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POTENTIAL FOR CARBON DIOXIDE EMISSIONS REDUCTIONS IN BUILDINGS

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POTENTIAL FOR CARBON DIOXIDE EMISSION REDUCTIONS IN BUILDINGS

BACKGROUND REPORT FOR

OFFICE OF TECHNOLOGY ASSESSMENT

CLIMATE CHANGE STUDY

by:

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Kennedy School of Government
Harvard University

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS . . . . . iii.

EXECUTIVE SUMMARY . . . . . iv.

POTENTIAL FOR CO_2 EMISSION REDUCTIONS IN BUILDINGS

I. INTRODUCTION . . . . . 1.

II. CO_2 EMISSIONS IN OECD COUNTRIES . . . . . 7.
- A. Past Trends and Current Energy Use . . . . . 7.
- B. The Structure of Residential Energy Use . . . . . 16.
- C. The Structure of Commercial Energy Use . . . . . 17.
- D. Methods and Costs for Reducing Fossil Fuel Use in Buildings . . . . . 18.
  - 1. **Residential Buildings: Space Conditioning, Appliances and Lighting** 20
    - a. *Space Conditioning* . . . . . 20.
    - b. *Appliances and Lighting* . . . . . 26.
  - 2. **Commercial Buildings: Space Conditioning and Lighting** . . . . . 31.
    - a. *Space Conditioning* . . . . . 31.
    - b. *Lighting* . . . . . 32.
    - c. *Energy Management, Operation and Maintenance* . . . . . 34.
    - d. *Examples of Energy-efficient Commercial Buildings* . . . . . 34.
  - 3. **Renewables** . . . . . 36.
  - 4. **Cogeneration** . . . . . 36.
  - 5. **Behavioral and Lifestyle Changes** . . . . . 40.
- E. Scenarios for Future CO_2 Emissions in the U.S. . . . . 41.
- F. Scenarios for Future CO_2 Emissions in Sweden . . . . . 55.
- G. Summary for CO_2 Emissions in OECD Countries . . . . . 57.

III. CO_2 EMISSIONS IN DEVELOPING COUNTRIES . . . . . 60.
- A. Past Trends and Current Use . . . . . 60.
- B. Future Growth of Energy Use and Emissions in LDCs . . . . . 65.
- C. Methods for Reducing Energy Use and CO_2 Emissions . . . . . 65.
  - 1. **Residential Sector** . . . . . 66.
  - 2. **Commercial Sector** . . . . . 67.
- D. Scenarios for CO_2 Emissions in Brazil . . . . . 68.
- E. Scenarios for CO_2 Emissions in China . . . . . 71.
- F. Summary for CO_2 Emissions in Developing Countries . . . . . 73.

IV. POLICIES TO REDUCE U.S. EMISSIONS . . . . . 74.
- A. Barriers to Investment in Energy Efficiency . . . . . 75.
- B. Policy Options for the U.S. . . . . 78.
  - 1. **Energy Use Tax** . . . . . 78.
  - 2. **Initial Purchase Tax** . . . . . 81.
  - 3. **Utility Least-Cost Planning** . . . . . 83.
  - 4. **Appliance Standards** . . . . . 89.

5. **Building Energy Codes** . . . . . 91.
6. **Consumer Information and Marketing** . . . . . 96.
a. *Energy Rating Systems* . . . . . 97.
b. *Home Energy Audits* . . . . . 98.
c. *Appliance Labels* . . . . . 99.
d. *Information Campaigns* . . . . . 99.
7. **Research and Development (R&D)** . . . . . 100.
8. **Financial Incentives** . . . . . 101.
a. *Loan Policies* . . . . . 101.
b. *Tax Credits* . . . . . 102.
c. *Subsidies* . . . . . 103.
9. **Energy Conservation in Federal Buildings** . . . . . 104.
10. **Technology Demonstrations** . . . . . 104.
11. **Government Procurement** . . . . . 105.
C. Policy Regarding Fuel Mix . . . . . 105.
D. The Relationship Between Policies to Reduce CO_2 Emission and Other Policy Goals . . . . . 106.
1. **Economic Efficiency** . . . . . 107.
2. **The Effect of Chlorofluorocarbon Reductions on Energy Efficiency** . . . . . 107.
3. **Indoor Air Quality** . . . . . 108.
E. Summary of Policies to Reduce U.S. CO_2 Emissions in the Buildings Sector . . . . . 109.

V. U.S. POLICIES FOR GLOBAL CO_2 EMISSIONS REDUCTIONS . . . . . 111.
A. Conventions and Protocols . . . . . 111.
B. Research and Information Programs . . . . . 112.
C. Programs of the Development Banks and AID . . . . . 112.
D. Trade Policies . . . . . 113.

APPENDIX . . . . . 114.

LIST OF TABLES . . . . . 128.

LIST OF FIGURES . . . . . 131.

REFERENCES . . . . . 132.

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EXECUTIVE SUMMARY

The buildings sector, which encompasses residential and commercial energy use, currently generates about 25% to 30% of global CO_2 emissions. This figure includes not only the direct burning of fossil fuels, but also the emissions from electricity used in buildings and deforestation caused by gathering fuel wood for domestic use. An end-use approach was used to assess the potential for emission reductions from this sector in the next 25 years. The major conclusions of this analysis are:

(1) Emission Reductions in Industrialized Countries. In the U.S. buildings sector, CO_2 emission reductions of 40% are feasible with technologies that are currently available and cost-effective on a life-cycle basis. Even higher reductions in emissions are possible using technologies that are currently available but more expensive. In addition, technologies which are expected to be commercially available in the next decade could reduce emissions still further. The 40% level is achievable without changing the mix or proportion of fossil fuels used for generating electricity. By combining energy efficiency improvements with electric utility fuel switching (either from fossils to renewables or nuclear, or from coal to gas or oil) even higher emission reductions are possible. Similar reductions are achievable for other OECD nations.

(2) Emission Reductions in Developing Countries. For the buildings sector in developing countries, there will be a large growth in the demand for energy services in the next 25 years. While energy efficiency can significantly slow the rate of growth of CO_2 emissions without compromising economic development, net reductions are unlikely.

(3) Policy Options. In order to achieve significant reductions in CO_2 emissions from the U.S. buildings sector, a broad range of policy options will have to be adopted. The

most promising policies are: energy use taxes, initial purchase taxes, utility least-cost planning, appliance standards, building codes, consumer information and marketing, and research and development.

A. CO_2 Emissions in the Buildings Sector in OECD Countries

In the OECD as a whole, the combined residential and commercial sectors accounted for 38% of primary energy use in 1985, with the residential sector accounting for 23% and the commercial sector for 15%.[1] In both the residential and commercial sectors, energy conservation since 1973 has significantly reduced the energy intensity of final demand. A countervailing trend has been an increase in electrification which, by increasing primary energy use per unit of final energy demand, has offset some of the gains from energy conservation.

Over the next 25 years, slow growth in the demand for energy services is expected in the residential sector due to a saturation of the main energy using amenities and slow population growth. In contrast, the commercial sector is expected to be the most rapid growth sector of the economy, with an increased demand for energy services. The impact of this demand for energy services on CO_2 emissions will depend on the rate of improvements in energy efficiency and the choice of fuels.

There is a large potential for cost-effective reductions in the use of fossil fuels. These reductions can be achieved through technical improvements in energy efficiency, fuel switching, and behavioral changes. Technical improvements offer by far the greatest potential for energy reductions in the next 25 years. The potential savings and cost data

[1]ECD, 1987.

presented below are based on U.S. buildings.

Residential Buildings: In the residential sector, space conditioning is the dominant end-use and offers the greatest potential for reduced fossil fuel consumption of any single end-use. The energy used for space conditioning can be reduced through improved thermal integrity (increased insulation and reduced infiltration), improved equipment efficiency, and siting and landscaping practices. There is also potential for significant savings through improved efficiency in the other major end-uses, including water heating, refrigeration, lighting, and cooking. These potential savings are presented in Table I.[2]

TABLE I: POTENTIAL ENERGY SAVINGS FROM RESIDENTIAL APPLIANCES AND LIGHTING
from Geller, 1988b

	1986 Best compared to 1986 Stock	1986 New compared to 1986 Stock	Advanced Technology for the 1990s compared to 1986 Best
gas space heat	32%	19%	0 to 67%
room ac	44%	33%	25 to 67%
central ac	49%	38%	20 to 50%
elec water heat	60%	54%	7 to 60%
gas water heat	26%	20%	33 to 100%
refrigerator	48%	32%	50 to 150%
freezer	59%	43%	43 to 115%
lighting	35%	35%	30 to 86%
elec range	13%	7%	40 to 75%
gas range	43%	20%	33 to 60%
elec clothes dryer	20%	11%	60 to 220%
gas clothes dryer	30%	13%	0 to 17%

[2]Geller, 1988b.

Examination of energy-efficient new homes and retrofits supports the conclusion that there is significant potential for reducing the space heating requirements in homes in a cost-effective manner. For space heating, energy-efficient new houses use only one-third to one-half of the energy required by the average new house. The most energy-efficient houses use far less, as little as 15% of the final energy for the average new home. Energy conserving retrofits can reduce home energy use by 20% to 25%.[3]

Commercial Buildings: In the commercial sector, the largest end-use is also space conditioning. Energy requirements for space conditioning can be reduced through improved thermal integrity, higher equipment efficiencies and proper siting. The best new HVAC equipment is 50% to 100% more efficient than the existing stock.[4]

Lighting, which is the second largest end-use in the commercial sector, offers the most cost-effective method for reducing energy use in the commercial sector. Reductions in energy use of up to 75% can be achieved by replacing incandescents with fluorescents, with a payback of 1.1 to 2.3 years. Continued improvements in lighting design are expected to offer reductions of 300% over the standard fluorescent lamp by the end of the century.[5] In addition, efficient lighting will reduce the demand for air conditioning.

Data on energy-efficient buildings indicate that new commercial buildings use about one-half the average energy of the existing stock and that this can be achieved without increases in initial cost. Commercial retrofits use 20% to 25% less energy than before retrofit, with paybacks of 2 to 3 years.[6]

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[3]Lawrence Berkeley Laboratory, 1986.

[4]Hirst, et al., 1986.

[5]Geller, 1988a.

[6]Lawrence Berkeley Labs, 1986.

Renewable Energy: The Solar Energy Research Institute's 1981 study estimated that renewable energy sources applied directly at the building site could replace 4.1 to 5.1 quads of energy by the year 2000. This is compared to 27 quads of energy consumption in the buildings sector in the U.S. in 1985. With the lack of progress in the development and penetration of solar technologies over the past 8 years, the year 2000 is no longer a realistic time frame for solar savings of this magnitude.

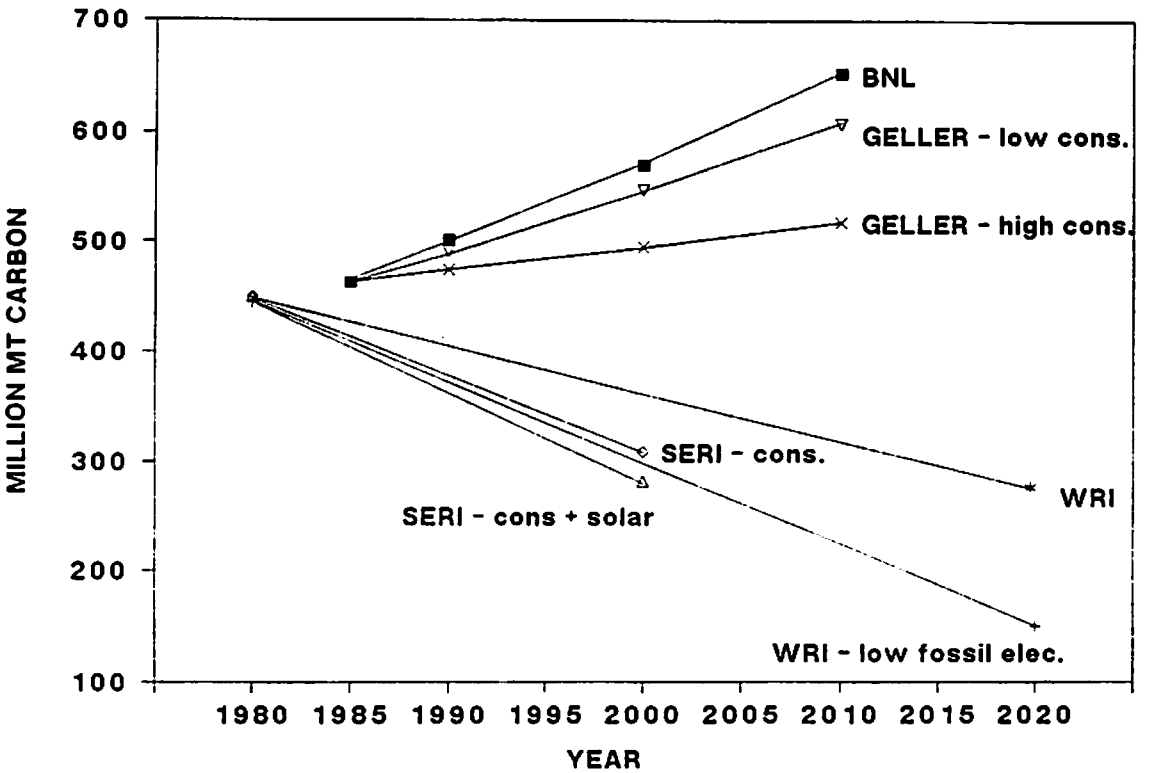
Cogeneration: The potential for cogeneration in the buildings sector is estimated to be 4 GW to 30 GW of installed capacity, corresponding to emission reductions of 2 to 19 million metric tons of carbon. This is compared to emission of 460 million metric tons in 1985.

Behavioral and Lifestyle Changes: Behavioral changes have contributed to energy savings in the past, particularly through thermostat setbacks. Lifestyle changes that could reduce energy use include smaller dwellings and more multifamily buildings.

Scenarios for Future CO_2 Emissions in the U.S. Buildings Sector: The penetration of currently available conservation measures can lead to a significant reduction in CO_2 emissions from this sector. In order to translate the potential emission reductions for individual buildings and appliances into an estimate of the total emission reductions for the buildings sector in the U.S., several scenarios of future energy use were examined. The results are presented in Figure I.

The base case forecast, BNL (Brookhaven National Lab), projected CO_2 emissions of 652 million metric tons of carbon per year by 2010, a 40% increase over 1985 annual

FIGURE I: SCENARIOS OF CARBON EMISSIONS FOR THE RESIDENTIAL AND COMMERCIAL SECTORS



emissions from the buildings sector.[7] The other scenarios, based on higher levels of energy conservation, gave much different results. The GELLER high conservation scenario, which is based on a more rapid adoption of energy-efficient appliances and space conditioning equipment, projects a much smaller increase: only 11% by the year 2010.[8] The SERI (Solar Energy Research Institute) scenario, based on the total penetration of energy saving technologies (including renewables) which are cost-effective on a life-cycle basis, gave net

[7]Brookhaven National Laboratory, 1988.

[8]Geller, 1988a and 1988b.

reductions in CO_2 emissions of 39% compared to 1985 emissions.[9] The WRI scenario, which is also based on total penetration of energy-efficient technologies, shows potential reductions of 40% by the year 2020.[10] Finally, the WRI low-fossil electricity scenario shows potential reductions in CO_2 emissions of 65% by the year 2020. This low-fossil electricity scenario combines on-site energy efficiency measures with an electricity-generating fuel mix based less on fossil fuels than the current mix. This last scenario highlights the importance of the generating fuel mix in determining the actual emission reductions achievable through electricity conservation.

These modeling efforts were examined in detail, along with information on the potential emissions reductions from efficient appliances, cogeneration, and fuel switching, in order to determine which end-uses offered the greatest potential for emission reductions. The results are shown in Tables II and III for the residential and commercial sectors, respectively. For each entry in the matrices, it was assumed that only that option was being implemented. Potential emission reductions are measured from 1985 levels, and categorized as large (greater than 10%), medium (5% to 10%) or small (less than 5%). The matrices also include a row called "limited growth", which shows options that will reduce emissions, but not enough to offset the expected growth from new buildings. In other words, if these measures were implemented alone, there would still be a net growth in emissions from the respective sector. Because of the interaction of various options, the columns are not strictly additive. The lead times of short (1 to 5 years), medium (5 to 15 years), and long (15 to 25 years) indicate the amount of time required to actually realize

[9]Solar Energy Research Institute, 1981.

[10]Goldemberg, et al., 1988.

the reduction indicated.

The conclusion of this analysis is that there is no "magic bullet" for reducing emissions in the residential and commercial sectors. Several options for emission reductions will have to be pursued simultaneously in order to achieve large reductions in these sectors. This is even more true when looking at the building sector as a whole. Emission reductions in only the residential sector, or only the commercial sector, would be overcome by growth in the other.

Scenarios for Future CO_2 Emissions: There is potential for dramatic reductions in CO_2 emissions, ranging from 78% to 90%.[11] These reductions would be the result of major efficiency improvements and a shift away from the use of fossil fuels to solar and biomass. The fact that there is the potential for large emission reductions in a country like Sweden, which has a relatively energy-efficient building stock, indicates that similar potential exists for other OECD nations.

[11] ibid.

TABLE II: SUMMARY OF TECHNICAL POTENTIAL FOR EMISSION REDUCTIONS: RESIDENTIAL SECTOR

	% EMISSION REDUCTION	SHORT 1 - 5 YEARS	MEDIUM 5 - 15 YEARS	LONG 15 - 25 YEARS
REDUCTIONS FROM CURRENT LEVEL ↑	LARGE > 10%			- space conditioning, new and retrofits, improvements to shell & equipment efficiency - appliance efficiency high penetration of most efficient appliances on market
	MEDIUM 5% - 10%		-retrofit space cond. equipment efficiency and shell improvements	
	SMALL < 5%	-retrofit space cond. equipment efficiency and shell improvements	- appliance efficiency, standards higher than NAECA	
REDUCTIONS FROM PROJECTED GROWTH ↓	LIMITED GROWTH	-appliance efficiency, NAECA standards	-appliance efficiency, NAECA standards -new home space conditioning -conversion oil to gas -cogeneration	-appliance efficiency, NAECA standards -new home space conditioning -20% reduction in fossil fuel for elec. generation -conversion oil to gas -cogeneration
	* TOTAL REDUCTIONS	5%	20%	40%

* Does not include potential reductions from electric utility fuel switching.

TABLE III: SUMMARY OF TECHNICAL POTENTIAL FOR EMISSION REDUCTIONS: COMMERCIAL SECTOR

	% EMISSION REDUCTION	SHORT 1 - 5 YEARS	MEDIUM 5 - 15 YEARS	LONG 15 - 25 YEARS
REDUCTIONS FROM CURRENT LEVEL	LARGE > 10%			-space conditioning & lighting in both new and retrofits
	MEDIUM 5% - 10%			-lighting only, new and retrofits
	SMALL < 5%			
REDUCTIONS FROM PROJECTED GROWTH	LIMITED GROWTH		-cogeneration -conversion oil to gas -space conditioning & lighting, new or retrofits, only	-cogeneration -20% reduction in fossil fuel for elec. generation -conversion oil to gas -space conditioning & lighting, new or retrofits, only
	* TOTAL REDUCTIONS	5%	20%	40%

* Does not include potential reductions from electric utility fuel switching.

B. CO_2 Emissions in the Buildings Sector in Developing Countries

Although the industrialized countries are currently responsible for the largest share of CO_2 emissions in the buildings sector, the developing countries' share of emissions is expected to increase over the next 25 years.

While LDCs differ substantially in their energy use patterns, there are some general features and trends.

(1) A large percentage of the energy is from non-commercial sources, particularly in the residential sector. Non-commercial energy use contributes to CO_2 emissions if it leads to deforestation.

(2) Consumption patterns differ between the urban and rural populations and are highly dependent on income. Commercial fuels are more common in urban areas, and their use increases with increasing wealth. The effect this move to commercial fuels has on CO_2 emissions is dependent on whether the commercial fuel is a fossil fuel or electricity generated by fossil fuels, the relative efficiency of commercial fuel use versus traditional fuel use, and whether the traditional fuel was causing deforestation.

(3) The penetration of electric appliances is growing at a rapid rate in some LDCs, causing residential electricity demand to climb sharply.

(4) Urbanization and wealth lead to the construction of Western-style modern buildings, both residential and commercial, which require modern fuels for space conditioning.

Structural changes are expected to continue to be a major influence on LDC residential and commercial energy use, with the demand for commercial fuels continuing

to grow. The rate of growth in the residential sector will depend largely on the rate of urbanization, the rate at which poor households change to modern carriers and modern cooking technologies, and the rate of acquisition of appliances. In addition, the rate of population growth and family size will affect the growth of total energy demand. A continued growth in energy use in the commercial sector is expected due to increases in the number of public and private buildings.

Energy conservation and fuel switching can help developing nations simultaneously meet their development and environment goals. In the residential sector, a reduction in the energy requirements for cooking is the most pressing need. This can be accomplished by switching to modern carriers or by using more efficient wood stoves. There are also significant opportunities for using electricity more efficiently. The technologies for reducing appliance and lighting energy use are basically the same as those discussed for industrialized nations.

Opportunities for energy conservation in the commercial sector are similar to those available in industrialized nations, with similar levels of potential savings.

Examination of energy use in Brazil and China indicates that there are large opportunities for cost-effective energy efficiency improvements. Nonetheless, because of the anticipated growth of demand for energy services in the buildings sector over the next 25 years, there is likely to be an aggregate growth in energy consumption, although at a much slower rate than would be experienced without increased efficiency.

C. U.S. Policies for Reducing Domestic CO_2 Emissions

Reducing CO_2 emissions from the buildings sector is a multifaceted problem. It requires implementing numerous technical options, influencing the behavior of many decision-makers and overcoming a variety of barriers to investment in energy conservation. Thus, significant reductions of CO_2 emissions are attainable only through the implementation of a combination of policies.

In both the residential and commercial sector, minimization of first costs is often more important than life-cycle costs. This creates a barrier to greater investment in energy conservation. The factors contributing to this emphasis on first costs in the residential sector include: higher initial costs, inadequate or unreliable information, the time and effort required to make such investments, uncertainty, and the choice of products on the market. Similar barriers exist in the commercial sector, including: the cost of finance, cash flow concerns, lack of expertise, the hassle and risk of energy conservation investments, and better use of capital in terms of the bottom line. The fact that those who make purchase decisions are often different from those who pay utility bills is a barrier in both sectors. Pricing energy below marginal cost is also a barrier in both sectors.

Policies for reducing emissions must address these barriers. The policy focus of this study is on measures to promote energy conservation, because they provide the greatest opportunity for emission reductions in the near term. The major policies for reducing CO_2 emissions in the building sector are: energy use taxes, initial purchase taxes, utility least-cost planning, appliance standards, building codes, consumer information and marketing, and research and development. Other policies with more limited impact include financial incentives, energy conservation in federal buildings, technical demonstrations and

government procurement.

The synergisms that are possible between taxation, regulation, incentive, information, and R&D programs are key to reducing emissions. Taxation sends the pricing signals for reducing energy consumption. Regulation (codes and standards) can be used to get the least efficient equipment, appliances and buildings off the market. Incentive and information programs can be used to create a market for exceeding the standards. Information programs also provide consumers with the information needed to make energy-conserving choices in response to price signals from taxation. And government-sponsored R&D is necessary to support innovation in an industry which is too fragmented to make capital-intensive and risky investments.

End-Use Taxes: Energy use taxes would increase the price of energy, thus bringing the price more in line with the social marginal cost, and accomplishing the goal of lower energy consumption. End-use taxes can stimulate conservation in both new and existing buildings, and send signals regarding energy use and purchases. However, end-use taxes will be less effective in influencing purchase decisions than other policy measures such as appliance standards, building codes, initial purchase taxes, and incentive programs. If based on CO_2 emissions, an end-use tax can also influence fuel choice. Price and income elasticities indicate that a very high tax rate would be needed to achieve substantial reductions in emissions over the 25-year time frame of this study. This raises equity questions and would impose hardship on lower-income households.

Initial Purchase Taxes: An initial purchase tax would place a lump-sum tax on appliances and equipment (and possibly buildings and homes) at the time of purchase. It could be applied to all equipment and appliances, to only the most polluting, or on a

revenue-neutral basis. The major advantage of an initial purchase tax is that it will send the appropriate signals regarding consumer purchasing decisions, which are often based largely on first cost. This type of tax would not affect usage decisions.

Utility Least-Cost Electricity Planning (LCP): Utility least-cost planning creates an environment where traditional supply technologies compete with energy conservation, renewables and cogeneration to provide energy services. Investment in energy conservation is called demand-side investment. Because many demand-side investments are less expensive than new supply, and because utilities traditionally have longer time horizons than consumers, LCP can result in greater investments in energy efficiency than would be made by consumers alone. Utility programs can capture the potential in both the new and retrofit markets, for both equipment efficiency and building shell improvements. The ability to reach retrofit markets is particularly attractive because they are difficult to reach through building codes.

In order for LCP to stimulate significant investment in conservation, incentive structures must be changed so that utilities are indifferent between supply and demand-side investments. One role for the federal government in LCP is to provide funding for evaluation of various incentive structures and forums for the exchange of ideas between states and utilities which are using different types of incentives.

Federal legislation to promote utility investment in demand-side resources could take several forms, including:

(1) Require states to formally consider demand-side resources in their planning.

(2) Require least-cost planning for utilities whose projects fall under the jurisdiction of FERC.

(3) Require all utilities to use least-cost planning.

(4) In conjunction with requiring least-cost planning, determine a cost for the environmental externalities of supply-side options which is to be used when evaluating least-cost options. Or, alternatively, define least-cost as the least expensive way of reaching a specified emission reduction. Require all states to develop a method for making demand-side investments equally attractive to supply-side investments.

Appliance Standards: Appliance standards overcome the problem of emphasis on first cost by requiring investment in conservation. Thus, standards bring the market closer to minimizing life-cycle costs; i.e., they bring the market discount rate closer to the social discount rate. Performance standards can achieve larger energy reductions than other policies aimed at increasing appliance efficiency, such as tax credits, rebates, labeling and voluntary targets.

The National Appliance Energy Conservation Amendments (NAECA), which were passed in 1988, are expected to lower residential energy use by about 0.9 quads by the year 2000. These standards do not come near fully exploiting the potential for emissions reductions through appliance efficiency improvements. The law requires that they be reviewed twice during the 1990s. This provides an opportunity to obtain additional energy reductions through more stringent standards.

Setting standards at or near maximum life-cycle cost is not politically or technically feasible, and may create a first-cost burden. Thus, standards are most effective when used in conjunction with incentives. Standards can be used to set a floor, taking the least

efficient equipment and buildings off the market, while policies such as utility programs, appliance labeling and tax schemes provide incentives to exceed the standards.

Building Energy Codes: Building energy codes serve a function analogous to that of appliance standards by preventing the least efficient buildings from being constructed. Similarly, they can be used in conjunction with other policies such as utility programs, building rating systems, and tax schemes.

Building codes have traditionally been under the jurisdiction of states and localities. There is little support from the states or the construction industry for a mandatory national building code.

Currently, there is a federal building code which is mandatory for federal buildings only. Changes in federal building code policy which could achieve greater energy savings include: (1) the establishment of a uniform code by either mandating compliance or creating incentives for states to adopt the national code, (2) the development of a more stringent national code, and (3) increased funding for implementation and enforcement. Adequate enforcement is difficult, and necessary for a building code to achieve significant savings.

Consumer Information and Marketing Programs: Lack of information and uncertainty have been identified as key barriers to greater investment in energy conservation. The federal government can play a role in overcoming these barriers by providing information about opportunities to increase energy efficiency. Information dissemination is a key element of several of the policy options discussed above, including appliance standards, building codes and utility planning. In addition, the federal government has played a role in several consumer information and marketing programs,

including energy rating systems (particularly for homes), home energy audits, appliance labels and general information campaigns.

Information and marketing programs work synergistically with taxes and standards to promote conservation. They provide consumers with the information they need to make appropriate choices when presented with price-based incentives from energy taxes. Labeling and ratings can also help create a market where buildings and appliances compete to beat the standards as part of their marketing strategy.

Research and Development: There are major barriers to private investment in R&D in the buildings sector, including the fragmented structure of this sector and the short-term perspective of many of the decision-makers. Thus, the federal government has a key role to play in funding R&D for this sector. Research is necessary not only for energy efficiency technologies, but also for the most promising on-site renewable technologies and technologies that will make cogeneration more applicable in buildings. In addition to R&D on building technologies, there is a need for better energy end-use data for the commercial sector.

D. U.S. Policies for Global CO_2 Emission Reductions

Policies the U.S. can pursue to achieve international reductions in CO_2 emissions in the buildings sector include:

(1) international conventions and protocols which require appliance labeling or standards,

(2) bilateral and multilateral research and information programs, including technology transfer,

(3) utilizing U.S. AID and U.S. influence in the policy of the development banks to finance conservation and renewables, encourage least-cost utility planning and provide technical assistance for conservation, standards and labeling, and

(4) trade policies which discourage barriers to the adoption of energy efficiency.

I. INTRODUCTION

Although there continues to be significant scientific uncertainty over the magnitude of climate change from a given increase in greenhouse gases, there is a scientific consensus that increased levels of greenhouse gases will cause a change in climate. The discussion of climate change has thus moved into the policy realm. Policies to limit climate change, as well as those to adapt to it, are being discussed. In order to develop policies to limit climate change, an in-depth look at the sources of emissions and the potential for reducing them is necessary. This paper contributes to that effort by taking a detailed look at the buildings sector. The buildings sector refers to all activities taking place in buildings[1]. It is synonymous with what is traditionally called the combined residential and commercial sector.

The two greenhouse gases of importance in the buildings sector are carbon dioxide (CO_2) and chlorofluorocarbons (CFCs).[2] CO_2 is emitted when fossil fuels are burned to provide building services such as space conditioning, water heating, lighting, cooking, refrigeration and entertainment. CFCs are used in air conditioners, refrigerators, and foam insulation. This report focuses exclusively on how to reduce CO_2 emissions in the buildings sector.

Table 1 shows the breakdown of CO_2 emissions by sector. In 1985, the direct burning of fossil fuels in the buildings sector accounted for 14% of the global anthropogenic

[1]This paper does not examine the energy used in the construction of buildings. Early studies indicated that this is a relatively small percent of total energy use in buildings, with construction energy use equal to about 5 years of operational energy use (Herendeen, 1977 and Stein, 1977).

[2]Estimates of methane (CH_4) released from extracting and distributing natural gas and from coal mining are uncertain. A portion of these emissions is also attributable to the buildings sector. For a review of the current state of knowledge on CH_4 emissions, see Chandler (1988b).

emissions of CO_2.[3] The buildings sector is also responsible for over half of the 23% of emissions from electricity generation. Table 2 shows the percentage of electricity used by the buildings sector in several regions. In addition, a small percentage of the CO_2 emissions from deforestation are attributable to the residential sector. It is estimated that deforestation accounts for 30% of global CO_2 emissions.[4] Deforestation in the residential sector is caused by gathering fuel wood for cooking and heating.[5] In sum, buildings account for at least a quarter of total CO_2 emissions. These statistics demonstrate the need for a careful examination of the potential to reduce emissions from this sector.

Another reason for carefully examining the opportunities for reducing the use of fossil fuels in the buildings sector is that buildings and their components have long lifetimes. In the United States, the average lifetimes are about 50 years for commercial buildings, 100 years for residential buildings, and 10 to 25 years for appliances. Thus, actions taken now not only affect the current emissions, but also determine emission levels into the next century. Because appliances and equipment are retired significantly faster than buildings, more efficient appliances can penetrate the market more quickly and can bring faster reductions in emissions. Nonetheless, careful attention should be paid to the thermal characteristics of buildings, because adding insulating features at the time they are built is less expensive and more effective than retrofitting.

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[3]EPA, 1988

[4]Ibid.

[5]Fuel wood cutting is only one cause of deforestation. Other significant causes are subsistence agriculture, livestock ranching, and logging. The areas where the demand for fuel wood is contributing significantly to deforestation are: the arid and semi-arid areas of the Sahara, the east and southeast, and the mountainous areas in Africa; the Himalayas and hills of South Asia in Asia; the Andean Plateau, the arid and semi-arid areas of the Pacific coast in South America; and the Caribbean (U.S. Office of Technology Assessment, 1984).

TABLE 1: GLOBAL CO_2 EMISSIONS BY SECTOR, 1985 (millions of metric tons of carbon)

	Teragrams/ year	Percent
RESIDENTIAL/COMMERCIAL (a)	1123	14%
INDUSTRY (a)	1501	19%
TRANSPORTATION (a)	985	12%
ELECTRICITY	1852	23%
DEFORESTATION	2400	30%
OTHER	100	1%
TOTAL	7960	

(a) includes direct burning of fossil fuels only

Based on EPA data

TABLE 2: PERCENT OF TOTAL ELECTRICITY USED IN BUILDINGS SECTOR

REGION	
OECD (a)	56%
NORTH AMERICA (a),(b)	64%
EEC (a)	51%
PACIFIC (a),(c)	40%
SOUTH AMERICA AND CARIBBEAN (d)	47%
AFRICA (d)	36%
MIDDLE EAST (d)	65%
ASIA (d)	38%

(a) For 1985, based on data from International Energy Agency, 1986b.
(b) Includes United States and Canada.
(c) Includes Australia, Japan, and New Zealand.
(d) For 1981, based on data from International Energy Agency, 1984. Includes all electricity not used in transport or industry. Thus, will include agricultural electricity use in addition to residential and commercial buildings. Data not available for all countries in these regions.

Industrialized nations are currently responsible for 78% of the emissions of CO_2 from the direct burning of fossil fuels in the residential and commercial sectors, as shown in Table 2. Thus, efforts to reduce emissions in industrialized nations can have the most significant impact in the short run. While the LDCs are currently responsible for only 22% of emissions, their share of emissions has been growing. This growth is expected to continue, accompanied by a rapid expansion of the infrastructure of LDCs in the next 25 years. While the LDCs often build infrastructures which are less energy-efficient than current practices in industrialized nations, in light of concerns over CO_2 emissions, it is important to consider how they might "leapfrog" ahead and build a state-of-the-art infrastructure.

Energy is used in buildings either through the direct burning of fuels or as electricity. The CO_2 emissions vary significantly by fuel type. Coal is the "dirtiest," discharging almost twice the carbon per BTU as natural gas. The emission factors, in units of million metric tons of carbon per quad BTU, are: 26.37 for coal, 20.02 for liquid fuel, and 14.16 for natural gas.[6] The emission factor for electricity depends on the fuel mix used to generate the electricity. In 1985, the average U.S. electricity emission factor was 17.57, based on a fuel mix of 57% coal, 12% gas, 4% oil, and 27% from non-fossil sources.[7] Because electricity is such a large component of building energy use, the generating fuel mix is a significant factor in determining current CO_2 emissions, as well as the potential for reductions in emissions from conserving electricity.

The approach used in this paper is an end-use analysis. End-use analysis looks in

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[6]Rotty, R.M., and Masters, C.D., 1985.

[7]The 1985 electricity generating mix is from U.S. Energy Information Administration, 1986.

detail at the way energy is used within a sector. It identifies the main services or amenities provided by energy and the characteristics of the technologies used to deliver these services. The end-use approach for the residential sector is described by the following equation:

(# households) * (energy service/household) * (emissions/energy service)

The approach for the commercial sector is similar, with square footage replacing households as the consuming unit. The potential for emission reductions is generally based on reducing the CO_2 emissions per unit of energy service through energy efficiency improvements or fuel substitution. This paper touches only briefly on the issue of changing the energy service per household as a way of reducing emissions.

The end-use approach can provide important information to policy-makers by answering questions such as: What levels of emission reductions are possible with the currently available technologies and with advanced technologies now in the development phase? What are the costs of emission reductions? If a goal of reducing emissions by 10%, 20% or 50% is chosen, how can this most effectively be achieved? The major shortcoming of an end-use approach is that it does not specifically take into account the effects of price or income on levels of energy use.

The term "energy intensity" is often used in describing changes in energy use over time. This term takes on several different meanings, all relating energy use to a key variable which is related to the level of energy consumption. It can be used to refer to energy use per unit GNP, per capita, per dwelling or per unit of floorspace. In keeping with the end-use perspective of this study, the term energy intensity will refer to energy use

per dwelling in the residential sector and energy use per unit floorspace in the commercial sector.

Chapter II presents a technical and economic assessment of the potential for CO_2 emissions reductions in OECD countries. Chapter III presents a parallel analysis for developing countries. Both chapters begin with a detailed look at energy use, including past trends and structural changes affecting the level of energy consumption. Next, ways of reducing the use of fossil fuels are examined. Finally, scenarios of future emissions, based on the adoption of various levels of emission reduction technologies, are presented. The chapter on OECD countries is dominated by information on the U.S., although it includes a scenario of future emissions in Sweden as well. Much less detailed information was available on LDCs, and this is reflected in the analysis presented. Brief case studies are presented for Brazil and China. Chapter IV examines policy tools for the U.S. Congress to reduce U.S. emissions of CO_2, while Chapter V looks at policy options for reducing global emissions.

II. CO_2 EMISSIONS IN OECD COUNTRIES

A. Past Trends and Current Energy Use

In the OECD as a whole, the combined residential and commercial sectors accounted for 38% of primary energy use in 1985, with the residential sector accounting for 23% and the commercial sector for 15%.[8]

In the residential sector, total energy use decreased continually from 1973 through 1983 and then increased slightly from 1983 to 1985. This is in the face of structural changes that would have increased energy use 10% to 20% without efficiency improvements.[9] Space conditioning dominates energy use in the residential sector, generally accounting for 60% to 80% of final energy demand. It is followed by hot water, electric appliances and cooking.[10]

The commercial sector is the fastest-growing sector in OECD countries. Delivered energy use has declined or grown very slowly from 1972 to 1982, while primary energy use has increased due to increased electrification. Energy conservation has been a critical factor in restraining energy growth; energy use per employee and per unit of floor area have both shown substantial reductions since 1973. Space conditioning also dominates the commercial sector, accounting for 60% to 65% of the energy use. Water heating and lighting are the two other major uses in most OECD countries. Air conditioning is

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[8]OECD, 1987.

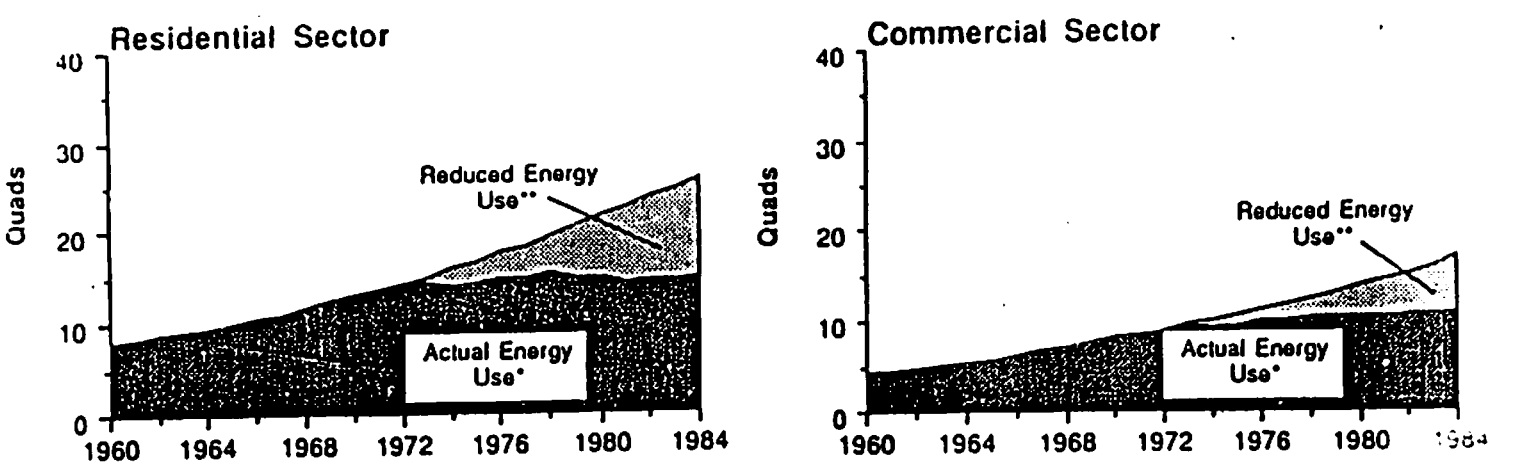
[9]Ibid.

[10]Schipper and Ketoff, 1985.

currently a significant end-use only in the U.S.[11]

For the United States, the trends are similar to the OECD as a whole. Between 1979 and 1985, primary energy use in transport and industry decreased while primary energy use increased by 9.1% in the commercial sector and 0.7% in the residential sector. These increases have occurred in the face of considerable energy efficiency improvements. Energy use per household declined from a high in 1972 of 217 million BTU to 176 BTU in 1985.[12] In the commercial sector, energy consumption per square foot of floor area dropped 12% during the years 1973 to 1985.[13] The effect of these energy efficiency improvements is illustrated in Figure 1, which shows the difference between actual energy

FIGURE 1: REDUCED ENERGY USE FROM INCREASES IN ENERGY EFFICIENCY SINCE 1973
from Brookhaven, 1988.



[11]Schipper, Meyers and Ketoff, 1986.

[12]Brookhaven, 1988.

[13]Geller, 1988a.

use and the energy use that would have resulted from pre-1972 end-use efficiency trends.

In the United States, the combined residential and commercial sectors accounted for 31% of the CO_2 emissions in 1985.[14] Electricity accounted for by far the largest share of emissions in both residential and commercial buildings.[15] Space heating is the dominant source of emissions for both residential and commercial buildings, accounting for 40% and 32% of emissions, respectively. Other important end uses in the residential sector are water heating, refrigeration, lighting, air conditioning and cooking. For the commercial sector, lighting, air-conditioning, ventilation, and water heating are the other dominant uses.[16] A detailed look at CO_2 emissions in the buildings sector, with breakdowns by fuel type and end-use, is presented in Table 3.

The energy use per capita, per dwelling, and per square foot are higher in the U.S. and Canada than in Europe. For example, after adjusting for climate differences, for the same level of amenity Swedish homes currently use about two-thirds of the energy used in the U.S.[17] In the commercial sector, even after accounting for differences in climate, the North American buildings have heating intensities that are 20% to 30% higher than European service sector buildings. Electricity intensity is also higher in North America, partially due to greater use of air conditioning.[18]

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[14]EPA data.

[15]Based on data from Energy Information Administration (1986) about fuels used for generating electricity. Assumes the generating fuel mix in the residential and commercial sectors equals the average electricity fuel mix.

[16]Brookhaven, 1988.

[17]Schipper, Meyers, and Kelley, 1985.

[18]Schipper, Meyers, and Ketoff, 1985.

Although the fuel mix used in the OECD is country-specific, for most countries there has been a general trend toward increased electrification since 1973 in both the residential and commercial sectors. This trend has been caused by increased use of electric appliances, increased use of electricity for space and water heating, and, in the U.S, increased use of air conditioning. For example, in the United States, 44% of new homes were electrically heated in 1986, compared to only 15% in 1983. The percentage of new homes built with central air conditioning has increased from 34% in 1970 to 63% in 1980 and 70% in 1986.

This trend toward electrification can have significant effects on CO_2 emissions. The net result of electrification depends on the generating fuel mix and the relative efficiencies of fuel versus electric equipment. If electricity is generated by solar, wind, geothermal, nuclear, or sustainable biomass, a move toward electrification can decrease CO_2 emissions. If, on the other hand, a large share is produced by coal or other fossil fuels, the emissions from the use of electricity will be higher.

The relative efficiency of electric versus gas or oil space-heating equipment can change over time. Electric resistance heat uses about three times as much primary energy as the most efficient gas or oil furnace. However, the most efficient electric heat pumps and the most efficient gas furnaces currently use about equal amounts of primary energy per delivered unit of final energy. On the other hand, when gas heat pumps reach the market, today's electric heat pumps will use more primary energy per unit of delivered

TABLE 3: U.S. CO_2 EMISSIONS IN THE RESIDENTIAL AND COMMERCIAL SECTORS FOR 1985 BY FUEL TYPE AND END-USE (millions of metric tons of carbon)

	elec	gas	oil	other	total	percent
RESIDENTIAL SECTOR (1)						
space heating	30.9	41.9	20.2	9.3	102.3	40%
water heating	27.4	11.9	2.0	1.4	42.7	17%
refrigerators	24.6	0.0	0.0	0.0	24.6	10%
lighting	17.8	0.0	0.0	0.0	17.8	7%
air conditioners	18.5	0.0	0.0	0.0	18.5	7%
ranges/ovens	11.0	3.0	0.0	0.7	14.7	6%
freezers	7.7	0.0	0.0	0.0	7.7	3%
other	20.2	7.8	0.0	0.0	28.0	11%
TOTAL	158.0	64.6	22.2	11.4	256.2	
% by fuel type	62%	25%	9%	4%		
COMMERCIAL SECTOR						
space heating	15.7	28.0	15.6	4.2	63.5	32%
lighting	51.5	0.0	0.0	0.0	51.5	26%
air conditioning	17.4	1.6	0.0	0.0	19.0	10%
ventilation	24.2	0.0	0.0	0.0	24.2	12%
water heaters	5.6	2.5	1.6	0.0	9.7	5%
other	24.1	3.4	0.2	2.3	30.0	15%
TOTAL	138.5	35.5	17.4	6.5	197.9	
% by fuel type	70%	18%	9%	3%		
TOTAL RES AND COMM	296.5	100.1	39.6	17.9	454.1	
% by fuel type	65%	22%	9%	4%		

(1) does not include .8 quads energy from wood

Based on energy data from Brookhaven National Laboratory, 1988 and CO_2 emission factors from Rotty, 1985.

energy than gas heat pumps.[19] The current choice of fuel type for buildings will have long-term implications, as heating plant turnover is slow and the infrastructure to deliver energy to a building and distribute it within a building is set in stone, so to speak.

This trend toward electrification in the U.S. residential and commercial sectors is shown in Figure 2.[20] As shown in Figures 3 and 4, while end-use energy decreased continually between 1972 and 1984, in both the residential and commercial sectors, primary energy use decreased at a slower rate, and actually increased slightly in the residential sector in 1984.[21] This trend in primary consumption of energy in the U.S. is primarily due to the increased use of electricity. With the current U.S. electricity generating mix, this results in higher CO_2 emissions.

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[19]A simple calculation shows that for the current fuel mix in the U.S., if electricity and gas equipment use the same amount of primary energy to deliver a service, the CO_2 emissions from the electric equipment will be 22% higher than those from the gas equipment. This is based on the average electricity fuel mix and could vary significantly depending on the utility service area.

[20]Brookhaven National Laboratory, 1987.

[21]Energy Information Administration, 1984 and 1986.

FIGURE 2: RESIDENTIAL AND COMMERCIAL PRIMARY ENERGY CONSUMPTION BY FUEL TYPE
from Brookhaven, 1988.

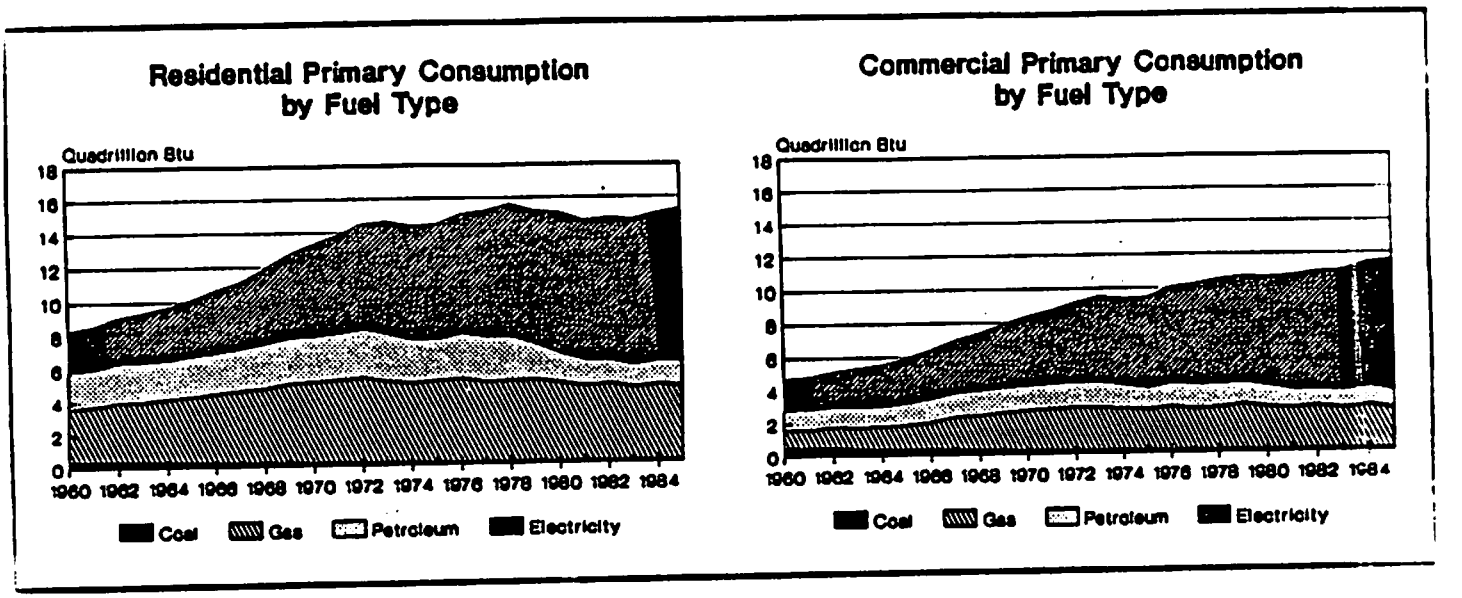
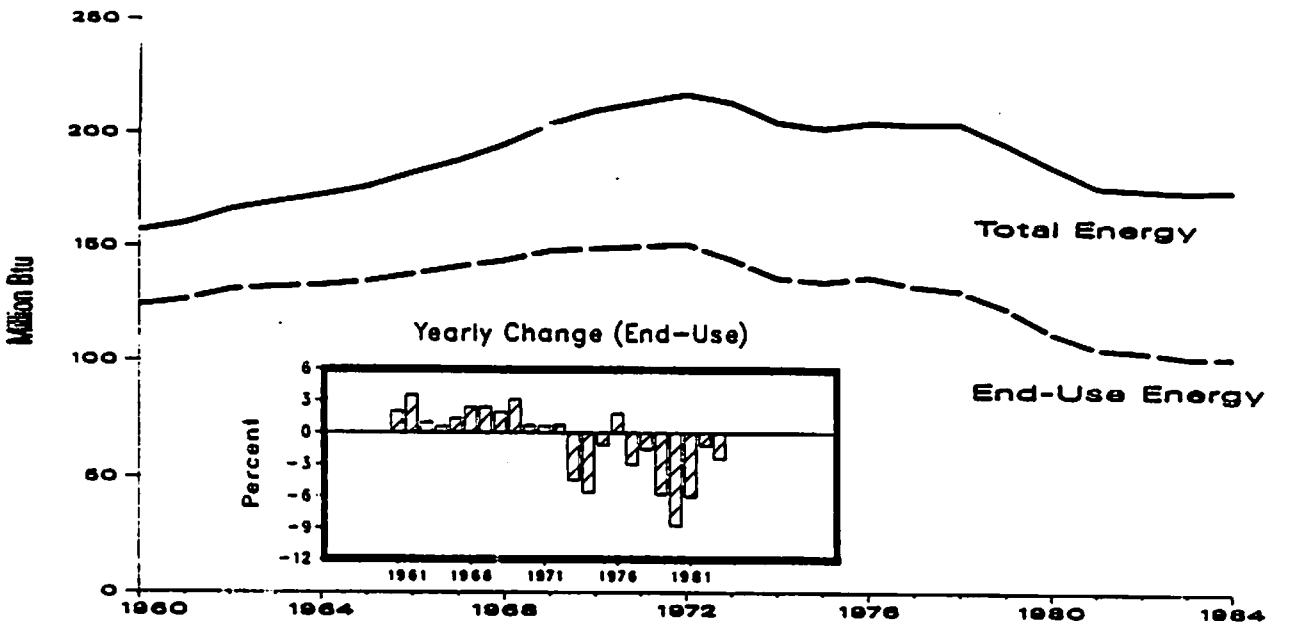


FIGURE 3: RESIDENTIAL ENERGY CONSUMPTION PER HOUSEHOLD
from Geller, 1988a.



Data Source: See Table A10 on page 67.

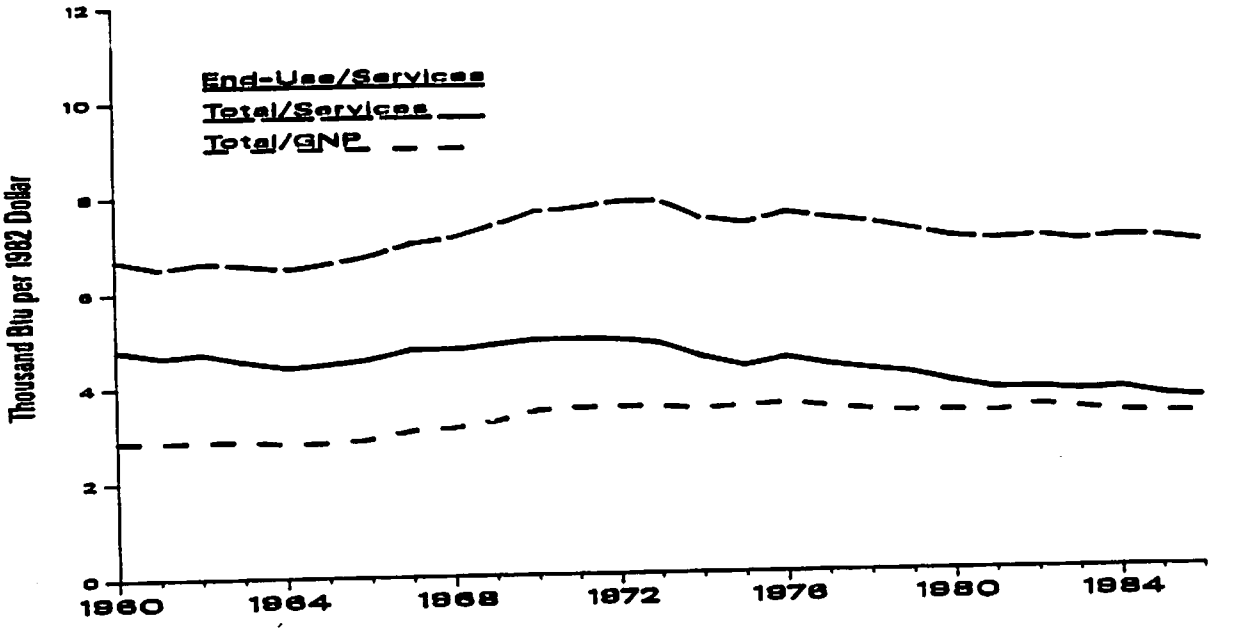
Approach

End-use and total residential energy consumption data are divided by the number of all households. The consumption data do not include consumption of wood.

Key Findings

- Beginning in 1972, end-use energy consumption per household decreased at an average annual rate of 3.5 percent through 1983. The estimate for 1984 end-use energy consumption per household shows a very small decrease.
- In 1984, total energy consumption per household increased slightly for the first time since 1978, reflecting the continued increased reliance on electricity.

FIGURE 4: COMMERCIAL ENERGY CONSUMPTION PER CONSTANT DOLLAR OF GROSS NATIONAL PRODUCT
from Geller, 1988a.



For Figure 1, data are displayed for both gross (including electricity losses) and end-use energy consumption per constant dollar of GNP services and gross energy consumption per constant dollar of GNP. The services portion of Gross National Product (GNP) was close to 47 percent in 1986. "Services" includes anything for use during the year which cannot be put into inventory (health care, for example) but excludes services which figure into the cost of goods sold (retail services, or office operations of manufacturers, for example). The service-orientation of the economy increased from 43 percent to 48 percent of GNP between 1960 and 1975, as the rate of industrial output slowed, and averaged around 47 percent between 1976 and 1986.

- Commercial end-use energy consumption per constant dollar of GNP services peaked in 1970, then fell from close to 5,000 Btu to 3,500 Btu per dollar of services between 1970 and 1986.

- Between 1973 and 1986, end-use energy consumption per dollar of GNP for services fell twice as fast as gross energy consumption per dollar of services (2.4 percent versus 1 percent annually) because of the rapid increase in electricity use.

Energy Information Administration/Energy Conservation Indicators 1986

B. The Structure of Residential Energy Use

Residential energy use is dependent on many factors, including climate, home characteristics such as size, insulation, and siting, efficiency of appliances and equipment, fuel choices, and life-style. These are affected by income, energy prices, demographics, and building and appliance technologies. The factors which have pushed up demand in the residential sector are increases in the number of dwellings,[22] increases in the number of appliances, and more centrally heated homes. The factors pushing down demand are improved thermal characteristics of existing homes (retrofits), new homes with better thermal performance, higher efficiency appliances and equipment, altered thermostat settings (higher in summer, lower in winter), and improved maintenance.

While there have been major structural changes in this sector over the past 25 years, structural changes are expected to play a smaller role in the future. First of all, population and household growth will be low. Secondly, in OECD countries there is now a saturation of the major domestic amenities: most homes have domestic hot water, central heating exists where space heating is important, space temperatures are comfortable, and homes have refrigerators and electric lights. Other appliances are not large energy users. Thus, there is a saturation of the most energy-intensive amenities in the residential sector. This leads some to the conclusion that increased personal income is therefore unlikely to have a large effect on residential energy use, as it will be spent on less energy-intensive domestic services and non-residential services.[23] On the other hand, increased income could be

[22]Increases in the number of dwellings are due not only to population growth, but to decreases in the number of people per household.

[23]Meyers, 1986 and Goldemberg, 1988.

accompanied by new domestic uses. An important example of this could be air conditioning. In 1980 it accounted for only 3% of residential energy use in the OECD. It is a large energy user with potential for increased use in OECD countries, particularly in the face of climate warming.

C. The Structure of Commercial Energy Use

The commercial sector encompasses various enterprises including offices, warehouses, educational buildings, health care, food sales and services, and lodging. There is much variance in the energy intensity of these "sub-sectors." In the U.S., their energy consumption ranges from 80 or fewer KBTU/sq. ft. for education and warehouses to more than 200 KBTU/sq. ft. for health care and food services.[24]

The key variables affecting energy use in the commercial sector are floor area, the mix of activities (i.e., the relative importance of each sub-sector), the age and corresponding thermal characteristics of the building stock, and the fuel type.

The service sector is expected to continue to grow at a faster rate than other sectors in the OECD countries. There will be some increase in energy intensity due to increased use of computers and other electronic equipment. There is potential to offset this through energy-efficiency improvements. In addition, geographic shifts can be important for countries with a varied climate such as the U.S. In the U.S., the geographic shift to the south and west has added to the trend toward electrification, as buildings in these regions are more likely to be electrically heated than buildings in the Northeast, which are generally

[24]Geller, 1988a.

heated by oil or gas.[25]

D. Methods and Costs for Reducing Fossil Fuel Use in Buildings

Reduced fossil fuel use can be achieved through: (1) technological improvements including improved thermal integrity and improved equipment and appliance efficiency, (2) substitution of renewables for fossil fuels, and (3) behavioral or lifestyle changes.[26] While all three of these methods for emission reduction will be discussed, the focus will be on technological improvements because they provide the most promise for reduced fossil fuel use in the near term. The discussion of technological improvements will be divided into two sections, residential and commercial, and will focus on the largest energy end uses in the buildings sector: space conditioning, lighting and appliances.

Where available, information on the costs of reducing fossil fuel use will be provided. These costs can be examined on both a first-cost and a life-cycle basis. Although many energy-efficient buildings and appliances have higher first costs, they often have lower life-cycle costs than less efficient models. While life-cycle costs would ideally include the costs of externalities such as global warming, it is virtually impossible to calculate such costs, and they are generally left out of the quantitative calculations. The effect of including them would be to place greater value on energy conservation, thus making even more expensive measures cost-effective.[27] The costs cited in this section are all from studies which did not

[25]Schipper, Meyers, and Ketoff, 1986.

[26]This study examines methods for on-site reduction in building fossil fuel use. While electric utility fuel switching (from fossils to renewables or nuclear, or from coal to gas or oil) can also reduce CO_2 emissions from the buildings sector, the technologies and costs of these measures are beyond the scope of this paper.

[27]The cost of conservation can also be compared to the marginal cost of new supply. If it is less expensive to purchase conservation than to purchase the energy that would be required without the conservation investment, then conservation is the better choice from a societal viewpoint (assuming that the externalities from conservation

include climate change, or any other environmental costs, in their analysis.

Throughout this section, it is important to keep in mind that improved building energy efficiency will generally depend on several small changes in building energy use rather than one or two big-ticket items. The most cost-effective techniques for reducing fossil fuel use will vary by country and by region within a country, and are dependent on geography, culture, building practices, access to resources, climate, and the current condition of the buildings' infrastructure.[28]

Two terms that are used throughout this section require definition. The term "cost of conserved energy" refers to the life-cycle cost of a unit of energy saved (e.g., kWh) through an investment in energy conservation or solar energy. The term "cost-effective" will be used to describe measures for reducing fossil fuel use which have a lower life-cycle cost than that of current equipment or buildings.

The data in this section is generally drawn from the U.S. However, the methods for reducing energy use are generally applicable to other OECD countries. The only caveat here is that the effect of reduced electricity use on CO_2 emissions will vary between countries based on their fuel generating mix.

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are smaller than or equal to those from energy use). For electricity, the cost of new supply is generally more expensive than the average or marginal cost for existing capacity. Thus, conservation actions that are not cost-effective under current prices may be attractive if new capacity is required to meet demand. For a detailed discussion of when conservation is economically efficient, see two articles by Cicchetti and Curkendall: "Are Energy-Efficiency Programs Worth It?" and "Conservation Subsidies: The Economist's Perspective".

[28]There are several excellent studies which discuss technologies for improved energy efficiency and potential savings in greater detail. These include: two papers by Howard Geller, "Residential Equipment Efficiency: A State-of-the-Art-Review" and "Commercial Building Equipment Efficiency: A State-or-the-Art Review"; a book by Eric Hirst et. al., Energy Efficiency in Buildings, Progress and Promise; and a book edited by Hafemeister, et. al., Energy Sources: Conservation and Renewables.

1. Residential Buildings: Space Conditioning, Appliances and Lighting

a. *Space Conditioning*

In the residential sector, there is more potential for reduced fossil fuel use in space heating than in any other single end-use. The energy used for space conditioning can be reduced through improved thermal integrity (i.e., a better building envelope), improved equipment efficiency, and improved siting and landscaping practices.

Thermal integrity can be improved by increasing the insulating value of buildings and reducing infiltration. Methods for achieving these goals include: additional insulation in the roof and walls; glazing materials with higher insulating values, including double and triple pane windows; insulating draperies or shades; and caulking and weatherstripping cracks around doors and windows. Earth-sheltered and super-insulated homes are examples of building types which capitalize on the opportunity to reduce space conditioning requirements through improved insulation.

Although the cost-effectiveness of improving the thermal integrity of residential buildings is site-dependent and building-specific, some generalizations can be made. The SERI study found that there are cost-effective improvements which apply for both new houses and retrofits using either fuel or electricity for heating.[29] These include storm windows, attic insulation, and reduction of infiltration. These results are supported by the data from the Buildings Energy Use Compilation and Analysis Project (BECA) which keeps a database of measured results of energy-efficient new and retrofit buildings. The BECA data show that for homes with little or no attic insulation, the addition of attic insulation alone can reduce space heating requirements by 15% to 33%, with simple paybacks of 2 to

[29]Solar Energy Research Institute, 1981.

6 years.[30]

The second method for reducing space conditioning requirements in buildings is the improved efficiency of space conditioning equipment, including furnaces, heat pumps and air conditioners. Because residential space conditioning equipment is generally classified as "appliances," the potential reductions and associated costs for this equipment are examined in the next section on appliances.

The third method for reducing the space conditioning requirements is the proper siting of buildings. Taking advantage of solar gains in the winter and shading in the summer can reduce the use of fossil fuels for heating and cooling. Proper siting and ventilation can allow for more use of natural ventilation and less use of fans or air conditioning. Landscaping, such as planting trees, can reduce the use of energy through direct shading effects.[31]

Homes with the lowest heating requirements combine high thermal integrity with efficient equipment and proper siting. The space heating requirements for a variety of

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[30]Goldman, 1986.

[31]The planting of large numbers of trees in urban areas, combined with making surfaces a lighter color, can reduce the urban heat island effect and thus reduce energy use (Akbari, et. al., 1988).

TABLE 4: SPACE HEAT REQUIREMENTS IN SINGLE-FAMILY DWELLINGS
(kilojoules per square meter per degree day) (a)
from Goldemberg, et. al. 1988

United States	
Average housing stock (b)	160
New (1980) construction in U. S. (c)	100
Mean measured value for 97 houses in Minnesota's Energy-Efficient Housing Demonstration Program (b)	51
Mean measured value for 9 houses in Eugene, Oregon, U. S. (d)	48
Calculated value for a Northern Energy Home, New York Area (a)	15
Sweden	
Average, housing stock (f)	135
Homes built to conform to the 1975 Swedish Building Code (g)	65
Mean measured value for 39 homes built in Skane, Sweden (h)	36
House of Mats Wolgast, in Sweden (i)	18
Calculated value for alternative versions of the prefabricated house sold by Faluhus (j)	83
Version #1	83
Version #2	17

(a) The required output of the space heating system (i.e., heat losses less internal heat gains less solar gains) per unit floor area per heating degree day. The number of heating degree days (HDD) is a measure of the severity of the winter heating season.

(b) See R. H. Williams, G. S. Dutt, and H. S. Geller, 1983.

(c) As reported by the National Association of Home Builders (J.C. Ribot, A. H. Rosenfeld, F. Flouquet, and W. Luhrsen, 1983).

(d) These are one-story houses, with an average floor area of 103 sq. metres, 15 sq. metres of double-paned windows, 15 cm (30 cm) of fibreglass insulation in the walls and floor (ceiling), and an average air infiltration rate of 0.25 air changes per hour. The energy performances of the houses were adjusted to standardized conditions: an internal heat load of 1.0kW and an indoor temperature of 20 C. See J.C. Ribot, A.H. Rosenfeld, F. Flouquet, and W. Lurhsen, 1983.

(e) The Northern Energy Home (NEH) is a super-insulated home design which is sold in New England. The NEH design is based on modular construction techniques. The house is constructed of factory-built wall and ceiling sections (120 x 240cm x 23cm) which are mounted on a post and beam frame. The calculations presented here were carried out by Dan McMillan of the American Council for an Energy-Efficient Economy, using the Computerized Instrumented Residential Audit computer program (CIRA), for a house with the following features: 120 sq. metres of floor area; 12% of wall area (14 sq. metres) in windows, with 60% on the south side; triple glazed windows with night shutters; 20 cm of polystyrene insulation in walls, 23 cm in ceiling; 0.15 ACH natural ventilation plus 0.35 ACH forced ventilation plus 70% efficient air-to-air heat exchanger; internal heat load of 0.65 kW, corresponding to the most energy-efficient appliances available in 1982 plus 3.06 occupants on average. The indoor temperature is assumed to be 21 C in the daytime, set back to 18 at night. The New York climate is characterized by 2700 degree days.

(f) In 1980 the average fuel consumption for space heating, floor area, and number of heating degree days were 98.5 GJ, 120 sq. metres, and 4474 DD respectively, for oil-heated single-family dwellings (Lee Schipper, 1982). Here a 66% average furnace efficiency is assumed.

(g) A single-storey house with 130 square metres floor area, no basement, electric resistance heat, an indoor temperature of 21 degrees, and 4010 degree days should consume this much for space heating (Lee Schipper, 1982).

(h) The average for 39 identical, 4 bedroom, semi-detached houses (112 square metres of floor area; 3300 degree days).

(i) The Wolgast house has 130 sq. metres of heated floor space, 27 and 45 cm of mineral wool insulation in the walls and ceiling respectively, quadruple glazing, low natural ventilation plus forced ventilation via air preheated in ground channels. Heat from the exhaust air is recoved via a heat exchanger. The local climate is characterized by 3800 degree days. Se P. Steen, T.B. Johansson, and R. Fredriksson, and E. Bogren, 1981.

(j) The Faluhus has a floor area of 112 square metres. The more energy-efficient Version #2 (with extra insulation and heat recuperation) costs 3970 SEK (U.S. $516) per square metre compared to 3750 SEK (U.S. $488) per square metre for Version #1.

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homes in the U.S. and Sweden are compared in Table 4.[32] While the average new home uses significantly less energy for space heating than existing homes, there is still great potential for improvement. In the U.S. the most efficient home has only 15% of the final energy demand for heating of the average new home. For Sweden, the best home uses 26% of the final energy of homes built to 1975 standards.[33]

An analysis of the BECA data for energy-efficient retrofits and new homes supports the conclusion that there is significant potential for reducing the space heating requirements in homes in a cost-effective manner.[34] Their conclusions are: (1) Energy-efficient new

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[32]Goldemberg, et. al., 1988.

[33]Residential energy conservation has been an important goal for Sweden, as reflected in the low space heat requirements for existing homes. Thus, although the percentage reduction for the best house as compared to existing stock is less for Sweden than the U.S., the actual energy use for the best house is the same in both nations.

[34]Lawrence Berkeley Lab, 1986.

houses use only one-third to one-half of the energy required by the average new house in U.S., with the best using far less. (2) Superinsulated, passive solar and active solar can all be cost-effective, although the active solar homes did not perform as well as the others. Earth-sheltered homes can be cost-effective in colder climates with low humidities and the proper soil and siting conditions.[35] (3) Retrofits of homes and multifamily buildings show typical savings of 20% to 25% with simple paybacks of 5 to 9 years. More detailed information on their data is presented in Tables 5 and 6.

[35]Hirst, 1985.

TABLE 5: SUMMARY OF COST AND ENERGY SAVINGS FOR RETROFIT PROGRAMS
from Goldman, 1985

	Utility Programs	Low-Income Programs	Research Studies	Multi-Family Bldgs.
1. Sample Size	43,730 homes	938 homes	352 homes	28 bldgs.
2. Cost of Retrofit (1983$)				
-Median	706	1370	824	533
-Average*	1044±702	1578±863	1685±2747	695±551
3. Space Heat Savings (GJ/Yr)**				
-Median	38.4	30.5	27.8	15.1
-Average	40.3±21.0	37.8±26.2	34.3±24.4	27.0±27.4
4. Space Heat Savings (Percent)				
-Median	24%	22%	22%	22%
-Average	26±11%	24±12%	25±14%	26±14%
5. Simple Payback Time (Years)				
-Median	5.7	9.2	6.4	4.7
-Average	10.3	11.4	9.5	7.9
7. Internal Rate of Return				
-Median	25%	6%	17%	11%
-Average	23±15%	13±14%	31±35%	27±31%

* Mean + standard deviation
** Electric space heat savings are measured in resource energy units, 12.1 MJ/kWh

TABLE 6: SUMMARY OF RESULTS FROM THE BECA DATA ON ENERGY-EFFICIENT NEW HOUSES
from Lawrence Berkeley Lab, 1986

Category	number of homes	K-value (Btu/°F-day)	Balance Temp. (°F)	Cost of Conserved Energy Elec. homes ($/MBtu)[a]	Gas homes ($/MBtu)
All homes	319	8648±4738	55.2±8.5	8.24±8.17	5.29±2.72
Superinsulated	196	6746±3404	59.0±7.2	6.09±8.49	4.14±2.82
Passive Solar	197	6072±4508	50.2±9.4	5.94±8.55	4.43±2.81
Active Solar	26	11224±6670	57.0±7.9	16.81±2.09	-
Earth Sheltered	9	5336±2668	50.4±10.1	-	-

* Values are mean ± standard deviation in parentheses
a. Electricity is converted in site energy, 3413 Btu/kWh

Source: J. F. Busch and A. K. Meier, "Monitored Performance of New, Low-Energy Homes: Updated Results from the BECA-A database," LBL-18306, Lawrence Berkeley Laboratory, August 1984.

b. *Appliances and Lighting*

The potential for efficiency improvements in equipment, appliances and lighting is presented in Table 7. The best 1986 models for refrigerators, freezers, gas space heaters, air conditioners, electric water heaters, and lights are all at least 30% more efficient than the typical 1986 models. Advanced technologies for the 1990's show promise for continued large efficiency gains.

The recently passed National Appliance Energy Conservation Act (NAECA) will take the worst energy guzzlers off the market and lower residential energy use by about 0.9 Quads by the year 2000.[36] This is equivalent to 6% of the 1986 residential energy use. However, as seen in Table 7, NAECA does not set standards as high as the best currently

[36]Geller, 1988b.

TABLE 7: SUMMARY OF ENERGY CONSUMPTION AND CONSERVATION POTENTIAL WITH MAJOR RESIDENTIAL EQUIPMENT from Geller, 1988b.

	1986 Stock UEC (a)	1986 New UEC (b)	1986 Best UEC (c)	Advanced technology for 1990s (d)	NAECA Stand.
	(kWh/yr or therms/yr				
Refrigerator	1450	1100	750	300-500	976
Freezer	1050	750	430	200-300	671
Central AC	3500	2900	1800	1200-1500	2600
Room AC	900	750	500	300-400	680(f)
El. water heating	4000	3500	1600	1000-1500	3300
El. range	800	750	700	400-500	
El. clothes dryer	1000	900	800	250-500	
Lighting	1000	1000	650(e)	350-500	
Gas space heating	730	620	500	300-500	570(g)
Gas water heating	270	250	200	100-150	230
Gas range	70	50	40	25-30	(h)
Gas clothes	50	40	35	30-35	

(a) Unit energy consumption per typical installation in the 1986 housing stock.

(b) Unit energy consumption for typical model produced in 1986.

(c) Unit energy consumption for best model mass-produced in 1986.

(d) Unit energy consumption possible in new models by mid-1990s if further cost-effective advances in energy efficiency are made.

(e) Assumes the most heavily used incandescent lamps are replaced with compact fluorescents.

(f) The central air conditioner standard applies to split systems; the minimum standard for package units is 9.7 SEER effective in 1993.

(g) The gas furnace standard is based on the isolated combustion air test, which is equivalent to about an AFUE rating with the test procedure currently used by the furnace industry association.

(h) The gas range standard bans the use of pilot lights in ranges and ovens having an electrical supply cord.

available models, nor is it technology-forcing.[37] For heating and cooling equipment, this is reasonable, as the most cost-effective equipment may vary from one region to another. While a high-efficiency furnace may be a reasonable investment in Maine, it would not save enough energy to recover first costs in Florida.

Current comprehensive cost data for appliance and equipment efficiency improvements are not available. Cost data from a review of NAECA standards for refrigerators, freezers and small gas appliances are presented in Table 8.[38] It demonstrates that there are net present value savings over a large range of efficiency improvements for refrigerators and freezers. For small gas furnaces, the net present value is about even over the range of efficiency improvements in this study.

Data from a 1984 study of the costs for higher-efficiency equipment is presented in Tables 9 and 10. This analysis first determined the efficiency level of equipment with the lowest life-cycle cost (LCC), using discount rates of 3% and 10%. It then calculated simple paybacks for the LCC equipment versus the average current stock and the average new equipment.[39] The range of paybacks for water heaters, refrigerators and freezers is between 1.3 and 2.6 years. The range of paybacks for furnaces is 4 to 7.3 years, and the range of paybacks for air-conditioners is 5 to 9 years. While these numbers are based on improving efficiency to an optimum level, there are efficiency improvements that can be made which have considerably shorter paybacks, but also save less energy.

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[37] There are provisions in the legislation for two reviews of the standards in the 1990's, with the possibility of raising standards at that time. A review of standards for refrigerators, small gas furnaces and televisions is currently under way.

[38] U.S. Department of Energy, November 1988.

[39] Levine, et. al, 1985. This study used a "simple" payback calculation. The increased first cost was divided by the dollar value of annual energy savings. Thus, the payback period is the number of years it would take to recover the higher first cost investment of the energy efficient equipment.

TABLE 8: PRICE AND LIFE-CYCLE COST FOR ENERGY EFFICIENCY IMPROVEMENTS IN REFRIGERATORS, FREEZERS, AND SMALL GAS FURNACES (a)
from U.S. Department of Energy, November 1988.

	PROPOSED STANDARD LEVEL					
	BASE (c)	1	2	3	4	5
REFRIGERATORS AND REFRIGERATOR/FREEZERS						
annual energy consumption (kwh/year)	959	808	763	733	655	529
projected purchase price	584	593	601	612	656	744
net present value of life cycle cost (b)	489	451	441	436	429	423
FREEZERS						
annual energy consumption (kwh/year)	618	537	496	470	424	339
projected purchase price	367	377	385	393	416	463
net present value of life cycle cost (b)	319	299	290	285	280	271
SMALL GAS FURNACES						
annual fuel use efficiency	80.3	81.6	82.6	84.3		
projected installed price	2597	2640	2671	2727		
net present value of life cycle cost (b)	1684	1685	1686	1689		

(a) All values based on shipment weighted average, 1987 dollars.
(b) Discounted to 1987 at 7% real (1987 dollars). Average over all new units purchased from 1992 - 2015. Net present value is difference in present value of unit life-cycle costs between the base case and standards case.
(c) Base level of energy consumption is based on NAECA 1988 standards.

TABLE 9: EFFICIENCIES OF APPLIANCES
from Levine, et. al., 1985

Appliance	1984 Stock	1984 SWEF (new units)	Efficiency* of LCC minimum at 10%	3%
Gas Furnaces (%)	64	73	85	90
Oil Furnaces (%)	74	79	90	93
Room A/C (EER)	6.6	7.5	9.3	10
Central A/C (SEER)	6.9	8.7	8.0	9.5
Elec. Water Heater (%)	81	82	94	94
Gas Water Heater (%)	50	56	80	83
Refrigerator-Freezer (ft^3/kWh/day)	4.7	6.6	11	12
Freezer (ft^3/kWh/day)	8.9	12	23	24

*For all products except gas furnaces, central air conditioners, and refrigerator-freezers, the efficiency at the LCC minimum is based on prototype designs that do not presently exist in the market.

SWEF stands for shipment weighted efficiency of new units.
LCC stands for life-cycle cost minimum.

TABLE 10: PAYBACK TIMES FOR INVESTMENT IN ENERGY EFFICIENCY THAT INCREASE EFFICIENCY FROM EXISTING LEVELS TO OPTIMUM LEVELS
from Levine, et. al., 1985

	Payback to Increase 1984 Existing Stock Eff. to LCC mix (in years)		Payback to Increase 1984 SWEF (new sales) to LCC minimum (in years)	
Discount Rate	3 %	10%	3 %	10%
Gas Furnace	5.4	4.3	7.3	5.7
Oil Furnace	4.9	4.0	5.7	4.5
Room A/C	5.8	4.9	6.7	5.5
Central A/C	7.1	6.0	8.9	7.4
Elec. Water Heater	1.5	1.3	1.5	1.4
Gas Water Heater	2.0	1.8	2.5	2.2
Refrigerator-Freezer	1.8	1.6	2.4	2.1
Freezer	2.3	2.0	2.6	2.2

Additional information on the cost of conserving electricity is available in studies of the cost of demand-side electricity resources (i.e., conservation). These studies are region-specific. Two studies with detailed information are the Northwest Conservation and Electric Power Plan[40] and Final Report: Analysis of Michigan's Demand-Side Electricity Resources in the Residential Sector.[41]

2. Commercial Buildings: Space Conditioning and Lighting

a. *Space Conditioning*

As in residential buildings, the methods for reducing space conditioning requirements in commercial buildings include improved building envelopes, higher equipment efficiencies and proper siting. The most successful methods for improving thermal integrity during the design stage of a new building include: developing a more compact form, reorientation of the entire building, reductions or reorientation of glazing, the use of different glazing, the use of interior shading, and increased insulation of walls and roofs. For most retrofits, only the options of improved glazings and increased insulation are available, and the design of many commercial buildings prohibits additional insulation. Thus, improved HVAC (heating, ventilating and air conditioning) equipment efficiency plays the dominant role in commercial retrofits.

New HVAC equipment offers large improvements over existing stock. Cooling systems are 50% to 100% more efficient than the existing stock, VAV (variable air volume) systems are 50% more efficient for cooling and provide even larger efficiency improvements

[40]Northwest Power Planning Council, 1986 and 1989.

[41]Krause, et. al., 1988.

during heating. Economizer cycles, which allow the use of outside air for cooling when the weather permits, are 10% to 50% more efficient than systems without economizers.[42]

b. *Lighting*

Lighting accounts for over 25% of CO_2 emissions in the commercial sector. It offers perhaps the single largest, and certainly the most cost-effective, method for reducing fossil fuel use in the commercial sector. Lighting energy use can be reduced by using more efficient technologies, through design improvements such as daylighting and task lighting, and by the use of lighting controls such as occupancy sensors and individualized control. Reductions in energy use of up to 75% can be achieved by replacing incandescents with fluorescents. Further gains of up to 50% are possible with the use of high-efficiency lamps and ballasts. Continued improvements in lighting design are expected to offer reductions of 300% over the standard fluorescent lamp by the end of the century.[43] The savings potential and simple paybacks for several lighting efficiency improvements are given in Table 11. Many of the options offer simple paybacks of less than 2 years.

In addition to reducing the electricity needed for lighting, more efficient lighting gives off less heat to the room, thus reducing the air conditioning load.

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[42]Hirst, et. al., 1986.

[43]Geller, 1988a.

TABLE 11: SAVINGS POTENTIAL AND COST EFFECTIVENESS OF ENERGY-EFFICIENT LIGHTING TECHNOLOGIES
from Geller, 1988a

Technology	Savings potential (a) (%)	Savings potential (a) (kWh/yr)	Unit cost (b) ($)	Simple payback (c) (yrs)
Compact fluorescent replacing incandescent	60-75	125-200	15-20	1.1-2.3
High-efficiency fluorescent lamp (d)	15-20	23-31	1-2	0.5-1.2
High-efficiency magnetic ballast (e)	10	30-40	4-6	1.4-2.8
Electronic ballast (e)	20-25	70-90	25-40	3.9-8.0
Optical reflector (f)	30-50	150-300	25-50	1.2-4.7
Daylighting controls (g)	25-50	2.2-4.4	0.5-1.5	1.6-9.6
Occupancy sensors (g)	30-50	2.6-4.4	0.4-1.0	1.2-5.4

(a) Lighting electricity savings assuming lights in a commercial building are used 3500 hours/yr.

(b) Cost includes installation for add-on retrofit measures. In cases, where a high-efficiency product replaces a standard product, the incremental equipment cost is given.

(c) Based on the 1986 national average commercial sector electricity price of $0.071/kWh.

(d) Based on a 48" fluorescent tube, the most common type.

(e) Based on a ballast that operates two 48" fluorescent lamps, the most common circuit design.

(f) Based on removal of one or two 48" lamps from a fixture originally containing three or four lamps.

(g) The electricity savings potential and unit cost values are provided per square foot of floor area, assuming installation in a large office building.

c. *Energy Management, Operation and Maintenance*

Energy management systems are used to automatically control HVAC systems and lighting. They can save about 10% of building energy use.[44] They are used in most new commercial buildings, and are often part of retrofit projects.

Operation and maintenance are an important part of energy conservation programs, particularly for retrofits. Proper operation, including temperature setbacks and lighting shut-offs, can significantly reduce energy use. Poorly maintained HVAC equipment will run very inefficiently. Thus, a program of proper maintenance will keep energy use to a minimum. The cost of operation and maintenance is generally small compared to the cost of energy saved.

d. *Examples of Energy-efficient Commercial Buildings*

Goldemberg et al. compared the results of energy-efficient demonstration buildings to existing buildings in the commercial sector.[45] These results are presented in Table 12. For commercial buildings, they found that, in the U.S., the best buildings use only 24% of the energy used by the average 1979 building stock and 42% of 1981 current practice. In Sweden, the best practices use 24% of average 1982 building stock and 33% of current practice.

MacDonald reviewed several studies of the potential for energy savings in existing commercial buildings.[46] He concluded that the technical potential for savings was 40% and the economic potential was around 20%. Technical potential was defined as all projects

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[44]International Energy Agency, 1986a.

[45]Goldemberg, et al., 1988.

[46]MacDonald, 1986.

TABLE 12: SITE ENERGY-INTENSITY FACTORS FOR COMMERCIAL BUILDINGS from Goldemberg, et. al., 1988

	(Gigajoules/m^2 per year)		
	Fuel	Electricity	Total
United States			
Average 1979 Building Stock (a)	0.82	0.49	1.31
Current U. S. Practice (b)	0.16	0.57	0.73
AIA/RC Redesigns (b)	0.07	0.40	0.47
AIA Lifecycle Cost Minimum Designs (b)	0.04	0.28	0.32
Enerplex South, Princeton, NJ (c)	--	0.31	0.31
Sweden			
Average 1982 Building Stock (d)	0.66	0.38	1.04
Swedish Norm for New Construction (b)	0.57	0.19	0.76
Folksam Building, Farsta (e)	0.07	0.39	0.46
Harnosand Building, Harnosand (f)	0.12	0.13	0.25

(a) For an average of 2700 heating degree C days (Energy Information Administration, December 1983)
(b) Table 1.12 (p. 39) and Figure 1.61 (p. 165) in Solar Energy Research Institute, 1981.
(c) For 2700 heating degree C days. Calculated, not measured, values (L. K. Norford, June 1984).
(d) Consumption corrected to normal weather (4010 heating degree C days) (Lars-Goran Carlsson, March 1984).
(e) Measured values for the representative period December 1978 to December 1979 (3810 heating degree C days). "Fuel consumption" is the energy actually delivered by the district heating system (K. Welmer, 1981).
(f) Measured values for 4600 heating degree C days (K-Konsult, February 1984).

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with a simple payback of 10 years or less. Economic potential was defined as all conservation measures with a payback of 5 years or less, with a combined payback for the entire project of less than 2 years.

Conclusions drawn from the BECA commercial buildings data are:

(1) New commercial buildings use about one-half the average energy for current stock.

(2) Energy efficiency in new buildings can be achieved over a large range of construction costs.

(3) Commercial retrofits use 20% to 25% less energy than before retrofit, with paybacks of 2 to 3 years.

3. Renewables

Renewable energy sources that can be applied directly at the building site include passive and active solar, wind, and biomass fuels. SERI estimated the potential contribution of renewables for all buildings to be 4.1 to 5.1 Quads by the year 2000.[47] A breakdown by source is given in Table 13. This estimate is from 1980, and nearly a decade has passed without major progress toward this goal. A new assessment would be most useful. At the least, it is clear that a time-frame beyond the year 2000 will be necessary to achieve the energy savings identified by this study.

4. Cogeneration

By producing electricity and heat at the same time, cogeneration improves the overall efficiency of the fuel used in buildings. While a typical fossil fuel generating station achieves 30% efficiency, cogeneration facilities can achieve 60% to 80% overall fuel use efficiencies. Cogeneration is particularly applicable in medium and large commercial buildings, multi-family buildings, and densely settled residential communities where the steam can be used for district heating.

Cogeneration has barely penetrated the buildings sector. In 1987, only about 50 MW of cogenerating capacity was installed in this sector. This is expected to climb to only 110

[47] Solar Energy Research Institute, 1981.

TABLE 13: SUMMARY OF YEAR 2000 POTENTIAL FOR RENEWABLES CONTRIBUTION TO THE BUILDINGS SECTOR (QUADS)
from SERI, 1981

Residential Buildings	
Wood Usage	1.0
Small Wind	0.8-1.1
Photovoltaics	0.3-0.45
Water Heating	0.5-0.6
Fuel	(0.2-0.3)
Electric	(0.3)
Space Heating	1.1-1.3
New Bldgs Fuel	(0.2-0.3)
New Bldgs Elec	(0.1-0.2)
Exist Bldgs Fuel	(0.6)
Exist Bldgs Elec	(0.2)
Subtotal	(3.7-4.45)
Commercial Buildings	
Water Heating	0.1
Daylighting	0.2-0.3
Photovoltaics	0.1-0.25
Subtotal	(0.4-0.65)
TOTAL RENEWABLES	4.1-5.1

() = Non-Additive

MW by 1990.[48]

The estimates of technical potential for cogeneration in the commercial and residential sectors span a large range. A 1983 U.S. Office of Technology Assessment study estimated the technical potential for cogeneration in the commercial, residential and agriculture sectors in the U.S. to be 3 to 5 GW by the year 2000. In agreement with this range, Ebasco Services estimates 1.9 GW installed capacity by 1995, while Cogenic Energy

[48]Andrews, et al., 1987.

Systems, Inc. estimates 4 GW of installed capacity by the year 2000.[49] Other studies suggest much greater potential. An assessment by Mueller and Associates suggests that the upper limit for cogeneration in the commercial sector is 77.3 GW.[50] This upper bound is based on the number of commercial and institutional buildings that are in the appropriate size range, with no screening for other factors that may prevent cogeneration from being a viable option in these buildings. A recent study by Andrews et al. suggests the potential to be around 30 GW.[51]

These higher estimates of potential are based on broader applicability of cogeneration. In order to achieve these levels, several technical and institutional issues need to be resolved. In the commercial sector, the major technical barrier is a lack of efficient and economical thermally activated refrigeration. In other words, further development of cooling technologies which can be run by "waste" heat are needed to make cogeneration attractive in commercial buildings. Without this cooling technology, cogeneration will be most applicable in areas with high heating loads, and the lower estimates of potential are more realistic. For the residential sector, the foremost technical needs are either to develop micro-cogenerators which are reliable and cost-competitive with purchased electricity and fuel, or to develop the storage and load management capabilities for modular systems which can serve several buildings. For both the residential and commercial sectors, there is also a need for R&D into computer monitoring and controls technologies for integrating cogeneration into the utility grid and for reducing maintenance costs. Finally, because residential and commercial cogeneration facilities are likely to be

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[49] As reported by Mueller and Associates, 1985.

[50] Ibid.

[51] Andrews, et al., 1987.

sited in urban and suburban areas, there is a need for further research into pollution control technologies.[52]

On the institutional side, development of businesses or other institutions to manage interconnected cogeneration facilities is needed. Also, the integration of cogeneration into electric utility planning is necessary to protect the interests of both utilities and cogenerators.

In addition to a resolution of the technical and institutional barriers described above, the viability of cogeneration will depend on its ability to compete with investments in conservation, the price of gas versus other fuels, electricity demand growth, and utility capacity.

Calculations were performed to get a ballpark estimate of the level of emission reduction possible from cogeneration. These calculations are presented in Table 14. Several key assumptions had to be made in order to calculate potential emission reductions. These include:

(1) Cogeneration facilities will operate at the minimum requirements under PURPA. This means that useful power output plus one-half thermal output will equal 42.5%. Assuming electrical output is 33% of input, thermal output will equal 18.4%.

(2) Facilities run for 4000 hours per year. This assumption was made because in many building applications, it is anticipated that cogeneration equipment will only run for a portion of the day or year.

(3) Cogeneration capacity is run by natural gas and replaces electricity generated from coal.

Under these assumptions, at 4 GW installed capacity, emission reductions total 2.5

[52]Andrews, et al., 1987.

TABLE 14: EMISSION REDUCTION POTENTIAL FROM COGENERATION

Assumptions:
1. Cogeneration facilities run at minimum requirements under PURPA. This means that useful power output plus one-half thermal output must equal 42.5%. Assuming electrical output is 33% of input, thermal output will equal 18.4%.
2. Facilities run at 4000 hours per year.

		CO_2 EMISSION SAVINGS (million metric tons carbon)		
INSTALLED COGENERATION CAPACITY	FUEL SAVINGS (QBTUs)	FROM FUEL SAVINGS	FROM ELECTRICITY (a)	TOTAL
4	0.03	0.4	2.1	2.5
30	0.23	3.2	15	19
77	0.58	8.2	40	48

(a) Assumes cogeneration capacity is natural gas and substitutes for electricity generated from coal.

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million metric tons carbon annually. For 30 GW, reductions are 19 million metric tons carbon annually. A doubling of these levels of savings is probably an upper limit, and could be achieved by a combination of greater efficiency and longer hours.

5. **Behavioral and Lifestyle Changes**

Changes in behavior can contribute to energy savings. Thermostat set-back contributed to the energy savings of the past decade. Other options are to heat and cool only some rooms of a home and to conserve hot water. These types of energy savings are very price-sensitive. With an increase in energy prices, these changes could offer relatively quick energy savings. Conversely, with a drop in real energy prices, such behavioral changes are easily reversed.

Another possible change is to have less conditioned space per person. This could be accomplished by new housing being smaller, or by having more occupants in existing housing -- for example, children living at home for longer periods, renting rooms to boarders and changing single-family houses to two-family houses. Energy could also be saved by a trend toward multi-family dwellings. Multi-family dwellings reduce space heating requirements by sharing outside walls and thus reducing the portion of the building that is exposed to the elements. A single-family townhouse with the same amount of space uses about 25% less fuel than a detached house.[53] There are indications that for economic and demographic reasons, more new housing is in multi-family units.[54]

E. Scenarios for Future CO_2 Emissions in the U.S.

In order to move from the potential emission reductions for a given building or appliance to an estimate of the total emission reductions for the buildings sector in the U.S., one must construct a plausible scenario of the characteristics of the future buildings sector. This scenario must describe characteristics of the existing building stock, building stock turnover, changes in the existing stock, the amount of new building and the characteristics of new buildings. The key variables which drive such scenarios are those which affect the structure of energy use as described previously. They include: GNP, energy prices, fuel mix, market penetration rates of new technologies, and population. For the residential sector, they also include dwelling size, number of people per household, and penetration of appliances. For the commercial sector, they also include growth of this sector, relative growth of sub-sectors within the sector, and floor area. A complex model

[53]Keyes, 1980.

[54]Council on Development Choices for the '80s.

may look at each of these factors separately, while the simplest model subsumes them all into a single energy intensity factor.

Numerous modeling exercises have been performed either to predict what future energy use will be, or to construct scenarios of the future based on "plausible" assumptions about key variables. The forecasts of CO_2 emissions based on several of these models are presented in Figures 5, 6, and 7 for the residential, commercial, and combined sectors, respectively. The results vary from a high of 653 MT carbon per year by 2010 to a low of 151 MT carbon per year by 2020, with several estimates in between. The high estimate represents an increase in emissions of 40% over 1985 annual emissions, while the low represents a decrease of 67%.

The salient features of each model will be briefly described below in order to point out the key reasons for the differences in the five scenarios. The BNL forecast serves as a base-case analysis.[55] It is based on a model in which energy price and income elasticities are key factors for determining the energy intensity of end-uses. Residential primary energy use per household is predicted to decline by 6% between 1990 and 2000, and then more slowly between 2000 and 2010. In the commercial sector, energy intensity is predicted not to decline until after the year 2000. Increased electrification is experienced in both sectors.

The other models presented are based on several quite different end-use analyses. For all the models, the growth rates of dwellings in the residential sector and floorspace in the commercial sector are key driving variables. As shown in Table 15, the projections for the number of households are fairly consistent for all scenarios, with the exception of WRI, which projects the number of households for 2020 at the level other models predict

[55] Brookhaven, 1988.

TABLE 15: NUMBER OF HOUSEHOLDS IN SCENARIOS FOR RESIDENTIAL SECTOR (millions)

	YEAR					
MODEL	1980	1985	1990	2000	2010	2020
BNL	80.8	86.9	91.8	105.0	118.5	
WRI	81.6					119.2
SERI	80.0			106.0		
OTA		86.9	92.8	105.9	120.1	

for 2010.[56] WRI also projects slower growth in commercial floorspace: 1% per year compared to 2% per year for the other models.

The calculations of emission reductions are based on the assumption that the future supply mix for generating electricity is the same as the 1985 supply mix. In other words, the emissions calculations assume that the same percentage of energy will be generated by coal, gas, oil, and non-fossil fuels as was the case in 1985. In addition, a WRI "low fossil electricity" scenario was calculated. In this scenario, the electricity fuel mix is based on a future supply mix presented in the WRI study which uses a smaller percentage of fossil fuels and a larger percentage of renewables than the 1985 supply mix. The two supply scenarios are presented in Table 16.

[56]Goldemberg, et al., 1988.

TABLE 16: COMPARISON OF FUEL MIX FOR GENERATING ELECTRICITY IN SCENARIOS FOR RESIDENTIAL AND COMMERCIAL SECTORS

	Percent	
	EIA 1985	WRI 2020
coal	57	24
oil	4	10
natural gas	12	
nuclear	16	27
hydro	11	15
wind and pv		10
cogeneration		15

FIGURE 5: SCENARIOS OF CARBON EMISSION FOR THE RESIDENTIAL SECTOR

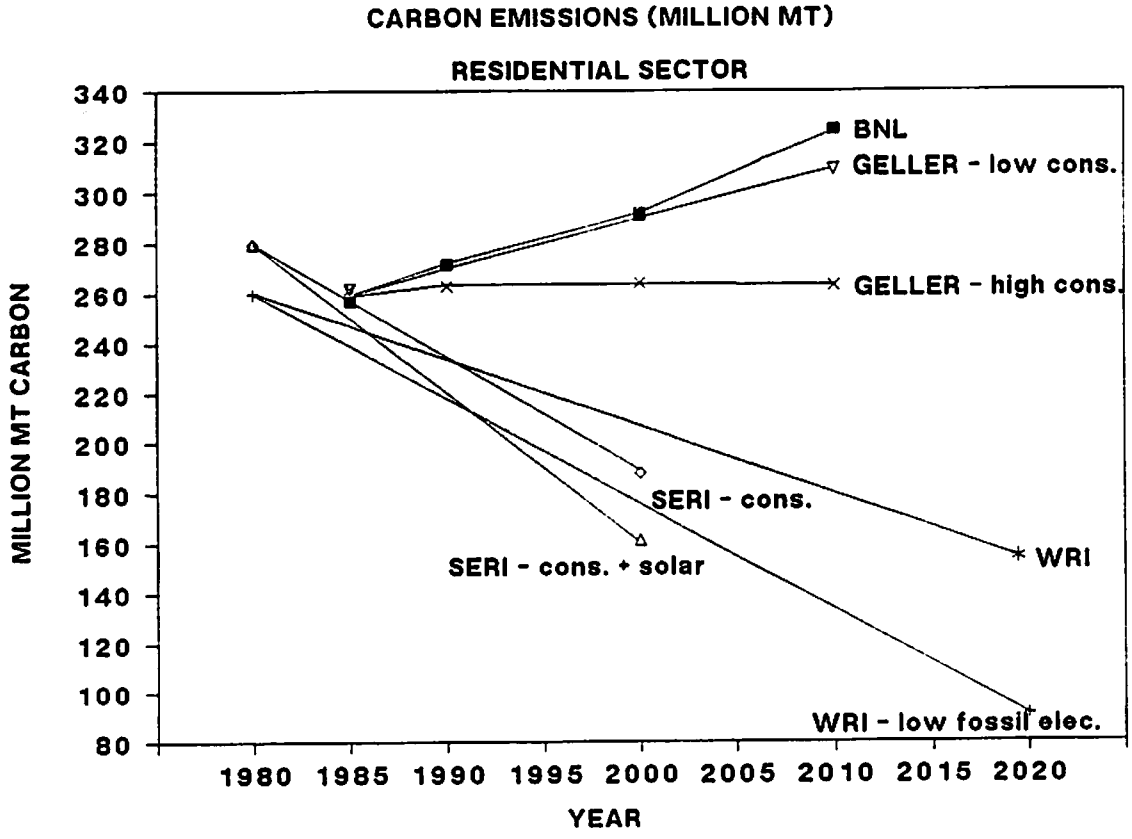


FIGURE 6: SCENARIOS OF CARBON EMISSION FOR THE COMMERCIAL SECTOR

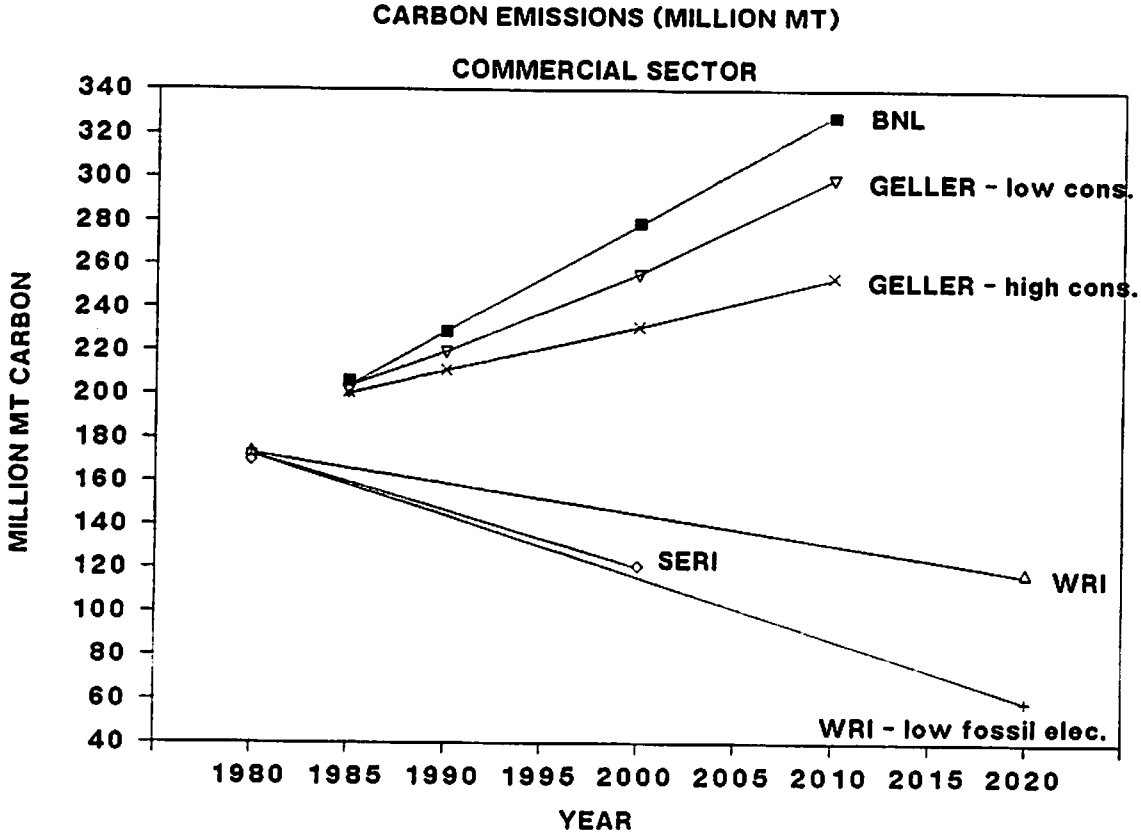
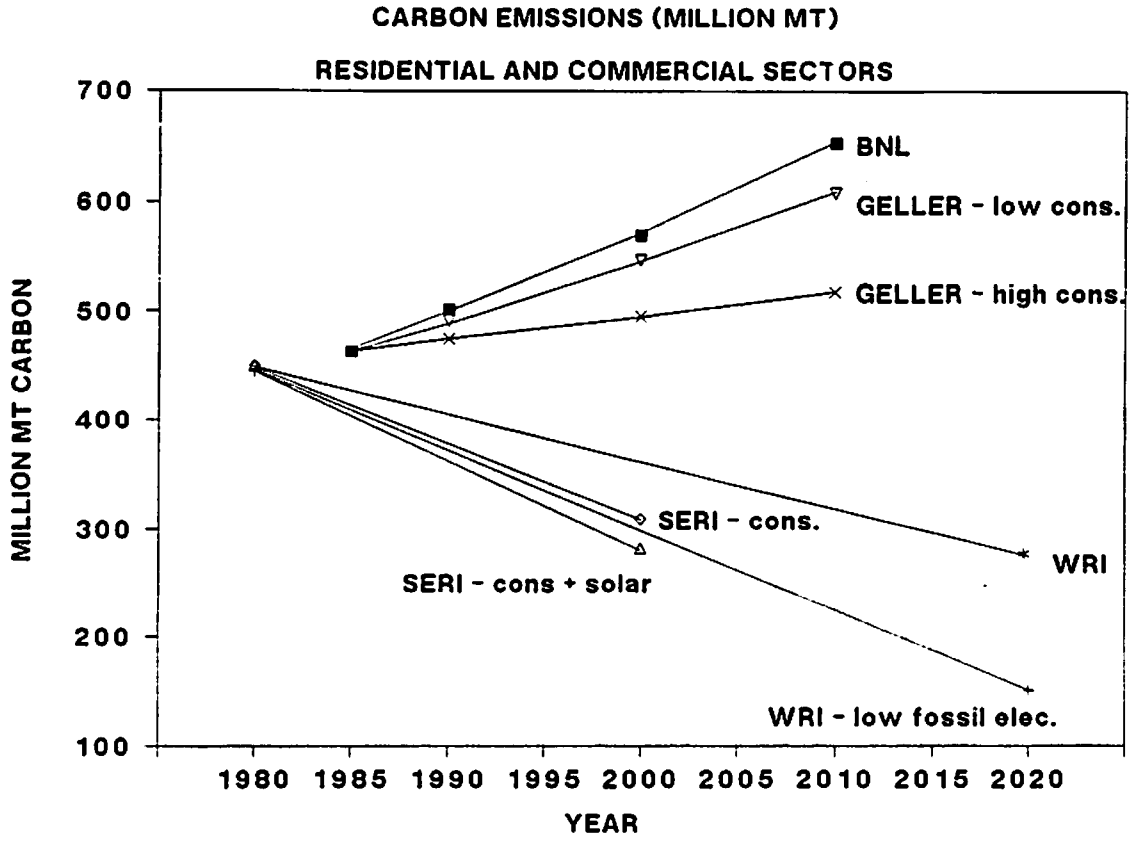


FIGURE 7: SCENARIOS OF CARBON EMISSION FOR THE COMBINED RESIDENTIAL AND COMMERCIAL SECTORS



The Geller models are the simplest presented here.[57] They examine only appliances and equipment, and do not consider improvements in the thermal integrity of the building shell.[58] They are based on a single energy intensity factor for each major end-use. These factors represent judgments about the rate of adoption of economically efficient appliances and equipment. In the high-conservation scenarios, the adoption proceeds at an accelerated rate through the active involvement of the government and the utilities. In the low-conservation case, adoption proceeds at a more modest rate. For the residential sector, the low case represents what is expected through the implementation of the existing appliance standards and other existing conservation programs. Note that this scenario is very close to the BNL base-case scenario. For the commercial sector, the low case represents a continuation of current trends of energy intensity reductions. Geller's commercial low case is slightly lower than the BNL base case.

The SERI residential scenario is based on the adoption of all energy conservation and renewable technologies which are cost-effective on a life-cycle basis, using a 3% constant dollar discount rate.[59] While some would consider a discount rate of 3% to be low, the SERI analysis shows that using a discount rate of 10% would reduce the savings in the year 2000 by only 10% to 20%. They assume that by the year 2000, there will have been a complete penetration of measures which are cost-effective for both retrofits and new buildings. Their commercial scenarios are based on the theoretical performance of new buildings and empirical evidence from demonstration buildings.

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[57]Geller, 1988a and 1988b.

[58]This is not an oversight. The purpose of the study was to look only at equipment and appliances.

[59]Solar Energy Research Institute, 1981.

WRI based their residential scenario on the most efficient commercially available equipment and appliances in the year 1982.[60] Heat loads were based on cost-effective savings as demonstrated in the utility based Modular Retrofit Experiment in New Jersey and the Minnesota Energy-efficient Housing Demonstration Program (new houses). WRI's commercial scenario is based on the same information as the SERI analysis. These analyses do not represent the limits of what can be achieved technically. The best demonstration buildings performed better than those used in the study.

Under similar assumptions regarding the electricity fuel generating mix, the SERI and WRI scenarios give comparable results in terms of total potential emission reductions: 40% for both the residential and commercial sectors. For the residential sector, while WRI has a larger number of households in the year 2020 than SERI in the year 2000, more of the housing stock is new and thus uses significantly less energy than the existing stock, even after retrofit. Thus, the two effects, increased stock and less energy per unit, counterbalance, ending in similar energy use and emissions for the two scenarios. For the commercial sector, the difference in assumed growth rates lead to similar predictions of 50% growth in floorspace at the end-point of their studies, the year 2000 and the year 2020, respectively. Because these studies were based on similar estimates of potential emission reductions, similar results are not surprising.

The WRI low-fossil electricity scenario combines on-site energy efficiency measures with reductions in the amount of fossil fuel in the electricity generating mix. This results in the greatest emission reduction, a decrease of 67%. This last scenario highlights the importance of the generating fuel mix in determining the actual emission reductions achievable through electricity conservation.

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[60]Goldemberg, et al., 1987a and 1988.

These modeling efforts were examined in detail, along with information that was presented in section II.D., "Methods for Reducing Fossil Fuel Use in Buildings", in order to disaggregate the potential for emission reductions and highlight the end-uses which could lead to the greatest emission reductions. The results are shown in Tables 17 and 18 for the residential and commercial sectors, respectively. For each entry in the matrices, it was assumed that only that option was being implemented. Because of the interaction of various options, the columns are not strictly additive. Potential emission reductions are measured from 1985 levels, and categorized as large (greater than 10%), medium (5% to 10%) or small (less than 5%). The matrices also include a row called "limited growth", which shows options that will reduce emissions, but not enough to offset the expected growth from new buildings. In other words, if these measures were implemented alone, there would still be a net growth in emissions. The lead times of short (1 to 5 years), medium (5 to 15 years), and long (15 to 25 years) indicate the amount of time required to actually realize the reduction indicated.

A detailed discussion of the calculations supporting Tables 17 and 18 is included to explain the assumptions behind these estimates. It is important to keep in mind that the goal here is to assess the proper time frame and range of potential emission reductions, rather than determine exact estimates.

Turning first to the residential sector, because space conditioning is the largest single end-use, it is not surprising that reductions in the energy used for space conditioning offer the largest opportunity for emission reductions in this sector. To achieve reductions greater than 10% will require a long lead time and must include improvements in both the thermal integrity of the building shell and in the efficiency of the heating and cooling equipment. In addition, large reductions require the retrofitting of existing homes as well as high

standards of energy efficiency in new homes. Again, this is not surprising, because existing buildings will represent about 50% of the building stock in 2010.[61] The SERI scenario (Appendix A, Table A1) shows potential emission reductions of 17% in a 40-year period while the WRI scenario (Appendix A, Table A2) shows reductions of 8% in a 20-year period. The key difference between these estimates is their relationship to the base case. In isolating heating and cooling efficiency improvements, it is assumed that water heating, cooking, etc. grow at the pace of the BNL "base-case" scenario. The 40 years of the WRI scenario allow for much greater growth than the 20 years of the SERI scenario. In conclusion, for residential heating and cooling, large reductions are feasible in the 15- to 25-year time frame.

These models were then examined to isolate the effects of improvement to existing homes (retrofits) from increased energy efficiency for new homes. These calculations are presented in Tables A3 and A4. Table A3, based on the SERI model, shows that without retrofit improvements, the emission reductions that are achievable from new homes would not offset the expected growth in the sector. However, full penetration of energy-saving retrofits, with new homes built to a baseline standard, results in net savings of 8% to 12%. Table A4, based on the WRI model, shows that in the long term, neither retrofits nor new homes alone can provide positive emission reductions. While these scenarios get us estimates that are in the correct range, they are based on 1980 information, and do not look at the current status of the housing stock. For example, it would be useful to know how much of the retrofitting has already occurred, and the energy intensity of houses built from 1980 to the present. Many of these houses may also be candidates for retrofits. The

[61]The WRI study estimates that 40% of the 2020 housing stock will be from houses existing in 1980. As noted previously, WRI estimates a slower growth in housing than the other models examined. Their 2020 estimate of the number of households is equivalent to the 2010 estimate of the other models. The SERI model estimates that 60% of the year 2000 housing stock will be from houses standing in 1980.

TABLE 17: SUMMARY OF TECHNICAL POTENTIAL FOR EMISSION REDUCTIONS: RESIDENTIAL SECTOR

	% EMISSION REDUCTION	SHORT 1 - 5 YEARS	MEDIUM 5 - 15 YEARS	LONG 15 - 25 YEARS
REDUCTIONS FROM CURRENT LEVEL	LARGE > 10%			- space conditioning, new and retrofits, improvements to shell & equipment efficiency - appliance efficiency high penetration of most efficient appliances on market
	MEDIUM 5% - 10%		-retrofit space cond. equipment efficiency and shell improvements	
	SMALL < 5%	-retrofit space cond. equipment efficiency and shell improvements	- appliance efficiency, standards higher than NAECA	
REDUCTIONS FROM PROJECTED GROWTH	LIMITED GROWTH	-appliance efficiency, NAECA standards	-appliance efficiency, NAECA standards -new home space conditioning -conversion oil to gas -cogeneration	-appliance efficiency, NAECA standards -new home space conditioning -20% reduction in fossil fuel for elec. generation -conversion oil to gas -cogeneration
	* TOTAL REDUCTIONS	5%	20%	40%

* Does not include potential reductions from electric utility fuel switching.

conclusion from these back-of-the-envelope type calculations is that in the short and medium term, retrofits alone provide the opportunity for medium energy savings, but that in the longer term, positive emission reductions from space conditioning require both energy-saving retrofits and energy-efficient new homes.

TABLE 18: SUMMARY OF TECHNICAL POTENTIAL FOR EMISSION REDUCTIONS: COMMERCIAL SECTOR

	% EMISSION REDUCTION	SHORT 1 - 5 YEARS	MEDIUM 5 - 15 YEARS	LONG 15 - 25 YEARS
REDUCTIONS FROM CURRENT LEVEL	LARGE > 10%			-space conditioning & lighting in both new and retrofits
	MEDIUM 5% - 10%			-lighting only, new and retrofits
	SMALL < 5%			
REDUCTIONS FROM PROJECTED GROWTH	LIMITED GROWTH		-cogeneration -conversion oil to gas -space conditioning & lighting, new or retrofits, only	-cogeneration -20% reduction in fossil fuel for elec. generation -conversion oil to gas -space conditioning & lighting, new or retrofits, only
	* TOTAL REDUCTIONS	5%	20%	40%

* Does not include potential reductions from electric utility fuel switching.

For appliances, large reductions can only be achieved in the long run. To achieve emission reductions of this level requires the equivalent of nearly full penetration of appliances which are as efficient as the best commercially available appliances of 1986. As continued improvements in appliance efficiency are expected in the 1990's, it may be possible to achieve large reductions with lower market penetration. Appliance efficiencies conforming to NAECA standards would limit growth, but not induce a net reduction in

emissions. The calculations supporting these conclusions are presented in Table A5. Note that for this analysis, home heating and cooling equipment were included as appliances. This is because appliance efficiency standards are likely to cover this equipment as well as refrigerators, freezers, stoves, etc. In this way, there is some redundancy between these predictions and those which look at space conditioning. In addition, lighting was included in this part of the analysis. For all of these individual end-uses, such as cooking, refrigeration, lighting, etc., while there is great potential for efficiency improvements, changes in only one of these uses, even of heroic proportions, would not be enough to offset the expected growth from other uses.

Turning now to the commercial sector, there is much less information for disaggregating the potential for reduction in this sector. The scenarios for large emission reductions were based on the projected savings for retrofits and efficiency levels for new buildings as a whole, i.e., not disaggregated by end-use. Thus, the major conclusion to be drawn is that simultaneous energy efficiency improvements in space conditioning and lighting, the two largest end-uses in the commercial sector, can achieve large emission reductions in the long-run.

Again, back-of-the-envelope calculations were made to try to determine the emission reductions available for retrofits alone versus new buildings alone. These are presented in Table A6. The conclusions are similar to the residential sector: energy efficiency improvements are required in both new and existing buildings in order to achieve net emission reductions.

A few scenarios were examined to determine the potential for emission reductions from fuel switching. In order to isolate the effects of this change only, the BNL base case was modified in three ways:

(1) All on-site fuel use was projected to be natural gas. This represents a switch mostly from oil to gas, but also assumes that the small amounts of coal, propane and motor fuel used in the buildings sector are replaced with gas.

(2) All on-site fuel and electricity-generating oil are replaced with natural gas.

(3) The use of fossil fuel for electricity generation was reduced by 20%.[62]

While all of these scenarios resulted in reductions from projected emissions, none of them resulted in net reductions from current emission levels. In the absence of conservation measures, a 37% reduction in the use of fossil fuel is required to achieve a zero growth in emissions in the year 2010 from utility fuel switching. Or, alternatively, retaining the share of electricity provided by oil and gas at current levels and reducing coal use by 42% would also result in zero growth in emissions in the year 2010.

The potential for emission reductions from co-generation was presented in Table 12, and discussed in section II.D. Under conservative estimates of the potential market penetration, cogeneration has little effect on emissions in the buildings sector. Higher estimates of its potential depend on favorable technological and institutional developments. Under these conditions, it is likely to save 20 to 50 million MT annually -- a significant savings, but, again, not enough to offset growth in this sector.

In conclusion, this analysis, as summarized in Tables 15 and 16, demonstrates that there is no "magic bullet" for reducing emissions in the residential and commercial sectors. Several options for emission reductions will have to be pursued simultaneously in order to achieve large reductions in this sector. This is even more true when looking at the buildings

[62]This assumes a 20% across-the-board reduction in the percentage of the utility fuel generating mix provided by each fossil fuel. Optimal CO2 emission reductions would be achieved by larger reductions in coal use rather than equal reductions for all fossil fuels.

sector as a whole. Emission reductions in only the residential sector, or only the commercial sector, would be overcome by growth in the other. Specifically, the SERI and WRI scenarios show the potential for reductions of 40% in both the residential and commercial sectors, respectively. However, the BNL scenario points to growth of 26% in the residential sector and 60% in the commercial sector. Thus, if the reduction goals were achieved in, for example, the residential sector, but no progress were made in the commercial sector, the overall buildings sector would still experience a significant growth in emissions.

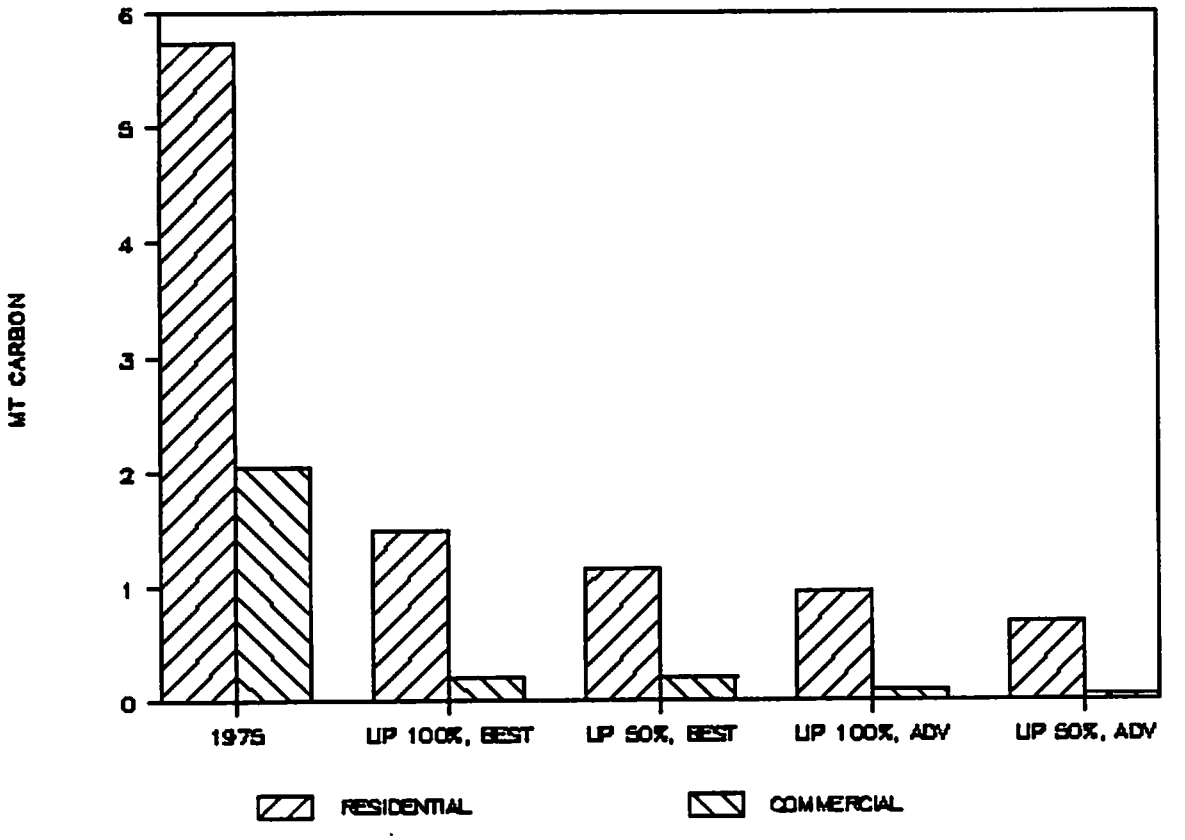
F. Scenarios for Future CO_2 Emissions in Sweden

Sweden is often viewed as a model energy-conserving society. As discussed in previous sections, the Swedish building stock is significantly more energy-efficient than that of the U.S. Nonetheless, there is still great potential for reductions in energy use in buildings through energy-efficiency improvements.

Goldemberg et al. modeled several scenarios of future energy use in Sweden, based on 50% and 100% growth in the consumption of goods and services, and on implementation of the best currently available technologies and advanced technologies expected to be commercialized between now and the year 2020.[63] The results of this study are presented in Figure 8. These scenarios show dramatic reductions in CO_2 emissions, ranging from 78% to 90%. These reductions are the result of two factors: major efficiency improvements, and a shift away from the direct use of fossil fuels and toward electrification based on non-fossil generating capacity. Currently, Sweden's electricity supply does not depend heavily on the burning of fossil fuels. No coal is used, and oil was used to generate only 3% of the

[63]Goldemberg, et. al., 1987a, and 1988.

FIGURE 8: SCENARIOS OF CARBON EMISSIONS FOR THE RESIDENTIAL AND COMMERCIAL SECTORS IN SWEDEN
based on scenarios from Goldemberg, et. al., 1988



electricity. The supply for 2020 is projected to include no fossil fuels. Although biomass is a significant portion of the 2020 supply scenario, it is assumed in this analysis that the biomass is used in a sustainable manner and thus does not contribute to atmospheric CO_2.

This scenario for Sweden demonstrates how reducing demand can create more options on the supply side. As demand is reduced, the most costly supply technologies, from an environmental, economic and national security standpoint, do not have to be pursued -- or, at least, their use can be minimized. In fact, Sweden's building energy reduction program is part of her strategy for eliminating nuclear power (which is perceived as unacceptably risky by Swedish society), and reducing dependence on foreign oil by the

end of the century.

Another important outcome of this analysis is that, based on the implementation of current cost-effective technology, the buildings sector falls from 35% to 20% of total energy use. This indicates that, with present knowledge, there are greater potential savings in buildings than in any other sector.

G. Summary for CO_2 Emissions in OECD Countries

The buildings sector represents a significant share of total energy consumption in OECD countries, with space conditioning, especially heating, as the dominant energy end-use. In both the residential and commercial sectors, energy conservation since 1973 has significantly reduced the energy intensity of final demand. On the other hand, there has been an increasing trend toward electrification which, by increasing primary energy use per unit of final energy demand, has offset some of the gains from energy conservation. Over the next 25 years, slow growth in the demand for energy services is expected in the residential sector, while continued rapid growth is expected in the commercial sector.

There is a large potential for cost-effective energy conservation, particularly through energy efficiency improvements. Scenarios of future energy consumption in the buildings sector indicate that the penetration of currently available, cost-effective energy conservation measures can lead to emission reductions of 40% in the next 25 years. Even higher emission reductions are possible using technologies that are currently available but more expensive. In addition, technologies which are expected to be commercially available in the next decade could reduce emission even further. Finally, if reductions in the proportion of fossil fuels in the electricity-generating fuel mix are added to energy efficiency improvements, even higher emission reductions are achievable.

This analysis also indicates that to achieve significant cuts in emissions in the buildings sector, several options for emission reductions must be pursued simultaneously. Emission reductions must be achieved in both the residential and commercial sectors, in both new and existing buildings, and in each of the major end-uses of this sector, including space conditioning, lighting, and appliances. Without this multifaceted approach, savings in one area will be overshadowed by growth in the buildings sector as a whole.

There are several avenues for future research which would improve this assessment of the potential for CO_2 emission reductions.

(1) This analysis was limited by the lack of cost information for energy-efficient technologies. Specifically, the costs of reducing emissions could only be compared to the costs of energy supply. In other words, this analysis was able to project the potential for emission reductions using currently cost-effective technologies, but was not able to project the costs for emissions reductions beyond that point. Better information on the costs of energy-efficient technologies would make it possible to compare the costs of various levels of emission reductions to the costs and risks of climate change.

(2) While this paper has pointed out the long-term implications of fuel choices, an assessment of potential costs and emission reductions from fuel switching would shed light on options for reducing CO_2 emissions.

(3) The assessment of the potential for emission reductions from the replacement of fossil fuels with on-site renewables in the buildings sector would benefit from an updated analysis.

(4) There was no information available on the potential for emission reductions in the centrally-planned, industrialized countries. Given that they are estimated to

contribute 30% of the global emissions in the buildings sector, information on the potential for reductions in these countries is crucial to an assessment of the potential for global emission reductions.

Finally, the effect of feedback from climate change needs to be considered. Assuming growth at current rates, a doubling of greenhouse gases (in CO_2 equivalents) is expected between 2010 and 2050.[64] This doubling would greatly increase cooling loads in all regions of the U.S. Although there would be a corresponding decrease in heating loads, it would not compensate for the increased cooling loads except in the coldest regions of the U.S.[65] Because buildings have lifetimes of 50 to 100 years, the effects of climate change should be considered during the construction of today's buildings. It is particularly important to construct more energy-efficient building shells. Geographical location will also be important. For example, the effects of rising shorelines and the availability of water should be considered before building on the coasts. Although this study of the buildings sector would not be complete without mention of these concerns, a detailed discussion of adaptation is beyond the scope of this study.

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[64]Keepin, W., I. Mintzer, and L. Kristoferson, 1986.

[65]Loveland, J.E. and G.Z. Brown, 1989.

III. CO_2 EMISSIONS IN DEVELOPING COUNTRIES

Much less information is available on energy end-uses for the developing countries than for the industrialized countries. There have been few in-depth studies of buildings sector energy uses, and even fewer studies which utilize end-use methods for projecting future energy use. With this in mind, the goal of this section is twofold: (1) To describe the structure of energy use in the buildings sector in developing counties, including past trends, current uses, and factors that will affect the rate of growth of this sector. (2) To demonstrate the potential for controlling the rate of growth of emissions in this sector by examples from Brazil and China. These countries were chosen because they represent two very different case studies, for both of which there was information available on the potential for reduced energy use in the residential and commercial sector. The study of Brazil only covers electricity use and demonstrates the role of energy conservation for a highly electrified developing country. The study of China looks at the problems of reducing CO_2 emissions in a country which relies largely on coal for all energy needs.

A. Past Trends and Current Use

In addition to presenting statistics on the growth trends in energy use in LDCs, this section will also highlight the key factors affecting energy consumption levels, including: the importance of non-commercial energy, the difference in consumption patterns between the wealthy and poor and between the urban and rural populations, the importance of modern technologies and modern carriers, trends in appliance penetration, and the effect of modern building styles.

The energy demand of the developing countries (LDCs) is generally growing faster than their GDPs. While commercial energy use per capita declined in Western Europe and

the U.S. from 1977 to 1984, it grew at rates of 3.9%, 3.4% and 2.2% per year in Asia, Latin America and West Africa, respectively. LDC energy use is also growing as a percentage of world energy consumption, from 13% in 1970 to 23% in 1985.[66] Based on anticipated population and GDP growth, this trend is expected to continue. Thus, although LDCs currently account for less than one-quarter of the global emissions from the residential and commercial sectors, the patterns of their energy use warrant close attention.

The residential and commercial sectors follow this trend of increasing energy consumption. From 1978 to 1984, per capita energy consumption (not including biomass) grew by 18% in Asia, 21% in Latin America, and 36% in West Africa.[67] In lower-income countries, a larger share of total energy use is in the residential sector. Based on a study of four low-income and four transitional LDCs, Leach found that households account for 35% to 60% of total energy use in low-income countries and 15% to 35% of total energy use in transitional countries.[68] This is compared to 20% to 30% in developed nations.

In contrast to the industrialized countries, a large percentage of the energy used in developing nations is from non-commercial sources. In a survey of sixteen developing nations, the percentage of total energy provided by non-commercial energy ranged from a high of 98% in Nepal to a low of 9% in Libya, with an average of 43%.[69] In looking at CO_2 emissions, it is important to consider both non-commercial and commercial energy use. The contribution to atmospheric CO_2 from the burning of fossil fuels has been discussed above. Non-commercial energy (NCE) encompasses various forms of biomass including

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[66]Sathaye, 1987.

[67]Ibid.

[68]Leach, 1986a.

[69]Goldemberg, et al., 1988.

wood, agricultural products or wastes, and dung. These contribute to atmospheric CO_2 through deforestation caused by non-sustainable harvesting.

The domestic (residential) sector is the main user of non-commercial energy. Thus, in order to understand energy consumption in the domestic sector, it is important to include non-commercial energy use in the analysis. Residential energy use patterns differ substantially between the urban and rural populations, and are highly dependent on income. Commercial fuels for lighting and cooking are more common in urban areas, and their use increases with increasing wealth. The poor tend to use fuel mainly for cooking, making it the largest end-use of household energy in LDCs. Survey results for one semi-urban town in India and three Chinese cities show that over 90% of household energy use was for cooking.[70] In contrast, the wealthy elites have energy consumption patterns similar to those found in industrialized nations, including the use of commercial fuels for space conditioning and appliances. The majority of LDCs are in warm climates. In these countries, there is no need for space heating, and thus they can achieve similar levels of amenity to the developed nations with lower energy consumption.

The use of modern carriers (i.e., natural gas, propane, fuel oil, kerosene, biogas) and cooking technologies makes a substantial difference in energy efficiency. The average consumption level for cooking with biomass is 10 to 15 GJ per year compared to 2 to 3 GJ per year for fossil fuels. As a specific example of how modern cooking methods can make a great difference in energy efficiency, in China the average monthly cooking fuel consumption was 180 MJ where town gas was used and 630 MJ where bituminous coal was used.[71]

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[70]Sathaye, 1985.

[71]Leach, 1986b.

Because the modern carriers are more efficient and are the fuel of choice as income rises, higher incomes are not necessarily associated with an increase in total residential energy use. In other words, with modern carriers, more service and amenity can be provided with the same or lower levels of primary energy consumption. What does this mean for CO_2 emissions? This depends on two factors: (1) whether the modern carrier is a fossil fuel or electricity generated by fossil fuels, and (2) whether the traditional fuel was causing deforestation.

The penetration of electric appliances is growing at a rapid rate in some countries, causing residential electricity demand to climb sharply. For example, the ownership of air conditioners in Taiwan grew from 6% in 1975 to 23% in 1982. Refrigerator ownership in China grew from 2% of households in 1981 to 15% in 1984, while washing machine ownership grew from 12% to 42% in same time period. Appliance penetration in urban households for Brazil, Taiwan, and China is given in Table 19.[72] Due to the increasing penetration of appliance ownership, the energy efficiency of appliances is a crucial factor in determining overall energy use in the residential sector.

Urbanization and wealth have led to the construction of modern buildings, both residential and commercial, which require central space conditioning. Prior to the availability of mechanical ventilation and air conditioning, traditional building techniques took advantage of building materials, siting, and design to keep indoor environments as comfortable as possible. Future energy requirements in the commercial sector will partially depend on the extent to which traditional building styles are replaced by Western-style

[72]Sathaye, et al., 1988.

TABLE 19: APPLIANCE PENETRATION IN URBAN HOUSEHOLDS
(% of households with appliance)
from Goldemberg, et. al., 1988.

Brazil	1970	1980	1984
Electric lighting	76	88	95
Refrigerator	43	66	74
TV	40	73	--
Taiwan	**1975**	**1979**	**1982**
Rice cooker	86	93	93
Refrigerator	63	89	94
Air conditioner	6	12	23
Washing machine	31	53	66
Color TV	16	50	85
China (Beijing)	**1981**	**1984**	
Refrigerator	2	15	
Washing machine	12	42	
Electric fan	47	77	
Black and white TV	80	87	
Color TV	2	8	

Sources: Institute Brasileiro de Geografia e Estatistica, Annurio Estatistico do Brasil; Taiwan Power Co.; Inst. for Energy System Analysis, Tsyinghua Univ.

modern buildings.[73]

While this discussion has pointed out general features of energy consumption in LDCs, it is important to stress that developing countries differ substantially in their energy use patterns, depending on their culture, climate, income, degree of urbanization, population, natural resources, and availability and price of fuels.

[73]Several references which discuss the effect of the abandonment of traditional building methods are: (1) Fitch, James Marston and Branch, Daniel P., "Primitive Architecture and Climate," Scientific American, LCVII (6): (Dec 1960); (2) Fathy, Hassan, Natural Energy and Vernacular Architecture (Chicago: University of Chicago Press, 1986); (3) Flavin, Christopher, Energy and Architecture: The Solar and Conservation Potential (Washington, D.C.: Worldwatch Institute, November 1980); and (4) Yuan, Lim Jee, "Traditional Housing: A Solution to Homelessness in the Third World -- The Malaysian Example," The Ecologist, Vol. 18 (1): 16-23 (1988).

B. Future Growth of Energy Use and Emissions in LDCs

Structural changes are expected to continue to be a major influence on LDC residential and commercial energy use. The residential use of commercial fuels is expected to continue to grow. The rate of growth will depend largely on the rate of urbanization, the rate at which poor households move away from traditional methods of cooking, lighting and heating to modern methods, and the rate of acquisition of appliances.[74] The rate of population growth and size of families will also significantly affect total (commercial plus non-commercial) energy use in the residential sector. All of these are dependent upon economic conditions and can be affected by government policy. A continued growth in energy use in the commercial sector is expected due to increases in the number of public and private buildings. The rate of growth of energy consumption can be minimized with the use of natural ventilation or energy-efficient design in this sector. Due to the anticipated growth of these sectors, emission reductions from individual buildings and appliances may not translate into absolute reductions.

Moving from energy demand to energy supply, there is a great need to consider integrated solutions for developing countries' energy needs. The choice of fuel type in the residential and commercial sector may depend upon opportunities in other sectors as well. This issue is discussed in detail for India by Reddy.[75]

C. Methods for Reducing Energy Use and CO_2 Emissions

The need for development is often viewed as being in conflict with the need for reductions in the burning of fossil fuels. While a net reduction in total commercial energy

[74]Sathaye, 1985.

[75]Reddy, 1986.

use may not be feasible, energy conservation and fuel switching can be an important part of a development program. Energy conservation can often provide more amenity for the energy that is used. It can also reduce foreign debt accumulation by minimizing the importation of fossil fuels and equipment for building electricity-generating installations. Fuel switching can also reduce the importation of fossil fuels while helping LDCs avoid the environmental impacts, such as acid rain and urban air pollution, that the industrialized nations now experience.

Developing nations are today building infrastructures that will last well into the next century. An energy-efficient infrastructure can meet development and environment goals simultaneously. This is illustrated in the "1 kW thought experiment" presented in Energy for a Sustainable World.[76] This experiment demonstrates that by using the best available cost-effective technologies in all sectors, 1 kW per capita of final energy is adequate to provide developing nations with the standard of living of Europe in the 1970's.

The remainder of this section will describe specific methods for reducing fossil fuel consumption.

1. **Residential Sector**

The energy requirements for cooking can be reduced by switching to modern carriers such as gas, LPG, kerosene, or electricity, or by using more efficient wood stoves. Switching to modern carriers will reduce CO_2 emissions if it replaces dirtier fuels, such as coal, or if it prevents deforestation. Much work has been done on finding appropriate stove designs that are more efficient. Traditional stoves provide services other than cooking, including heating, lighting, convenience, and protection from insects. However, their smoke can also

[76]Goldemberg, et al., 1987b.

contribute to health problems. New designs must take into account the full range of cultural norms, amenities, and problems if they are to be acceptable replacements for traditional stoves.[77]

There are opportunities for using electricity more efficiently for lighting, refrigerators and water heating. Lighting is the predominant end-use of electricity in LDCs. Fifty percent reductions are possible and are two and one-half to five times less costly than producing power. Technologies for reducing lighting energy use are the same as those discussed for industrialized nations. This is true for refrigerators and water heaters also. Industrialized countries have improved the efficiency of refrigerators 30% to 70%, and the LDCs should be able to achieve these savings as well. First costs are typically 5% to 15% greater with paybacks of a few years. The penetration of electric water heaters is growing in LDCs. Heat-pump water heaters offer 50% savings over electric resistance water heaters. They could replace tank style heaters cost-effectively, but are not currently competitive with point-of-use water heaters.[78]

2. Commercial Sector

The commercial sector in LDCs has similarities to those of the industrialized nations. As LDCs construct Western-type buildings in their cities, many of the same methods for energy conservation are available as in the industrialized nations. In general, electricity can be saved through energy-efficiency improvements in lighting and air conditioning. A study in Singapore indicated that 15% to 20% reductions in energy use are cost-effective in the

[77]Leach, 1986b.

[78]Geller, 1986b.

near term, and 40% reductions may be cost-effective in the future.[79] These are in the same range as the savings potential for commercial buildings in the U.S.

D. Scenarios for CO_2 Emissions in Brazil

The residential and commercial sectors in Brazil each accounted for 21% (a total of 42%) of electricity use in 1982. The end-use of electricity in the residential and commercial sectors in Brazil is shown in Figure 9. As in much of Latin America, electricity plays an important role in Brazil. Ninety-five percent of urban households have electric lighting.

The potential for saving electricity through improvements in energy efficiency was studied by Geller.[80] He concluded that there are great opportunities for electricity reductions when compared to official forecasts based on trend extrapolation. Improvements in the five major energy users listed in Table 20 could provide a savings of 51.6 TWh, a 57% savings compared to official forecasts of demand. While this is a significant savings, it nonetheless represents a growth of about 30% over current consumption levels.

In the residential sector, major savings come from refrigerators and lighting. The levels of efficiency improvement in refrigerators are based on technologies that are on the market in industrialized nations. The increased first cost of more efficient refrigerators has a payback of 2 to 3 years and is significantly less expensive than new generating capacity. The lighting savings are based on fluorescent or other high-efficiency lamps. For water heating, the other major end-use of electricity, more efficient technologies (i.e. heat pumps), are currently not economically feasible. If hot water usage doubled or tripled, they would

[79]Ching, 1984.

[80]Geller, 1984.

become cost-effective on a life-cycle basis. For television, there is large room for efficiency improvements, even with a switch from black-and-white to color.

In the commercial sector, lighting accounts for 51% of end-use. There are numerous ways to reduce lighting demand, as described for commercial buildings in industrialized nations. Geller found that for both new buildings and retrofits, the use of efficient fluorescent fixtures was attractive economically. At discount rates of 10% to 15%, the cost of improvements in lighting efficiency was less than the marginal cost of new generating capacity.

In 1982, 92% of Brazil's electricity was produced by hydroelectric plants. While

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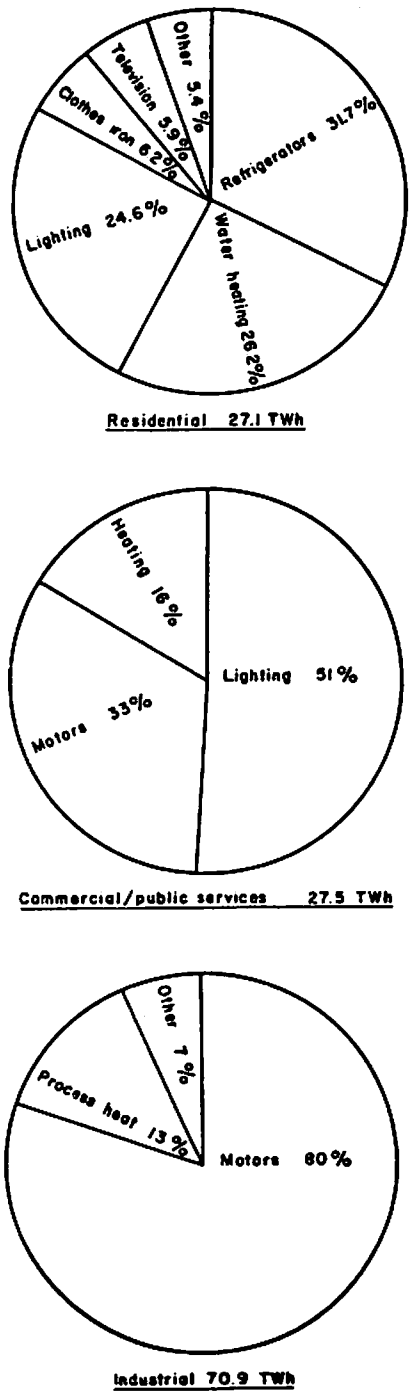
TABLE 20: POTENTIAL ELECTRICITY SAVINGS BY THE YEAR 2000 IN BRAZIL from Geller, 1986b.

	Current Forecast (TWh/yr)	Savings Potential (%)	Savings Potential (TWh/yr)
Domestic refrigerators	28.3	50 (b)	14.2
Domestic lighting	17.7	50 (c)	8.8
Commercial motors	29.7	20 (a)	5.9
Commercial lighting	25.8	60 (d)	15.5
Street lighting	17.9	40 (e)	7.2
TOTAL (f)	119.4	43	51.6

(a) Includes savings from adopting motor speed controls as well as more energy efficient motors.
(b) Assumes conversion to highly efficient models like those now produced in other countries.
(c) Assumes conversion from incandescent to fluorescent lighting in the most heavily used lamps.
(d) Assumes a combination of efficiency measures are adopted as discussed in section II.B.1.
(e) Assumes conversion from mercury vapor to high pressure sodium street lamps.
(f) The forecast for these six end uses represents about 66% of the total electricity demand forecast for Brazil in 2000.

reduction in electricity use generated by hydroelectric plants will not directly affect CO_2 emissions, efficiency improvements in the residential and commercial sectors free up electricity for use elsewhere. In this way, they reduce the need to develop oil generating plants. In general, lower energy intensities facilitate the move toward a non-fossil future. The above discussion also highlights areas where there are large potential savings in LDCs. For countries more dependent on fossil fuels for generating electricity, this could translate into direct reductions in emissions.

FIGURE 9:
ELECTRICITY DEMAND IN BRAZIL BY END-USE (totals apply to 1982)
from Geller, 1986b.



E. Scenarios for CO_2 Emissions in China

China has the highest rate of carbon emission per unit of economic output in the world. It also has the highest absolute rate of growth of carbon emissions. Coal use has grown 8% per year since 1950 and now supplies three-quarters of China's energy.[81] As in most developing nations, commercial energy use is dominated by the industrial sector. With increasing wealth, non-commercial fuels will be replaced by commercial fuels in the residential sector. This will increase the importance of the buildings sector as a consumer of commercial energy.

In contrast to most developing nations, China's residential sector is characterized by large energy requirements for residential space and water heating. Household fuel is generally consumed in small, inefficient stoves. Thus, cooking has about 250 times the energy intensity of electric cooking in the U.S. The sector is also characterized by large increases in appliance ownership, as was shown in Table 16. As the Chinese are still far from universal ownership of appliances, this trend is expected to continue, making appliance efficiency an important determinant of growth in electricity use.

It is likely that greater efficiency will be taken as more amenities rather than reduced energy use. In addition, although Chinese stoves are inefficient for cooking, they are also used for heating the sleeping area.[82] Modern stoves and modern building design would require another method of space heating.

In an assessment of carbon emission control strategies, Chandler used the Edmonds-Reilly simulation model to examine the effects of population planning, energy-efficiency

[81]Chandler, 1988.

[82]Wirtshafter, et. al.

standards, energy prices, and coal bans on CO_2 emissions.[83] He found that only the energy efficiency scenarios both significantly reduced carbon emissions and increased Chinese per capita income. Although the Edmonds-Reilly model is a partial equilibrium approach, rather than an engineering end-use approach, this result points toward the conclusion that energy efficiency may be the best short-run alternative.

Chandler's assessment of energy end-use shows that China could maintain 2% per year energy-efficiency improvements for 80 years by evolving toward an economy as efficient as Japan or Austria, and could do even better with today's best available technologies. As is common for LDCs, most of China's infrastructure will be built or replaced in the coming decades. Thus, China has the opportunity of making efficient choices regarding energy use. Rather than slowly evolving toward an efficient infrastructure, it may be possible for them to "leapfrog" and reach higher efficiency levels in a shorter time span. China has achieved a 3.4% annual rate of improvement during the 1980s and intends to continue this through the end of the century.

For China, while energy efficiency will achieve substantial short-term gains, it is important to also look at options for switching from the direct burning of coal for heating and cooking, and the use of coal-generated electricity, to non-fossil fuels, or, as a short term goal, to natural gas. Further research into realistic supply options for China is necessary.

[83]Chandler, 1988.

F. Summary for CO_2 Emissions in Developing Countries

The demand for energy in the buildings sector of LDCs is expected to grow more rapidly than that in industrialized countries over the next 25 years. Structural changes in LDCs are expected to continue to be a major influence on residential and commercial energy use, with the demand for commercial fuels continuing to grow.

Energy conservation and fuel switching can help developing nations simultaneously meet their development and environment goals. In the residential sector, a reduction in the energy requirements for cooking is the most pressing need. This can be accomplished by switching to modern carriers or by using more efficient wood stoves. There are also significant opportunities for using electricity more efficiently and for energy conservation in the commercial sector.

Examination of energy use in Brazil and China indicates that there are large opportunities for cost-effective energy efficiency improvements. Nonetheless, because of the anticipated growth of demand for energy services in the buildings sector over the next 25 years, energy consumption is expected to increase, although at a much slower rate than would be experienced without increased efficiency.

As is apparent from this report, there is very little quantitative information available on energy end-use in developing countries, and even fewer in-depth studies on the potential for energy conservation and fuel switching. This kind of basic information would significantly improve assessments of future CO_2 emissions from the buildings sector in developing countries.

There is also a need for considering what type of policies will enable LDCs to build energy-efficient infrastructures. In particular, special attention should be paid to the problem of financing increased initial costs.