficacious by Hg isotope enrichment, applied axial magnetic field, the use of two photon phosphors and operating them at

Table 2
Lighting Equipment Performance

	1976	1988	2000++
Fluorescent Lamp Efficacy	80 lm/W	100 lm/W	200 lm/W
Life (hours)	20,000	20,000	100,000
Ballast Efficiency	80%	90%	90%
Fixture Efficiency: Flour.	--	+10%	+10%
HID	--	--	+20%
Light Level	100 fc	50-70 fc	50-70 fc
Power Density	4-6 W/ft2	1.5-2 W/ft2	0.5 W/ft2
Edison Sockets Efficacy	15 lm/W	30 lm/W	80 lm/W
HID Lamp Efficacy	100 lm/W	100 lm/W	150 lm/W
Controls	--	25%	50%

megahertz frequencies with surface waves. The above mode extends lamp life — perhaps by a factor of five — because there are no filaments to fail. The improvement in the fixture efficiency is due to the control of the lamp wall temperature with Peltier devices, heat pipes or venting of the fixtures. Today fluorescent lamps in most fixtures operate 10-20 °C above the optimum temperature of 40 °C, reducing both their light output and efficacy.

The new lamp to repace incandescents and the present compact fluorescent lamps in Edison sockets will be the electrodeless compact fluorescent lamp. This lamp will be a sufficiently intense light source to provide light flux equivalent to a 150 watt incandescent lamp with a longer life than the present compact fluorescents (no electrodes), and be the same physical size as the incandescents.

Electrodeless high-intensity discharge (HID) lamps will be available with higher efficacies, especally for the lower wattage lamps. These lamps will restrike instantly and can be dimmed without significant color shifts. (Presently HID lamps do not possess the latter two qualities, which limits their applications.) All gas discharge lamps will be controlled with electronic ballasts.

The control systems will use power line carrier for communication between the sensors and the dimming controls. These systems will be capable of controlling the light level of the lamps in each fixture independently of the lamps in other fixtures. This will maximize the energy savings possible as well as provide optimum lighting conditions for all of the occupants of the space.

Future Scenario

The average efficacy of the lamps in *incandescent* sockets increases from 15 lm/W to 80 lm/W (electrodeless compact fluorescents). Only 19% of the energy is required to supply the same illumination. About 70% of the sockets in the residential sector have the compact fluorescent. Elsewhere incandescent sockets are largely replaced. The efficacy improvements in the *fluorescent* lamp systems are based on the increased lamp efficacy, ballast efficiency, and fixture efficiency. The new fluorescent system will provide the same illumination with 32% of the energy consumed by the 1976 fluorescent lamp systems.

The *HID* lamp system will use only 53% of the energy to provide the same light based upon the improved lamps and fixtures. The use of *lighting controls* will be driven by the occupants need for large variation in illumination levels in the electronic workplaces. In addition, controls will provide a means to dynamically control power demands for building operators as well as the utilities.

Based upon the above technological innovations, we estimate the future energy use for each type of lamp system for the U.S. (see Table 3). Assuming a three-fold growth in floor space, the total projected energy consumption for lighting is only 58% of the consumption in 1976 despite three-fold growth in floor space. Assuming a two-fold increase in floor space, total energy use is 157 BkWh or 37% of the 1976 level. In addition, with lighting controls, peak demand can be dynamically controlled. The lighting energy used in the industrial, commercial and other sectors is during peak demand hours; power demand amounts to about 53,000 MW. For short periods of time it would be possible to shed 10 to 20% of this load without affecting reducing productivity, reducing the need for peak power generating capacity.

Table 3
Energy Consumption for Lighting in the U.S., Post-2000
High Growth Rate
(Billion kWh)

	Incandescent	Flourescent	HID
Residential	29	6	5
Commercial	25	82	10
Industrial	10	29	19
Street, Outdoor	--	--	13
Other	3	10	1
Total	67	127	48

The new, more efficient technologies that have been developed in the past ten years are now penetrating the market place and should impact lighting techniques in the next ten to twenty years. A requirement for the realization of the above projection is expansion or at least continuation of the current research efforts by the government. New lighting innovations that are based upon different technologies not currently practiced by the lighting industry have been catalyzed by government research efforts. The major lighting manufacturers have continuously reduced their investments in future lighting innovations to low levels that would delay the future implementation of innovations without public activities and endeavors by small entrepreneurs.

The growth of illuminated areas will will be much faster in the developing countries. The application of the latest lighting technologies is thus very important for these nations, as their financial resources expended for generating capacity could be used for their industrial growth.

1. E.A. Krupotich, Business Development Strategy and Market for a New General Purpose Lamp, SRI Report MEC-5670, pp.18-20 (December 1976).

Energy Efficiency in Buildings: Progress and Potential

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Progress Since 1973

Dramatic improvements have occurred over the past 15 years in the average energy efficiency of U.S. buildings. A typical large office building constructed in 1973 has an annual energy bill of $\$3.00/ft^2$ (shown way off the chart in Figure 1). Since 1973, efficiency improvements in response to ASHRAE standards, state and local building codes, and market forces have brought typical annual energy costs down to less than $\$1.50/ft^2$, and new energy efficiency standards in California promise to bring annual energy costs down to less than $\$1/ft^2$. The trend in non-residential construction has been towards all-electric buildings—and even then new office buildings in 1987 are using 50% less electricity than 1973 office buildings.

For a large set of all-electric office buildings for which data were compiled by LBL,[1] the average measured energy use was 19 kWh/ft^2-yr. However, ten of the most efficient new buildings use less than 14 kWh/ft^2-yr, and the best-performing building, the Ohbayashi Technical Research Institute in Tokyo, Japan, uses about 3.5 kWh/ft^2-yr and has an energy bill less than $\$0.25/ft^2$-yr.[2] When changes equivalent to these "best-practice" commercial buildings capture the entire new-construction market and eventually replace existing stock, we will be saving primary energy equivalent, in our terms, to about one "Alaskan Pipeline" and about 90 power plants.*

Figure 2 also shows trends in the U.S. residential housing stock from 1978 through 1984. Fuel use has gone down by 25% since 1978 with only a slight reduction in electricity use despite increased saturations of electric heat and central air conditioning in new homes. Current practice in Sweden shows similar electricity use as in the U.S., but one-half to one-third the fuel use despite a much colder climate. Our analysis of several hundred single-family houses shows that good passive solar design, insulation, and low-infiltration construction practices can reduce space heating loads (i.e., the output of the heating system) to as low as 1.5 Btu/ft^2-HDD (heating degree-day, base 65 ° F) or roughly half the heating requirements of typical new U.S. homes.[3]

Energy Efficiency as a Demand-side Energy Resource

The concept of energy efficiency as a demand-side energy resource rests on the underlying idea that demand for energy as a *commodity* (e.g., coal, oil, or gas) is secondary to the demand for energy *services* (e.g., heat, light, transport of people or goods, or shaft-power in an industrial process). If improvements in energy efficiency provide the same end-use service at a lower level of energy consumption, then they can be considered as much a part of the future resource mix as new energy supply.

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* To provide a sense of scale for these large demand-side savings, we employ the conventions that one "Alaskan Pipeline" equals the amount of fuel currently delivered by the Alaskan Pipeline, about 1.9 Mbod (U.S. EIA, 1987) and that one "power plant" equals the annual electricity output of a large, baseload (1 GW) power plant, or 5 TWh.

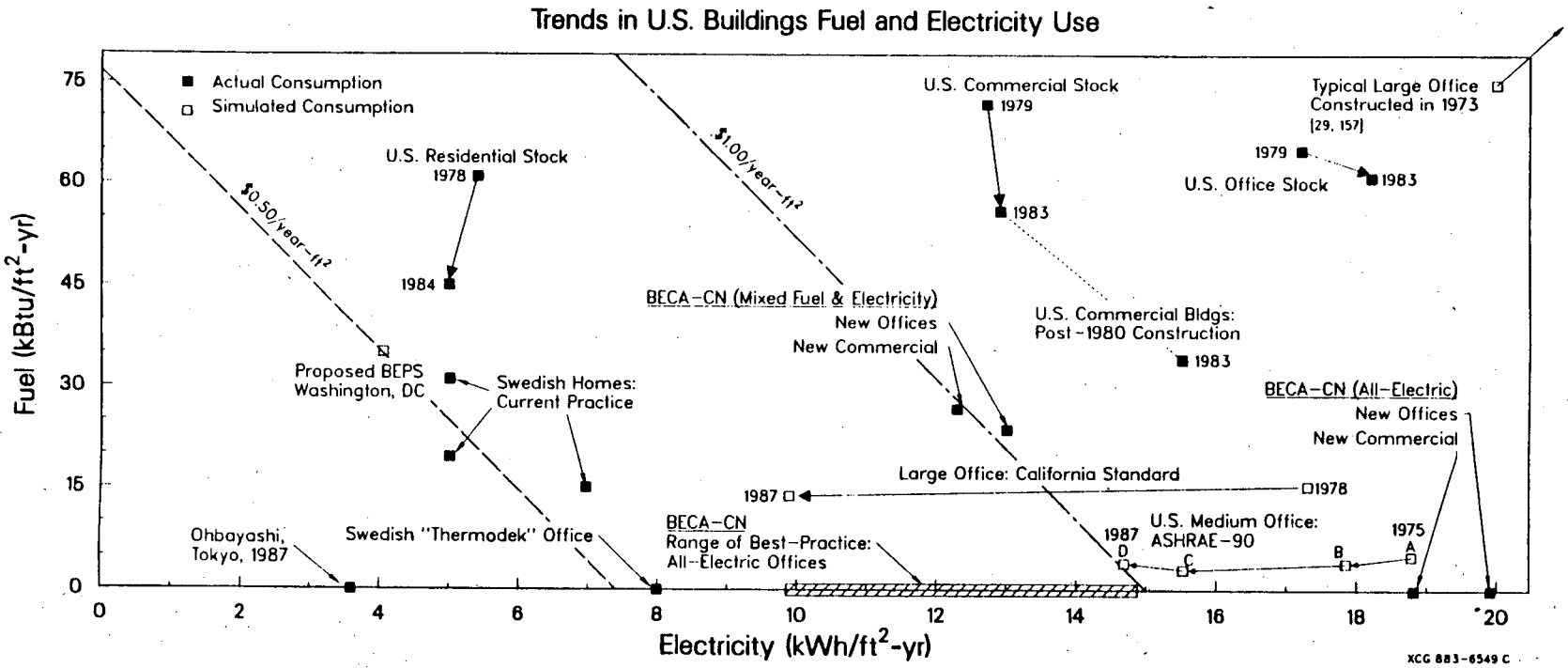
The technical potential for conservation as a demand-side resource can be determined using a "supply curve of saved energy" (or peak power).[4] A conservation supply curve ranks efficiency measures (or programs) in terms of their cost-effectiveness in order to compare the energy savings with energy supply options or with the average cost of today's energy. As an indicator of cost-effectiveness, we often use the *cost of conserved energy* (CCE) or cost of avoided peak power. This is the annualized cost of implementing a demand-side measure (including costs for program implementation), divided by the annual energy or peak power savings of the measure. The advantage of the CCE over other cost-effectiveness indicators (payback time, etc.) is that it can be compared directly with the cost of purchasing the same quantity of energy.

The conservation supply curve shown on the right side of Figure 2 is for the state of Michigan. It can be used to determine a reduced energy demand scenario, as compared with a "business-as-usual" forecast. This supply curve is for efficiency measures in the residential sector and is projected to the year 2005.[5] Each "step" represents a collection of conservation measures for one end-use, applied to the current stock of Michigan residences. Options include more efficient air conditioners, lights, water heaters, space heaters, refrigerators, and freezers. Both costs and penetration rates reflect actual experience with customer incentives or other programs implemented in other states. The height of each step is the CCE (in ¢/kWh) for a package of measures related to one end-use; the width is the estimated annual electricity savings (in GWh). This plot makes it easy to see which conservation measures save the most electricity and which are economically most attractive. The LBL program-based scenario would save 29% of Michigan's present electricity demand at a cost of conserved energy less than 3.3 ¢/kWh, which is the operating cost of existing coal power plants.

References

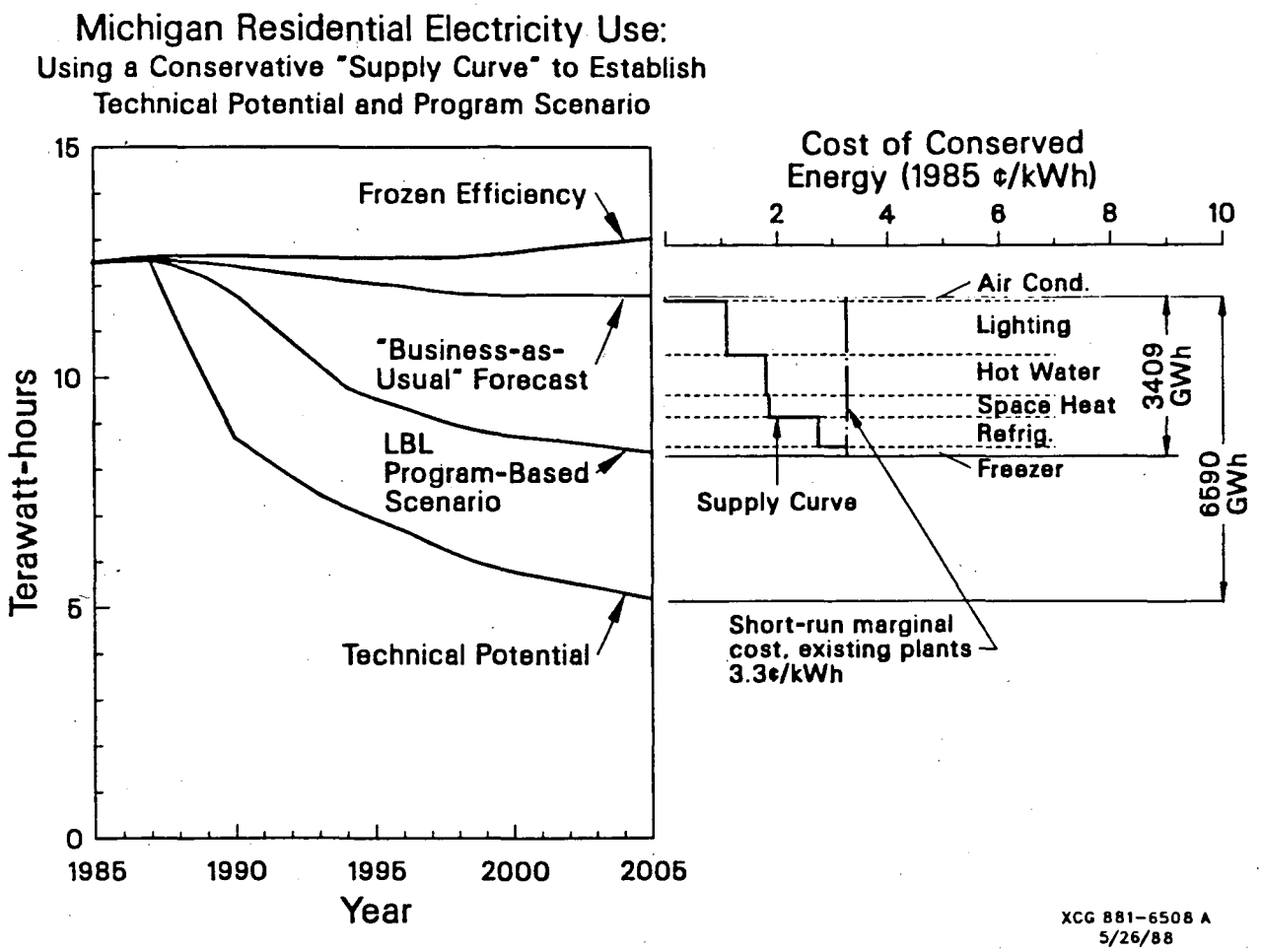
1. Piette M.A., L.W. Wall, and B.L. Gardiner (1985). *Measured Energy Performance of Energy-Efficient New Commercial Buildings: Results from the BECA-CN Data Compilation*, LBL-19413, Lawrence Berkeley Laboratory, Berkeley, CA.
2. Piette, M.A., and Andersson, B. (1988). *Ohbayashi Corporation Technical Research Institute Headquarters Building*, ASHRAE/LBL Case Studies of ASHRAE Energy Award Winners, Lawrence Berkeley Laboratory, Berkeley, CA.
3. Busch, J.F., and A.K. Meier (1985). *Monitored Performance of New, Low-Energy Homes: Updated Results from the BECA-A Data Base*, LBL-18306, Lawrence Berkeley Laboratory, Berkeley, CA.
4. Meier, A., J. Wright, and A.H. Rosenfeld (1983). *Supplying Energy through Greater Efficiency: The Potential for Conservation in California's Residential Sector*, Berkeley: University of California Press.
5. Krause, F., A. Rosenfeld, M. Levine, J. Brown, D. Connell, P. duPont, K. Greely, E. Mills, and B. Nordman (1987). *Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector*, LBL-23025, Lawrence Berkeley Laboratory, Berkeley, CA.

Figure 1



Trends in Buildings' Fuel and Electricity Use. Measured and simulated energy intensities are shown for new U.S. non-residential and residential buildings, with fuel use on the vertical axis and electricity on the horizontal axis. Both axes are scaled to primary energy costs; the 45-degree diagonal lines represent annual energy costs of \$0.5 and \$1.00 per square foot (assuming average U.S. energy prices of \$0.65/THERM and 6.7¢/kWh). The average new office building in 1973 is off the scale, with an energy bill of \$3/ft^2-yr. Since 1973, efficiency improvements in response to ASHRAE standards, state and local building codes, and market forces have brought typical energy costs down to less than \$1.50/ft^2-yr. New energy efficiency standards in California promise to bring annual energy costs down to less than \$1/ft^2-yr. The trend in U.S. non-residential construction has been towards all-electric buildings; this explains some of the change in fuel use, in addition to improved envelope and heating system efficiency. New commercial buildings are also more likely to be air-conditioned; this offsets some of the efficiency gains in lighting and other electricity uses. Based on measured performance, the most efficient all-electric offices in the U.S. cost only \$0.75—1.00/ft^2-yr, down to one-third of the 1973 average. The best measured performance to date for an office building is the "super-energy-efficient" Ohbayashi Corporation Technical Research Institute Headquarters in Tokyo, Japan, which uses under 3.5 kWh/ft^2-yr. At U.S. prices, its annual energy bill would be less than \$0.25/ft^2-yr. Trends in the U.S. residential housing stock show fuel use going down by 25% since 1978 with only a slight reduction in electricity use. Current practice for new homes in Sweden shows similar electricity use as in the U.S. stock, but almost one-third the fuel use despite a much colder climate.

Figure 2



Michigan Residential Electricity Use, 1985-2005: Using a Conservation "Supply Curve" to Establish Technical Potential and Program Scenario. The left-hand side of the Figure shows baseline residential electricity demand forecasts for the state of Michigan, as modified by two energy conservation scenarios. The "Frozen Efficiency" line, shown for comparison, represents the effect of population growth and changes in appliance saturation only. The right-hand side of the Figure shows how a "supply curve of saved energy" defines the difference between the baseline and conservation scenarios. To construct the supply curve, we estimate electricity savings and costs (in ¢/kWh saved) for many end-use measures. The measures are then ranked by increasing cost per kWh saved, until the unit cost of conservation reaches an economic limit (in this case, 3.3 ¢/kWh, or the average short-run cost of supplying power). Thus, saved energy can be compared in economic terms with equivalent new sources of energy supply. The "steps" shown in this supply curve are aggregates of individual measures, by end-use. In this analysis, the total "conservation resource" potential was 6590 GWh/year, as of 2005. The final supply curve modifies this technical potential based on expected participation rates. The program scenario shown would achieve about 50% of the potential savings, or 3409 GWh, through consumer information and incentive programs.

Urban Trees and Light-Colored Surfaces: Inexpensive and Effective Strategies for Reducing Air Conditioning Energy Consumption

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Urban climatologists have demonstrated that developed urban areas create summer heat islands with typical daily average temperatures 3 to 5 degrees Centigrade hotter than the rural forested areas surrounding them. In high-latitude cities with cooler weather, heat islands can be an asset in reducing heating loads, but in mid- and low-latitude cities, heat islands contribute to the urban dweller's summer discomfort and significantly increase air conditioning loads. Long before the era of air conditioning, people cooled their homes in the summer by planting trees around the house and painting the walls and roofs white. Planting trees in urban areas can reduce summer heat islands and cooling energy use in buildings through shading, evapotranspiration, and wind shielding at only about 1% of the cost of avoided power plants and air-conditioning equipment. Using light-colored paints and surfacing the asphalt of streets and parking lots with lighter-color sand are also effective in reducing heat islands and summer air conditioning electricity use.

In addition to saving energy, urban trees and light-colored surfaces are probably the most cost-effective ways for decreasing the growth of atmospheric CO_2. By reducing the need to burn coal for generating electricity, urban trees are indirectly many times more efficient than rural forestation in sequestering CO_2. Our research shows that urban trees and light-colored surfaces can save 0.5 quad per year with a payback time of 0.2 to 1 year, and decrease carbon emissions by about 25 million tons per year.

Energy Savings and CO_2 Effects

Of the 86 million households in the United States, 51 million own air conditioners. With average use of 2000 kWh per year, total usage is about 100 BkWh or 1.16 quads of source energy per year. (Air conditioning power is mainly "on-peak" and cost of new peak power is close to 10 ¢/kWh.) Our analysis shows that the **direct** effect of planting three trees per house along with increasing building albedo for 50% of the 51 million air conditioned houses can result in roughly 15% air conditioning energy savings.[1] This corresponds to a savings of 0.17 quad equivalent and a reduction of 7 million tons of carbon. (see Table 1). The corresponding direct savings for small commercial buildings is about 0.05 quad (a total of 25 million more trees/light surfaces around small commercial buildings, streets, and parks). These direct savings of 0.22 quad would be achieved by planting a total of 100 million urban trees.

As for **indirect** savings, our preliminary results from simulating the effect changes in the amount of urban vegetation and the magnitude of urban albedo have on urban microclimates suggest a total savings of 0.23 quad of residential energy use. By reducing temperatures throughout the city, these measures also decrease cooling energy demands for commercial buildings by about 0.10 quad as well. The combination of direct and heat island savings due to both residential and commercial buildings represents 0.55 quad of primary energy and 23 million tons of carbon emissions each year.

The Cost of Conserved Energy and Carbon

Table 2 compares the effectiveness of urban trees/light surfaces to other conservation strategies. For example, the trend to more efficient electric appliances yields a cost of conserved energy (CCE) of about 2¢ per kWh saved. This corresponds to a cost of conserved carbon (CCC) of 2¢ per pound of carbon, since coal-fired power plants burn and emit approximately 1 lb of carbon in the form of CO_2 for each kWh generated. Another strategy is improving efficiency in automobiles. The cost of conserved carbon in going from an automobile that gets 26 mpg to one that gets 36 mpg is estimated at about 8¢/lb C. Both these measures are effective and proven, but urban trees and light-colored cities, with an approximate CCC of about 0.1-1.0¢/lb of C, is perhaps ten times cheaper than either of the examples mentioned above. The point in the comparison is not to discredit the other conservation strategies, but to suggest that planting urban trees and modifying urban albedos seems even more attractive, and definitely worth investigating.

Issues of Implementation

An estimate of the costs for a large-scale urban tree planting program can be obtained from the recent experience of Los Angeles. A vigorous tree-planting program was undertaken in 1983, when it was decided to beautify the city by planting a million trees before the 1984 Olympic games. This effort was spearheaded by the Tree People. Georgia Pacific supplied more than a million drought-resistant seedlings, which were distributed by a fast-food resaurant. The project cost less than $1 million, mainly for printing and advertising, which translates to a cost per seedling of only $1. In addition to the planting costs, there are potential problems associated with increased urban trees.

There are many ways to modify the albedo of a city: when it is time to repaint or reroof or resurface asphalt, lighter colors can be substituted for the existing color of buildings, reflective rooftops can be used, and white sand can be rolled onto the top of asphalt. Since many urban surfaces need to be recoated eventually, the cost of these methods may be less than the cost of planting and maintaining trees. In contrast to planting new trees, altering the urban albedo starts to pay for itself immediately. If done slowly, it need not create major conflicts. An essential element in any undertaking to modify the urban albedo should be an ongoing dialogue with the public to obtain their input and cooperation.

The cost of trees/light surfaces is quite small (~$15-75/home once compared to $100/year for air conditioning), but there are questions as to how the cost should be apportioned. Businesses and residents alike benefit from a more comfortable environment and from lower summer cooling costs. Utilities benefit from reduced peak power demand, which translates into the construction of fewer new power plants. Cities benefit from an improved local climate since environment is an important consideration for people and businesses deciding where to locate. The cost of planting and maintaining trees in large quantities are low. Since most home owners like to plant trees anyway, all that is needed is a little encouragement and some information on what kind of trees and where to plant them for the most energy savings benefits.

References

1. Akbari, H., Huang, J., Martien, P., Rainer, L., Rosenfeld, A., and Taha, H. (1988). *The Impact of Summer Heat Islands on Cooling Energy Consumption and Global CO_2 Concentration.* LBL-25179, Lawrence Berkeley Laboratory.

Table 1. Yearly savings of primary energy used for air conditioning in the U.S. and consequent reductions in released carbon[1].

	Residential[2]			Small Commercial[3]			Large Commercial[4]		
	Energy (%)	Energy (10^{15} Btu)	Carbon (M Tons)	Energy (%)	Energy (10^{15} Btu)	Carbon (M Tons)	Energy (%)	Energy (10^{15} Btu)	Carbon (M Tons)
Direct Savings	15	0.17	7	8	0.05	2	0	0.0	0
Heat Island Savings	20	0.23	10	12	0.07	3	5	0.03	1
Total	35	0.40	17	20	0.12	5	5	0.03	1

1. Production of carbon (as CO_2) from a coal-fired power plant assumes 11,600 Btu/kWh sold, and ~11,600 Btu/lb of carbon.
2. **Residential.** US annual residential electric use is ~ 100 BkWh/yr, corresponding to 1.16 Quad. We assumed 3 trees (plus light surfaces) for 50% of our 50 million air conditioned homes, so 75 million trees (plus light surfaces).
3. **Small Commercial.** US uses 50 BkWh (= 0.58 Quads). We assumed 25 million more trees (near these buildings and in parks and parkways), so 100 million trees in all.
4. **Large Commercial.** US uses 50 BkWh (= 0.58 Quads). We assumed no additional trees.

Table 2. Cost effectiveness, energy savings, and carbon savings of urban trees/light surfaces, efficient electric appliances, and efficient cars.

Measure	CCE[1] (¢/kWh) or (¢/gal)	Payback Time (yr)	CCC[1] (¢/lb C)	Implemented $Fraction$[1] (%)	ΔUEC[1] by 2000	ΔE (Quad/yr)	ΔC (M Tons/yr)	Cost of Program ($B)
Urban Trees/ Light Surfaces[2]	0.2-1.0	0.3-1.8	0.2-1.0	50	24%	0.55	23	0.5-2.5
Efficient Electric Appliances[3]	2	3	2	100	17%	.6	26	10
Efficient Cars[4]	50	2.5	8.3	100%	38%	2.8	60	50

1. a) CCE is Cost of Conserved Energy, CCC is Cost of Conserved Carbon, and UEC is Unit Energy Consumption.
   b) Program cost is the nation-wide cost for implementing the measure.
2. **Urban Trees/Light Surfaces**
   a) To estimate the CCE and CCC, we assumed that 100 M trees (Table 3) cost $5-25 each (including their water consumption for two years) for a total cost of $B 0.5 to 2.5. The real interest rate is assumed 7%. We would plant 3 seedlings per air conditioned house, and it takes about 10 years for seedling to yield adequate shade.
   b) In calculating CCC, we assumed that electricity is produced from coal-fired power plants at 1 kWh = 11,600 Btu = $\sim$ 1 lb of carbon.
   c) ΔUEC for air conditioning is the sum of direct and indirect effects of urban trees/white surfaces for both residential and commercial sectors.
3. **Appliances**
   All entries for this row are based on information provided by Geller 1987.
4. **Cars**
   The entries for this row are based on Ross 1987.
   a) The fleet average is assumed to improve from 26 to 36 mpg.
   b) The CCE for improving the efficiency of cars from 26 to 36 mpg is estimated to be 50¢/gal.
   c) The CCC assumes 6 lb of carbon in a gallon of gasoline.
   d) Today, at 18.6 mpg, we use 6.63 Mbod of transportation gasoline. The 26 mpg standard will reduce this 6.63 to 4.75 Mbod. Further gain from 26 to 36 mpg will reduce 4.75 to 3.42, saving of 1.33 Mbod, corresponding to 2.8 Quads.
   e) Program cost is based on 125 million cars and light trucks at an additional cost of $400 each.

Efficiency and Structural Change in Industry in Europe

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From 1973 to 1979 the final energy use in industry for 10 countries of the European Community dropped by 4.2%, despite growth in industrial output of 16%. In our study of European industrial energy use, we found that intersectoral structural changes had an effect on final energy use of -3.4%. Increased energy efficiency, with an effect of -14.1%, was responsible for most of the overall reduction of final energy use (Figure 1).

During the period 1979-83 European industry experienced a recession and value added fell by 2.3%. Between 1983 and 1985 value added increased by 3.9%, reaching a higher level than in 1979. While industrial fuel consumption fell drastically by 21.9% from 1979 to 1983, it grew slightly by 1% during the following two years. Electricity consumption in industry fell by 5.8% between 1979 and 1983, then increased significantly by 7.1% during the following two years.

Specific fuel consumption dropped by almost 20% from 1979 to 1983. Reductions were achieved in all countries, but differed in size. They were rather low in still industrializing countries (Greece, Ireland, Portugal) and high in countries where significant structural changes took place (Denmark, Luxembourg). Intersectoral structural changes reduced specific fuel consumption by 3.3%, since the fuel-intensive branches experienced an above-average decline during the economic recession.

About 80% of the decrease in specific fuel consumption of European industry was due to technological/organizational measures favoring a more efficient use of fuels, and to other structural changes towards less energy-intensive production. During the period 1983-85, however, the influence of these factors weakened perceptible, leading to specific fuel "savings" of only 2.2%.

The reduction in specific electricity consumption during 1979-83 was mainly attributable to technical and organizational measures and other structural changes. In 1983-85, however, further efforts towards a more efficient use of electricity were more than offset by short-term structural influences due to the business cycle and technological developments favoring a rising electricity consumption. These included increasing automation and mechanization, growing application of electricity-using process technologies, increasing use of computer-assisted systems, and technologies for environmental protection. As a result, specific electricity consumption rose by 1.5%. As in the previous period there was, however, a great disparity in the results among individual countries.

Future Energy Use in Industry

From our analysis of the components of change in energy use in European industry from 1973 to 1985, we estimate the long term effect of structural change on energy use at -0.5%/year. This estimate includes intersectoral as well as intrasectoral structural changes (the effects of the business cycle have already been subtracted). Further in the future, the long term effect of structural changes in the European industry will increase to -0.7%/year because of the industrialization of Spain, Portugal, Greece, and Ireland. The effect might, however, be lessened if energy-intensive products are produced in developing countries.

In 1985 the average energy efficiency in Europe was about 50%, but exergy efficiency is still less than 10%. Improvements in energy efficiency can be reached through an enlargement of system boundaries, e.g. using cold outdoor air in winter for refrigerators, through energy cascading or by using cogeneration. There follows estimates of the long term potential for rational energy use and efficiency improvements in industry.

(1) Recycling of used and energy-intensive material (e.g., metals, paper, plastics) as secondary raw materials could apply to 50% of energy-intensive basic materials. In these areas, the energy-saving potential is 40-50%.

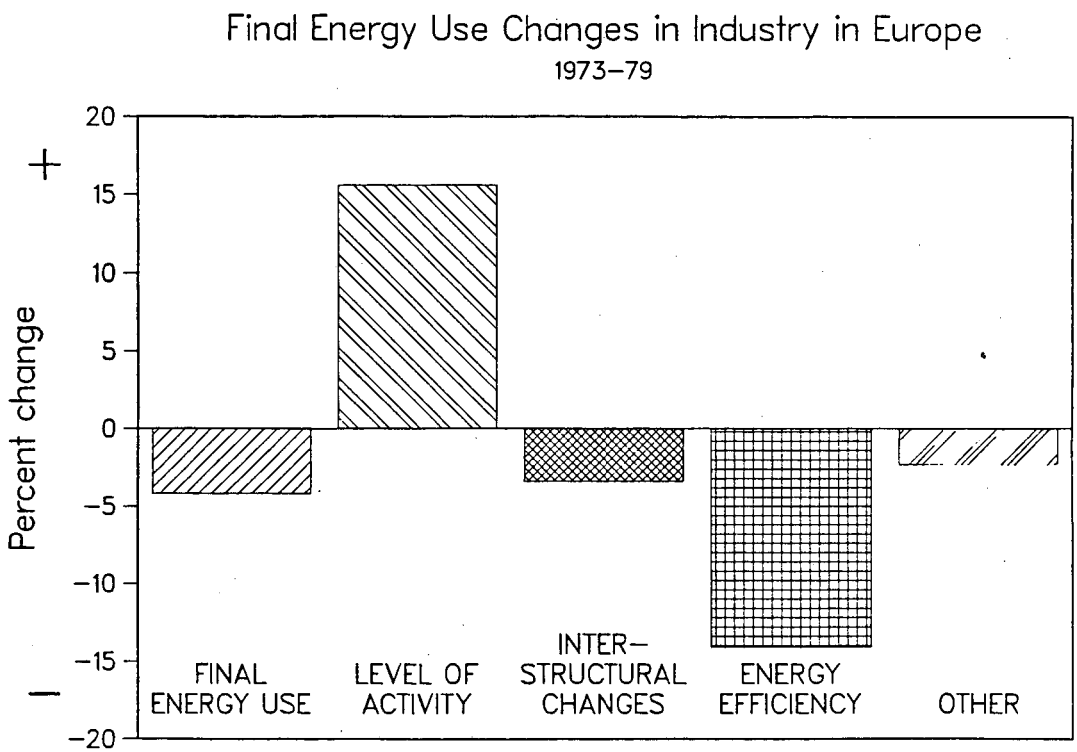
(2) Reduction of material requirements by improved construction and design and longer lifetimes could apply to 50% of capital and consumer goods. The energy-saving potential is 30-50%.

(3) Process improvements include reducing waste heat by heat insulation, heat exchangers, and better control, and reducing energy use by addition of catalysts, enzymes, and higher turbulence. These could affect 30-50% of industrial production and bring energy savings of 10-30%.

(4) Process substitution by membrane technologies and absorption extraction, by substitution of solvents with low evaporation energy needs, and use of biotechnological rather than thermal process could effect 20% and more of industrial production. Energy savings could range from 10% to 90%.

There are also long-term tendencies to increased energy demand, mainly electricity, because of circulation of raw materials and waste heat, environmental protection, and further automation. But the prospects for increase are probably an order of magnitude smaller than the potential for energy savings.

Figure 1


Final Energy Use Changes in Industry in Europe
1973–79
Percent change
+
−
20
15
10
5
0
−5
−10
−15
−20
FINAL ENERGY USE
LEVEL OF ACTIVITY
INTER–STRUCTURAL CHANGES
ENERGY EFFICIENCY
OTHER

Structural Change in Industry Over the Long Run

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In considering long-run trends in the world's production of industrial goods, one must look at projection issues concerning population, gross domestic product (GDP), political and social factors, and industrial shares of GDP.

Population projections, despite their use of sophisticated age cohort analysis and the fact that they are among the most accurate of our long run projections, ultimately depend upon assumptions about age-specific death rates and changes in age-specific birth rates until the magical point is reached at which the net reproduction rate equals 1. For a number of years, "median" population projections for many countries have been decreasing, but recently there has been some tendency to project higher future totals. For the industrial market countries the World Bank currently forsees a drop in population by about 10 million (-14%) between the year 2000 and the eventual, hypothetical stationary size total.

Trends in the annual growth rates of GDP have been shown to be influenced by, among other factors, population growth, capital investment, foreign trade, and the level of per capita GDP already attained. Country variations, however, are large, and one-fourth to one-third of intercountry variations in growth rates prove difficult to explain. Projecting rates into the future is difficult without accurate estimates for the various "independent" variables (population, capital investment, etc.). Even this method would leave out possible negative effects resulting from resource depletion, global pollution, and perhaps the effect of AIDS. Such "feed-back" effects on growth have not been seriously looked at since the first Club of Rome studies.

Perhaps the most that can be said about GDP growth is that, historically, rates have tended to follow a rough bell-shaped curve. Country growth rates have tended to rise, often after many discouraging years of development efforts, reach a peak at some middle level of income, and then gradually decline as countries became richer.

The historical record is clearer about changes in the composition of GDP during the course of economic development. Such longer-run changes as the transformation of agriculture and the relative increases first of manufacturing and then of services are well-documented. Less well-known is the fact that relative prices also change during the process of economic development. This means that our "constant price" measures of GDP components will inevitably be distorted as will our judgements on the growth and decline of these components. Further, several important elements are left out of all official GDP measurements. Examples include most family labor and losses from pollution, congestion, and natural resource depletion. The GDP concept itself gives but an imperfect idea of differences among countries and of changes in a country's welfare over time.

Among countries, the realignment of international power continues, especially as former middle-income countries move into the ranks of the richer countries. The distribution of political power has undoubtedly had some effect on the past international division of labor, and it is likely that the relationship between political power and economic activities will continue. In addition, there are often power realignments within a country during the course of economic development. These are especially relevant to questions of

equity, and they may have an indirect effect on the pattern of industrial production.

Industrial Shares

Much of my study of changing production patterns during the course of economic development has followed in the tradition of Chenery, namely that of cross-country statistical analyses for a particular period of time. I have shown, for example, that:

1. For almost all of our more common bulk commodities (crude steel, paper, lumber, nonferrous metals, etc.), per capita consumption increases at a constantly declining rate as incomes rise. Consumption goes up, in other words, but at a slower rate of increase. In most cases the equations suggest that consumption will reach an absolute upper limit (per capita) at some time in the future.

2. The consumption of the more energy-intensive materials, perhaps unduely influenced by the global economic doldrums of the last decade or so, appears to have fallen even more dramatically in the richer countries than the cross-country relationships would have predicted.

3. In the case of foreign trade in manufactured goods, a 1985 study done for the United Nations Industrial Development Organization suggests a serious conflict. As countries get richer, their desire to export manufactures far outpaces their desire to import manufactures. This means that serious imbalances are likely to occur, certainly until the end of the century, between potential global exports and potential global imports. Even greater inconsistencies between potential supply and demand are likely for individual commodity groups. If these tentative findings prove correct, they suggest that international trade balances can only be achieved by (a) more structural change than so far observed in favor of agricultural and service exports and away from manufacturing exports, or (b) serious price reductions in order to bring desired exports in line with desired imports.

Conclusions Relevant for Global Environmental Change

Our ability to make long-run economic projections is still quite poor. We can say something about population trends, we can hope that technology will continue to find ways around potential natural resource scarcities, and we are fairly sure that poor people will continue to want to become richer. (It is much less clear where today's richer countries are headed with respect to the quest for increased material wealth.) There is some evidence, furthermore, for a theory of evolving comparative advantage as a country's endowment of natural resources, capital stock and human skills change over time.

Uncertainties, however, abound. At what point might major shifts be brought about by natural resource scarcities, global pollution (including global warming), and possibly an increasing disillusion with materialistic pursuits? How will global solutions be found for conflicts between those who wish to export and those who wish to reduce their imports, between those who wish to consume and those who wish to conserve, between those who wish to clean up the environment and those who feel they cannot afford to do their share?

Two conclusions appear firm. The world's richer countries are not going to be able to deny the increasing economic and political power of the world's middle-income countries. Thus, the shape of their future will be largely determined outside of their own borders.

Industrial Processes in the Long Run

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In thinking about the long-run prospects for industrial processes, it is useful to consider the fundamental relationship between energy and production. First, in every instance where we use energy, we do so to cause a specific, desired change in a material body. We use energy by causing two or more material bodies to interact. When we use energy, the change we seek to impose on the object is one which will make it more distinguishable from its surroundings. A finally-formed gear is easily distinguishable from the blank from which it is formed, which is in turn distinguishable from the bulk metal stock from which it was cast. This principle applies to reconfiguring the electronic states of a computer memory to record data as well as to the gross mechanical deformations of metal forming.

Another way of stating the above is that at each stage of production we use energy to inscribe information on matter. The key to economic efficiency in any production process is to inscribe the desired information upon the object rapidly, directly, and accurately. By directly one means that it is better to inscribe the information in one step rather than two if it can be done without sacrificing speed or accuracy. Accuracy is important because the need to compensate for information that has been transcribed incorrectly is often at the root of production costs that are unnecessary in principle. The information inscribed on the object defines its function, and extraneous information can obscure that function.

In a production system we take information from some source and transfer it to a material body. The medium of transmission is the flux of power one directs upon the object. The content of the information originates in the human brain. One is concerned with establishing effective coupling between the transmitter, the medium of transmission, and the receiver.

In most cases, the inscribing of information on matter makes use of electromagnetic phenomena. One wants to use the power flux to excite certain responses in the material, while not exciting others. For it is the effect of the interactions on other bodies (the atmospere, the earth, the oceans) in which almost all environmental concerns arise. The power flux should also have no or little noise and be capable of transmitting information over a large band width.

Electricity is a stream of power capable of carrying a large flux of information with minimal loss or error, and it can be converted to other forms of electromagnetic power with little loss of information. It thus offers far greater opportunities in production technology than obtain in the family of techniques based upon directing a flux of heat upon the object. It is not surprising that increased use of electric power has been correlated with accelerations in productivity growth. Along with electric power, another avenue that appears to offer important opportunities to impress information on matter with relatively high speed, control, and precision is the use of biological phenomena in production.

Long-Term Energy Demand: Production or Pleasure?

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To consider future energy demand in industrialized countries in the long term, it is useful to divide energy users into two kinds of activity: production and consumption. *Consumption* includes uses in the home and on the road, as well as uses for consumers in aircraft and in buildings that house personal services. *Production* includes energy use in industry, freight transport, business services and government administration. As industrial economies evolve, production gradually comes to account for a diminishing share of total energy use (see Figure 1, based on analysis done by the author for West Germany).

Producer Energy Uses

In **industry**, energy intensity (energy per ton, or per unit of value added) has declined steadily in the U.S. and other countries for decades. This decline was led by falling fuel intensity, while electricity intensity in most countries moved up slowly. Temporarily lower energy prices are unlikely to reverse the trend. In addition, the U.S., as well as most other wealthy countries, has been heading towards lower materials intensity for a long time. This means that less bulk is produced, reducing energy use for freight as well.

In **business services** -- mostly energy use in offices for public and private administration -- activity will likely grow faster than GDP. Demographic change, particularly ageing, may change the role of education and medical care, which might force government (and private) expenditures for these activities to increase. For all services, space conditioning and lighting, which dominate energy use today, will become less energy intensive. Information technology uses are exerting upward pressure on electricity use. At the margin, this sector depends more on electricity than any other sector in the economy. Note, however, that business services are still less electricity intensive than manufacturing.

In **freight** transport, energy use per ton-kilometer fell as oil and electricity replaced coal in the railroads, but then increased as trucks took an increasingly larger share of freight. But the modal shares are now changing more slowly, while trucks have improved in both energy efficiency and in their utilization since 1973. More recently, air freight has grown dramatically as its costs have decreased. But the most important part of the evolution of energy use for freight is its ever diminishing share of total energy use as the amount of *bulk* in mature economies decreases.

Consumer Energy Uses

Energy use for personal transportation, personal services (including restaurants and hotels, cultural and leisure services, shopping) and homes is directly affected by consumer choices. These choices present the energy planner with different kinds of uncertainties than the technological uncertainties of energy use in factories or for freight. To be sure, energy prices and the level of personal incomes will affect energy use choices. But once a society reaches the level of affluence enjoyed by most Swedes, Germans, or Americans, the basic "needs" as related to energy are satisfied, and changes in the *utilization* of the stock become more important than changes in the level of ownership. Consumer choices as to

how to use their homes, cars, and where to spend their time when away from home, will play an increasingly important role in the determination of overall energy use.

In **homes**, space comfort needs dominate energy use. Central heating is saturated in most countries, and air conditioning is in more than 60% of homes in the U.S. and Japan. Buildings now leak 20-40% less heat (or cold) than before 1972, reducing energy needs considerably. Hot water use and the services of appliances are still growing, albeit slowly, while cooking energy use has been declining for decades. In all these applications, the conversion of delivered into useful energy has improved markedly, but there remains an enormous potential for increased efficiency. If this potential is realized over the next three decades, total household energy use will decline in most wealthy countries. Westerners are spending increasingly for low-energy, high-tech appliances with trivial energy use. It appears that the structure of home energy use is headed towards lower energy intensity. That is, the income elasticity of home energy use is now less than one.

Demography is exerting a small offsetting force. The shrinking of household size, which is expected to continue slowly for several decades, increases energy use per capita by spreading uses for heating and many appliances over fewer people. For Holland this "unbundling" increased per capita residential gas use by 33% between 1960 and 1985; for the U.S. the effect was around 15%. Even if house size remains constant, space per person will increase. In all, household energy use per capita will not fall as rapidly as use per household.

One way to examine the question of utilization is to consider the time people will spend in their homes, and what they will do with that time (Figure 2). Particularly important is the disposition of free time, which has increased in most countries. During the past several decades, out-of-home leisure has increased, while increased work-force participation decreased occupancy of homes further. The reduction in time spent at home reduced home energy use somewhat, as energy use for water heating, cooking, and many appliances tends to be proportional to time spent at home, or occupancy. Reduced occupancy also had a downward impact on space heating needs. Whether future families are home more or less, whether more people choose to live alone, will have an important impact on energy use, but the magnitude and sign is very uncertain. The ageing of the population will be important, but here too the impact is uncertain.

The nature of the home -- its physical shape and location, its utilization as a place for increased paid or unpaid work -- will doubtless change because of economic pressures, changing tax policies vis a vis home ownership, family size/structure, and most of all, technology. There are many new technologies today, mostly related to information, as well as pasttimes (gardening, do-it-yourself) that might grow in popularity and cause people to stay home more. The uncertainties in residential energy use arise mainly from non-energy factors, and as such, lie outside of the approach taken by most energy modellers and planners. As a rough estimate, plausible lifestyle variations in today's American households, applied to the present stock of houses and appliances, could cause changes of +25 to -33% in home energy use. Some of this change would appear (with the opposite sign) in the services sector.

In **personal services**, energy-use patterns are determined by the functions in the building and the location. For much of this sector, energy use depends on where and how people choose to spend their money and free time, and how those competing for this time and money make their business attractive. As with homes, there are many opportunities for energy savings, but many customer-related factors prevent them from being fully realized. The calculus of those operating buildings may not take all energy saving opportunities into account, unless cost pressures rise. Like business and government services, the

personal services sector holds potential for structural growth, and this growth would be more electricity dependent than in either the residential or industrial sectors.

In **personal transport** lies the most important source of variability in future energy use. The pattern of automobile use at present (in the U.S., roughly 1/3 to/from work, 1/3 for family business, 1/3 for leisure) is sensitive to distances between where we work, sleep, and play, as well as how often we choose to move about. Very little car use is simply for excursions. Similarly, airline travel, already dominated by personal rather than business travel in the U.S., is increasingly determined by how and where people choose to spend their free time.

Traditional economic factors may explain part of the behavior of consumers vis a vis travel, at least in the short run. Airline travel is very sensitive to costs (including the costs of staying at the destination), as the recent boomlet in US air travel that accompanied airfare wars showed. Automobile use tends to be relatively insensitive to income changes once people have cars, and car owners will only sacrifice their mobility for short periods when gasoline becomes expensive or hard to get, preferring instead to shop for more efficient cars.

The level of mobility is the most significant uncertainty in future energy use. The pattern of time use will determine how much mobility is required, unless severe congestion, a sudden increase in energy costs, or some other disruption occurs that makes it difficult to travel. Less mobility means more time spent at or near home, living closer to work, taking advantage of information and the local network of friends and shops. This is already being encouraged by home electronics and catalogue shopping, ie., changes that make the home useful for more activities. Demographic change will also affect travel. Smaller families, particularly the increasing number of singles, increase per capita vehicle miles, although singles living in-town fit better the services that mass transit offer. How older people will choose to travel is still uncertain, although at least one travel services company has indicated that it expects the retirees of the future to be extremely active.

However people chose to spend their increasing free time, they will indirectly make energy choices when they choose whether to stay home (or in the "neighborhood") or move around. The growing freedom to **choose** makes forecasting uncertain: the purposes for travel -- and the distances involved -- are no longer related just to shopping for essentials, getting to work, visiting friends (or the local pub) in the immediate vicinity. As a result, I would not trust a model to predict the level of automobile or air travel in 20 or 30 years, because of the uncertain impact of the lifestyle factors discussed above. Nor would I want to predict the tradeoff between time and home and time in service buildings using past behavior.

Conclusion

Ultimately the energy intensities of most economic and personal activities spiral downward, even without the pull of higher energy prices. The wealthy countries have moved in this direction for much of the past decade or two. In the development phase of most economies, energy use for producing goods and services dominates the picture. But I believe that energy use for "pleasure" -- comfort, entertainment, and mobility -- is now the driving force in energy demand, and the uncertain element in continued progress in energy conservation. This shift in the structure of energy demand places new challenges on the planner and analyst as well, who may have to look in entirely different directions for signals on the future development of energy demand.

Figure 1

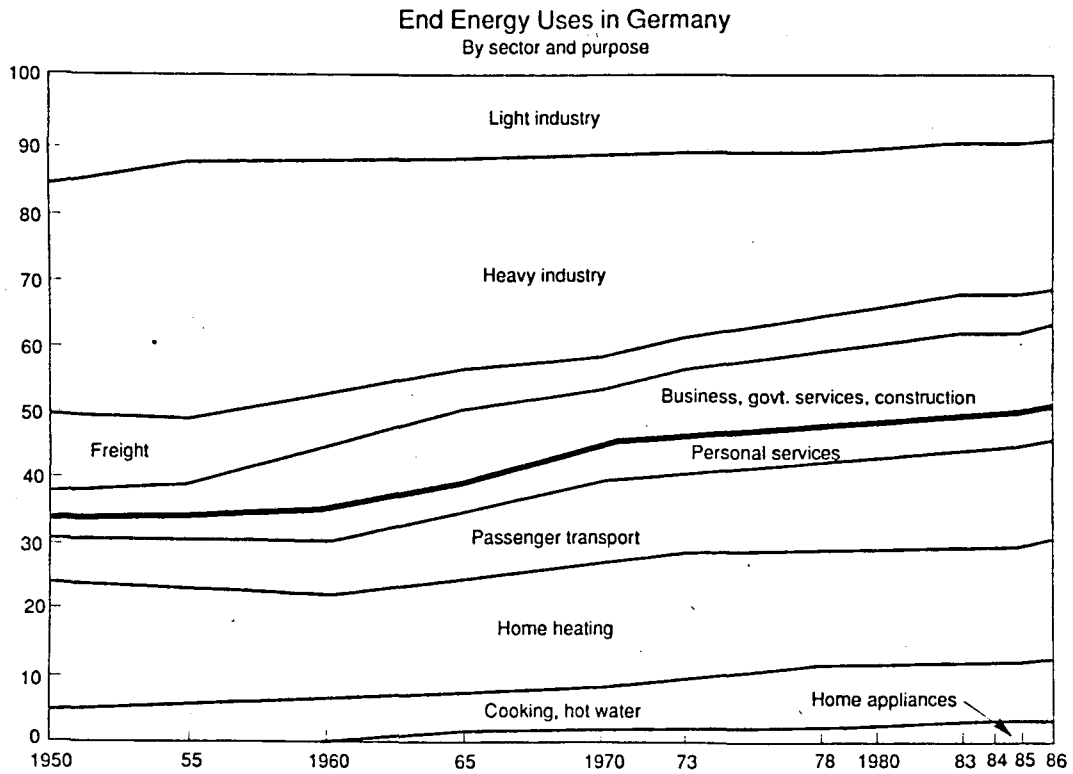
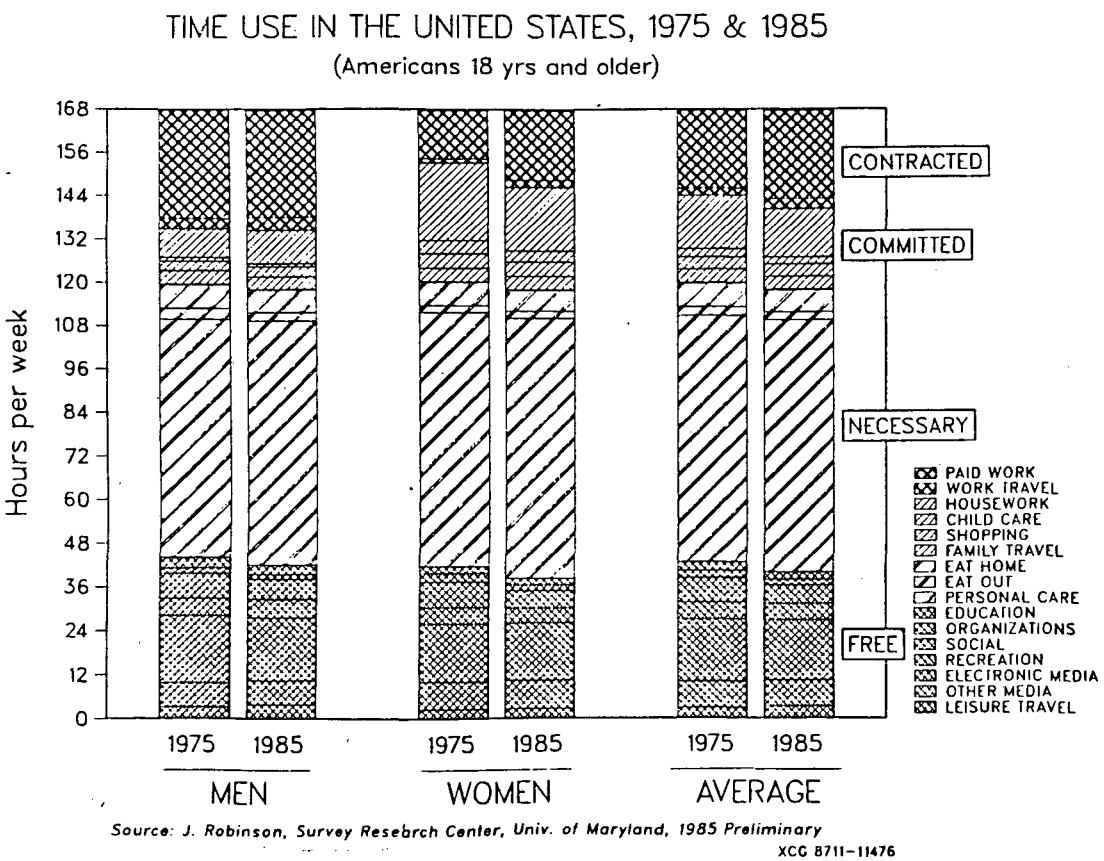


Figure 2



Perspective on Long-Run Energy Demand Projections

W.R. Finger
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Making a projection of world energy use 50 to 100 years in the future is a totally subjective exercise. Approaching the effort by investigating specific technological or lifestyle energy use activities will probably result in misleading conclusions.

If we thought about the view of 1988 in 1888, we would not have several major technologies in our inventory. The semiconductor, the airplane, the gasoline automobile, the radio, and the television had not yet been invented. All of us recognize the major impact these inventions have on life today. Two world wars and the Great Depression have occurred since then, all of which helped form today's society. Attempting to predict these specific events (as well as the multitude of others that impact today's society) is not something that one could have done. Therefore, a projection of almost any aspect of 1988 life made in 1888 would have been seriously flawed. Working through the foregoing exercise with a beginning date of 1938 leads to the same view for a 50-year horizon as well.

One way to approach the long-term future energy question is to make a "gross" projection based on historic trends that indicate widely different energy behavior patterns. For instance, U.S. energy use per capita increased at a rate of 3.6 percent per year from 1965 through 1970 and decreased at a rate of 1.5 percent per year from 1980 to 1985. If the Census Bureau's Middle Growth Trend population projection to 2030 is applied to these historic trends beginning with 1985 U.S. energy use of 76 quadrillion BTUs, an estimated 2030 U.S. energy use range is 49 to 473 quadrillion BTUs. If there is no change in energy consumption per capita between 1985 and 2030, an estimate of 2030 U.S. energy consumption is 97 quadrillion BTUs.

Certainly there are many ways to estimate energy consumption in the very long term. The sensitivity in using energy conservation measures conceived of today is that their impact is rapidly utilized. For instance, the U.S. auto fleet turns over in about 15 years, household appliances have an average life of 15 to 25 years, and industrial facilities are replaced about every 20 years. If the conservation technology known today is implemented in the first turnover of stock, there is no specific addition beyond that time. One way to get around this dilemma would be to estimate an environmentally acceptable level of energy use in 2030, assume a ratable change in use between 1985 and 2030, and estimate the level of conservation implementation necessary to accomplish the change. At that point, a comparison of available conservation measures with the estimated level of conservation need for the next several years should provide some insight into whether or not this factor alone is adequate.

Second, energy source needs to be considered. Fuel mix does change as indicated by the fact that electric utility fuel share shifted from 28 percent oil and gas in 1970 to 16 percent in 1985. One could determine an environmentally acceptable fuel mix for 2030 and look at a ratable change. Comparison of the estimated ratable change with what is possible over the next several years should provide insight into which parameters need further study.

Energy Policies for Averting Global Warming: The Importance of Energy Efficiency

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There is an immense technical potential for reducing energy use more cheaply than producing new energy supplies, both in the U.S. and in the rest of the world. This conclusion draws on a large and growing literature from the national laboratories and the academic community, from public interest organizations, and from state and regional energy planning bodies. The energy savings, ranging from 50% to 80% and more of current energy consumption, could allow the current trends of increasing carbon dioxide emissions from fossil fuels to be reversed and instead yield ever-diminishing CO_2 emissions, thus averting most of the threatened greenhouse effect due to this pollutant.

These gains are not just theoretical; actual recorded energy performance has been much more encouraging than anyone dared to believe fifteen years ago. First, consider California's electricity use. When California passed the Warren Alquist Act to initiate rational electricity planning in 1974, I prepared a scenario for the Environmental Defense Fund for what could be accomplished through proposed policies. The scenario was consciously chosen to be aggressive: to include all conservation measures that the newly formed California Energy Commission had the authority to implement. This potential embraced all feasible and cost-effective technologies, regardless of their current commercial status.

As it turned out, the conservation optimists of the early 1970s were not disappointed. The high-conservation EDF scenario more closely predicted the actual trend of energy consumption over the next 10-15 years than any of the standard forecasts (Figure 1). The Public Utilities Commission forecast overestimated consumption by the equivalent of 17,000 megawatts.

The track record in California shows a steady 2% per year decline in the ratio of electricity demand to gross state product since the state began to move toward least-cost electricity planning in 1974. The result is all the more impressive because the California economy was already less electricity intensive than the U.S. average. This result demonstrates the practical feasibility of decoupling economic growth from electricity growth.

The Commission forecasts that this trend will continue for the foreseeable future. California's energy planners now recognize the importance to economic growth of this decline in electricity intensity: higher efficiency decreases the costs of energy services and improves the competitiveness of the state's economy. This is a lesson with vast implications for the developing countries.

An important source of electricity savings has been refrigerators. Average energy use increased at an annual rate of 5% to 6% per unit from the end of World War II to 1972, mostly due to increase in size and the introduction of more features (Figure 2). Extrapolating this upward trend, coupled with population growth, to the year 1995, one would project the need for some 100,000 megawatts of electric capacity to power U.S. refrigerators in 1995. Actually, the refrigerator industry has made remarkable strides toward higher efficiency due primarily to California, and more recently, federal standards. Refrigerators have been transformed; energy consumption will be down 50% from its 1972 values by the time the redesign to 1990 consensus levels is complete, and down

roughly 66% by the time the California and Florida standards of 1993 are met. It is now reasonable to project 1995 electricity needs of only slightly more than 20,000 megawatts for refrigerators, or about the same as 1973 use.

Similar results have occurred in new houses in California. Compared to 1973 energy use, heating energy has been reduced by more than 80% due to the new Title 24 residential standards, which will be implemented in 1988 with the consensus support of the building industry as well as government and public interest organizations. Equally dramatic reductions -- 60% for office buildings -- follow from California's commercial energy standards, which were implemented last year with the support of the regional Illuminating Engineering Society and the construction industry.

Lessons for Forecasting

An important policy lesson illustrated by past forecasting experience is the danger of model-dependent thinking. In 1970s-vintage energy studies, such as those which heavily over-forecast today's energy consumption, the models by their structure attributed virtually all energy savings to price elasticities. Since the only way to affect energy consumption in the model was price, policy discussions focussed on the political feasibility of raising energy prices. Due to analysts' (correct) belief that energy prices would not be raised substantially by policy, little elasticity effect was predicted. Yet, in fact, elements not within the model, such as the Federal miles-per-gallon standards and state building and appliance standards, led to significant unpredicted reductions in energy use.

The danger with a focus on single-point forecast models is that the policymaker is inclined to ask the question, "Are we in trouble with global climate change or not?" rather than asking what I believe is the more relevant question, "What policy actions do we have to take to make sure that we do not get in trouble?"

Conservation policies can reduce the level of uncertainty inherent in the forecast. For example, if we enact policies requiring high efficiency in new additions to the stock of energy-consuming devices, uncertainties about how many additions there will be -- uncertainties about economic growth -- will have less effect on the final result. By implementing policies that explicitly lead to a predictable result, we can eliminate uncertainty over price elasticity effects. Consider a refrigerator. Reasonable price forecasts and elasticities might predict an annual energy consumption anywhere between 300 and 1300 kilowatt-hours (kWh). In such a case, a refrigerator standard of 400 kWh will drastically reduce the remaining range of variability due to elasticity effects. As we found in an appliance efficiency study NRDC performed for the New England Governor's Conference, progressively more ambitious appliance standards reduce the uncertainty of energy forecasts, as well as reducing the overall energy demand in the final year of the forecast.

EPA should account for the uncertainties in energy forecasts explicitly by modelling a defensible range of energy forecasts from high to low based on a range of possible energy prices and reactions to them. Then, for each set of policy choices, similar forecasts and ranges of uncertainty can be calculated. This leads to a more reasonable framing of the global warming question as: **How much global warming can we live with?** and, **What policies will it take to assure to 95% confidence (or some other desired value) that we will get there?**

In conclusion, it is hard to dispute that the technical means for averting the bulk of the global warming problem are available, and that the costs are remarkably low compared to conventional energy options. The global economy would save trillions of dollars by embarking on the path of high energy efficiency and low CO_2 emissions rather than continuing current trends.

Figure 1

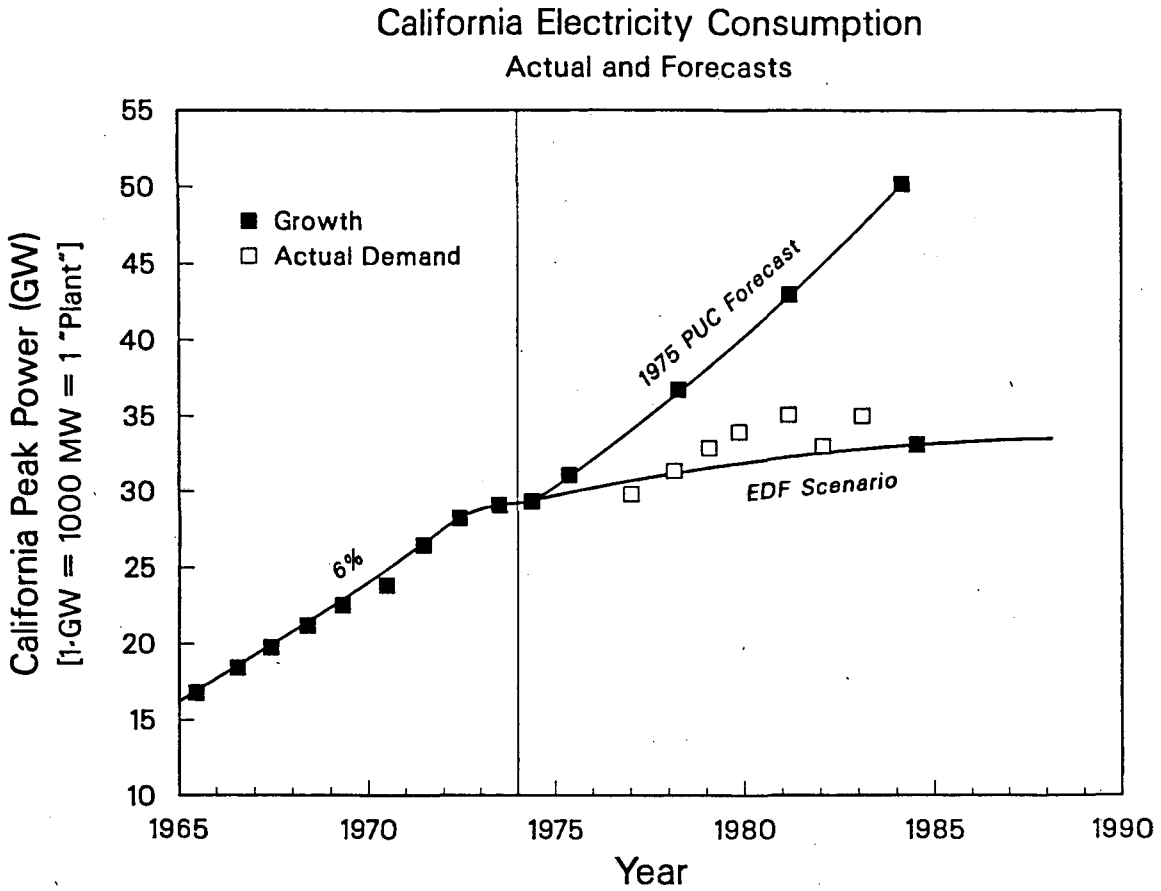
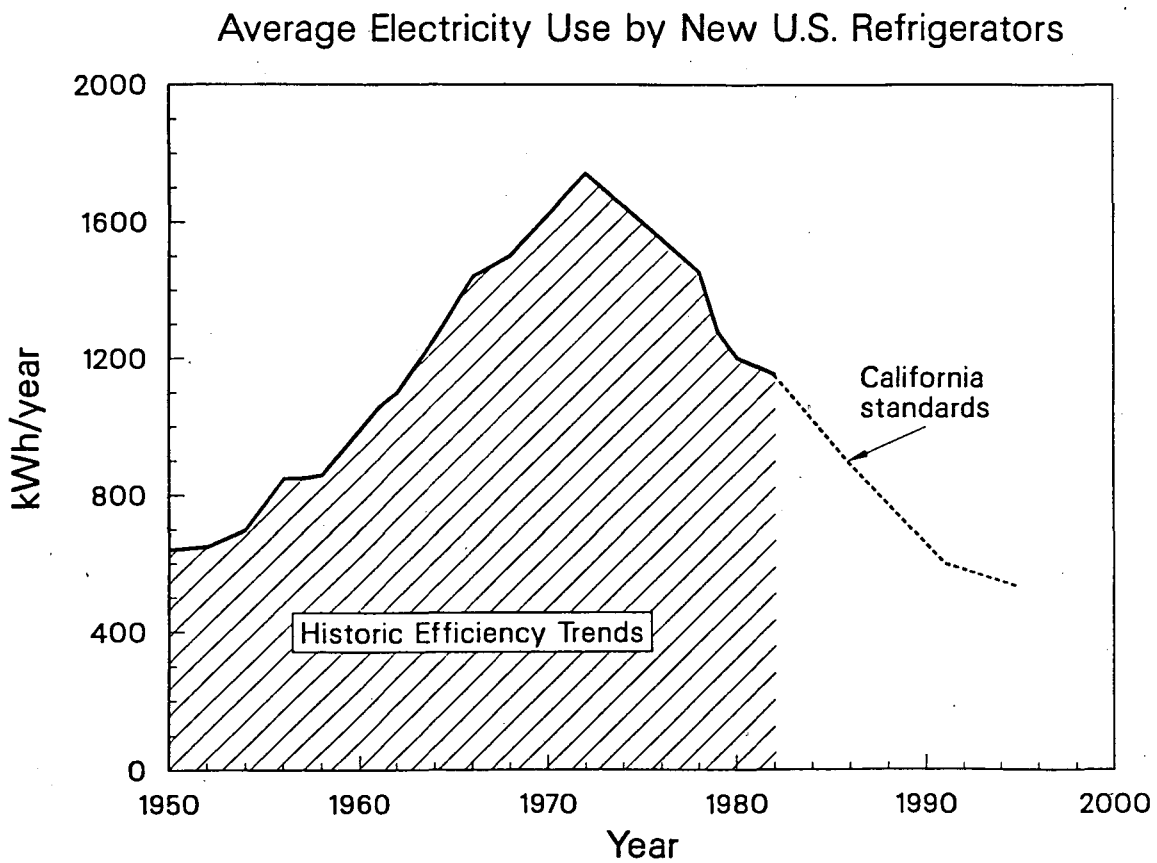


Figure 2



Motor Vehicles and Global Air Pollution

Michael P. Walsh
International Consultant

Motor Vehicles Are The Major Global Pollution Source

Motor vehicles generate more air pollution than any other single human activity. They are the dominant source of carbon monoxide, oxides of nitrogen, and hydrocarbons, as well as a significant source of carbon dioxide and, particularly in the U.S., chlorofluorocarbons (CFCs). Most of these cause or contribute to the formation of ground level ozone. Some also destroy stratospheric ozone or contribute to its destruction. Further, most of these pollutants are now known to contribute to global warming.

Some of the motor vehicle emissions react in ways only recently understood. For example, hydroxyl radicals (OH), which scavenge many anthropogenic and natural trace gases from the atmosphere, are themselves removed by carbon monoxide (CO). Therefore, as concentrations of CO increase, tropospheric concentrations of OH decrease, thus allowing other trace gases (e.g. methane and reactive hydrocarbons) to accumulate.

Doubled concentrations of carbon dioxide (or the trace gas equivalent thereof) are projected to increase the global average temperature between 1.5 and 4.5 degrees Centigrade. Changes likely to accompany this temperature increase include: large stratospheric cooling (with the potential to accelerate stratospheric ozone depletion); global mean precipitation increase; reduction of sea ice; polar winter surface warming; summer continental dryness; high latitude precipitation increase; and rise in global mean sea level.

Means of abating these pollutants are both economically and technically feasible, but they are being implemented at a rate far short of what technology would allow and prudence would dictate.

The Problem Will Likely Get Worse Without Action

To put the global problems with motor vehicle pollution in perspective, it is important to realize that motor vehicle usage has increased tremendously in a relatively brief period of time. In 1950, less than 50 million cars were on the world's roads, 85 percent of them in North America. Only one generation later, the car population is approaching 350 million, almost a seven-fold increase. Outside North America, the growth has been especially high, from slightly under 7 million in 1950 to 125 million by 1980. While the rate of growth has slowed in the highly industrialized countries, population pressures, increased urbanization and industrialization are accelerating motor vehicle growth in other areas. By the year 2000, the global vehicle population will likely exceed 500 million, with annual car production rising from about 33 million today to about 38 million.

Control Options

Although emissions from cars have been substantially reduced from uncontrolled states, further reductions could be achieved by tightening tailpipe standards (especially on trucks, buses, heavy duty engines, and diesel-powered vehicles) and by expanding the areas of the world in which stringent standards apply.

Legislation awaiting consideration in the U.S. Congress would lower emissions from both gasoline and diesel powered vehicles in an effort to reduce air pollution in the

roughly 70 cities where air quality levels are unhealthy. It would also impose additional requirements on use of motor vehicles, including more stringent inspection and maintenance programs and controls on refueling emissions.

In Europe, small cars represent almost 60 percent of the car population and their standards are scheduled to be tightened during the 1990's. Should they be lowered to levels in the range of 15 grams per test for CO, and 2 grams per test each for HC and NOx, the overall environmental impact of the package could improve considerably. If relatively weak levels (for example, equal to or more lenient than the medium car standards of 30 for CO and 8 for HC plus NOx, as proposed earlier this year by the European Commission) are adopted, Europe will be condemned to serious air pollution problems well into the next century.

Globally, mobile source emissions of carbon dioxide could be substantially reduced through the use of more fuel efficient vehicles. U.S. automobiles average 19 miles per gallon (mpg), and non-U.S. cars about 24 mpg. Much greater fuel economy is possible and should be encouraged.

Significant reductions in CFC releases could be achieved through improvements in air conditioner seals and, especially, through changes in repair shop work practices because CFCs are intentionally vented to the air when air conditioners are repaired.

To comply with emission standards in-use, cars must be maintained properly. Inspection and Maintenance (I/M) programs are essential to assure this and therefore are a key element in the control programs of many countries. While I/M programs in the U.S. have focused on HC and CO control, countries such as Germany have taken the lead in exploring the feasibility of I/M for NOx and diesel particulate control. I/M programs should be expanded around the globe.

Conclusions

Motor vehicles account for more of the world's air pollution than any other human activity. They are responsible for virtually all of the carbon monoxide and lead in the air of cities, and a major portion of the NOx, VOC's, fine particles and toxic chemicals. In addition, as the major consumer of oil in the world, vehicles also emit substantial amounts of carbon dioxide and other gases which contribute to global warming. Due to expanded CFC use in vehicle air conditioners, vehicles also play a significant role in the stratospheric ozone depletion.

The damage caused by vehicular pollutants is becoming inescapably apparent. Increases in the number of vehicles and the number of vehicle miles travelled is overwhelming the reductions in emissions that have been achieved to date, although almost 50% of all new cars produced this year are equipped with state of the art emissions controls.

The Common Market countries of Europe stand out as the slowest industrialized area to implement state of the art requirements. It is likely that unless the Community moves closer to the standards of the Stockholm Group, Europe will see further deterioration of its environment. More stringent small car standards, on the order of 15 grams per test for CO and 2 grams per test each for HC and NOx, would represent a large step in the right direction.

While NOx and particulate control technologies for diesel cars are not as advanced as for gasoline cars, progress is accelerating and very low levels have been demonstrated. Emission control of trucks and buses is of particular importance because of past neglect, but fortunately, it appears that technologies developed for cars can be transferred.

Eliminating the use of CFCs in automotive air conditioners or, in the short term prohibiting unnecessary venting to the air, would not only protect the stratosphere, but the troposphere as well. Mandatory fuel efficiency standards throughout the world would slow the growth in carbon dioxide emissions.

However, continued growth in the number of vehicles and their use is undercutting the overall benefits of these technological gains. The global vehicle population has climbed from under 50 million just one generation ago to more than 350 million. By the year 2000, it is projected to exceed 500 million. Unless this growth is constrained, global pollution will continue to increase, many areas which currently have relatively clean environments will deteriorate, and the few areas which have made progress will see some of these gains erode.

With the increasing likelihood that the global changes will be irreversible and of unknowable proportions, it is imperative that the nations of the world confront and surmount these obstacles. Otherwise, as 250 of the world's scientists warned in Villach, Austria in December, 1985, "Mankind is conducting a gigantic experiment with the Earth's future without knowing the outcome."

Policy Options on Energy Efficiency and Global Warming: A Congressional Perspective

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Between 1974 and 1981, Congress established several complementary programs, primarily at the Department of Energy (DOE), to foster energy efficiency. The initial motivation was strategic concerns related to petroleum consumption, but other benefits of increased efficiency soon became apparent: Improved industrial competitiveness through lower production costs and products with lower life-cycle costs; the saving of capital for investment; the creation of international markets for advanced equipment designed to conserve energy such as cogeneration systems, advanced engines, and heat pumps; and environmental benefits such as decreased air and water pollution, decreased nuclear waste, and decreased greenhouse gases.

Despite these benefits, federal spending for conservation R&D has dropped 75% from FY 79 to FY 88. In constant (1982) dollars, federal spending for DOE energy conservation programs has gone from $1.21 billion in FY 79 to $301 million in FY 88.

Congress' attention to the energy/environmental interface has been focussed less on enhancing energy efficiency and much more on ways to enhance energy supply through the "environmentally benign" use of abundant, indigenous resources such as coal. "Clean coal" technology programs are popular and well supported. There is, at present, no discernible consensus forming among U.S. policy makers or the international community on the scientific facts regarding global warming, the potential for damage from such warming or the appropriate policy to follow if we unambiguously detect a warming signal with definite long-term dire consequences.

In the meantime, the multiple benefits from increased energy efficiency provide a rationale for some policy decisions that will benefit the mitigation of any global warming phenomenon. For example:

1) Better data should be collected on the effectiveness of energy conservation programs and on the linkage of conservation technology to oil use, competitiveness and trade, electric power demand, and environmental protection.

2) The procurement powers of government should be more intensively used to set good examples and push innovative technologies and products that conserve energy. New federal buildings ought to reflect state-of-the art energy efficiency improvements.

Ultimately, any proposed restructuring of energy use in America will have to be dealt with through the same process that will be needed to deal with challenges to our international economic competitive position -- through a partnership involving government, industry, and the general public to achieve consensus on goals. This will not be easy and will require strong Presidential leadership as the *sine qua non.*

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