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Towards a Climate-Friendly Built Environment

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June 2005

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Foreword *Eileen Claussen, President, Pew Center on Global Climate Change*

Buildings in the United States—homes, offices, and industrial facilities—account for over 40 percent of our nation's carbon dioxide emissions. Most of these emissions come from the combustion of fossil fuels to provide heating, cooling, and lighting and to run electrical equipment and appliances. The manufacture of building materials and products, and the increased emissions from the transportation generated by urban sprawl, also contribute a significant amount of greenhouse gas (GHG) emissions every year. In this report, authors Marilyn Brown, Frank Southworth, and Theresa Stovall identify numerous opportunities available now, and in the future, to reduce the building sector's overall impact on climate.

This Pew Center report is part of our effort to examine key sectors, technologies, and policy options to construct the “10-50 Solution” to climate change. The idea is that we need to tackle climate change over the next fifty years, one decade at a time. Looking at options for the near (10 years) and long (50 years) term, this report yields the following insights for reducing GHG emissions from the largest portion of our nation's physical wealth—our built environment.

- **This sector presents tremendous challenges.** There are so many different energy end uses and GHG-relevant features, multiple stakeholders and decision-makers, and numerous market barriers to energy efficiency.

- **Yet numerous opportunities exist.** In the near term, simply bringing current building practices up to the level of best practices would yield tremendous energy and cost savings. Past studies have shown that many climate-friendly and cost-effective measures in the buildings sector are not fully utilized in the absence of policy intervention. The R&D and six deployment policies examined in this report could reduce forecasted energy consumption and carbon emissions of buildings in the United States in 2025 by almost one-quarter, or by an amount roughly equal to 10% of total projected U.S. carbon emissions. In 2025 and beyond, newly constructed net-zero-energy homes and climate-friendly designs for large commercial buildings and industrial facilities could begin to generate sizeable GHG reductions by displacing the energy-intensive structures that embody today’s standard practices.

- **An integrated approach is needed to reduce GHG emissions from the diverse and fragmented building sector.** Such an approach coordinates across technical and policy solutions, integrates engineering approaches with architectural design, considers design decisions within the realities of building operation, integrates green building with smart-growth concepts, and takes into account the numerous decision-makers within the industry.

- **An expansive view of the building sector is needed to completely identify and capitalize on the full range of GHG-reduction opportunities.** Such a view needs to consider future building construction (including life-cycle aspects of buildings materials, design, and demolition), use (including on-site power generation and its interface with the electric grid), and location (in terms of urban densities and access to employment and services).

The authors and the Pew Center would like to thank Robert Broad of Pulte Home Sciences, Leon Clarke of the Pacific Northwest Laboratory, Jean Lupinacci of the U.S. Environmental Protection Agency, and Steven Nadel of the American Council for an Energy Efficient Economy for their review of and advice on a previous draft of this report, and Tony Schaffhaeuser for contributions to an early version this paper.

Executive Summary

The energy services required by residential, commercial, and industrial buildings produce approximately 43 percent of U.S. carbon dioxide (CO_2) emissions. Given the magnitude of this statistic, many assessments of greenhouse gas (GHG) reduction opportunities focus principally on technologies and policies that promote the more efficient use of energy in buildings. This report expands on this view and includes the effects of alternative urban designs; the potential for on-site power generation; and the life-cycle GHG emissions from building construction, materials, and equipment. This broader perspective leads to the conclusion that any U.S. climate change strategy must consider not only how buildings in the future are to be constructed and used, but also how they will interface with the electric grid and where they will be located in terms of urban densities and access to employment and services. The report considers both near-term strategies for reducing GHGs from the current building stock as well as longer-term strategies for buildings and communities yet to be constructed.

The United States has made remarkable progress in reducing the energy and carbon intensity of its building stock and operations. Energy use in buildings since 1972 has increased at less than half the rate of growth of the nation's gross domestic product, despite the growth in home size and building energy services such as air conditioning and consumer and office electronic equipment. Although great strides have been made, abundant untapped opportunities still exist for further reductions in energy use and emissions. Many of these—especially energy-efficient building designs and equipment—would require only modest levels of investment and would provide quick pay-back to consumers through reduced energy bills. By exploiting these opportunities, the United States could have a more competitive economy, cleaner air, lower GHG emissions, and greater energy security.

GHG Emissions: Sources and Trends

GHG emissions from the building sector in the United States have been increasing at almost 2 percent per year since 1990, and CO_2 emissions from residential and commercial buildings are expected to continue to increase at a rate of 1.4 percent annually through 2025. These emissions come principally from the generation and transmission of electricity used in buildings, which account for 71 percent of the total. Due to the increase in products that run on electricity, emissions from electricity are expected to grow more rapidly than emissions from other fuels used in buildings. In contrast, direct combustion of natural gas (e.g., in furnaces and water heaters) accounts for about 20 percent of energy-related emissions in buildings, and fuel-oil heating in the Northeast and Midwest accounts for the majority of the remaining energy-related emissions. Based on energy usage, opportunities to reduce GHG emissions appear to be most significant for space heating, air conditioning, lighting, and water heating.

Mechanisms of Change

Because the building industry is fragmented, the challenges of promoting climate-friendly actions are distinct from those in transportation, manufacturing, and power generation. The multiple stakeholders and decision-makers in the building industry and their interactions are relevant to the design of effective policy interventions. Major obstacles to energy efficiency exist, including insufficient and imperfect information, distortions in capital markets, and split incentives that result when intermediaries are involved in the purchase of low-GHG technologies. Many buildings are occupied by a succession of temporary owners or renters, each unwilling to make long-term improvements that would mostly benefit future occupants. Regulations, fee structures in building design and engineering, electricity pricing practices, and the often limited availability of climate-friendly technologies and products all affect the ability to bring GHG-reducing technologies into general use. Some of these obstacles are market imperfections that justify policy intervention. Others are characteristics of well-functioning markets that simply work against the selection of low-GHG choices.

Numerous individual, corporate, community, and state initiatives are leading the implementation of "green" building practices in new residential development and commercial construction. The most impressive progress in residential green building development and construction is the result of communities and developers wanting to distinguish themselves as leaders in the efficient use of resources and in waste reduction in response to local issues of land-use planning, energy supply, air quality, landfill constraints, and water resources. Building owners and operators who have a stake in considering the full life-cycle cost and resource aspects of their new projects are now providing green building leadership in the commercial sector. However, real market transformation will also require buy-in from the supply side of the industry (e.g., developers, builders, and architects).

Affordability, aesthetics, and usefulness have traditionally been major drivers of building construction, occupancy, and renovation. In addition to climatic conditions, the drivers for energy efficiency and low-GHG energy resources depend heavily on local and regional energy supply costs and constraints. Other drivers for low-GHG buildings are clean air, occupant health and productivity, the costs of urban sprawl, electric reliability, and the growing need to reduce U.S. dependence on petroleum fuels.

Technology Opportunities in Major Building Subsectors

The technical and economic potential is considerable for technologies, building practices, and consumer actions to reduce GHG emissions in buildings. When studying the range of technologies, it is important to consider the entire building system and to evaluate the interactions between the technologies. Thus, improved techniques for integrated building analyses and new technologies that optimize the overall building system are especially important. In this report, homes and small commercial buildings and large commercial and industrial buildings are analyzed separately for their energy-saving and emission-reduction potential, because energy use in homes and small businesses is principally a function of climatic conditions while energy use in large buildings is more dependent on internal loads.

Applying currently available technologies can cost-effectively save 30 to 40 percent of energy use and GHG emissions in new buildings, when evaluated on a life-cycle basis. Technology opportunities are more limited for the existing building stock, and the implementation rate depends on the replacement cycles for building equipment and components. However, several opportunities worth noting apply to existing as well as new buildings, including efficiencies in roofing, lighting, home heating and cooling, and appliances. Emerging building technologies, especially new lighting systems and integrated thermal and power systems, could lead to further cost-effective energy savings. All of these potential effects, however, are contingent upon policy interventions to overcome the barriers to change.

Community and Urban Subsystems

Evidence suggests that higher-density, more spatially compact and mixed-use building developments can offer significant reductions in GHG emissions through three complementary effects: (1) reduced vehicle miles of travel, (2) reduced consumption for space conditioning as a result of district and integrated energy systems, and (3) reduced municipal infrastructure requirements. Both behavioral and institutional barriers to changes in urban form are significant. The effect of urban re-design on travel and municipal energy systems will need to be tied to important developments in travel pricing, transportation construction, and other infrastructure investment policies.

Past studies have concluded conservatively that changes in land-use patterns may reduce vehicle miles traveled by 5 to 12 percent by mid-century. More compact urban development could also lead to comparable GHG reductions from efficiencies brought about by district and integrated energy systems, with a small additional decrement from a reduced need for supporting municipal infrastructures. In total, therefore, GHG reductions of as much as 3 to 8 percent may be feasible by mid-century, subject to the near-term enactment of progressive land-use planning policies.

Policy Options

Policy research suggests that public interventions could overcome many of the market failures and barriers hindering widespread penetration of climate-friendly technologies and practices. The mosaic of current policies affecting the building sector is complex and dynamic, ranging from local, state, and regional initiatives, to a diverse portfolio of federal initiatives. Numerous policy innovations could be added to this mix, and many are being tried in test-beds at the state and local level.

In this report, buildings energy research and development (R&D) and six deployment policies are reviewed that have a documented track record of delivering cost-effective GHG reductions and that hold promise for continuing to transform markets. The six deployment policies include (1) state and local building codes, (2) federal appliance and equipment efficiency standards, (3) utility-based financial incentive and public benefits programs, (4) the low-income Weatherization Assistance Program, (5) the ENERGY STAR® Program, and (6) the Federal Energy Management Program. Annual energy savings and carbon-reduction estimates are provided for each of these policies, both retrospectively and prospectively. Summing these values provides a reasonable estimate of the past and potential future impacts of the policies.

Annual savings over the past several years from these R&D and six deployment policies are estimated to be approximately 3.4 quadrillion Btu (quads) and 65 million metric tons of carbon (MMTC), representing 10 percent of U.S. CO_2 emissions from buildings in 2002. The largest contributors are appliance standards and the ENERGY STAR Program. Potential annual effects in the 2020 to 2025 time frame are 12 quads saved and 200 MMTC avoided, representing 23 percent of the forecasted energy consumption and carbon emissions of buildings in the United States by 2025. The largest contributors are federal funding for buildings energy R&D (especially solid-state lighting) and appliance standards.

Conclusions and Recommendations

The analysis presented in this report leads to several conclusions:

- **An expansive view of the building sector is needed to completely identify and exploit the full range of GHG-reduction opportunities.** Such a view needs to consider future building construction (including life-cycle aspects of buildings materials, design, and demolition), use (including on-site power generation and its interface with the electric grid), and location (in terms of urban densities and access to employment and services).

- **There is no silver bullet technology in the building sector because there are so many different energy end uses and GHG-relevant features.** Hence, a vision for the building sector must be seen as a broad effort across a range of technologies and purposes.

- **An integrated approach is needed to address GHG emissions from the U.S. building sector**—one that coordinates across technical and policy solutions, integrates engineering approaches with architectural design, considers design decisions within the realities of building operation, integrates green building with smart-growth concepts, and takes into account the numerous decision-makers within the fragmented building industry.

- **Current building practices seriously lag best practices.** Thus, vigorous market transformation and deployment programs are critical to success. They are also necessary to ensure that the next generation of low-GHG innovations is rapidly and extensively adopted.

- **Given the durable nature of buildings, the potential for GHG reductions resides mostly with the existing building stock for some time to come.** However, by 2025, newly constructed net-zero-energy homes and climate-friendly designs for large commercial buildings and industrial facilities could begin to generate sizeable GHG reductions by displacing the energy-intensive structures that embody today's standard practices. By mid-century, land-use policies could have an equally significant impact on GHG emissions. This inter-temporal phasing of impacts does not mean that retrofit, new construction, and land-use policies should be staged; to achieve significant GHG reductions by 2050, all three types of policies must be strengthened as soon as politically feasible.

- **Similarly, applied R&D will lead to GHG reductions in the short run, while in the long run basic research will produce new, ultra-low GHG technologies.** This does not mean that basic research should be delayed while applied R&D opportunities are exploited. The pipeline of technology options must be continuously replenished by an ongoing program of both applied and basic research.

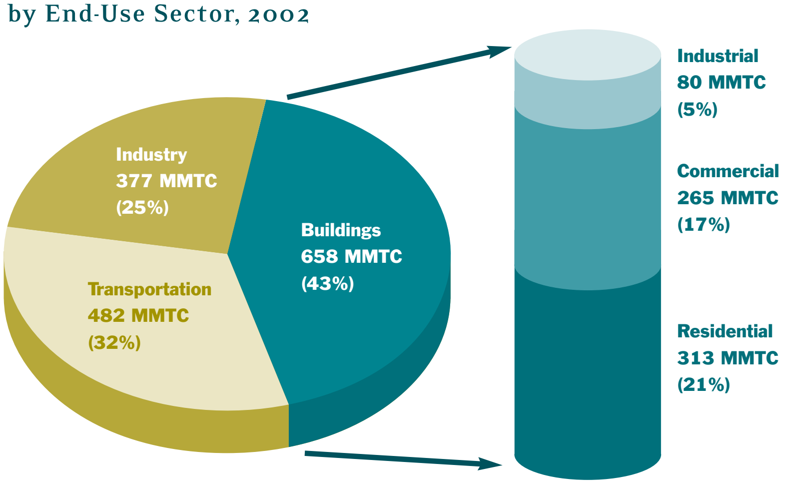
By linking near-term action to long-term potential, the building sector can assume a leadership role in reducing GHG emissions in the United States and globally.

I. Introduction

Approximately 43 percent of U.S. carbon dioxide (CO_2) emissions result from the energy services required by residential, commercial, and industrial buildings (Figure 1).[1] When combined with other greenhouse gas (GHG) impacts of buildings—such as emissions from the manufacture of building materials and products, the transport of construction and demolition materials, and the passenger and freight transportation associated with urban sprawl—the result is an even larger GHG footprint. Thus, an effective U.S. climate change strategy must consider options for reducing the GHG emissions associated with building construction, use, and location. To promote a least-cost strategy and to maximize the likelihood of success, it is useful to consider both near-term strategies for reducing GHGs from the current building stock, as well as longer-term strategies for buildings yet to be constructed. To this end, this report develops a "2015–2050" vision for shrinking the GHG footprint of the U.S. buildings sector. This is done by analyzing technology and policy options taking into account the competing goals, multiple actors, and specific characteristics of this sector.

Figure 1

CO_2 Emissions From Fossil Fuel Combustion by End-Use Sector, 2002

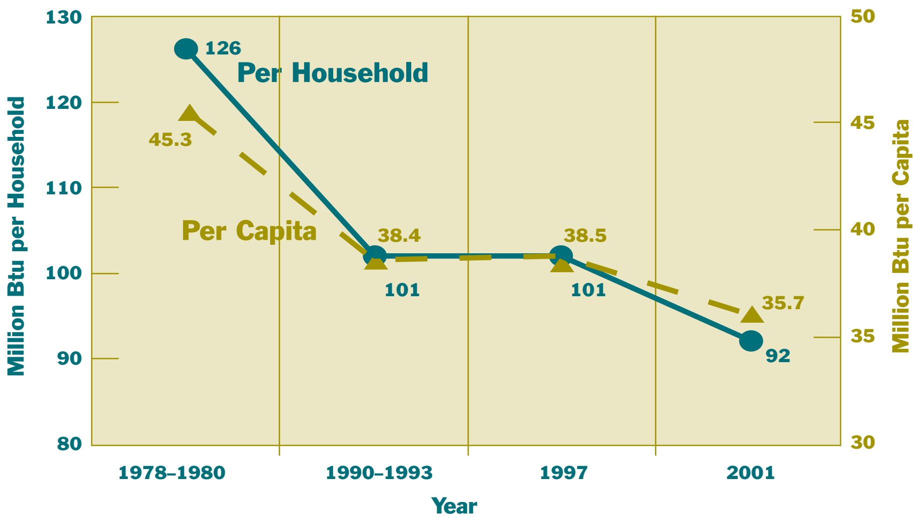


Units are in million metric tons of carbon (MMTC), assuming 40 MMTC per quadrillion BTU (quad) of energy consumed in industrial buildings. The total emissions for all sectors is 1,516 MMTC (excluding 13 MMTC for U.S. territories). Sources: U.S. Environmental Protection Agency. 2004. U.S. Greenhouse Gas Emissions and Sinks: 1990–2002. EPA/430-R-04-003 (2004). U.S. EPA, Washington, DC, 3-7, table 3-6. Pacific Northwest National Laboratory. 1997. An Analysis of Buildings-Related Energy Use in Manufacturing, PNNL-11499, Pacific Northwest National Laboratory, Richland, WA table 4.1.

Reducing energy end use in transportation, buildings, and industry is key to reducing global GHG emissions in the future. A reduction in end-use energy

Figure 2

Declining Energy Consumption per Household



Sources:
1. Rawlings, Steve W. and Arlene F. Saluter. 1995. *Household and Family Characteristics: March 1994,* p. A-1, table A-1.U.S. Government Printing Office, Washington, DC.
2. U.S. Census Bureau. 2002. *Statistical Abstract of the United States: 2001,* No. 54 , p. 49. U.S. Census Bureau, Washington, DC.
3. U.S. Census Bureau. 2004. *Statistical Abstract of the United States: 2003,* No. 66, p. 61. U.S. Census Bureau, Washington, DC.
4. Energy Information Administration. 2003. *Annual Energy Review 2002*, p. 53, table 2.5. EIA, Washington, DC.
5. Energy Information Administration. 2004. *2001 Residential Energy Consumption Survey: Household Energy Consumption and Expenditures Tables,* table CE1-1c, EIA, Washington, DC.

consumption provides system-wide savings throughout the energy supply chain; for instance, lowering household electricity consumption reduces the amount of fossil fuel consumed at power plants as well as the transmission and distribution losses associated with delivering the electricity to the consumer. This energy supply-chain savings is particularly relevant in the building sector, which accounts for 70 percent of U.S. electricity consumption (excluding industrial buildings).

The United States has made remarkable progress in reducing the energy use and carbon intensity of its building stock and operations. These improvements are largely the result of advances in the energy efficiency of U.S. buildings that followed the 1973–1974 OPEC oil embargo. Since 1972, building energy use overall has increased at less than half the rate of growth of the nation's gross domestic product (GDP). And since the late 1970s, when detailed energy use data first became available, residential energy use per household has declined by 37 percent, residential energy use per capita has declined by 27 percent, and commercial energy use per square foot of commercial building space has declined by 25 percent (Figure 2).[2]

These energy intensities have decreased despite two trends toward greater building energy services. First, the size of homes has increased significantly, which in turn increases heating and cooling requirements. According to the vice president of research at the National Association of Home Builders, "as family size decreased almost 25 percent over 30 years, the size of new houses increased about 50 percent, to slightly more than 2,300 square feet today, from 1,500 square feet."[3] Second, the range of electric equipment provided in buildings has increased significantly, especially air conditioning in the South and electronic equipment, televisions, and other "plug loads" in buildings nationwide.[4] Central air conditioning is now a feature of 85 percent of homes in the United States, up from 34 percent in 1970.

Examples of technology improvements during the past 30 years help document this progress. Compact fluorescent lamps, now in common use, are 70 percent more efficient than are incandescent lamps; refrigerators use 75 percent less energy; and new horizontal-axis clothes washers are 50 percent more efficient than current minimum standards. Between 1978 and 1999, the typical level of insulation in walls increased from R-11 to R-13, and typical insulation levels in ceilings and attics rose from R-19 to R-30.[5] Advances in window performance have also been notable over the same period. The market penetration of high-efficiency low-emissivity (low-E) coated windows[6] in homes grew to almost 30 percent, and the use of insulated glass increased from nearly 68 percent to 87 percent. Finally, a research, development, and demonstration (RD&D) partnership sponsored by the U.S. Department of Energy (DOE) helped industry replace ozone-depleting chlorofluorocarbons (CFCs) in foam insulation and in refrigerants, consistent with the Montreal Protocol.[7]

Yet despite these impressive improvements in the energy intensity of building use over the past 30 years, there is no room for complacency. The U.S. population and economy are projected to grow significantly in absolute terms over the next 50 years, which will likely require a sizeable increase in the physical U.S. building stock and corresponding energy use. Specifically, the U.S. population is expected to grow from 295 million in 2005 to 378 million by 2035 and 420 million by 2050.[8] Over the next

30 years, the built environment in the United States is expected to increase by an amount roughly equal to 70 percent of today's existing building stock.[9] At the same time, the explosion of new energy services in buildings is expected to continue. Absent significant increases in building energy efficiency or on-site low-GHG energy production, the building sector is likely to continue to be a major contributor to GHG emissions. Reductions in the life-cycle emissions of building materials and in building-sector-related transportation are also needed.

Today and well into the future, many opportunities exist for further curtailing GHG emissions from the U.S. building sector. For example, current homes, stores, offices, and factory buildings rarely incorporate the full complement of cost-effective, energy-efficient technologies and design strategies to maximize the use of recycled building products and minimize construction waste. Renewable energy sources account for only a small (but growing) fraction of the energy used on-site by buildings.[10] In addition, the sprawling urban landscape has spawned the need for ever-longer commutes to work, shopping, and services, with associated energy use and GHG penalties. Consideration of life-cycle issues surrounding energy use, building materials, waste streams, and sprawl suggest the need for an integrated approach to GHG reductions. Thus, this report draws heavily on the "green buildings" and "sustainable communities" literature.

Some of the opportunities for creating a "climate-friendlier" built environment require greater societal investment and costs. But others, particularly those focused on increased energy efficiency, could yield net savings by lowering energy bills, reducing operating and maintenance costs, and enhancing worker productivity and occupant comfort. Similarly, managing sprawl to reduce vehicle miles traveled (VMT) and GHG emissions could yield significant co-benefits of reduced pollution, congestion, utility infrastructures, and lanes of highway construction.

This report describes the short-term (by 2015) and long-term (by 2050) potential for reducing GHG emissions from the U.S. building sector. The report analyzes technology and policy options for GHG reductions that take into account the competing goals, market imperfections, multiple actors, and specific characteristics of this sector. Section 2 describes the nature and sources of GHG emissions from the building sector, the way energy is used in buildings, the role of new construction compared with renovation, “green buildings” and other construction trends, and regional markets for best practices.[11] Section 3 details the structure of the building industry, the obstacles to climate-friendly building technologies and practices, and the societal, economic, and technological drivers of change. Section 4 focuses on the technical and economic potential for technologies and consumer actions to reduce GHG emissions in major building subsectors. Section 5 extends the discussion to community and urban systems, describing the effect of building densities and land-use configurations on consumer and freight transport, on utility and other infrastructure requirements, and on high-efficiency energy systems such as district heating and cooling. Section 6 discusses the policy options that could translate these various opportunities into reality. The report ends with a summary of its findings and recommendations.

II. Greenhouse Gas Emissions: Sources and Trends

Greenhouse gases are generally divided into two categories: (1) the three principal greenhouse gases (carbon dioxide, nitrous oxide, and methane) and (2) other gases (primarily, hydrofluorocarbons [HFCs], perfluorocarbons, and sulfur hexafluoride).[12] Based on overall emission levels and global warming potential,[13] CO_2 is by far the most important GHG, accounting for 85 percent of total U.S. GHG emissions in 2002.[14] Methane and nitrous oxide account for almost 14 percent. The three "other gases" account for less than 2 percent of total U.S. GHG emissions when weighted by their 100-year global warming potential.[15]

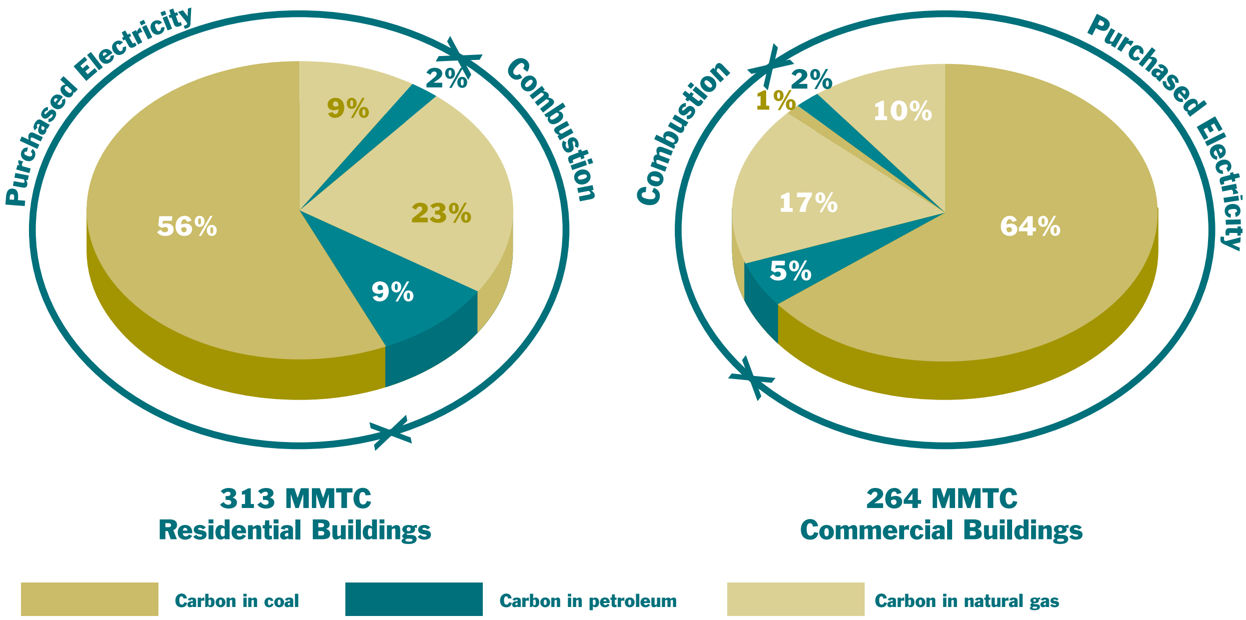
Residential, commercial, and industrial buildings are responsible for 43 percent (658 MMTC) of U.S. CO_2 emissions—the GHG most focused on in this report.[16] Among the other two principal GHGs, buildings are responsible for an estimated 7 percent of methane (an estimated 10 MMTC-equivalent from construction and demolition debris in landfills and 2 MMTC-equivalent from the incomplete combustion of wood in fireplaces and cookstoves) and 8 percent of nitrous oxide (0.3 MMTC-equivalent, principally from fireplaces and woodstoves).[17]

Among the three "other gases," only HFCs are significantly related to buildings. HFC emissions are increasing because of their use as replacements for CFCs, halons, and other ozone-depleting chemicals that damage the earth's stratospheric ozone layer and are being phased out under the Montreal Protocol. In particular, HFCs are used as refrigerants in refrigeration, chillers, and automobile air conditioning, and as blowing agents in insulation. In 2002, the United States emitted an estimated 23 MMTC-equivalent of HFCs and an additional unknown amount of CFCs and hydrochlorofluorocarbons (HCFCs) that will eventually be replaced. With the exception of automobile air conditioning and a few other minor uses, the majority of these emissions are from applications in buildings.[18]

Figure 3 shows a breakdown of the CO_2 emissions generated by the U.S. building sector, by energy source.[19] Emissions from electricity consumption dominate in both residential and commercial buildings, accounting for 71 percent of CO_2 emissions. Direct combustion of natural gas (e.g., in furnaces and water

Figure 3

CO_2 Emmissions from U.S. Residential and Commercial Buildings, by Energy Source, 2002



Source: Based on U.S. Environmental Protection Agency. 2004. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002. p. 3-4, 3-7, 3-17, tables 3-3, 3-6, and 3-10. Note: units are in million metric tons of carbon (MMTC).

heaters) accounts for about 23 percent of emissions in residential buildings, while it emits slightly less CO_2 in commercial buildings (17 percent of emissions). Direct combustion of petroleum, mostly from fuel oil heating in the Northeast and Midwest, is also more significant in the residential sector (9 percent of residential building emissions) than in the commercial sector (where it represents only 5 percent of commercial building emissions).

Additional CO_2 emissions from the following sources can be attributed to the building sector and need to be considered when evaluating GHG reduction opportunities:

- The energy used in industrial buildings (only residential and commercial buildings are included in EIA and EPA statistics on the building sector);
- The energy used to produce building materials such as brick and steel and building products such as appliances and furniture (this “embodied energy” is included in EIA’s industrial sector statistics);
- The fuel used to transport construction and demolition materials (this is included in EIA’s transportation sector statistics); and

- The energy associated with urban sprawl—including passenger and freight transport and the construction and maintenance of low-density, dispersed infrastructures.

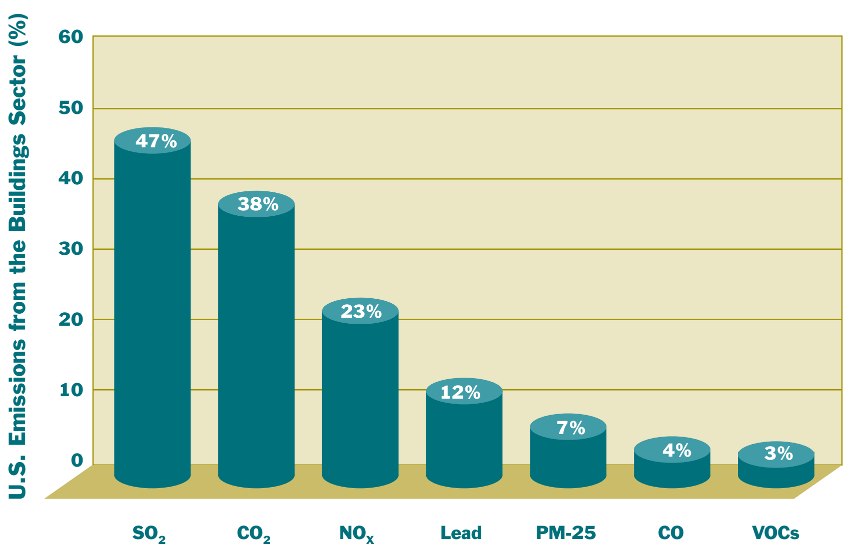
The fact that many building products, especially wood-intensive products, can serve as a carbon sink—reducing net CO_2 emissions—should also be considered when assessing alternatives.

GHG emissions from the U.S. building sector have been increasing at about 2 percent per year since 1990, and the EIA forecasts that they will continue to increase at approximately 1.4 percent annually through 2025. Population and economic expansion are expected to increase the demand for energy-related building services, and the energy requirements of an expanded building stock. Since the GDP is forecast to grow much faster (by 3 percent annually), the CO_2 intensity of the building sector (i.e., building-related CO_2 emissions divided by GDP) is expected to continue to decline according to this EIA forecast.

Just as CO_2 emissions from buildings are forecasted to grow over time, so are other air emissions. As Figure 4 shows, buildings are responsible for a significant proportion of the energy-linked U.S. emissions of sulfur dioxide and nitrogen oxides; they also contribute to lead, fine particulates, carbon monoxide, and volatile organic compounds (VOCs). Measures that reduce CO_2 often have the collateral benefit of reducing these pollutants.

Figure 4

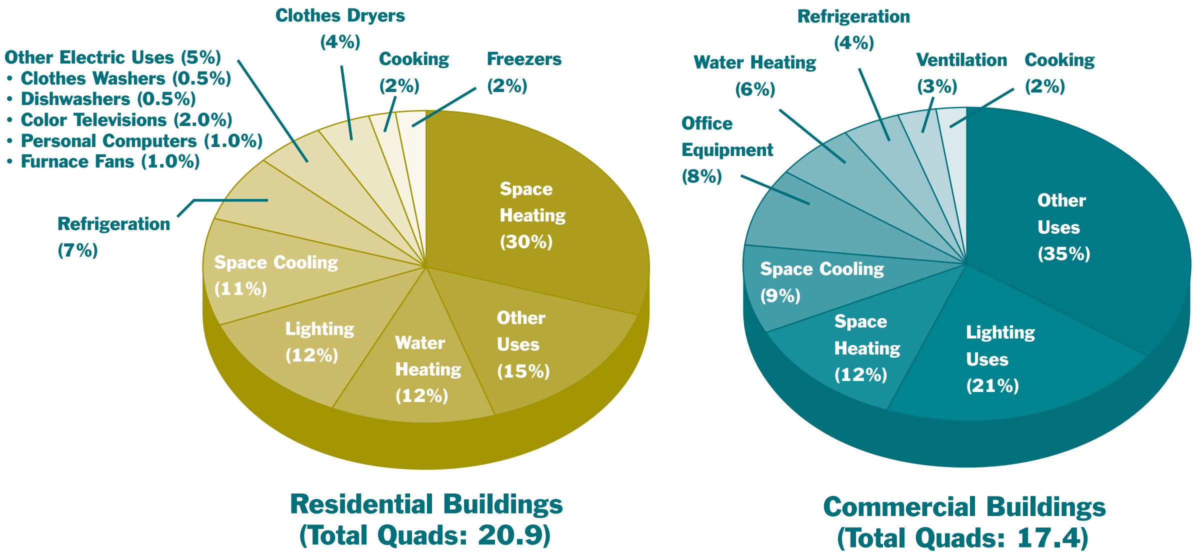
Energy-Linked Emissions from Residential and Commercial Buildings as a Percentage of Total U.S. Emissions



Sources: U.S. Environmental Protection Agency. 2000. National Air Pollutant Emissions Trends Report, 1998, EPA-454/R-00-0002-March 2000. EPA, Washington, DC; and Energy Information Agency. 2000. Emissions of Greenhouse Gases in the United States. DOE/EIA-0573(00). EIA, Washington, DC.

Figure 5

Primary Energy Consumption in Residential and Commercial Buildings, 2002



Note: Other energy uses in the residential sector includes small electric devices, heating elements, and motors; such appliances as swimming pool and hot tub heaters, outdoor grills, and outdoor lighting (natural gas); wood used for primary and secondary heating in wood stoves or fireplaces; and kerosene and coal.

Note: Other energy uses in commercial buildings include service station equipment, automated teller machines, telecommunications equipment, medical equipment, pumps, emergency electric generators, combined heat and power in commercial buildings, and manufacturing performed in commercial buildings.

Source: Energy Information Administration. 2004. Annual Energy Outlook 2004. DOE/EIA-0383, p. 139-142, tables A4 and A5. EIA, Washington, DC.

A. Energy Use and Trends in U.S. Buildings

The building sector is the largest consumer of energy in the United States. The nation's 106 million households, 4.6 million commercial buildings, and 15.5 trillion square feet of industrial building floorspace consumed approximately 40.3 quadrillion Btu (quads) of energy in 2002, or about 41 percent of the U.S. total; most of this energy is consumed by residential buildings (20.9 quads), somewhat less by commercial buildings (17.4 quads), and the remainder is consumed by industrial buildings (2.0 quads).[20] Energy consumption is directly tied to GHG emissions—every quad of energy consumed in the building sector results in approximately 40 MMTC emissions (and costs almost $8 billion in 2001$).[21]

Most of the energy used in buildings is consumed by equipment that transforms fuel or electricity into end uses such as heat or air conditioning, light, hot water, information management, and entertainment (Figure 5).

Within the residential sector, most of the energy consumed is for space heating (30 percent) and air conditioning (11 percent); both of these uses are geared to maintaining occupant comfort in response to climatic conditions. An additional 12 percent is used for water heating, and a further 12 percent is for lighting. The remainder of the energy consumed in homes goes for appliances, electronics, and other purposes.

Table 1

U.S. Residential Primary Energy Consumption by Building Type, 2001

	% Total Units (2001)	% Total Owned (2001)	% Total Rented (2001)	% Total Btu (1997)
Single-family detached	59.0	52.1	6.9	73.4
Single-family attached	9.9	7.0	2.9	9.2
Building of 2–4 units	8.9	2.0	6.9	5.0
Building of 5 or more units	15.9	1.7	14.2	7.5
Mobile home	6.3	5.3	1.0	4.9
Total	100	68.0	32.0	100

Sources: Energy Information Administration. 2004. *2001 Residential Energy Consumption Survey: Housing Characteristics Tables*, EIA, Washington, DC. Table HC1-2a. Energy Information Administration. 2000, *1997 Residential Energy Consumption Survey,* EIA, Washington, DC. table 2.1.2, 1.2.6.

In the commercial sector, a great deal of energy is used for lighting (21 percent) and office equipment (8 percent). Air conditioning (9 percent) requires almost as much energy as space heating (12 percent), caused in part by the need to offset the heat generated by lighting and other electric equipment. The remainder of energy use in commercial buildings is for water heating, refrigeration, and other purposes.

Table 2

U.S. Commercial Primary Energy Use by Building Type, 1999

Building Type	Percent of Total Square Footage	Percent of Total Energy Consumption
Office	22	21
Retail Sales and Services	15	14
Education	10	12
Health Care	8	10
Warehouse and Storage	8	9
Food Services	7	8
Lodging	7	8

Sources: Energy Information Administration, 2002. *1999 Commercial Buildings Energy Consumption Survey: Consumption and Expenditures Tables*, p. 124, table C1. EIA, Washington, DC.

In the residential sector, 59 percent of all housing units are single-family detached homes (Table 1). These units account for 73 percent of residential energy consumption. Single-family attached units represent the second largest building type in terms of energy consumption. Therefore if the potential for CO_2 reduction is judged by the amount of energy used, then the greatest potential among residential users lies with single-family residences.

Commercial buildings range widely in size, energy intensity, function, and ownership. Table 2 characterizes them according to primary function. Offices dominate, both in terms of square footage (22 percent) and energy consumption (21 percent).

In sum, these statistics suggest that the most obvious opportunities to reduce GHG emissions through improvements in end-use efficiency are space heating (especially in the residential sector), air conditioning, lighting (especially in the commercial sector), and water heating (especially in the residential sector). In the residential sector, the biggest opportunity lies with single-family residences; in the commercial sector, office buildings are the most important single target.

B. New Construction versus Renovation

For policy purposes, it is important to distinguish between new and existing buildings and communities. New construction can more easily incorporate novel, low-GHG technologies and is therefore often a harbinger of future trends. In addition, new building technologies are often introduced in the new construction market but then spill over into the building retrofit and renovation trades. While new buildings amount to only 2 to 3 percent of the existing building stock in any given year, new construction practices will have an increasing impact over time.

The value of U.S. construction in 2000 is estimated to have been $1.3 trillion (2000$) including new construction, renovation, heavy construction, and public works. This represents 13.2 percent of U.S. GDP. New buildings construction represents almost half of this total ($562 billion), and building renovation was valued at $265 billion.[22] Given the longevity of buildings and the amount spent annually on renovation, the existing building market represents a key, yet often harder, opportunity for GHG reduction.

The vast majority of the buildings that exist today will still exist in 2015, and at least half of the current stock will still be standing by mid-century. As a result, retrofitting structures and upgrading the efficiency and operation of their heating, ventilation, and air-conditioning systems offer an important near-term opportunity to significantly reduce GHG emissions. Existing communities also can be made more efficient by adding new structures in passed-over parcels of land, allowing mixed uses that reduce transportation requirements, and building new pedestrian and bicycle paths to encourage non-motorized travel. With appropriate policy interventions, these improvements could be implemented quickly and could significantly reduce overall GHG emissions.

C. Green Buildings

Several individual, community, and state initiatives are promoting the implementation of green building practices in new residential and commercial construction. The most impressive progress in residential green building development and construction is the result of communities and developers wanting to distinguish themselves as leaders in efficient use of resources and reducing waste in response to local issues of land-use planning, energy supply, air quality, landfill constraints, and water resources. Developers and owner/operators who have a business purpose in considering the life-cycle cost and resource aspects of their new projects are providing the

Box 1

Greening Four Times Square

Four Times Square, a 48-story skyscraper and the first major construction project in Manhattan in 10 years, is one of the most environmentally and technologically advanced buildings in the nation—and it is being called the first environmental office building in New York.[23]

The Durst Organization set out to build an environmentally responsible or "green" 1.6 million square foot office building that would adopt exemplary standards for energy efficiency, indoor ecology, sustainable materials, and responsible construction, operations, and maintenance procedures.

The developer's determination to build green drew the interest and assistance of many energy experts. A New York state research and development grant, funded by DOE's State Energy Program, supported the developer's use of the advanced energy analysis program "DOE-2." The program assisted in the selection of all heating, ventilation, air conditioning, and lighting systems and exterior cladding materials and techniques. The architects found that the robust economic framework of DOE-2 was critical in gaining tenants' favor for energy-efficiency measures by showing their financial benefits.

The energy-efficient technologies employed in the skyscraper have reduced operational costs by 10 to 15 percent relative to comparable projects. For example, low-emissivity glass windows take up 7 feet of a 9-foot ceiling height, providing daylight to 25 percent of each floor. Extremely efficient natural gas-fired CFC-free absorption chillers avoid the substantial energy waste normally lost in transmission from electric power plants to electric chillers in buildings.

The two on-site fuel cells generate about 3,500 megawatt hours per year—they are fueled by natural gas, but no combustion is involved and the byproducts are hot water and CO_2 derived from natural gas. In addition photovoltaic cells are being used to a limited degree to generate energy as an on-site demonstration. The "thin-film" photovoltaic (PV) cells are integrated into the "spandels" on the building—the area of the façade between the top of one window and the bottom of another—an example of BIPV (building integrated PV).

green building leadership in the commercial sector. One segment of the current leadership is from organizations that are committed to "walking-the-talk" on the environment and energy, such as the Chesapeake Bay Foundation, Durst Corporation (see Box 1: Greening Four Times Square), and the federal government. State and local governments are also demonstrating and requiring green building practices in their new buildings. Several whole-buildings standards have been developed to promote green buildings (see Box 2: Reducing GHG Emissions through Whole-Building Standards). While there is disagreement about some of the specifics of these rating systems, they have proven to be effective in the absence of aggressive state or federal green building codes. Real market transformation, however, will require buy-in also from the supply side of the industry—due to the complex supply chain structure of the industry.

Box 2

Reducing GHG Emissions through Whole-Building Standards

The term "green building" is used by a number of programs to promote environmentally friendly construction practices. Most of these programs use labeling based on a point system to communicate the relative value of these practices to the market. Further research is merited to understand better the life-cycle GHG emissions of various building materials and account for them appropriately in all of these building standards.

Leadership in Energy and Environmental Design (LEED): The U.S. Green Building Council has developed LEED to help commercial building developers evaluate a variety of green building design choices in the early stages of development.[24] Under LEED, building projects are awarded points in six categories: sustainable sites, water efficiency, energy and atmosphere, incorporation of local and recycled materials and resources, indoor environmental quality, and innovation and design process. It has proved to be an effective voluntary standard, although some concerns exist regarding a lack of direct correlation between some of the points awarded and the life-cycle GHG reductions (or life-cycle costs) from the building.[25]

Model Green Home Building Guidelines: The National Association of Home Builders Research Center (NAHB-RC) has developed this system based on eight guiding principles: lot design, preparation, and development; resource efficiency; energy efficiency; water efficiency; indoor environmental quality; operation, maintenance and homeowner education; and global impact.[26] Many of these categories are common to the LEED program, but the NAHB rating system requires a minimum number of points in each category. This tends to place a greater emphasis on energy and resource efficiency and a lesser importance on the site selection and preparation.

The Minnesota Sustainable Design Guide: The University of Minnesota has developed a design tool that assigns points in the categories of site, water, energy, human factors, materials, and waste for both new and renovated facilities.[27] This guide includes an impressive tool, the Minnesota Building Materials Database, for comparing the lifecycle impact of material alternatives.[28]

Green Building Initiative™: This initiative originated in the U.K. and Canada and is now available in the U.S. as well.[29] Its interactive web protocol is significantly simpler than the LEED certification process. The score generated by the web-based tool has been partially harmonized with LEED, and is integrated with EPA's ENERGY STAR Target Finder[30] and the NAHB-RC Model Green Home Building Guidelines.

D. Regional Markets for Best Practices

The opportunities and drivers for widespread adoption of aggressive climate-friendly building goals vary greatly across different economic conditions and climatic regions of the country. In the residential sector, significant opportunities for climate-friendly homes and communities are in the growth areas of the West, Southwest, and Southeast. These regions have particularly large peak electricity requirements for cooling. Improvements in the design of subdivisions for optimal building orientation, shading for passive solar heating and cooling, and efficient building shells, windows, cooling systems, and appliances are the key to reducing energy consumption. These regions also have the best solar resources and greatest opportunities for building integrated photovoltaic and solar hot water systems to meet a large fraction of the remaining energy demand.

The heating demands in the colder northern plains, Northeast, and upper Midwest are primarily provided by natural gas. However, several of these areas also have summer peaking demands for cooling and dehumidification. Efficient building shells, HVAC systems, and appliances are the key to reducing building energy consumption in these regions. Opportunities for photovoltaic, solar heating, and combined heat and power systems are capable of meeting the remaining energy loads for individual homes and communitywide systems.

E. The Technical and Economic Potential for GHG Reductions

Based on current usage of building products and practices, most owners and occupants could significantly improve the energy efficiency of their buildings. HVAC equipment, appliances, and lighting systems currently on the market vary from 20 percent to more than 100 percent efficient (heat pumps can exceed this level by using "free" thermal energy drawn from the air, water, and ground). Only 40 percent of residences are well insulated, and less than 40 percent of new window sales are of advanced types (e.g., low-E). In commercial buildings, only 17 percent of all windows are advanced types. Only 30 percent of commercial buildings have roof insulation and somewhat fewer have insulated walls. Nationally, reflective roofing materials still comprise less than 10 percent of the roofing market; asphalt comprises 95 percent of urban pavements despite its high heat absorption (compared with concrete), which contributes to the urban heat island effect. Design tools for energy efficiency are used by fewer than 2 percent of the professionals involved in the design, construction, and operation of commercial buildings in the United States. A larger fraction of commercial buildings have central building-control systems. However, few diagnostic tools are available commercially beyond those used for air balancing or tools integrated into equipment.[31]

Some improvements in energy efficiency are projected by the EIA to occur by 2015 through the operation of market forces—assuming that fuel prices rise according to EIA projections. These improvements are partly a function of "learning curve" or "induced innovation" effects—that is, reductions in the cost of new technologies and improvements in their performance that reflect economies of scale, learning over time, and rising energy costs. For energy-using consumer durables (such as refrigerators, room air conditioners, washing machines, and dryers), Newell and coauthors estimate that the learning curve results in an average decrease of 1.5 percent of costs per year.[32] As discussed later in this report and as articulated by others, policies can produce additional "induced technological change," thereby lowering the cost of reducing GHG emissions.[33]

The actual market uptake of energy efficiency improvements depends on many factors. The market success of most new equipment and appliances is virtually ensured if the efficiency improvement has a three-year payback or better and amenities are maintained; technologies with payback of four to eight or more years also can succeed in the market, provided that they offer other customer-valued features (e.g., reliability, longer life, improved comfort or convenience, quiet operation, smaller size, and lower pollution levels).[34]

The result is a forecasted annual increase in energy consumption over the next decade of only 1 percent in residential buildings and 1.7 percent in commercial buildings—or an overall annual rate of increase of 1.3 percent for the building sector. Over the same period, energy supplies are anticipated to become somewhat more carbon intensive. The combination of these energy consumption and production trends is a forecasted rate of increase in GHG emissions of 1.1 percent annually in the residential sector and 1.9 percent annually in the commercial sector—or an overall annual rate of increase of 1.4 percent.

Studies suggest that significant improvements in the energy efficiency of buildings appear to be cost-effective, but they are not likely to occur without extensive policy changes.[35] The *Scenarios for a Clean Energy Future,* for example, estimates that 10 years of moderate to more aggressive policy interventions could cut the annual growth rate of energy consumption in buildings to 0.5 percent.[36] A second decade of moderate to aggressive policy interventions could result in annual reductions in the energy consumption in buildings of 0.1 to 1 percent. Similar conclusions are reported in *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions* (the "11-Lab Study").[37] For CO_2, for instance, the 11-Lab Study concluded that a vigorous RD&D program could produce significant carbon emission reductions while sustaining economic growth.

On the other hand, critics claim that the existence of cost-effective energy-efficiency opportunities (i.e., an "energy-efficiency gap") has not been justified on the basis of market inefficiencies.[38] Critics emphasize that in a competitive and efficient market, suppliers produce what consumers want and are willing to pay for. Because there is limited evidence that consumers are willing to pay for closing an energy-efficiency gap, detractors assert that the gap must not exist.[39] Critics also note that the existence of market failure is not a sufficient justification for government involvement. Feasible, low-cost policies must be available that can eliminate or compensate for these failures. Some analysts argue that policies to date have not been low cost. In addition, they argue that policies have not been adequately evaluated by measuring consumer surplus (i.e., the difference between how much a consumer is willing to pay for a commodity such as energy efficiency and the amount that the consumer actually pays when a policy is implemented).[40]

III. Market Structure and Change Mechanisms

A. The Fragmented Buildings Industry

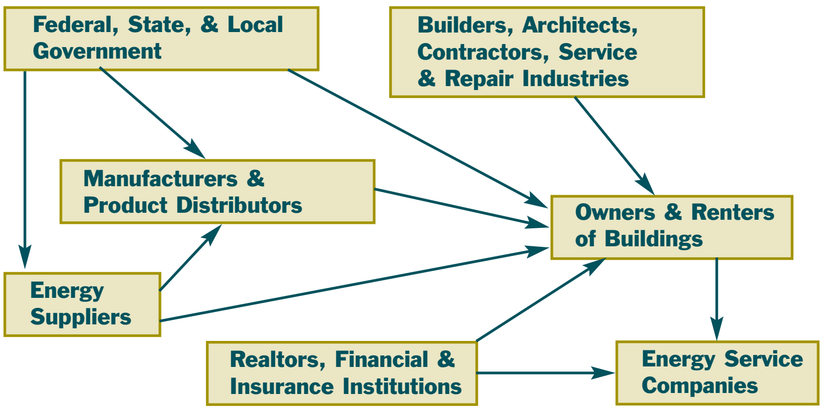
The building industry comprises hundreds of thousands of firms designing, building, and maintaining the nation's building stock and affecting its urban landscape. Figure 6 portrays the roles of some of the more influential types of decision-makers and stakeholders who affect GHG-related purchases and building operation decisions. This illustration is necessarily a simplification of the actual maze of influences rooted in the building industry's geographic, vertical, and horizontal fragmentation.[41] This fragmentation distinguishes the challenges to a low-GHG emitting future in the buildings sector from those in the transportation, industrial, and power generation sectors.

On the consumption side, the nation's 106 million households and the occupants of millions of commercial and industrial buildings make up the largest group of energy end-use decision-makers in the U.S. economy. Their decisions influence the operation and sustainability of the largest component of the nation's physical wealth—its buildings.

Nearly one-third (32 percent) of U.S. households rent their homes. Similarly, 40 percent of privately owned commercial buildings are rented or leased.[42] For these segments of the market, landlords have a powerful influence over the energy efficiency of the building structures and their equipment.

Figure 6

Multiple Stakeholders and Decision-makers in the Building Sector



On the production side, buildings are the largest handmade objects in the economy. Regional differences in climate, energy prices, building codes, and building style traditions complicate standardization in buildings. Nevertheless, there is a limited trend in manufacturing and production techniques toward mass customization through factory-made building components, with the manufactured housing industry accounting for 6.3 percent of U.S. housing units.[43]

The building construction industry, especially homebuilding, is dominated by small and medium-sized firms. This is problematic because it means that a large number of firms and individuals need to be influenced to have a significant collective impact on energy efficiency. There were 1.65 million new home closings in the United States in 2002, and nearly 500,000 homebuilders operated that year. The five largest of these homebuilders accounted for less than 7 percent of new homes, while the top 100 accounted for just another 7 percent.[44] However, there is a trend toward consolidation. According to *Professional Builder*, the top five builders accounted for approximately 10 percent of new homes in 2003, and industry experts predict a 20 percent share before 2010.[45] The renovation and home repair business is likewise dominated by very small firms, typically with fewer than 10 employees.[46]

Similarly, small construction companies account for a large share of small commercial building construction. Commercial buildings under 50,000 square feet account for only 52 percent of commercial floor space but more than 95 percent of the number of commercial buildings.[47] Large office developers, mall developers, and chains and retailers complete a significant percentage of new construction. But here again, the technological needs of different commercial sub-markets (e.g., office, retail, lodging, education) are not uniform, requiring a highly articulated approach to influencing change.[48] Only for large-scale commercial and mixed-use projects is the majority of the market dominated by a small number of large construction firms.

Numerous decision-makers are also involved in the design, operation, renovation, and repair of buildings. An estimated 125,000 architects are licensed to participate in the design of buildings today, and only a small number of these are employed by large design firms. The design of many large commercial buildings typically involves an architect for the building envelope (roof, walls, and foundation) and mechanical engineers for the heating, ventilation, and air-conditioning systems. This division of responsibilities can produce sub-optimal results (e.g., energy-efficient approaches to envelope design that do not capitalize on opportunities to down-size HVAC equipment).

Manufacturers and product distributors also exert profound influences on the use of energy-efficient, renewable energy and other climate-friendly products in buildings by controlling the supply of building products and materials. Their product selections and choice of geographic markets for product distribution determine the availability and ease of access to climate-friendly options.

The realty, financial, and insurance industries also can considerably influence the uptake of energy-efficient and climate-friendly building products. The realty industry is considerably decentralized, although recent trends in national franchising of local offices may afford the opportunity for improving information dissemination through realty channels. The federal refinancing agencies, Fanny Mae and Freddie Mac, offer additional information advantages by virtue of their large share of the market. Both now support energy-efficient residential mortgages; however, this lever is substantially underutilized perhaps because of cumbersome requirements for participation.[49] The insurance industry also could become a powerful advocate of low-GHG buildings in response to the increased property damage liabilities it could suffer as the result of extreme climatic events associated with global warming.[50]

Finally, energy suppliers, energy service companies,[51] and their regulators represent additional players that have been instrumental in motivating and enabling energy-efficiency improvements in buildings. With the restructuring of electricity markets, electric utilities face little incentive to promote energy efficiency, and as a result their impact in the demand-side management arena has shifted to involvement in public benefits programs (see Section VI). Over the past decade, energy service companies have become important players in delivering energy-efficiency upgrades to industrial and commercial markets and government facilities through the use of energy-saving performance contracting. Since its inception in the late 1970s, the energy service industry has installed an estimated $2 billion in projects.[52]

An example of how multiple decision-makers thwart the innovation process is provided by a recent Rand Report:[53]

> "…A homebuyer may request that the builder use a new building material that he or she read about on the Internet. However, the builder may resist if the innovation's costs, benefits, or risks are unfamiliar; if trade contractors do not know how to install it; and if suppliers do not stock it. Finally, builders may also resist if they fear that code inspectors will not allow it."

Understanding the complexities of such decision-making is critical to the design of effective policy interventions.

B. Other Obstacles to GHG Reductions in the Building Sector

Many obstacles in addition to fragmentation hinder the widespread use of energy-efficient and other low-GHG technologies in the building sector. These obstacles include the involvement of intermediaries in decision-making; regulatory, pricing, and fee barriers; insufficient and imperfect information; decision-making complexities; and lack of availability of climate-friendly technologies.[54] Each of these categories is discussed below.

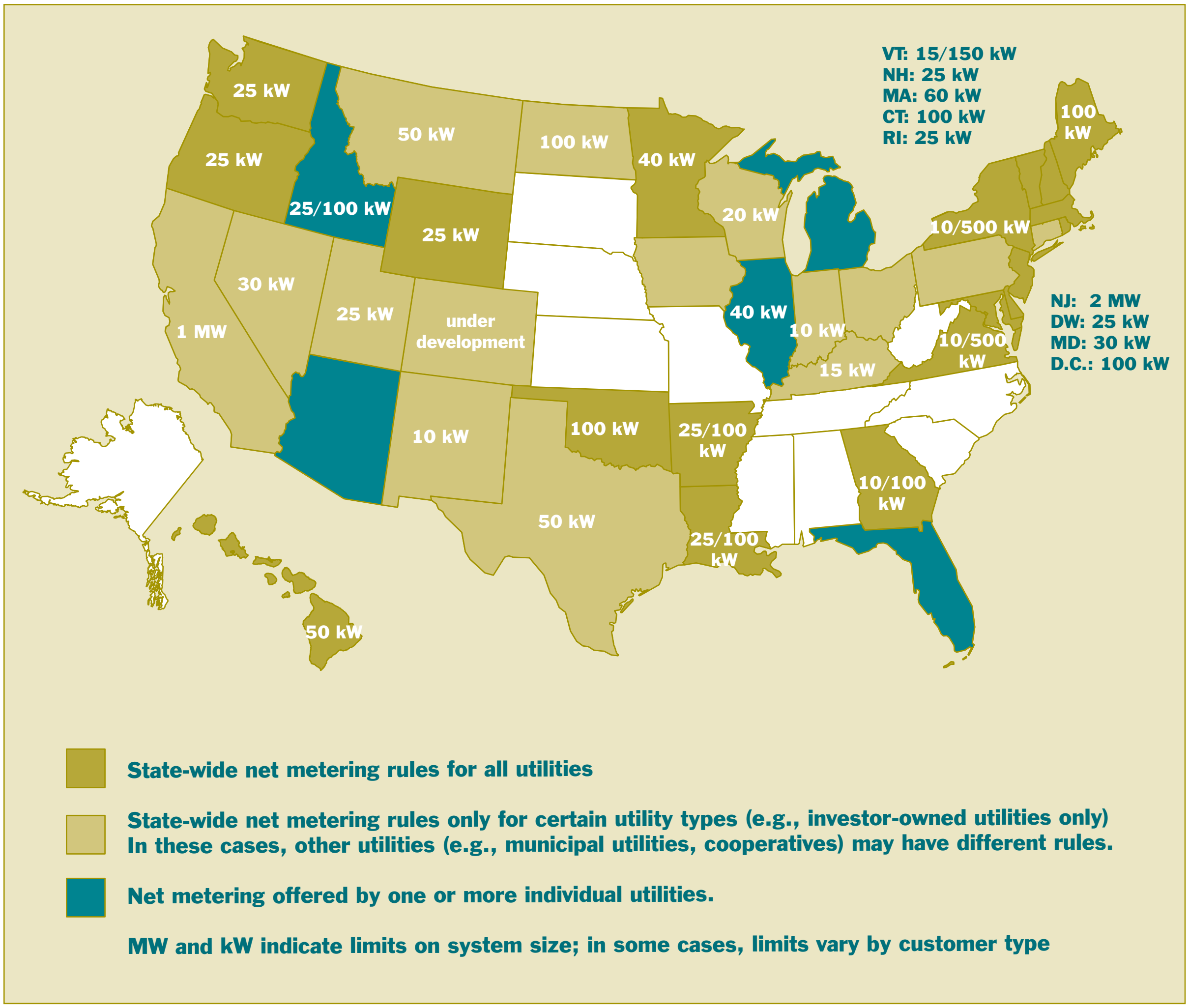
The involvement of **intermediaries** in the purchase of energy technologies limits the ultimate consumer's role in decision-making and leads to an under-emphasis on life-cycle costs, which works against investments in energy efficiency. This obstacle is typically called the "principal–agent problem" in the economics literature. This problem occurs when an agent has the authority to act on behalf of a consumer but does not fully reflect the consumer's best interests. Decisions about the energy features of a building (e.g., whether to install high-efficiency windows and lighting) are often made by people who will not be responsible for the energy bills. For example, landlords often buy the air-conditioning equipment and major appliances, while the tenant pays the electricity bill. As a result, the landlord is not generally rewarded for investing in energy efficiency. Conversely, when the landlord pays the utility bills, the tenants are typically not motivated to use energy wisely.

The prevailing **fee structures** for building design engineers cause first costs to be emphasized over life-cycle costs.[55] Projects are often awarded in the first place to the team that designs the least-cost building; their fees are typically reduced if actual construction costs exceed the estimated costs. This schism tends to hinder energy efficiency because initial capital costs are typically higher for the installation of superior heating, ventilation, and air-conditioning systems that reduce subsequent operating costs.

Another clear-cut example of market failure lies in **electricity pricing practices.** The electric sector is characterized by a highly variable load that cycles widely over seasonal and daily time periods. The result is a real-time cost of electricity production that can vary by a factor of 10 within a single day.[56] The consumer, however, is not generally aware of the time-of-day or seasonal cost schedule the utility faces. Instead, the consumer sees a monthly electricity bill that is essentially an average monthly cost. Some companies even allow customers to avoid billing spikes in high usage months by averaging costs over entire years such that no price variation is seen. In this case, the consumer is likely to be entirely unaware when production costs are high. These flat rates cause households to over-consume during peak

Figure 7

Net Metering Programs in the United States



Source: Database of State Incentives for Renewable Energy (DSIRE), http://www.dsireusa.org, February 2005.

periods and under-consume during slack periods, compared to how they might behave if they received accurate price signals.

Numerous **regulatory barriers** have been shown to stand in the way of distributed generation technologies, including photovoltaics, reciprocating engines, gas turbines, and fuel cells.[57] These barriers include state-to-state variations in environmental permitting requirements that result in significant burdens to project developers. Similar variations in net metering policies cause confusion in the marketplace and represent barriers to distributed generation (Figure 7). Net metering allows customers with small generating facilities to use a single meter to measure the difference between the total generation and consumption of electricity by allowing the meter to turn both forward and backward. Customers effectively receive retail prices for the excess electricity they generate. When combined with time-of-use pricing, this can result in an attractive value proposition for photovoltaics and other on-site power production. In states that do not have net metering, a second meter must be installed to measure the electricity flowing back to the host utility, and the utility purchases the power at a rate much lower than the retail price—which is a disincentive to the development of distributed generation.[58]

Insufficient and imperfect information can also hamper energy efficiency. Information about energy-efficient options is often incomplete, unavailable, expensive, and difficult to obtain. When knowledge about the energy features of products and their economics is insufficient, investments in energy efficiency are unlikely. This insufficient knowledge is compounded by uncertainties associated with energy price fluctuations and risks related to irreversible investments, both of which lead to high hurdle rates (i.e., the expected rate of return on a potential investment that is required by the investor) and a slow pace of technology diffusion.[59]

While information for most goods and services is imperfect, it is particularly difficult to learn about the performance and costs of energy-efficient technologies and practices, because the benefits are often not directly observable. For example, households receive a monthly electricity bill that provides no breakdown of individual end uses, making it difficult to assess the benefits of efficient appliances and other products. The complexity of design, construction, and operation of buildings makes it difficult, in fact, to characterize the extent that any particular building is energy efficient. What looks like apathy about energy use may more accurately reflect confusion, uncertainty, and lack of time to explore more efficient alternatives.

Even while recognizing the importance of life-cycle calculations, consumers often encounter **decision-making complexities,** and end up falling back on simpler first-cost rules of thumb. While some energy-efficient products can compete on a first-cost basis, many of them cannot. Properly trading off energy savings versus higher purchase prices involves comparing the time-discounted value of the energy savings with the present cost of the equipment—a calculation that can be difficult for purchasers to understand and compute, even assuming one knew future energy costs. This is one of the reasons builders generally minimize first costs, believing (probably correctly) that the higher cost of more efficient equipment will not translate into a higher resale value for the building.

Lack of availability of climate-friendly technologies is often a problem. For example, the purchase of heat-pump water heaters and ground-coupled heat pumps[60] has been handicapped by limited access to equipment suppliers, installers, and repair technicians.[61] The problem of access is exacerbated in the case of heating equipment and appliances, because they are often bought on an emergency basis, thereby limiting choices to available stock. A survey of 639 consumers who had recently replaced their gas furnaces estimated that in one-third of the cases the old furnace was not functioning.[62] High-efficiency furnaces represent a more costly inventory that dealers tend to prefer to sell on special order. Thus, a potential barrier to the selection of high-efficiency furnaces by emergency buyers is the lack of available units in the stock maintained by dealers.

C. Drivers for Low-GHG Buildings: Now and in the Future

Affordability, aesthetics, and utility have traditionally been major drivers of building construction, occupancy, and renovation. In addition to climatic conditions, the drivers for energy efficiency and low-GHG energy resources depend on the local and regional energy supply costs and constraints, incentives, public utility commission rules, and utility business practices. The opportunities for climate-friendly building and savings in water and materials are substantial in most regions of the United States; however, the drivers depend very much on local and regional land and natural resource constraints. Other drivers for low-GHG buildings are increasingly considered such as indoor air quality and worker productivity, clean air regulations,[63] the costs of urban sprawl, and electric reliability.[64]

The U.S. electric power system has been evolving (although the transition is currently stalled) from a centrally planned and utility-controlled structure to one that depends on competitive market forces for investment, operations, and reliability management. Electric system operators are being challenged to maintain the reliability levels needed for the increasingly digital economy in the face of a cost-competitive generation market, grid bottlenecks, excessive price volatility, and increasingly costly blackouts. One of the fixes being pursued and growing in popularity is price-responsive demand—that is, providing incentives to building owners and industrial customers to reduce loads in response to high prices and electric system stresses. While requiring greater sensors, controls, and communications in buildings, the GHG impacts of demand-responsive buildings are unclear, because shifting loads in time may increase or decrease total energy consumption and may move toward more or less carbon-intensive electricity. There is likely to be considerable regional variation in the environmental impact of real-time pricing and demand-responsive buildings, with the most positive effects occurring where peak capacity is oil fired.[65]

In a dynamic technological society, projecting beyond the immediate future based on current trends can be misleading. The drivers determining where people work and live, and how they use buildings, could change radically over the next 50 years. Short- and long-term trends may influence future decisions about buildings, with GHG consequences:[66]

- High-fidelity communications may promote more telecommuting and teleshopping, increasing the space and communications requirements in homes and allowing employers and employees to be more locationally footloose.

- If hybrid vehicles and other more fuel-efficient vehicles gain market share and the relative cost of driving versus other activities falls, high-mobility lifestyles and sprawling urban landscapes may continue.

- More flexible, modular, and adaptable interior designs could more easily enable homes to be converted for a variety of purposes, allowing occupants to age in place.

- Wireless technologies will increase the potential for monitoring and controlling the operation of buildings; smart sensors and controls will adjust environments to respond to the needs of occupants.

- Increased requirements for high-quality electricity to support the digital economy could promote the development of on-site power production, offering greater energy efficiency by putting waste heat to productive uses.

- Mass customization will offer the opportunity to use more manufactured components in buildings—increasing quality control and energy efficiency, and reducing on-site labor costs.
- Buildings will increase their use of materials and products that require less maintenance, including steel and concrete, engineered wood, and recycled products.
- The development of distributed sources of hydrogen fuel produced in a low-GHG manner could radically decrease GHG emissions from buildings and vehicles.

Many of these trends would increase GHG emissions—bigger houses, more sprawl, and people buying their own diesel generators in case of blackouts. Other trends could lead to GHG emission reduction—smart sensors to optimize HVAC operations, more manufactured components of buildings, and a hydrogen-based energy economy.

IV. Technology Opportunities in Major Building Subsectors

Technology opportunities and building system innovations for reducing GHG emissions in homes and small businesses are similar. In both cases, energy use is currently dominated by a combination of space heating and cooling loads, which are principally a function of climatic conditions. In contrast, energy use in large commercial and industrial buildings is generally dominated by HVAC, lighting, and other internal loads and depends more on the type of business and occupancy than on climate. Across all building subsectors, there is a growing trend to use green building design, natural daylighting, recycled materials, and solar energy technologies for on-site heat and power.[67]

A. Homes and Small Businesses

An energy-efficient building system must address two things: reduction of heat flow through the building envelope and improvement in the efficiency of all energy-consuming equipment. In the long run, integrated building systems in homes and small businesses have the potential of requiring net zero input of energy through the incorporation of solar hot water, photovoltaic systems, and other on-site renewable energy technologies.

Building Envelope. The building envelope is the interface between the interior of a building and the outdoor environment. The envelope separates the living and working environment from the outside environment to provide protection from the elements and to control the transmission of cold, heat, moisture, and sunlight to maintain comfort for occupants. Energy pathways through the building envelope are traditionally divided into attic/roof, walls, windows, foundation, and air infiltration. Another important category of energy consumption is the embodied energy of the building envelope itself.[68]

Roof

The building's roof presents a large surface exposed to year-round direct sunlight. The heat available from this source is welcome during the winter, but summertime heat gains inflate air-conditioning loads. New reflective roof products address two shortcomings of current products. First, new pigments reaching the market reflect most of the incident thermal energy. Early tests of these products in Miami show a cooling energy savings of 20 to 30 percent with a simple payback period of one to two years.[69] Second, research efforts are underway to develop "smart" roofing materials that absorb solar energy when the outdoor temperature is cool and reflect solar energy when the outdoor temperature is warm.[70] Because roof surfaces are replaced on regular, albeit long, intervals, these technology opportunities are pertinent for both new and existing buildings.

Wall Systems

Wall systems include framing elements and insulated cavities. In traditional wall designs, the framing portions of the wall are not insulated and represent a much greater portion of the total wall surface than is generally realized. New wall designs minimize heat loss by as much as 50 percent by reducing the amount of framing used and by optimizing the use of insulated materials.[71] These designs include optimal value engineering, structural insulated panels, and insulated concrete forms.[72] Even with conventional wall design, minor modifications can significantly reduce energy transport. For example, polyurethane bearing blocks have twice the insulating capability of wood and can be used to thermally isolate steel walls from foundations and from steel attic beams.[73]

Improved wall system designs, however, generally apply only to new construction; the options for walls in existing buildings are more limited. Insulated sheathing is available for wall retrofits but often requires modifications to window jambs and doorframes. In the long term, the coatings under development for roofs could become a constituent of siding materials. Another approach is to take advantage of new insulating fabrics that could be hung from or applied to interior wall surfaces. The reflective properties of such materials can also be engineered to provide greater human comfort at reduced (winter) or elevated (summer) indoor temperatures, further increasing the energy savings.[74]

Windows

Energy travels through windows via radiant energy, heat conduction through the frame, and air leakage around the window components. The higher-quality windows on the market today address all three of these energy paths, and they can be six times more energy efficient than lower-quality windows.[75] Low-E coatings for windows reduce the flow of infrared energy from the building to the environment, effectively increasing the window's R-value. Some of the low-E coatings are also designed to reject infrared energy from the sun, thus reducing air-conditioning loads. Electrochromic window coatings in the development stage offer dynamic control of spectral properties. For example, they can be controlled to reflect infrared energy during the summer but transmit this energy into the building during the heating season. Predicted HVAC energy savings for office buildings in arid climates using electrochromic windows range from 30 to 40 percent.[76]

Air Infiltration

The twin goals of reducing energy use while controlling moisture levels can often be at odds. For example, a reduction in the infiltration of air into a building may also reduce a significant drying mechanism. Adding insulation inside a wall changes the temperature profile within the wall, and so could create pockets of condensation that would not occur in a less energy-efficient wall. Faced with a choice between a less efficient but sound structure and a more efficient but rotting one, building managers will likely choose the former. However, current research efforts are expected to identify which structural combinations are more likely to be more successful in different climates, thus removing this barrier to more efficient buildings.[77]

Thermal Storage

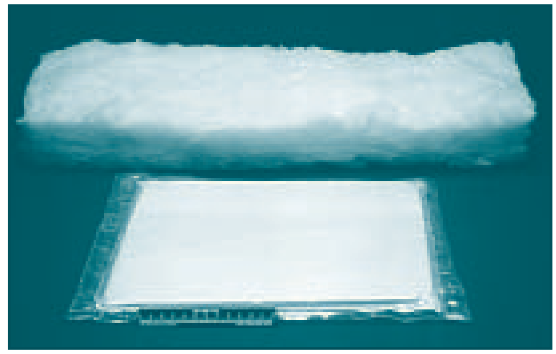
One way to reduce energy consumption is to increase the thermal storage of the structure, especially in climates where daily temperature swings require both heating and cooling in the same 24-hour period. Massive construction materials, such as stone or adobe, have long been used for this purpose. However, lighter-weight thermal storage would be more attractive to consumers. In the near term, phase change materials (PCMs), including water, salts, and organic polymers, can be used for thermal storage. In the long term, new solid-solid PCMs based on molecular design or nanocomposite materials may expand the opportunities for building-integrated thermal storage.[78] Ideally, such materials will be incorporated as an integral element of existing building components. Annual heating and cooling savings estimates for simple residential buildings with PCM wallboard range from 15 to 20 percent.[79]

Insulation

Vacuum insulation, while more expensive than other insulation products, offers 5 to 10 times the R-value for a given thickness of conventional insulation (Figure 8). It is therefore most likely to be used in confined spaces. It is already used in refrigerators and historic building renovations. These insulation panels could be used in exterior doors, ceilings, and floors in manufactured homes, floor heating systems, commercial building wall retrofits, and attic hatches and stairs.[80]

Figure 8

A Fiberglass Batt and a Vacuum-Insulation Panel of Equal R-Values



Building Envelope Embodied Energy

The complexity of calculating embodied energy has given rise to a wide range of estimates. Recently, an extensive consortium of 15 research institutions (the Consortium for Research on Renewable Industrial Materials [CORRIM]) was formed to examine the environmental and economic costs of building materials—from tree planting to building demolition.[81] Results show that the building's embodied energy equals about 8 to 10 times the annual energy used to heat and cool it and that the GHG emissions range from 21 to 47 metric tons over the life of a house. The best way to reduce this significant embodied energy in a building is to salvage and reuse materials from demolished buildings, even considering the extensive cleaning and repair often required of the salvage materials.[82]

The building design, size, regional material sources, and framing material selection all greatly affect the embodied energy and GHG emissions. The CORRIM compared two house designs (wood framed versus concrete or steel framed) and found that for the same amount of living space, a wood frame house contains about 15 percent less embodied energy and emits about 30 percent less GHGs than does either a concrete frame or a metal frame house.[83] Other studies in this area have reached similar conclusions.[84]

The GHG-footprint of building materials depends on many factors. This complicates the setting of green building standards, and means that optimizing the appropriate mix of low-GHG building materials will likely be determined on a project-specific basis. For example, wood is a renewable material that can be obtained from sustainably harvested sources and can store carbon that would otherwise have been emitted to the atmosphere as CO_2, and can be engineered to further reduce the amount of harvested timber required. Concrete can reduce operating energy consumption by providing thermal mass to buffer temperature swings. Metal frames may contain up to 90 percent recycled material, and can be advantageous where moisture, termites, or other natural pests are a problem, or where occupants are particularly sensitive to chemicals used in other products.

Energy-Consuming Equipment. Energy-consuming equipment in homes and small businesses include systems such as HVAC, water heating, and lighting.

HVAC Systems

Many technical opportunities exist to save energy used in HVAC systems. Smarter control systems could maximize the use of natural ventilation, especially if used with some form of thermal storage. Controlling relative humidity in air-conditioned spaces within the proper range would permit higher air temperatures while providing equal occupant comfort.[85] Successful methods are already available to reduce the large (estimated in the 15–20 percent range) duct energy losses including aeroseal techniques.[86] Variable speed air handlers are also available to improve system efficiency and performance.[87] In the long term, selective water sorbent technology offers the promise of meeting the performance of ground-coupled heat pumps at the cost of traditional systems. Moreover, the sorbent technology inherently includes a variable temperature energy storage mechanism that can be used to shift electric loads from peak to off-peak times.[88]

Matching HVAC size to the building load has multiple implications for GHG emissions. Historically, contractors have considered it conservative to oversize HVAC installations, often using "rules of thumb" unrelated to any particular house design and especially inappropriate for the newer, more energy-efficient houses. Such oversizing causes units to cycle on and off more often, increasing thermal losses during each on/off transition. Frequent cycling also reduces occupant comfort, which in turn often leads occupants to adjust their thermostats to a value that increases total energy consumption. Therefore, downsizing HVAC equipment to match the reduced requirements of an energy-efficient building envelope can save investment dollars up front and can decrease energy consumption and GHG emissions as well.

Until recently, oil furnace efficiencies above the low- to mid-80s were rare. The availability of high-efficiency oil furnaces could significantly affect energy use through installation in new homes or as replacement units.[89] One manufacturer has developed a condensing oil furnace with an Annual Fuel Use Efficiency (AFUE)[90] rating of 95 that has overcome sooting problems prevalent with earlier versions of this technology.[91]

Other products in development should reduce energy consumption in the near future. For example, breakthroughs in the design of heat chambers result in higher heat transfer coefficients with thermal efficiencies of 97 percent.[92] This technology is under research for commercial and manufacturing uses, but with further R&D could be applied to residential heating systems as well.[93]

Water Heating

Water heating is the second largest consumer of energy in homes, accounting for 12 percent of total energy use. Given the current status of water-heater technology, water heaters offer large potential energy savings. Three technical improvements in water heating (heat pump water heaters, water heating dehumidifiers, and heating water with waste heat) are described below. Other technology innovations include solar water heaters, gas condensing water heaters, and tankless (or instantaneous) water heaters, each of which is considered by the U.S. Department of Energy (DOE) to be "promising technologies" for energy savings.[94] Another approach to reducing water heating energy is to improve the design of plumbing within buildings by moving the water heater tank closer to the points of use, which wastes less energy through thermal losses in hot water pipes.

- The **heat pump** water heater (HPWH) moves heat from the house, garage, or outside air into the water tank—requiring less energy than would be needed to heat the water with an electric resistance water heater. An average HPWH uses less than 5 kWh of electrical energy to produce 64.3 gallons of hot water (the average daily hot water consumption for a typical U.S. household; a conventional water heater requires 13.3 kWh to accomplish the same task). As a side benefit, the HPWH can also provide cool, dehumidified air in the space where it is installed.[95]

- The **water heating dehumidifier** combines the efficiency of a HPWH with dedicated dehumidification. Humidity control is a growing issue for new houses, which are insulated so tightly that outside air (along with its undesirable humidity) must sometimes be brought in to meet fresh air requirements. Several working prototypes are being built, and laboratory and field testing will begin shortly.[96]

• Multi-functional equipment and integrated systems offer the opportunity for a significant increase in efficiency through **heating water with waste heat.** For example, an integrated system that uses heat pumping to meet space heating, air conditioning, and water heating needs could be 70 percent more efficient than the combined efficiencies of systems in use today. A demonstration supported by DOE, the Tennessee Valley Authority, and industrial partners, is analyzing the operation of such integrated systems.[97]

Solar Photovoltaic Systems

Solar photovoltaic (PV) arrays are made from semiconducting devices that convert sunlight into electricity without producing air pollution or GHG emissions. A variety of PV system configurations are being used by electric utilities to provide "green power" to customers. Three types of systems are particularly relevant to buildings:

• **Stand-alone systems** produce power independently from the utility grid. In some off-the-grid locations, stand-alone PV systems can be more cost effective than extending power lines. Most systems rely on battery storage that allows energy produced during the day to be used at night. Hybrid systems combine solar power with additional power sources such as wind or diesel. For most of the PV industry's history, stand-alone systems have dominated, but today grid-connected systems are moving to the forefront.

• **Grid-connected systems** supply surplus power back through the grid to the utility and take from the utility grid when the building system's power supply is low. These systems remove the need for storage, although arranging for the grid interconnection can be difficult.

• **Building-integrated photovoltaic (BIPV) systems** produce electricity and serve as construction materials at the same time. They can replace traditional building components, including curtain walls (for warming ventilation air), skylights, atrium roofs, awnings, roof tiles and shingles, and windows. They may be stand-alone or grid-connected systems.

Almost all locations in the United States have enough sunlight for PV systems, and these arrays can be easily sited on roofs, integrated into building components, or placed above parking lots. While integrating large quantities of solar photovoltaics into the electricity grid is not simple due to its intermittence, the supply curve for photovoltaics makes it a potentially valuable contributor to peak-shaving. In addition, distributed power offers the prospect of increased security and grid reliability.

The relationship between the building owner and the utility is important to the success of grid-integrated systems. Most owners want to maximize the output of their system, and they normally have little concern about the utility's peak load. One way to benefit both the owner and the utility is by providing time-of-use net metering, which values the electricity produced during the peak period higher than that produced during off-peak times. This more sensitive metering would encourage owners to orient their systems to provide the highest-value electricity and would help the utility address its peak demand.[98] Utilities continue to have concerns about the safety, reliability and costs of net metering. Addressing barriers to metering should be feasible with accelerated development of low-cost metering devices, along with education and demonstration activities such as DOE's Million Solar Roofs Program.[99]

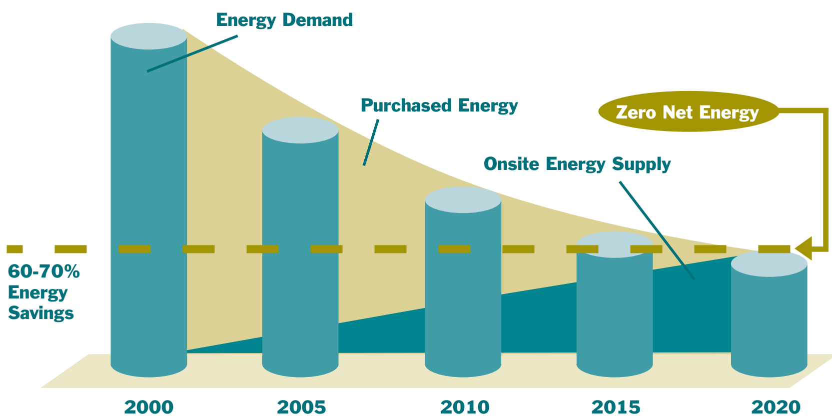
Thin-film photovoltaic technology is the focus of current federal R&D efforts because it holds considerable promise for cost reductions due to its need for less semiconductor material. In the long term, research into nanocomposites offers the promise of an inexpensive and high-efficiency solar energy conversion device.[100]

Currently, grid-connected photovoltaic systems cost an order of magnitude more per kilowatt hour than do fossil, nuclear, and wind generation energy sources. However, a more appropriate comparison with end-user prices (which include transmission and distribution costs, taxes, profits, and other fees, and are therefore much higher than generation costs) suggests that solar power is more closely competitive with these other sources. The market for solar power is expected to grow rapidly over the next decade, due to production tax credits, renewable portfolio standards, and buy-down programs (such as California's subsidies for residential and commercial photovoltaic systems), combined with anticipated cost reductions of at least 5 percent per year.[101]

Integrated Building Systems. By 2010, advances in building envelopes, equipment, and systems integration, may lead to 50 percent reductions in the energy requirements of new buildings relative to 2000. Incremental cost estimates for these advanced building systems run from 0 to 2 percent of the total building cost, because most of the additional building envelope cost is offset by cost savings on the downsized HVAC system.[102] If augmented by on-site power, buildings could reduce their net energy requirements by perhaps 75 percent by 2015. A few large prototype buildings incorporating such technology have been constructed with incremental costs of only 5 to 7 percent, which is generally recovered from reduced energy bills in fewer than five years.[103]

Figure 9

The Pathway to **Net Zero Energy Homes**



Photovoltaics offer the possibility of "net-zero-energy" buildings, when combined with 60–70 percent whole building energy reductions. This goal may be achievable as a cost-competitive housing alternative by 2020 (see Figure 9). The estimated cost premium for such a system today is approximately 25 percent.[104]

A net-zero-energy building in 2020 would likely include a careful site plan to optimize the use of solar energy and take advantage of any sheltering terrain; a super-insulated and airtight structure with high-performance building components with low embodied energy but high thermal storage; heat-recovery air exchangers and exhaust systems, coupled with integrated low GHG-emitting energy systems that produce electricity on site while productively using waste heat; highest-efficiency appliances and HVAC equipment; and smart controls that optimize the thermostat and reduce wasted energy.

In the longer term, research in the field of thermoelectric materials, in which heat can be transformed directly into electrical energy and that can act as solid-state heat pumps, could play a useful role in an integrated building. Such materials would enable self-powered sensors for the control systems and waste heat recovery for appliances. Given adequate breakthroughs in material science research, they could also serve as localized heating and cooling systems, reducing the need to heat and cool much larger volumes of air.[105]

B. Large Commercial and Industrial Buildings

Efficient lighting and distributed energy technologies hold great promise in large commercial and industrial buildings. Current research also holds the promise for improved wireless sensor technologies, along with advances in control technology such as neural networks and adaptive controls. In the long term, these components will be combined into robust building management systems. Unlike today's simple thermostats and timers, these sophisticated systems will enable true optimization of building energy services including the continuous recommissioning[106] of HVAC systems, both reducing energy use and improving conditions for building occupants.[107]

Lighting. Current lighting technologies are expected to benefit from incremental improvements over the next 20 years, and two areas of research (hybrid solar lighting and solid state lighting) should be able to deliver even greater savings. The efficiency of fluorescent lighting used in many larger commercial and industrial buildings is expected to improve by about 10 percent by 2025.[108] This improvement, when combined with more adaptive lighting arrangements, could increase savings by about another 15 to 20 percent. Incandescent lighting, although used less in commercial and industrial buildings (compared with homes), is also predicted to increase in efficiency by about 10 percent.[109]

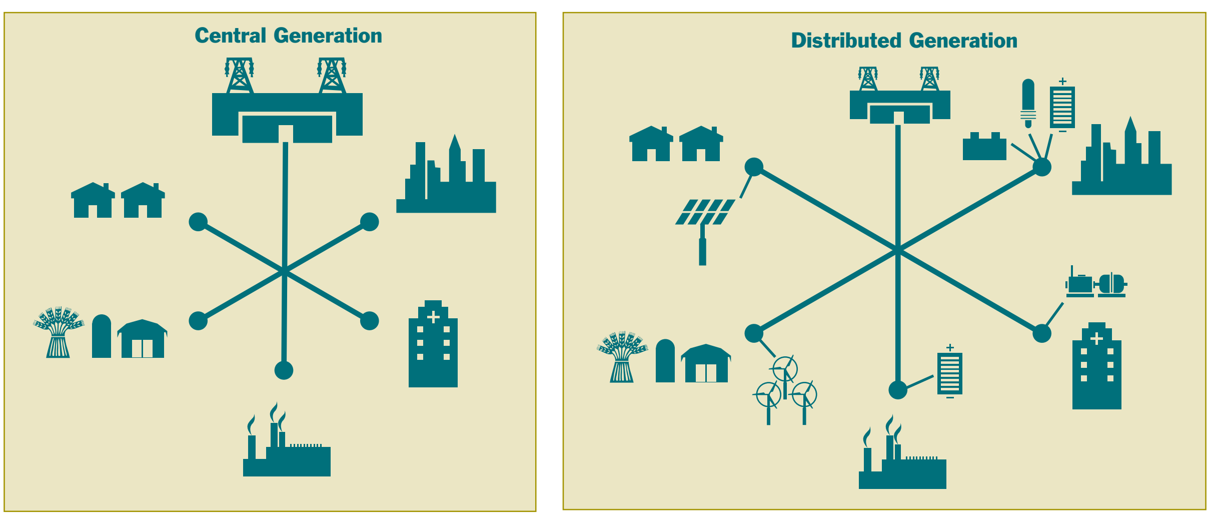
One alternative lighting system for commercial buildings is called hybrid solar lighting. In this system, a roof-mounted solar collector sends the visible portion of solar energy into light-conducting optical cables, where it is piped to interior building spaces. Controllers supplement this light as necessary with fluorescent lights to provide the desired illumination levels at each location. Early experiments show that hybrid lighting is a viable option for lighting on the top two floors of most commercial buildings. It would therefore be applicable to roughly two-thirds of the commercial floor space in the United States. In retrofit markets, hybrid lighting can be more readily incorporated than skylights into existing building designs, and unlike skylights, the flexible optical fibers can be rerouted to different locations during renovations. This technology is estimated to have a payback period of fewer than five years for some applications.[110]

For the long term, research into solid-state lighting shows great promise. Preliminary roadmaps estimated that cumulative savings by 2020 could amount to 16.6 quads of electrical energy and 258 million metric tons, or 0.2 percent, of the projected total U.S. carbon emissions over that time period.[111] Today's light emitting diodes (LEDs) produce light at an efficiency only slightly higher than standard incandescent lights and are already used for specialty applications such as traffic lights and exit signs. Technology improvements are expected to bring brighter LEDs that provide light equivalent to existing fluorescent fixtures with 25 to 45 percent less electricity usage. With successful LED R&D, energy savings over all sectors could be as high as 3 to 4 quads, or 60 to 75 MMTC, in 2025.[112] Global use of this technology is projected to save 1,100 billion kWh/year, corresponding to reduced carbon emissions of roughly 200 MMTC.[113]

Climate-Friendly Distributed Energy. Distributed energy resources are small power generation or storage systems located close to the point of use. Not all distributed energy is climate-friendly, a case in point being diesel-generator sets. But other distributed generation technologies offer significant potential for reduced emissions of CO_2 and local air pollutants, partly because of their higher efficiencies through cogeneration and partly through their use of on-site renewable resources and low-GHG fuels such as natural gas. Other advantages include fuel flexibility, reduced transmission and distribution line losses, enhanced power quality and reliability, and more end-user control. Many experts believe that these potential advantages will bring about a "paradigm shift" in the energy industry, away from central power generation to distributed generation (Figure 10).

Figure 10

The Transition to **Distributed Energy Resources**



Some distributed generation technologies, like photovoltaics and fuel cells, can generate electricity with no, or at least fewer, emissions than central station fossil-fired power plants. Additional emissions can also be avoided using fuel cells, microturbines and reciprocating engines, if the waste heat generated is usefully employed on site to improve overall system efficiency. Based on the remaining technical potential for cogeneration in the industrial sector alone, it is estimated that nearly 1 quad of primary energy could be saved in the year 2025.[114] Packaged cogeneration units that include cooling capabilities (and are therefore more attractive to commercial building operators) are projected to save 0.3 quads in 2025.[115]

Today's distributed generation market in the United States is largely limited to backup generation. Customers include hospitals, industrial plants, Internet server hubs, and other businesses that have high costs associated with power outages. Markets are likely to grow as wealth increases and more consumers are willing to pay to avoid the inconvenience of blackouts. Smaller niche markets are growing where distributed energy resources are used as a stand-alone power source for remote sites, as a cost reducer associated with on-peak electricity charges and price spikes, and as a way to take advantage of cogeneration efficiencies (see Box 3). Distributed generation could be particularly advantageous in newly settled areas by requiring less infrastructure investment, by reducing transmission line requirements, and by being more responsive to rapidly growing demand for power. Increased demand will likely continue and possibly accelerate well into the future as small-scale modular units improve in performance; as decreases in cost, interconnection, and other barriers are tackled; as the demand for electricity continues to grow; and as the worldwide digital economy expands. Over the next half-century, it is possible that the demand for ultra-reliable power service will increase far more rapidly than the demand for electricity itself. This demand could be met by distributed energy resources.

For distributed generation to enhance system-level efficiency, improvements would be needed in the performance of power-producing equipment. A next generation of power electronics, energy storage, and heat exchangers would be needed to improve waste heat recovery and cycle efficiencies, and advanced sensors and controls would also be required. With successful RD&D, the United States (and much of the rest of the world) could realize a paradigm shift to ultra-high-efficiency, ultra-low-emission, fuel-flexible, and cost-competitive distributed generation technologies. These technologies would be interconnected with the nation's energy infrastructure and operated in an optimized manner to maximize value to users and energy suppliers, while protecting the environment.

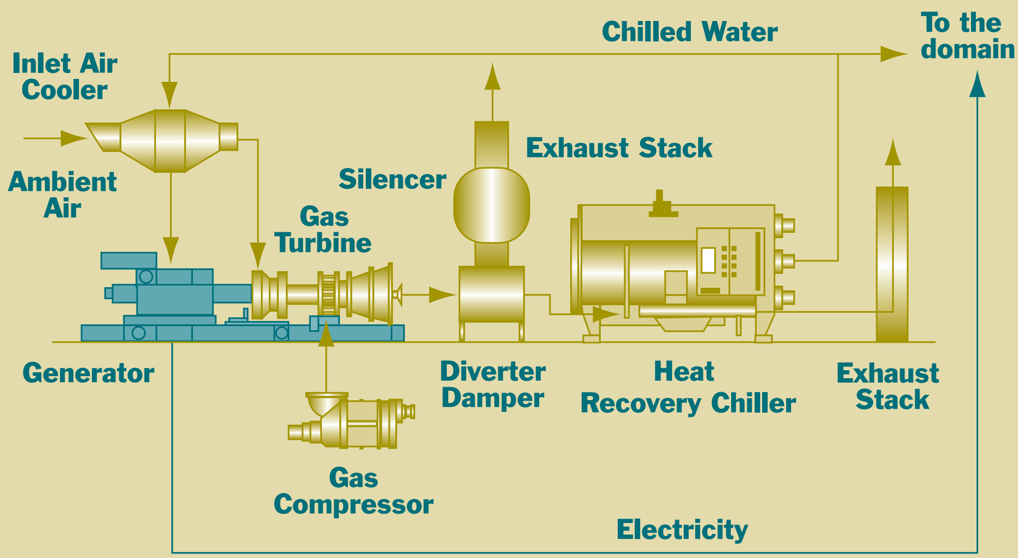
Box 3

Integrated Energy Generation Prototype[116]

A prototype power plant could revolutionize on-site generation for businesses. Burns & McDonnell developed, installed, and is testing (with Austin Energy) one of the largest integrated energy systems in the nation (Figure 11). This demonstration project uses the waste heat exhaust from a natural gas-fueled generator as the only fuel source for a chiller that provides air conditioning. Recycling waste heat to power another generator or to help run a chiller is not new. What is new is for a chiller of this size to be fueled by waste heat alone. The project's chiller is capable of delivering 2,500 tons of chilled water, enough to cool 1 million square feet of office space. Operation, which began in June 2004, should verify fuel efficiency of 70 to 80 percent against the 55 percent efficiency of the best central power plant technology available today.[117]

Figure 11

Integrated Energy System Includes a Natural Gas Turbine and a Heat Recovery Chiller



V. Community and Urban Systems

The spatial arrangement of buildings in communities and urban systems can play an important role in GHG reduction. Higher-density, more spatially compact and mixed-use developments offer the potential for significant reductions in GHG emissions through three complementary effects:

- Reduced per-unit-area consumption of district energy for cooling, heating, and power generation;
- Reduced municipal infrastructure requirements, including the reduced need for construction of streets and electric, communication, water, and sewage lines, and other services; and
- Reduced VMT, including shorter freight and person trips, as well as the substitution of these trips with public transit, walking, and cycling.

The achievement of significant reductions, however, will require a major change in the way U.S. urban systems have been evolving over the past half-century. The well documented post-World War II flight to the suburbs by both households and businesses has created the phenomenon now known as urban sprawl.[118] Enabled and encouraged by the popularity of the private automobile, inexpensive gasoline, and an extensive high-speed highway network expansion program, a key characteristic of sprawl has been the emergence of large tracts of essentially single-use land developments. This includes land given over to detached single-family homes, as well as large areas devoted to commercial strip developments and multi-store shopping centers. The resulting separation of trip origins and destinations has translated to a significant increase in not only daily commuting distances, but also in the frequency as well as the length of many vehicle-based shopping and other personal service trips.[119] Between 1969 and 2001, the average annual VMT per household increased from 12,400 to 21,500 (while average household size fell from 3.2 to 2.6 persons, and the average number of vehicles per household grew from 1.2 to 1.9).[120]

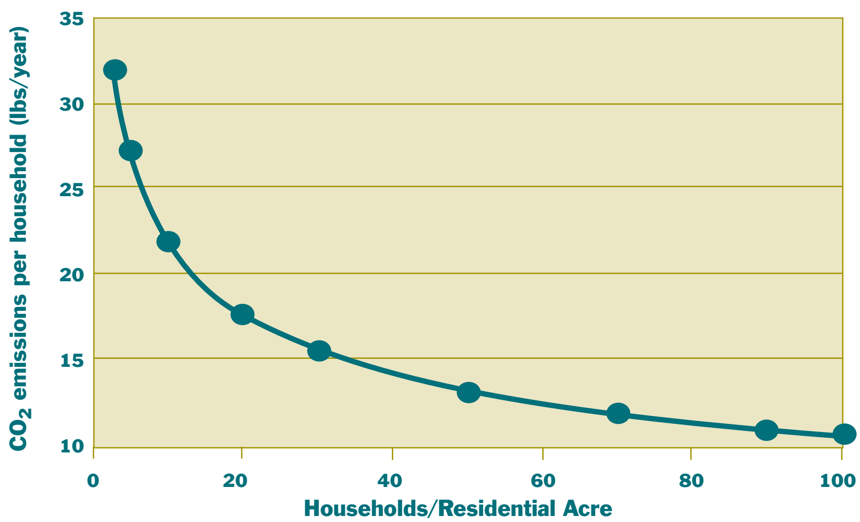
A. Estimates of GHG Reduction Potentials

Well-planned compact growth consumes 45 percent less land and costs 25 percent less for roads, 20 percent less for utilities, and 5 percent less for schools, than does sprawling growth.[121] One study found a direct relationship between the number of dwellings per acre and the level of GHGs released. At a fairly common suburban density of four homes per acre, CO_2 emissions per household were estimated to be 25 percent higher than in an urban neighborhood with 20 homes per acre.[122] Figure 12 shows the hypothesized impact of residential density on travel-related CO_2 emissions.[123]

Locational efficiency research by Holtzclaw and coauthors, based on detailed spatial data for the San Francisco Bay Area, Los Angeles, and Chicago, found energy efficiency to be highly correlated with per-acre residential density, with public transit service density within walking distance of the house, with household income, and with household size.[124] They concluded that differences in density and access to public transit are significant predictors of per household vehicle miles of travel. Burer and coauthors show that higher residential and employment densities, mixed land use, and job–housing balance are associated with shorter trips and lower automobile ownership and use.[125] The most recent set of U.S.-based locational efficiency studies project considerable potential for GHG reductions, with savings on the order of 10 percent of the 2001 level of GHGs produced in the United States suggested as possible within as few as 10 years.[126]

Figure 12

How Residential Density Affects Travel-Related CO_2 Emissions



Source: Computed using the San Francisco League of Conservation Voters calculator, http://www.sflcv.org/density/index.html.

In an analysis of the costs of sprawl in Canada, Walker and Rees used a metric called the "ecological footprint" that converts, for comparative purposes, all energy, materials, and other resources associated with different built environments into equivalent land area requirements. The authors found lot size to be a very important factor in the analysis because lot size determines house frontage, which in turn dictates the length requirements for infrastructure such as local streets and electricity, communications, and water and sewage lines.[127]

Walker and Rees's study also provides a breakdown of the resource requirements of these different dwelling types. It indicates that only 53 percent of the ecological footprint of a detached house is related directly to the type of housing, while 44 percent is related to its associated travel requirements, with an additional 3 percent associated with the need for municipal infrastructure. This finding corresponds quite well with a recent Finnish study on the effects of urban form on GHG emissions—a continuation of that country's urban sprawl is compared with a 30-year scenario based on locating new housing much closer to employment and regional activity centers.[128] The study suggests that 48 percent of the reduction in GHG emissions from this more compact spatial development would come from efficiencies brought about by district heating of residential and service buildings, another 48 percent would come from reduced passenger travel within each commuting region, and an additional 4 percent savings would be due to a reduced need for supporting municipal infrastructures.

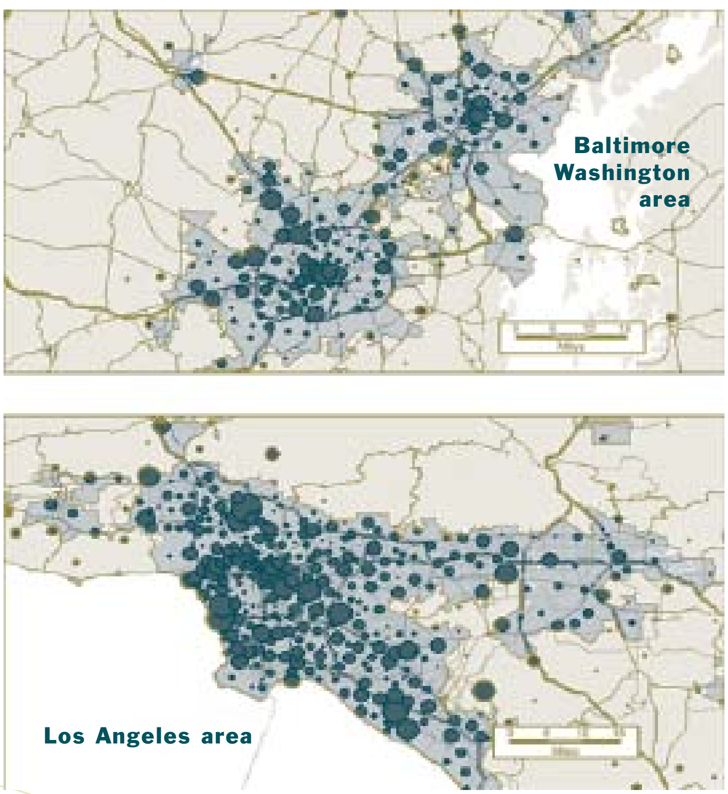
B. Possible Policy Instruments

Policy actions that have been proposed to curtail the worst effects of sprawl encompass a variety of "smart growth" initiatives.[129] These initiatives include land-use zoning ordinances to encourage higher density, mixed-use (residential, commercial, recreational, light industrial) land developments; promotion of urban designs based on gridded street plans and other compact and readily accessible local street systems; the provision of more pedestrian and cyclist-friendly pathways;[130] and the use of green areas such as small urban parks and tree-lined streets to act as carbon sinks and to help break up the well-documented "heat island" effect that often accompanies asphalt, concrete, and other heat absorbing surfaces.[131] Efforts to impact the future form of entire metropolitan areas include the application of urban growth boundaries, as well as the use of financial incentives to build housing subdivisions or employment centers at infill sites within the urban boundary.[132] Both of these approaches limit the common practice of "leap-frog" development that leads to the construction of residential subdivisions on the outskirts of the current urban area, resulting in more roads and other municipal services per household. Zoning restrictions and financial incentives also have been policy instruments promoted in an effort to reduce work trip lengths (reducing regional VMT), and therefore as a means of creating a better jobs-to-housing balance within specific suburbs.[133]

Many jobs are now found in higher-density suburban activity centers, which appear to have arisen as a natural response to increased travel times associated with traffic-congested suburb-to-central city trips.[134] Many of these centers have now become small "edge cities" in their own right.[135] Figure 13 shows two examples of the spread of employment concentrations throughout metropolitan areas such as Los Angeles and the Washington–Baltimore regions, leading to the gradual absorption of surrounding towns and the spaces between them, creating ribbon-like urbanized areas spanning 100 miles from end to end.

Figure 13

Metropolitan Area **Employment Distribution**



Source: U.S. Census Bureau Zip Code Area database, 1997

Over the past decade, many states, as well as individual planning districts and metropolitan areas, have begun to enact anti-sprawl legislation based on spatially defined growth management strategies. This legislation may take the form of urban growth boundaries that place geographic limits on urban area expansion; or the imposition of "concurrency requirements" that ensure adequate provision of municipal services such as power and water prior to new residential or other forms of building development.[136] A variety of financial incentives have also been tried, including the use of developer impact fees, local and regional business tax incentives, and subsidies to home buyers through Location Efficient Mortgages® (LEMs),[137] all geared towards more compact energy and travel-efficient land-use arrangements. A recent variant on this idea is the Smart Growth Tax Credit (SGTC), a legislative tool recently developed for state use by the Natural Resources Defense Council (NRDC).[138] The idea grew out of New York state's Green Building Tax Credit, signed into law in May 2002.

The SGTC legislation, introduced into the New Jersey legislative sessions in 2004, seeks to create an incentive program to encourage developers to invest in locationally efficient residential and mixed-use construction projects that minimize land and water consumption, are pedestrian friendly, and facilitate use of public transit. The program proposes a credit against income taxes equal to 4 percent of the developer's project costs (excluding the cost of the land), with additional credits up to 11 percent of the costs possible if a development includes a brownfield site, creates mixed land-use, encourages significant increases in residential density, limits the area developed for automobile parking, encourages public transit use, and includes green buildings that are LEED certified. This and related locational efficiency research has led to the LEED for Neighborhood Development (LEED-ND) concept of using the existing LEED Green Building Rating System® to create a new rating system that takes into account location, density, and proximity to transit, as well as green building practices—that is, combining green and smart growth practices based on comparable measures of energy savings.[139]

Other efforts to reduce region-wide VMT include the promotion of improved transit services and planning support for "transit-oriented developments" that encourage the construction of residential, commercial, and public agency buildings along public (notably light rail) transit lines.[140] Policies that address the rapidly growing urban freight sector also need to be developed, including policies that recognize the growing importance of a now large fleet of small "service commercial" vehicles,[141] as well as the larger semi-trailers that deliver to retail and industrial land uses spread throughout the modern metropolitan area. In all cases, better coordination of local, citywide, and statewide planning will be required to achieve significant VMT reductions and to avoid "not in my back yard" (NIMBY) responses.[142]

C. Potential Influence of Urban Form on Vehicular Travel

Planners now generally recognize that urban areas can no longer simply build their way out of costly urban traffic congestion by adding more highway lane miles. The cost of maintaining existing highway lane-miles has become a serious burden in most regions of the country.[143] This suggests that new forms of travel pricing and transportation infrastructure investment policies are likely to play an important role in shaping U.S. urban systems in the decades to come.[144] Complicating the pricing picture, however, are hybrids and other more fuel-efficient vehicles that will likely over the long term reduce the relative costs of driving—and thus reduce the financial incentive to alter high-mobility lifestyles. Telecommuting, teleshopping, and other forms of computer-aided travel substitution may also influence future building locations and within-unit space designs. While land use arrangements may account for as much as 50 percent of the variation in travel volumes across cities, past studies have concluded that land-use patterns are difficult to change and may therefore be able to reduce VMT by only 5 to 12 percent, with or without the assistance of supportive travel demand management measures.[145] It is much easier to adapt travel habits than it is to change urban form. There are numerous other and initially much less costly ways to influence travel. These include a growing number of travel pricing policies that can only now be implemented as a result of recent advances in telecommunications systems and their incorporation within traffic monitoring and control technologies.

With the above comments in mind, any politically feasible solutions based on land-use policies are unlikely to show much impact in the short term. While the payoff may indeed be considerable in terms of VMT reductions, GHG reductions, and energy savings, it will require a carefully crafted set of policy instruments and possibly as much as three decades before the effects begin to have major quantitative national impacts. A key policy driver may be traffic congestion. To avoid the considerable economic and environmental effects associated with urban gridlock, as well as reducing GHG and other pollutant emissions, solutions will need to go well beyond traditional traffic management.

VI. Policy Options

The mosaic of current policies affecting the building sector is complex and dynamic, ranging from local, state, and regional initiatives to a portfolio of federal policies and programs. Numerous policy innovations could be added to this mix, and many are being tried in test-beds at the state and local levels.[146]

Various taxonomies have been used to describe policy instruments. Typically these distinguish between regulations, financial incentives, information and education, management of government energy use, and subsidies for R&D.[147] Each of these is described below, first in general terms and then by focusing on specific examples that are accompanied by a documented track record of producing cost-effective GHG reductions. These policies offer the potential to deliver significant GHG reductions from the building sector, both in the short term and continuing well into the mid-century.

A. Regulation

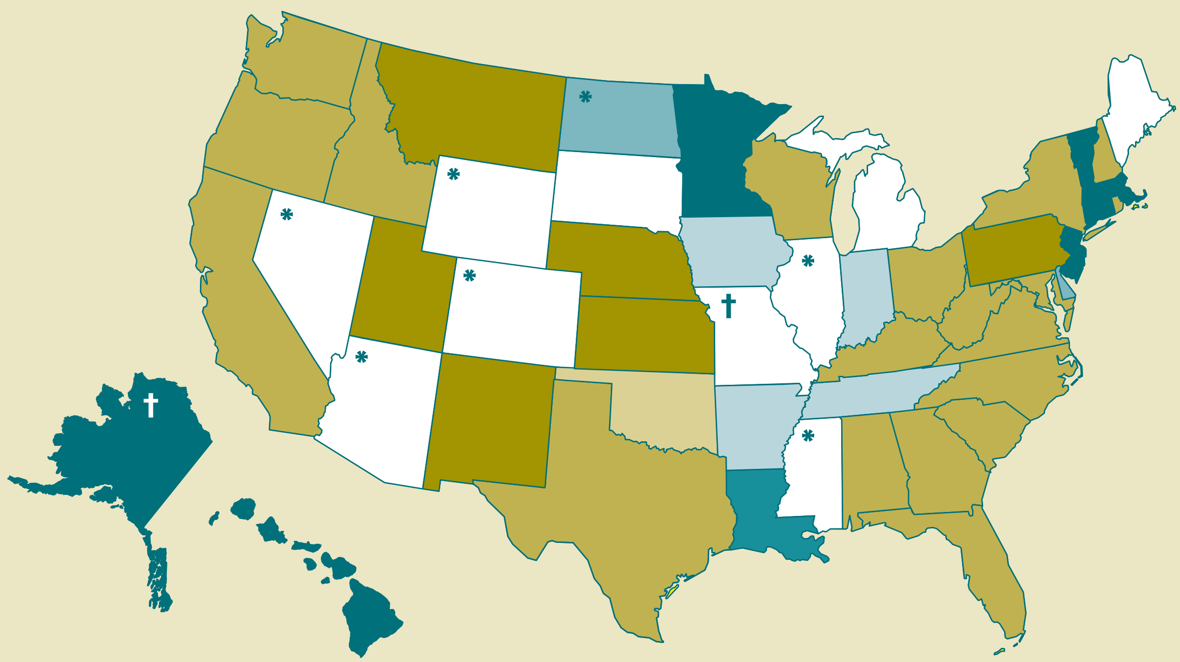
Regulatory policies include building energy codes, appliance energy efficiency standards, clean energy portfolio standards, electricity interconnection standards for distributed generation equipment, and land-use zoning to promote smart growth. Numerous regulatory innovations have been launched at the state and local levels, including features of California's Title 24 standards, output-based air quality permitting standards implemented by Texas, and the Texas energy efficiency portfolio standards that requires a percentage of the state's growth in electricity consumption be offset by energy-efficiency improvements.[148]

The past and potential future role of state building codes and appliance and building equipment efficiency standards are particularly relevant to the discussion of accelerating the market penetration of carbon-friendly building technologies and practices. Both of these policies address a number of market failures that exist in the building sector, including the problems introduced by decision-making intermediaries and the failure of energy prices to incorporate externalities. Evidence to date indicates that they have been quite successful at promoting cost-effective energy-efficiency investments, and they appear to offer considerable potential for generating future GHG reductions.

Building Codes. The greatest opportunity to make buildings more efficient is during the construction phase. Many efficiency options are lost if they are not built into the original design. By requiring new buildings to achieve at least a minimum level of energy efficiency, building codes reduce these lost opportunities. The inclusion of energy efficiency requirements in building codes began in the 1970s and has become widespread since then. Because buildings codes are implemented by states and localities, the codes vary considerably across the country. While substantial progress has been made over the past decade, opportunities to strengthen code requirements and compliance remain. As shown in Figure 14,

Figure 14

Residential Energy Code Status as of May 2004



Mandatory statewide code including state-owned buildings

- 2003 IECC or IRC
- 2003 IECC or IRC or equivalent state code
- 1998 IECC
- 1995 MEC or equivalent state code
- 1995 MEC or equivalent state code (partial adoption)
- 1993 MEC or equivalent state code
- 1992 MEC or equivalent state code
- No code or code not EPAct compliant

IECC: International Energy Conservation Code
IRC: International Residential Code
MEC: Model Energy Code

*** Code implementation depends upon voluntary adoption by local jurisdictions.**
† 90.1 Mandatory for state owned residential buildings three stories or less in height.
NOTE: This map should be used in conjunction with BCAP's Status of the State newsletter.
Go to bcap-energy.org to view current newsletter.

Source: The Business Council for Sustainable Energy. 2004. Energy at the State Level. Business Council for Sustainable Energy, Washington, DC.

only 26 states are using the latest residential codes or their equivalent, and only 25 states have adopted the latest and most energy-efficient commercial codes.[149] In addition, many states lack consistent enforcement and support programs, resulting in a shortfall in energy performance.[150]

The DOE's Building Energy Codes Program has worked for 25 years with the building industry, state and local governments, public interest groups, and others to improve the design and implementation of building codes. The program provides information and a comprehensive set of support tools to help builders, designers, and code officials to upgrade and comply with energy codes. In particular, DOE has produced widely disseminated software tools to simplify and improve code compliance, and supporting materials such as a consolidated workbook with prescriptive compliance tables. The National Association of Home Builders incorporated these tools into their builder manual in early 1996; as a result, these tools are now widely used by both builders and code officials. The DOE Building Energy Codes Program budget in recent years has been approximately $8 million, about half of which goes to state agencies.

An estimated 0.15 quads of energy were saved in 1998 and 3.55 MMTC were avoided as a result of energy code upgrades through 1998[151] (this represents about 1 percent of the 318 MMTC emitted from the building sector in 2002). This estimate of past impacts assumes that roughly half of the potential energy savings are actually achieved—actual energy performance is not as energy efficient as rated performance. Even with this conservative assumption, consumers nationwide saved around $1.1 billion in 1998 (1994$) as a result of the adoption and implementation of improved energy codes, equivalent to about 1 percent of expenditures for space heating and cooling in all buildings. These savings are limited in part by the slow turnover of the nation's building stock. Savings will grow over time, however, as more buildings are constructed and more jurisdictions adopt state-of-the-art codes.

Rosenquist and coauthors estimate the nationwide energy savings potential from upgrading residential and commercial building codes in 2010 and again in 2020.[152] Residential building codes are modeled in terms of improvements to shell measures such as insulation, glazing, and infiltration that reduce heating and cooling loads. Commercial building codes are modeled in terms of improved space heating, air conditioning, and commercial sector lighting.[153] The result is an estimated cumulative energy savings of 2.2 quads for residential building codes and 3.0 quads for commercial codes—totaling 5.2 quads over the 20-year period or an annual estimated potential savings of 0.26 quads.[154] While this estimate assumes complete code compliance combined with some ongoing technology improvements (optimistic), it does not take into account that an aggressive level of technological innovation and cost reduction could fuel a significantly greater tightening of building codes and associated energy savings (conservative).

Appliance and Equipment Efficiency Standards. Appliance and equipment standards require minimum efficiencies to be met by all regulated products sold; they thereby eliminate the least efficient products from the market. First introduced in California in the 1970s, the state's efficiency standards were followed a decade later by federal standards implemented through the National Appliance Energy Conservation Act (NAECA) in 1987. By the end of 2001, federal standards were in effect for more than a dozen residential appliances, as well as for a number of commercial sector products.

Many studies have found federal standards to be highly cost effective—the established appliance standards in effect in 2000 cut U.S. electricity use in that year by 2.5 percent, primary energy consumption by 1.3 percent (1.2 quads), and U.S. carbon emissions from fossil fuel use by 1.7 percent (25 MMTC).[155] The cumulative cost for establishing and implementing appliance standards between 1987 and 2000 was $200 to $250 million. The cumulative net benefit to consumers and businesses over this same period is estimated to be $17 billion (in 2001$).[156]

The federal standards covering clothes washers, water heaters, central air conditioners and heat pumps, and fluorescent lighting ballasts are set to be updated between 2004 and 2007. These four updated standards, along with the established appliance standards, are expected to reduce primary energy use by 3.3 quads in 2010 and by 4.2 quads in 2020. Carbon emission reductions are estimated to be 61 MMTC and 75 MMTC, respectively. (Were this rate to continue through 2025, 75 MMTC would represent a 9% reduction in the forecasted 848 MMTC of emissions from buildings in that year.) In addition, consumers and businesses are projected to save billions of dollars in reduced utility costs, as previous rounds of standards have accomplished.[157] Two recent studies suggest that upgrading residential and commercial codes and extending federal standard to a list of products not currently covered could save 1.07 to 1.4 quads in 2010 to 2030.[158] In combination with the 4.2 quads to be saved in 2020 from the four most recent standards, this results in a total estimated energy savings of 5.27 quads in 2020. Carbon emission reductions are estimated to be 88 MMTC.

While generally found to be cost effective, critics claim that appliance and equipment energy standards can have negative effects (e.g., leading to increased demand by reducing the effective cost of energy services and forcing consumers with high discount rates (disproportionately found among the poor) to purchase a minimum level of efficiency). Also, uniform national standards may not be ideal for a country with highly variable climate conditions, energy prices, and preferences. Based on a large body of literature to date, these concerns would appear to be small relative to the magnitude of the national benefits. Also, any impacts on low-income households can be addressed as part of a larger package that includes progressive elements such as weatherization assistance for the income-qualified.

B. Financial Incentives

Financial incentives can best induce energy-efficient behavior where relatively few barriers limit information and decision-making opportunities (e.g., in owner-occupied homes). Financial incentives include tax credits, rebates, low-interest loans, energy-efficient mortgages, and innovative financing, all of which address the barrier of first costs.

State agencies have a great deal of experience implementing financial incentives to promote investments in energy efficiency and renewable energy. Much of this experience comes from revolving loan mechanisms targeting energy efficiency in state facilities. Revolving loans allow borrowers to repay the debt through the stream of cost savings generated by the funded projects. Examples include the Iowa Energy Bank, the Maryland Revolving Loan Program, the Oregon Public Benefit Funds Program, and the Texas LoanSTAR Program.[159] State and local governments have also experimented with developer-based incentives (such as New Jersey's Smart Growth Tax Credit)[160] and impact fees, including locationally efficient mortgages and reduced business taxes to promote more compact, mixed-use, and pedestrian-friendly urban development; however, these practices have seen limited application to date. Two well-documented financial incentives—utility-based financial incentive programs and low-income weatherization assistance—are the exception.

Utility-based Financial Incentive Programs. Utility-based financial incentive programs have been in operation since the early 1980s, when it became clear that information and education alone produced only limited energy and demand savings. By reducing demand, energy efficiency is a low-cost contributor to system adequacy—the ability of the electric system to supply the aggregate energy demand at all times—because it reduces the base load as well as the peak power demand. This reduction in peak power requirements can also contribute to system security—the ability of the system to withstand sudden disturbances—by reducing the load and stress at various points in the power distribution system, thereby decreasing the likelihood of failures.

The incentive programs operated by electric and gas utility companies have offered rebates, low-interest loans, and direct installation programs that have led to the accelerated market penetration of many energy-efficient building products such as high-efficiency fluorescent lighting and air conditioning, as well as low-flow showerheads and attic insulation. However, these programs have been designed by individual utility companies, each with their own unique goals and resources, thereby further contributing to geographic variability in the supply of and demand for energy-efficient building products and services. More recently, a number of public benefits programs have taken on the functions that have been traditionally part of the incentive programs, and have produced strong returns on investment.[161] A recent review of the performance of utility-based financial incentive programs concluded that in 2002, the programs saved 0.626 quads of energy and averted 10.2 MMTC (representing almost 2 percent of the 599 MMTC emitted from the building sector in 2002).[162] Despite the strong evidence of the cost effectiveness of these programs, more work is needed to fully account for costs and benefits.[163]

Low-Income Weatherization Assistance. Residences occupied by low-income citizens tend to be among the least energy efficient in the housing stock. Partly as a result, low-income households spend, on average, 14 percent of their income for energy needs, compared with the 3.5 percent of income spent by other households. The DOE's Weatherization Assistance Program has served as the nation's core program for delivering energy conservation services to low-income Americans since it was created under the 1976 Energy Conservation and Production Act. More than five million homes have been weatherized since the inception of the program.

The program reduces average annual energy costs by an estimated $218 per household (at current prices). Energy savings for each home weatherized is estimated to average 29.1 MBtu/year. For the 104,683 homes weatherized in 2002, this amounts to energy savings of 3.05 TBtu.[164] Assuming a comparable number of homes have been weatherized by the DOE program annually over the past 20 years, the energy savings of the program in 2002 is estimated to be 0.061 quads. Based on an average of 0.25 metric tons of carbon avoided each year per weatherized home, the total carbon emission reduction in 2002 is estimated to be 0.52 MMTC (representing a fraction of a percent of carbon emissions from buildings in 2002).[165]

While millions of the low-income working poor need affordable housing, the number of low-income rental units is declining by almost half a million per year. In high-growth, major metropolitan areas, thousands of people commute 100 miles or more to work because of the lack of affordable housing in the communities where they work.[166] The Weatherization Assistance Program helps to maintain the viability of the existing low-income housing stock, thereby preventing some of the movement of low-income households to increasingly exurban locations distant from available employment, and avoiding travel-related GHG penalties. With nearly 28 million households federally eligible for weatherization assistance, this program could continue to deliver GHG benefits for decades.

C. Information and Education

Information policies and programs include a range of activities directed at improving the knowledge of the public and key decision-makers about carbon-reduction opportunities and providing technical assistance with their implementation. While many businesses and homeowners express interest in making energy-efficiency improvements for their own buildings and homes, they often do not know which products or services to ask for, who supplies them in their areas, or whether the real energy savings will live up to the claims.

Information and education policies include GHG registries[167] and GHG reduction targets or goals; energy labels, ratings of products and buildings, and mandatory disclosure of energy use information at time of the sale of a building; audit and other decision tools such as PLACE3S sustainable community design software;[168] educational and training activities (for students, faculty, and professionals); and technical assistance. Included among the current federal technical assistance activities are DOE's Industrial Assessment Centers Program (which helps small businesses and manufacturers improve their energy efficiency, reduce their waste streams, and enhance productivity), Rebuild America (which focuses on the development of strategic partnerships and alliances to improve the efficiency of government and commercial buildings), and Building America (which focuses on educating builders).

The economic rationale for these policies lies primarily in the public goods nature of knowledge and information provision. Being a public good, information will be under-produced in a competitive market. Policies can help make up for incomplete knowledge by reducing the consumer's cost of acquiring and using needed information. They can also simplify decision-making and help consumers focus on energy and CO_2 issues that may seem small to an individual consumer but are large from a societal perspective. The ENERGY STAR® program—run jointly by EPA and DOE—is arguably one of the most successful energy information programs in operation in the United States.

ENERGY STAR Program. The ENERGY STAR program was introduced by EPA in 1992 to fill the information gap that hinders market penetration of energy-efficient products and practices, and to enable businesses, organizations and consumers to realize the cost savings and environmental benefits of energy-efficiency investments. Its market-based approach involves four parts: (1) using the ENERGY STAR label to clearly identify which products, practices, new homes, and buildings are energy efficient; (2) empowering decision-makers by making them aware of the benefit of products, homes, and buildings that qualify for ENERGY STAR by providing energy performance assessment tools and project guidelines for efficiency improvements; (3) helping retail and service companies in the delivery chain to easily offer energy-efficient products and services; and (4) partnering with other energy-efficiency programs to leverage national resources and maximize impacts.

Since its introduction in 1992 for energy-efficient computers, the ENERGY STAR label has been expanded to more than 40 product categories. EPA collaborates with DOE, which now has responsibility for certain product categories. Efficient new homes became eligible for the label in 1995, and efficient buildings became eligible for the label in 1999 when EPA unveiled a new standardized approach for measuring the energy performance of an entire building.

The ENERGY STAR label has become the national symbol for energy efficiency, recognized by 56 percent of the American public, according to a recent survey conducted by the Consortium for Energy Efficiency. In addition, a majority of consumers report that the label has influenced their product choice.[169] Market penetration statistics suggest that considerable progress has been made.[170] The ENERGY STAR label for superior energy quality has been earned by more than 200,000 new U.S. homes. The label has been used by over 1,400 manufacturers, covering some 28,000 individual product models in over 40 different product categories, with in excess of one billion ENERGY STAR qualified products purchased by Americans to date. ENERGY STAR partners now represent about 18 percent of the market in new commercial buildings, and over 12 billion square feet of building space.

In 2002, EPA estimates that the ENERGY STAR program saved 104.6 billion kWh (equivalent to 1.08 quads) and 21.5 MMTC in its commercial and residential buildings (representing almost 4 percent of the 599 MMTC emitted by the building sector in 2002).[171] Total costs of administering the program are unknown. EPA suggests that there are no costs to consumers because the reduced energy expenditures due to the ENERGY STAR program exceed any costs incurred by participating in the program. Several studies confirm this cost-effectiveness.[172] If the budget for ENERGY STAR were to be increased, it is likely that there would be an increase in carbon reduction; however, the magnitude is difficult to predict. While the market penetration of ENERGY STAR products and ratings has been significant, the statistics provided above suggest that large opportunities remain.

D. Management of Government GHG Emissions and Energy Use

A variety of mechanisms are available to ensure that government agencies lead by example in the effort to build and manage more energy-efficient buildings and reduce GHG emissions. One of the most proactive steps an agency can take is to publicly declare and take steps to achieve a target for energy or GHG emission reductions. Maine was one of the first states to set into law a GHG-reduction target: to reduce CO_2 emissions to 1990 levels by 2010, followed by a further 10 percent reduction (from the 1990 levels) by 2020. The cities of Seattle, Salt Lake City, and Austin have set similar goals.[173] Other policies that manage government GHG emissions and energy use include procurement guidelines and technical and financial assistance.

Federal Energy Management Program. Chartered in 1973, the Department of Energy's Federal Energy Management Program (FEMP) "works to reduce the cost and environmental impact of the Federal government by advancing energy efficiency and water conservation, promoting the use of distributed and renewable energy, and improving utility management decisions at federal sites. As the largest single energy consumer in the United States, the Federal government has both a tremendous opportunity and a clear responsibility to lead by example with smart energy management."[174] Federal agencies have multiple energy management goals established by statute or executive order. The best known goal is to reduce energy intensity in standard federal buildings by 30 percent by 2005 and 35 percent by 2010 (relative to a 1985 statutory baseline).

FEMP manages a portfolio of technology deployment activities in support of all federal agencies. Activities include alternative financing, direct technical assistance, training and information, publication of an annual report to Congress, and procurement recommendations. In addition, Congress and the President have set stringent energy intensity and GHG reduction goals for federal facilities.

DOE reports that, based on information from 29 federal agencies, the energy intensity of the federal government's standard buildings dropped by 25.6 percent in 2002 compared with the FY 1985 baseline year.[175] Although not all energy savings can be directly attributable to FEMP's portfolio of activities (DOE assesses that 50 percent of savings are due to FEMP's leadership), over the past 20 years of activities, the annual investment in FEMP ($25 million in 2002) saved 0.074 quads of energy and 1.1 MMTC in FY 2003 (representing less than one percent of the 599 MMTC emitted by the building sector in 2002).[176]

E. Research and Development

In the long run, the opportunities for a low-GHG energy future depend critically on new and emerging technologies. The design of public policies to promote green buildings and sustainable communities needs to consider and anticipate the full range of these technological possibilities. Some technological improvements are incremental and have a high probability of commercial introduction over the next decade (such as low-cost compact fluorescents and greater building automation). Other technology advances will require considerable R&D before they can become commercially feasible (such as solid state lighting, electrochromic windows, smart roofs, fuel cells powered by renewable sources of hydrogen, and indoor environmental sensors operating off microwatt sources of power). A 2003 report by DOE's Basic Energy Sciences Advisory Committee describes a set of research directions that could deliver such fundamental technological breakthroughs.[177]

The fragmented and highly competitive structure of the building sector and the small size of most building companies discourages private R&D, on both individual components and the interactive performance of components in whole buildings. As a result, the building and construction industries spend only 1.7 percent of revenues on R&D, compared with 3.5 percent for the overall U.S. economy.[178] Some R&D on equipment is undertaken by appliance and HVAC companies and on materials by chemical companies, but their R&D generally does not extend to interactive performance with other components of the building. These characteristics also retard the market entry and penetration of new energy-efficient technologies. A further dampener and rationale for public investment is the restructuring of the electric industry, which has caused a downturn in electric utility R&D.[179] State public benefits programs, on the other hand, are spending considerable resources on applied energy R&D. Funding for fundamental energy R&D is dominated by DOE.

Federal Funding for Building Energy R&D. Coordinating R&D efforts among federal and state agencies, the private sector, academia, and the national laboratories is often cited as being vital to leveraging scarce resources, reducing duplication of effort, and comprehensively addressing energy challenges. Reports by the Office of Technology Assessment, the Building Energy Efficiency Program Review Group, and the Secretary of Energy Advisory Board conclude that federal R&D programs play a critical a role in financially supporting and coordinating building research among the various participants.[180]

What evidence do we have that climate change technology R&D can deliver products that consumers, industry, and businesses will choose to use? Consider the results of a study completed in 2001 by the National Academies.[181] This study concludes that energy efficiency research at DOE has produced economic net benefits. Specifically, the total net realized economic benefits associated with selected energy efficiency programs were estimated to be approximately $30 billion (in 1999$), substantially exceeding the roughly $7 billion (in 1999$) in total energy efficiency RD&D investments made by DOE from 1978 through 2000.

Several of the most successful energy efficiency research activities documented by the National Academies involved building technology innovations (see Box 4: The Refrigerator Story). According to the National Academies report, three building technology successes (advanced refrigerator/freezer compressors, electronic ballast for fluorescent lamps, and low-E glass) saved 4.7 quads of energy and 80 MMTC. On an annual basis (over a 22-year period), these impacts amount to 0.21 quads and 3.6 MMTC (representing less than one percent of the carbon emissions from the building sector in 2002). These three technology development efforts account for a small fraction of the $2 billion (averaging $91 million annually, in 1999$) invested by DOE between 1978 and 2000 on buildings R&D. A fuller accounting of impacts could increase these estimated benefits substantially. Although significantly increasing the DOE's level of spending would accelerate technological progress, it is not possible to determine if there would be an increasing or decreasing rate of return on the investment.[182]

Emerging energy-efficient technologies have been identified in past studies by the American Council for an Energy-Efficient Economy.[183] Five such technologies were recently evaluated in detail by Oak Ridge National Laboratory scientists:[184]

- **Solid state lighting** (inorganic and organic light-emitting diodes that replace incandescent and fluorescent lighting in a variety of end uses)
- **Advanced geothermal heat pumps** (selective water sorbents and other technologies that greatly reduce the capital cost and land requirements for geothermal heat pumps in residential and commercial buildings)
- **Integrated energy equipment** (multi-function—cooling, heating, power, hot water, dehumidification—technologies that integrate multiple energy services into single pieces of equipment to lower cost and increase efficiency)
- **Efficient operations technologies** (information and control technologies to improve the functioning of energy-using equipment within buildings)
- **Smart roofs** (nano- and micro-technologies that change the reflectance and infrared emissivity of roof materials as a function of temperature to retain heat in winter and reflect heat in summer)

The results indicate that these five buildings technologies have the potential to save roughly 4.2 quads of energy and 71 MMTC in 2025, or 8 percent of the forecasted energy consumption and carbon emissions for the building sector in that year. Although the five technologies would overlap somewhat (resulting in lower projected savings), the calculations only consider subsets of the possible markets.

Taken together, these findings demonstrate that the United States is not running out of technologies to improve energy efficiency and will not exhaust its efficiency-improving options in the foreseeable future. Additional GHG reduction breakthroughs are likely in other related areas and especially in renewables such as photovoltaic systems, hydrogen fuel cells, and solar heating and lighting.

F. The Potential for Reduced Emissions

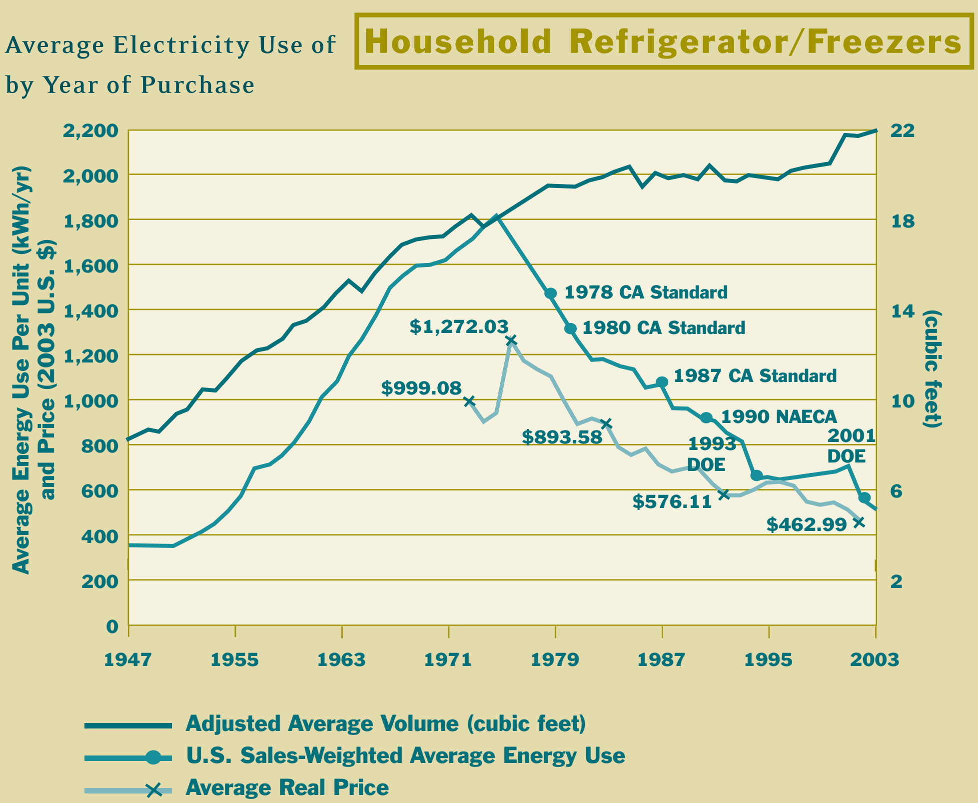
Box 4

The Refrigerator Story

Between 1977 and 1982, DOE invested approximately $1.6 million in R&D to make home refrigerators more energy efficient. Working in a public/private partnership with compressor and appliance manufacturers, DOE and two federal laboratories identified ways of improving the performance of refrigerator compressors, motors, insulation, and controls, and they provided test data for use in setting national standards. These technology investments, in conjunction with the issuance of appliance standards, cut the energy use of the average new refrigerator in half by the year 1990 and saved U.S. consumers $7 billion in energy costs from 1981 to 1990 (1999$).

In 1997, a DOE–industry cooperative R&D effort developed a prototype "fridge of the future" that further reduced energy consumption by nearly 50 percent compared with refrigerators then on the market and surpassed the 2001 U.S. efficiency standard for refrigerators (Figure 15). These developments, in combination with the 2001 standard, is expected to save consumers billions of dollars over the years of operation of these improved appliances.

Figure 15



Source: Geller, H.S. and D.B. Goldstein. 1999. "Equipment Efficiency Standards: Mitigating Global Climate Change at a Profit." Physics and Society 28, No. 2:4. and The National Commission on Energy Policy. 2004. *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, December, http:www.energycommission.org, and National Research Council, 2001. op cit.

Summing the estimates of energy and carbon emission reductions for the R&D and six deployment policies discussed above provides a reasonable estimate of the past impacts of these policies (Table 3). It also characterizes the benefits that could be achieved by extending and expanding these policies into the future.

In summing the estimates in Table 3, consider on the one hand that to some extent, the R&D and six deployment policies overlap, causing total savings to be lower. On the other hand, additional funding could substantially improve the cost-effectiveness of some of these programs, causing total savings to be greater. For example, the Weatherization Assistance Program currently can only retrofit the homes of a small fraction of eligible households each year. Also, the retrospective impact of past investments in buildings energy R&D is underestimated and does not include savings from renewable energy technologies.

With these caveats in mind, annual savings over the past several years from these R&D and six deployment policies are estimated to be approximately 3.4 quads and 65 MMTC, representing 10 percent of U.S. CO_2 emissions from buildings in 2002. The largest contributors are appliance standards and the ENERGY STAR Program. Potential annual impacts in the 2020 to 2025 time frame are 12 quads saved and 200 MMTC avoided. This represents 23 percent of the forecasted carbon emissions of buildings in the United States in 2025, or 9 percent of total projected carbon emissions. The largest contributors are federal funding for buildings energy R&D (especially solid-state lighting) and appliance standards.

This prospective energy savings estimate is larger than the results derived from an advanced policy case modeled over a 25-year period in the *Scenarios for a Clean Energy Future* (which were 8 quads for the building sector).[185] However, the prospective carbon reductions are smaller than in the scenarios study (238 MMTC). The scenarios study did not model as large a potential impact for research-driven technology breakthroughs in the building sector, which accounts for its smaller energy savings estimates, but it did model a significant decarbonization of the power sector associated with the advanced policies, which accounts for its larger carbon reduction estimates.[186]

Table 3

U.S. Energy Savings and Carbon Emission Reductions from Selected Policies: Retrospective and Prospective

	Annual energy savings, in quads (period)	Annual carbon emission savings, in MMTC	Annual government implementation costs, in millions (dollar year)	Prospective annual energy savings, in quads[a] (period)	Prospective annual carbon emission savings, in MMTC
Regulation					
Building codes	0.15 (1998)	3.5	$8 (1998$)	0.26 (2015)	6.0
Appliance and equipment efficiency standards	1.2 (2000)	25	$14–$18 (2002$)	5.27 (2020)	88
Financial incentives					
Utility-based financial incentive programs	0.63 (2000)	10.2	NA	0.63 (2020)	10.2
Low-income weatherization assistance	0.06 (2002)	0.5	$141 (2002$)	0.06 (2020)	0.5
Information and education					
ENERGY STAR Program	1.08 (2002)	21.5	NA	1.08 (2020)	21.5
Management of government GHG emissions and energy use					
Federal Energy Management Program	0.07 (2003)	1.1	$25 (2002$)	0.07 (2020)	1.1
Research and Development					
Federal funding for buildings energy R&D	0.21 (1978–2000)	3.6	$91 (1999$)	4.2 (2025)	71
Totals	3.4 (variable)	65		11.6 (variable)	198

Note: Sources for all numbers are cited in the text, and the assumptions used for the estimates are summarized, including the time frames of policy enactment.

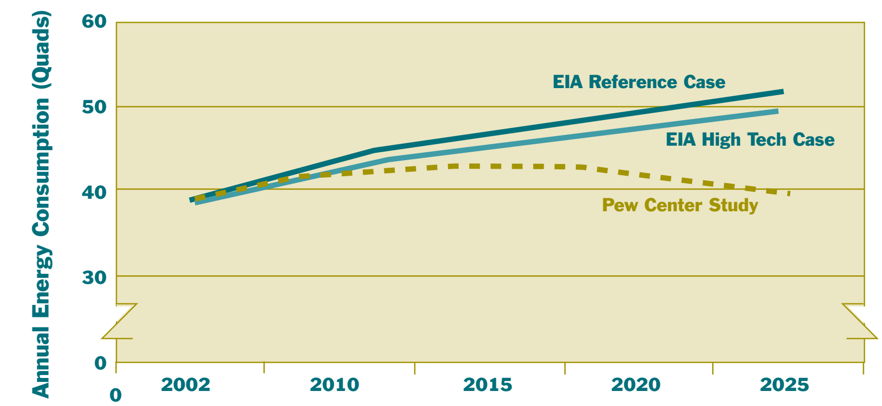
NA = Not available.

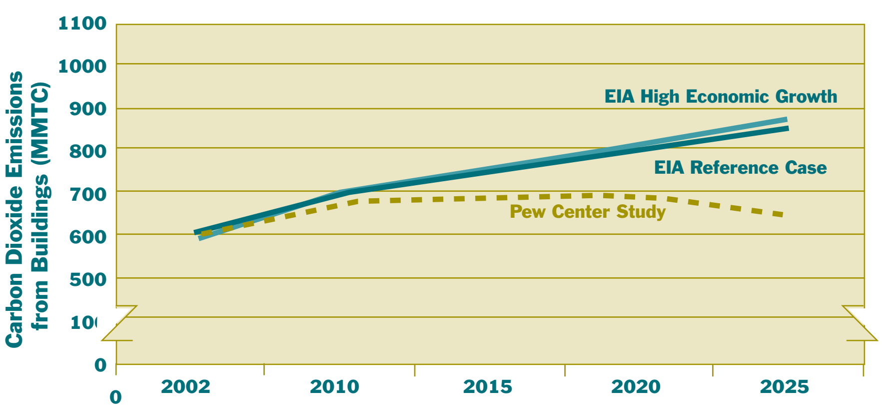
[a] Prospective energy savings and carbon reductions are estimated for future policies that represent extensions and/or expansions of these R&D and six deployment policies. Where otherwise not known, carbon emission reductions are estimated by assuming the same carbon content of the energy saved as was estimated retrospectively for these policies. In one case (building codes), the year used for the estimates is the midpoint of a longer period—e.g., 2015 is the midpoint of a 20-year range.

Figure 16 compares the R&D and six deployment policies examined here (referred to in the figure as the Pew Center Study) with the EIA's "Reference Case Forecast" and its "High Technology Alternative Scenario" for the building sector. The EIA high technology case assumes that modeled technologies are introduced into the marketplace more rapidly than they are in the reference case, as a result of increased R&D. Market transformation policies are not enhanced in the high technology scenario. Thus, it results in only a modest reduction in energy consumption in 2025, relative to the forecasted growth. The R&D and

Figure 16

Scenarios of U.S. **Energy Use and Carbon Emissions** in the Buildings Sector: 2002 to 2025



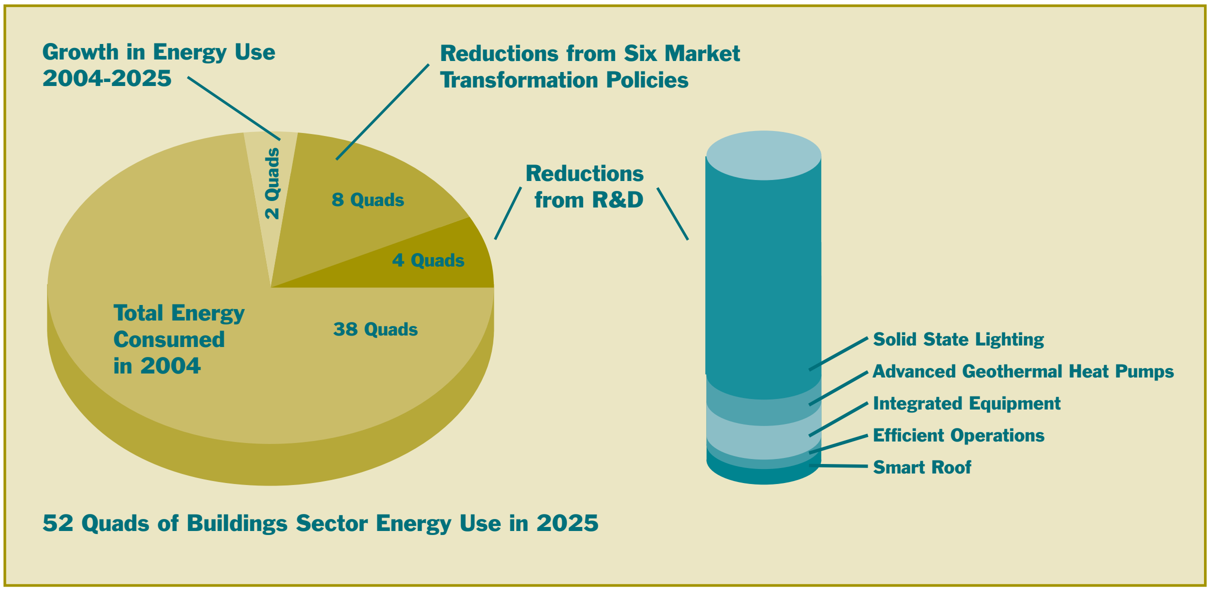


six deployment policies examined here, in contrast, would bring energy consumption and carbon emissions from buildings in 2025 almost back to 2004 levels (Figure 17).

At the same time the built environment in 2025 will be meeting the needs of an economy that will have grown by 96 percent.[187] After 2025 the nation could begin to get the much deeper reductions that many believe are needed to mitigate climate change.

Figure 17

Building Sector Energy Use in 2025 Based on a Scenario of Six Market Transformation Policies and Expanded R&D.



VII. Conclusions

The energy services required by residential, commercial and industrial buildings produce approximately 43% of U.S. CO_2 emissions. Additional GHG emissions result from the manufacture of building materials and products, the transport of construction and demolition materials, and the increased passenger and freight transportation associated with urban sprawl. As a result, an effective U.S. climate change strategy must consider options for reducing the GHG emissions associated with how buildings are constructed, used, and located.

Homes, offices, and factories rarely incorporate the full complement of cost-effective climate-friendly technologies and smart growth principles, despite the sizeable costs that inefficient and environmentally insensitive designs impose on consumers and the nation. To significantly reduce GHG emissions from the building sector, an integrated approach is needed—one that coordinates across technical and policy solutions, integrating engineering approaches with architectural design, considering design decisions within the realities of building operation, integrating green building with smart-growth concepts, and taking into account the timing of policy impacts and technology advances.

A. Technology Opportunities in the 2005 to 2025 Time Frame

In the short run, numerous green products and technologies could significantly reduce GHG emissions from buildings, assuming vigorous encouragement from market-transforming policies such as expanded versions of the six deployment policies studied here. In the coming decade, given the durable nature of buildings, the potential for GHG reductions resides mostly with the existing building stock and existing technologies. Some of the numerous promising off-the-shelf technologies and practices outlined in this report include reflective roof products, low-E coating for windows, the salvage and reuse of materials from demolished buildings, natural ventilation and air conditioning systems that separately manage latent and sensible heat, smart HVAC control systems, and variable speed air handlers.

Federally funded R&D for energy savings in buildings must also be expanded in the short term so that an attractive portfolio of new and improved technological solutions will be available in the mid and long term. Achieving the goal of a cost-competitive net-zero-energy home by 2020, for example, will require scientific breakthroughs to be incorporated into new and improved photovoltaic systems, power electronics, thermochemical devices, phase-change insulation and roofing materials, and other components. In addition, policies that promote higher-density, spatially compact, and mixed-use building developments must begin to counteract the fuel-inefficient impact of urban sprawl.

In the 2025 timeframe, newly constructed net-zero-energy homes and climate-friendly designs for large commercial buildings and industrial facilities will need to begin to displace the GHG-intensive structures that embody today's standard practices. The emerging technologies described in this report could help significantly reduce GHG emissions from the building sector including

- sealing methods that address unseen air leaks,
- electrochromic windows offering the dynamic control of infrared energy,
- unconventional water heaters (solar, heat pump, gas condensing, and tankless),
- inexpensive highly efficient nanocomposite materials for solar energy conversion,
- thermoelectric materials that can transform heat directly into electrical energy,
- solid state lighting that uses the emission of semi-conductor diodes to directly produce light at a fraction of the energy of current fluorescent lighting,
- selective water sorbent technologies that offer the performance of ground-coupled heat pumps at the cost of traditional systems,
- abundant sensors dispersed through buildings with continuously optimizing control devices, and
- 80–90 percent efficient integrated energy systems that provide on-site power as well as heating, cooling, and dehumidification.

Market transformation policies are expected to continue to improve the existing building stock and play an essential role in ensuring the market uptake of new technologies. In addition, land-use policies could begin to have measurable benefits.

The analysis reported here suggests that six expanded market transformation policies—in combination with invigorated R&D—could bring energy consumption and carbon emissions in the building sector in 2025 back almost to 2004 levels. At the same time, the built environment will be meeting the needs of an economy (and associated homes, offices, hospitals, restaurants, and factories) that will have grown from $9.4 trillion in 2002 to $18.5 trillion in 2025.

B. Building Green and Smart in the 2050 Time Frame

Green building practices and smart growth policies could transform the built environment by mid-century. Some of the climate-friendly features of this transformed landscape that are outlined in this report include:

- building efficiency measures that dramatically reduce the energy requirements of buildings;
- high-performance photovoltaic panels, fuel cells, microturbines and other on-site equipment that produce more electricity and thermal energy than is required locally, making buildings net exporters of energy, thereby transforming the entire demand and supply chain in terms of energy generation, distribution, and end use;
- higher-density communities that enable high-efficiency district heating and cooling;
- gridded street plans and other compact and readily accessible local street systems that also enable mass transit, and pedestrian and cyclist-friendly pathways to displace other forms of travel;
- parks and tree-lined streets to act as carbon sinks and to mitigate the "heat island" effect; and
- in-fill and mixed-use land development to shorten trip distances while reducing infrastructure requirements.

In the long run, improving the locational efficiency of communities and urban systems could possibly have as large an impact on GHG emissions as improving the design, construction, and operation of individual structures.

C. Linking Near-Term Action with Long-Term Potential

Given the durable nature of buildings, the potential for GHG reductions resides mostly with the existing building stock for some time to come. However, by 2025, newly constructed net-zero-energy homes and climate-friendly designs for large commercial buildings and industrial facilities could begin to generate sizeable GHG reductions by displacing the energy-intensive structures that embody today's standard practices. By mid-century, land-use policies could also significantly reduce GHG emissions. This inter-temporal phasing of impacts does not mean that retrofit versus new construction versus land-use policies should be staged; to achieve significant GHG reductions by 2050, all three elements of an integrated policy approach must be strengthened in the near term.

Similarly, applied R&D will lead to GHG reductions in the short run, while basic research will take longer to produce new, ultra-low GHG technologies. This does not mean that fundamental research should be delayed while applied R&D opportunities are exploited. The pipeline of technology options must be continuously replenished by an ongoing program of both applied and basic research. Vigorous market transformation and deployment programs will be needed throughout the coming decades to shrink the existing technology gap and to ensure that the next generation of low-GHG innovations is rapidly adopted.

By linking near-term action with long-term potential in an expansive and integrated framework, the building sector can be propelled to a leadership role in reducing GHG emissions in the United States and globally.

Endnotes

1. “Residential” buildings refer to single-family detached and attached dwellings, buildings with 2–4 units, and larger apartment buildings and condominium complexes, as well as mobile homes.

2. In residential buildings, improvements in energy efficiency are generally quantified in terms of energy consumption per household. Between 1978 and 1980 (when data were first available from the Energy Information Administration [EIA] Residential Energy Consumption Survey), annual energy consumption per household ranged from 114 to 138 million Btu. From 1990 to 1993, this figure dropped to between 98 and 104 million Btu, and in 1997, it stood at 101 million Btu (EIA. 2003. *Annual Energy Review 2002.* p. 53 table 2.5, EIA, Washington, DC. In 2001, the most recent year of available data, annual energy consumption per household was 92 million Btu (EIA. 2004. *2001 Residential Energy Consumption Survey: Household Energy Consumption and Expenditures Tables.* http://www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html, February 4, 2005, table CE1-1c. EIA, Washington, DC.) In commercial buildings, energy-efficiency improvements are documented by examining energy consumption per square foot of commercial building space. Between 1979 and 1983 (when data were first available from EIA’s Commercial Buildings Energy Consumption Survey), annual energy consumption per square foot ranged from 98 to 115 million Btu; between 1989 and 1992, 81 to 92 million Btu; and in 1999, (the most recent year of available data) 85.1 million Btu (EIA. 2003. op cit, p. 65, table 2.11).

3. Heavens, Alan J. 2004. “Social changes affect housing market.” Detroit Free Press Inc., Detroit, MI. July 2, 2004. www.freep.com, July 29, 2004.

4. “Plug loads” refer to electric devices that that are plugged into wall sockets.

5. R-value is a measure of resistance to heat flow with units of hr °F/Btu/in.

6. Low-E coatings for windows reduce the flow of infrared energy from the building to the environment, effectively increasing the window’s R-value. Some of the low-E coatings are also designed to reflect infrared energy from the sun, thus reducing air-conditioning loads.

7. CFCs also contribute to global warming. Thus, with the Montreal Protocol ban on CFCs, future emissions of an important GHG were also curtailed (U.S. Climate Change Technology Program. 2003. *Technology Options for the Near and Long Term,* pp. 23–24. http://www.climatetechnology.gov, February 4, 2005. National Association of Home Builders (NAHB). 2000. *Housing Facts, Figures and Trends*, p. 45. NAHB, Washington, DC).

8. U.S. Census Bureau. 2004. *Statistical Abstract of the United States: 2003.* op cit, p. 9, table 3.

9. Nelson, A.C. 2004. The context for transportation sustainability. Presentation delivered on July 13 at the Transportation Research Board Sustainability Workshop, http://www.trb.org/Conferences/Sustainability/Nelson.pdf, February 4, 2005.

10. In 2001, buildings in the United States consumed 0.34 quad of wood for space heating, 0.01 quad of geothermal energy in heat pumps, 0.05 quad of solar water heating, and less than 0.001 quad of solar photovoltaics (Office of Energy Efficiency and Renewable Energy. 2003. *2002 Buildings Energy Databook,* p. 1-11, table 1.1.4. U.S. Department of Energy, Washington, DC.)

11. According to the U.S. Green Building Council, green products and technologies are those that offer environmental benefits (e.g., improve air and water quality), economic benefits (e.g., reduce operating costs), and health and community benefits (e.g., enhance occupant comfort and health) http://www.usgbc.org/AboutUs/whybuildgreen.asp. In this report, we use the terms “low-GHG” and “climate-friendly” synonymously to refer to those technologies and products that result in lower greenhouse gas emissions than would the standard practice. Thus, while low-GHG and climate-friendly technologies are not always green technologies and vice versa, they significantly overlap.

12. For more information on non-CO_2 greenhouse gases, see Reilly, J.M., H.D. Jacoby, and R.G. Prinn. 2003. *Multi-gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of Non-CO_2 Gases.* Pew Center on Global Climate Change, Arlington, VA.

13. Global warming potential (GWP) is an index used to compare the relative radiative forcing of different gases. GWPs are calculated as the ratio of the radiative forcing that would result from the emission of one kilogram of a greenhouse gas to that from the emission of one kilogram of CO_2 over a fixed period of time, such as 100 years (EIA. 2003. *Emissions of Greenhouse Gases in the United States 2002,* DOE/EIA-0573 (2002), EIA, Washington, DC, p. 101).

14. EIA. 2003. op cit, p. x.

15. EIA, 2003, op cit, p. 63.

16. EPA. 2004. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002,* EPA/430-R-04-003. Washington, DC, p. 3-7, table 3-6.

17. The estimates for contributions to methane from landfills and stationary combustion and for contributions from nitrogen oxides come primarily from EIA (EIA, 2003, op cit, pp. 36–37): U.S. methane emissions from landfills: wastes include wood (27 percent of total), drywall, cardboard, metals, vinyl, masonry, and landscaping materials. According to DOE's *2002 Buildings Energy Databook* (Office of Energy Efficiency and Renewable Energy, 2002, op cit), construction and demolition debris accounts for roughly 24 percent of the U.S. municipal solid waste stream. The methane emissions from landfills attributable to buildings are therefore estimated to be 24 percent of the total U.S. methane emissions from landfills. The estimate for stationary combustion comes from EIA, 2003, op cit, pp. 33–35 and p. 45, table 17. For stationary combustion, see EIA, 2003, op cit, pp. 33–35 and p. 45, table 17. For contributions from nitrous oxides, see EIA, 2003, op cit, p. 59, table 25.

18. EIA, 2003, op cit, p. 63–71, table 25; and Office of Energy Efficiency and Renewable Energy, 2002, op cit, p. 3-5, table 3.2.1.

19. CO_2 emissions associated with electricity generation are allocated to the residential and commercial sectors according to each sector's share of national electricity consumption. This method of distributing emissions assumes that each sector consumes electricity generated from an equally carbon-intensive mix of fuels and other energy sources.

20. Pacific Northwest National Laboratory. 1997. *An Analysis of Buildings-Related Energy Use in Manufacturing,* PNNL-11499, p. 4.2, table 4.1 and p. 4.4, table 4.3. Pacific Northwest National Laboratory, Richland, WA.

21. Office of Energy Efficiency and Renewable Energy, 2002, op cit, p. 1-4, 1-7, and 4-1, tables 1.2.1, 1.3.1, and 4.1.2.

22. Office of Energy Efficiency and Renewable Energy, 2002, op cit, p. 4-9, table 4.5.1.

23. Lippe, Pamela (editor). 1997. *Lessons Learned Four Times Square: An Environmental Information and Resource Guide for the Commercial and Real Estate Industry,* Earth Day, New York, NY. http://www.earthdayny.org/lessons_learned/4timesSquare.html, February 4, 2005.

24. U.S. Green Building Council, Washington DC, For the most current versions for commercial buildings, existing building operations, commercial interiors projects, core and shell projects, homes, and neighborhood development, see U.S. Green Buildings Council. 2003. *Leadership in Energy and Environmental Design,* http://www.usgbc.org/LEED/LEED_main.asp, February 4, 2005.

25. See: Green Building Alliance. 2004. *LEED-NC: The First Five Years, Report on the Greater Pittsburgh Region's Experiences using Leadership in Energy & Environmental Design for New Construction,* Green Buildings Council, Pittsburgh, PA (www.gbapgh.org/MiscFiles/LEEDSurveyReport_Final.pdf. February 13, 2005). Also see: Rachel Reiss and Jay Stein. 2004. *LEED Scores Early Successes but Faces Big Challenges,* ER-04-3, Platts Research & Consulting, New York, NY.

26. NAHB. 2004. *Model Green Home Building Guidelines, Version 1,* NAHB, Washington DC. (www.nahb.org/gbg, February 11, 2005).

27. University of Minnesota, College of Architecture and Landscape Architecture. 2002. *Minnesota Sustainable Design Guide,* University of Minnesota, Minneapolis-St. Paul, MN (www.sustainabledesignguide.umn.edu, February 11, 2005).

28. University of Minnesota, College of Architecture and Landscape Architecture, 2004, *Minnesota Building Materials Database,* University of Minnesota, Minneapolis-St. Paul, MN (www.buildingmaterials.umn.edu, February 11, 2005).

29. Green Building Initiative™. 2004. *Green Globes,* The Green Building Initiative, Portland OR (www.thegbi.com/commercial/greenglobes/newdefault.asp, February 11, 2005).

30. To access EPA's energy performance rating system called "Target Finder" go to: www.energystar.gov/index.cfm?c=target_finder.bus_target_finder, February 13, 2005.

31. U.S. Climate Change Technology Program. 2003. *Technology Options for the Near and Long Term,* U.S. Department of Energy, Washington, DC, pp. 24, 27, 30. November.

32. Newell, R., A. Jaffe, and R. Stavins. 1999. "The induced innovation hypothesis and energy saving technological change," *The Quarterly Journal of Economics,* 114(3): 941-975.

33. See, e.g., Goulder, L.H. 2004. *Induced Technological Change and Climate Policy,* Pew Center on Global Climate Change, Arlington, VA.

34. U.S. Climate Change Technology Program, 2003, op cit, p. 21.

35. Brown, M.A., Mark D. Levine, Walter Short, and Jonathan G. Koomey. 2001. "Scenarios for a clean energy future." Energy Policy 29(14): 1179–1196; Office of Technology Assessment (OTA). 1991. *Changing by Degrees: Steps to Reduce Greenhouse Gases.* OTA-0-482. U.S. Government Printing Office, Washington, DC, February; National Academy of Sciences. 1992. *Policy Implications of Greenhouse Warming: Mitigation, Adaptation, and the Science Base.* National Academy Press, Washington, DC; Tellus Institute. 1998. *Policies and Measures to Reduce CO_2 Emissions in the United States: An Analysis of Options for 2005 and 2010.* Tellus Institute, Boston, MA, August.

36. Interlaboratory Working Group. 2000. *Scenarios for a Clean Energy Future.* ORNL/CON-476 and LBNL-44029. Oak Ridge National Laboratory, Oak Ridge, TN, and Lawrence Berkeley National Laboratory, Berkeley, CA, November, http://www.ornl.gov/sci/eere/cef/index.htm, February 4, 2005. The *Scenarios for a Clean Energy Future* was a study conducted by five DOE National Laboratories that involved enumerating on a technology-by-technology basis the difference between current practice and best practice, where best practice is defined as the utilization of the energy technologies with the lowest life-cycle costs. Keeping in mind the natural rate of turnover of new equipment and consumer purchases, one can then estimate the size of the lost opportunities or gap that exists. Brown et al. (2001, op cit) used this technology-based accounting approach and concluded that removing obstacles to energy efficiency through policy interventions initiated in the year 2000 could have reduced the forecasted U.S. energy consumption in 2010 by 10 percent. By 2020, the reduction could grow to nearly 20 percent.

37. DOE National Laboratory Directors. 1998. *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions.* Oak Ridge National Laboratory, Oak Ridge, TN. September, http://www.ornl.gov/~webworks/cppr/y2003/rpt/110512.pdf, February 4, 2005.

38. The "energy-efficiency gap" is the difference between the actual level of investment in energy efficiency and the higher level that would be cost-beneficial from the consumer's and society's point of view. Jaffe, A.B., and R.N. Stavins. 1994. "The energy-efficiency gap," *Energy Policy* 22(10): 804–810.

39. Sutherland, R.J. 1996. "The economics of energy conservation policy," *Energy Policy* 24(4): 361–370.

40. Braithwait, S., and D. Caves. 1994. "Three biases in cost-efficiency tests of utility energy efficiency programs." *The Energy Journal* 15(1): 95–120.

41. For a detailed examination of the U.S. housing industry and the homebuilding process, see Scott Hassell, Anny Wong, Ari Houser, Debra Knopman, and Mark Bernstein. 2003. *Building Better Homes.* Rand Corporation, Pittsburgh, PA.

42. EIA. 1999. Commercial Buildings Energy Consumption Survey, table B12, p. 46-48. EIA, Washington, DC.

43. EIA, 1999. Residential Energy Consumption Survey, table HC1-2a, p. 35. EIA, Washington, DC.

44. Office of Energy Efficiency and Renewable Energy. 2003. *Buildings Energy Databook.* U.S. Department of Energy, Washington, DC, 5-1, table. 5.1.1, EIA, Washington, DC.

45. *Professional Builder, Annual Issue.* April 1, 2004.

46. OTA. 1992. *Building Energy Efficiency*. OTA-E-518. U.S. Government Printing Office, Washington, DC, pp. 76–78, May.

47. EIA. 1995. *Commercial Buildings Energy Consumption and Expenditures.* 1992. DOE/EIA-0318(92). U.S. Department of Energy, Washington, DC, Table 3.1, April.

48. Reed, J.H., K. Johnson, J. Riggert, and A. D. Oh. 2004. *Who Plays and Who Decides.* DE-AF26-02NT20528. Innovologie, LLC, Rockville, MD. March.

49. Farhar, Barbara C., Nancy E. Collins, and Roberta W. Walsh. 1996. *Linking Home Energy Rating Systems with Energy Efficiency Financing: Progress on National and State Programs.* NREL/TP-460-21322. National Renewable Energy Laboratory, Golden, CO, October.

50. Coleman, Tony. 2004. *The Importance of Climate Change on Insurance Against Catastrophes.* Insurance Australia Group, Melbourn, VIC. http://www.iag.com.au/pub/iag/media/shc/presentation-20021219.pdf, February 4, 2005.

51. An energy service company (ESCO) is a business that develops, installs, and finances projects designed to improve the energy efficiency and maintenance costs of facilities. ESCOs generally act as project developers for a wide range of tasks and assume the technical and performance risk associated with the project (Source: http://www.naesco.org/meminfo.htm, February 4, 2005).

52. Ibid.

53. Hassell, S., et al. 2003. op.cit, p. 47.

54. Brown, M.A. 2004. "Obstacles to Energy Efficiency," *Encyclopedia of Energy,* Elsevier, London, U.K., Volume 4, pp. 465-475.

55. Jones, D.W., D.J. Bjornstad, and L.A. Greer. 2002. *Energy Efficiency, Building Productivity, and the Commercial Buildings Market.* ORNL/TM-2002/107. Oak Ridge National Laboratory, Oak Ridge, TN, May. In addition, a study in which more than 50 design professionals and analysts were interviewed shows that the prevailing fee structures provide incentives to control the capital cost of the project (Lovins, A. 1992. Energy-Efficient Buildings: Institutional Barriers and Opportunities. Strategic Issues Paper. E-Source, Inc., Boulder, CO, December).

56. Hirst, E., and B. Kirby. 2000. *Retail-Load Participation in Competitive Wholesale Electricity Markets.* Prepared for Edison Electric Institute, Washington, DC.

57. Alderfer, R.B., M.M. Eldridge, and T.J. Starrs. 2000. *Making Connections: Case Studies of Interconnection Barriers and their Impact on Distributed Power Projects.* NREL/SR-200-28053. National Renewable Energy Laboratory, Golden, CO, May.

58. Many states do not have net metering programs. Other states require net metering only for investor-owned utilities. In a few states, the Public Utilities Commission has mandated net metering programs for all utilities. There are also state-by-state variations in the types of on-site power that are eligible for net metering—photovoltaics and wind almost always qualify, but fuel cells are rarely covered by net metering legislation (Office of Energy Efficiency and Renewable Energy. 2003. The Green Power Network, Green Power Markets, "Net Metering Policies" webpage. U.S. Department of Energy, June, http://www.eere.energy.gov/greenpower/markets/netmetering.shtml, February 4, 2005).

59. Hassett, K., and G. Metcalf. 1993. Energy conservation investments: do consumers discount the future correctly? *Energy Policy* 21(6): 710–716.

60. A ground-coupled heat pump (also known as a geothermal or ground-source heat pump) is a heating and

cooling system that uses the earth's thermal energy. It consists of a loop (a series of pipes) that is installed below the ground or submersed in a pond or lake. In winter, a ground-coupled heat pump transfers heat from the ground or groundwater to provide space heating. In summer, the heat transfer process is reversed and the ground or groundwater absorbs heat from the living or working space and cools the air.

61. Brown, M.A., Berry, L.G., and Goel, R. 1991. "Guidelines for successfully transferring government-sponsored innovations." *Research Policy* 20(2): 121–143; Technical Marketing Associates, Inc. 1988. *Ground-Source and Hydronic Heat Pump Market Study.* EPRI EM-6062. EPRI, Palo Alto, CA.

62. Cantor, R., and D. Trumble. 1988. *Gas Furnace Purchases: A Study of Consumer Decision-making and Conservation Investment.* ORNL/TM-10727. Oak Ridge National Laboratory, Oak Ridge, TN.

63. In addition to accounting for a high percentage of GHG emissions, the energy demanded to service buildings also generates a high percentage of U.S. sulfur dioxide and nitrogen oxides (see Figure 4).

64. The demand for reliable power is a recent phenomenon that has gained momentum following California's rolling blackouts of 2000 and 2001 and the Northeast blackout of August 2004. The public is beginning to understand the relationship between using energy efficiently and having sufficient power to meet demand. They are also beginning to value the ability for clean, on-site power generation to provide back-up generation for critical functions.

65. Holland, Stephen P., and Erin T. Mansur. 2004. *Is Real-Time Pricing Green? The Environmental Impacts of Electricity Demand Variance.* Center for Study of Energy Markets Working Paper 136, August, http://www.ucei.berkeley.edu/PDF/csemwp136.pdf, February 4, 2005.

66. Many of these trends are discussed in Reed, 2004, op cit; and in NAHB, 2000, op cit, p. 4.

67. The overview in this report illustrates the technology possibilities; numerous existing publications provide more expansive and detailed coverage. Several sources of information on green building guidelines are available in publications and websites of the Sustainable Buildings Industry Council, http://www.SBICouncil.org February 4, 2005; National Association of Homebuilders, NAHB Research Center, http:// http://www.nahbrc.org/, February 4, 2005; and the U. S. Department of Energy, Smart Communities Network, http://www.sustainable.doe.gov, February 4, 2005. Additional organizations providing national, regional, and local information on green building can be accessed through these websites. Other sources include Kats, Greg. 2003. *The Costs and Financial Benefits of Green Buildings, A Report to California's Sustainable Building Task Force,* http://www.usgbc.org/Docs/News/News477.pdf, February 4, 2005 Tuluca, Adrian. 1997. *Energy Efficient Design and Construction for Commercial Buildings,* McGraw-Hill, Columbus, OH; Nadel, S., L. Rainer, M. Shepard, M. Suozzo, and J. Thorne. 1998. *Emerging Energy-Saving Technologies and Practices for the Buildings Sector.* American Council for an Energy Efficient Economy, Washington, DC.

68. The embodied energy of a building includes the energy required to extract the raw materials, process the materials into a final product, to transport and install each component, and finally to recycle or retire the product.

69. Miller, W.A., A.O. Desjarlais, H. Akbari, R. Levenson, P. Berdahl, and R.G. Scichille. 2004. Special IR reflective pigments make a dark roof reflect almost like a white roof. In *Thermal Performance of the Exterior Envelopes of Buildings, IX,* Proceedings of ASHRAE SP-95, Performance of Exterior Envelopes of Whole Buildings IX, Clearwater, FL, December; and Akbari, H., P. Berdahl, R. Levinson, R. Wiel, A.O. Desjarlais, W.A. Miller, N. Jenkins, A. Rosenfeld, and C. Scruton. 2004. Cool colored materials for roofs. In *ACEEE Summer Study on Energy Efficiency in Buildings,* proceedings of American Council for an Energy Efficient Economy, Pacific Grove, CA, August.

70. Hadley, S.W., J.M. MacDonald, M. Ally, J. Tomlinson, M. Simpson, and W. Miller. 2004. *Emerging Energy-Efficient Technologies in Buildings: Technology Characterizations for Energy Modeling.* Prepared for the National Commission on Energy Policy. ORNL/TM-2004/63. Oak Ridge National Laboratory, Oak Ridge, TN.

71. The 50 percent calculation is based on comparison of whole-wall R-values for standard wall construction and structural insulated panels. See http://www.ornl.gov/sci/roofs+walls/calculators/wholewall/index.html, February 4, 2005.

72. Optimum value engineering limits wood use, which reduces wood costs and allows for greater insulating space. Structural insulated panels are generally plywood or oriented-strand board sheets laminated to foam board that serve as both framing and insulation. Insulating concrete forms are foam boards (one layer lies inside and one outside the building envelope) that provide form for a steel-reinforced concrete center (*Thermal Envelope from Energy Savers,* http://www.eere.energy.gov/consumerinfo/factsheets/ca3.html, February 4, 2005).

73. U.S. Department of Housing and Urban Development and Partnership for Advancing Technology in Housing (HUD PATH). 2003. "Building Envelope Technologies." *Technology Scanning.* Issue 3 – May 2004. http://www.pathnet.org/si.asp?id=1165, February 4, 2005.

74. HUD PATH. 2001. "Building Envelope Technologies." *Technology Scanning.* Issue 1 – November 2001. http://www.pathnet.org/si.asp?id=591, 2004, February 4, 2005.

75. The National Fenestration Window Council has developed a standardized rating system. The U-factor is only one of several performance values given in this system. See http://www.nfrc.org/label.aspx.

76. For more information on electrochromic window coatings, see the website sponsored by Lawrence Berkeley National Laboratory: http://windows.lbl.gov/materials/chromogenics/howtheywork.html, December 6, 2004.

77. Kunzel, Hartwig, and Achilles Karagiozis. 2004. "Vapor Control in Cold and Coastal Climates Zones" *in Proceedings of eSIM 2004.* SIM 2004, Vancouver BC, Canada, http://www.esim.ca/2004/documents/proceedings/eSim2004_Proceedings.pdf, February 4, 2005.

78. Stringer, J., and L. Horton. 2003. *Basic Research Needs to Assure a Secure Energy Future.* Oak Ridge National Laboratory, Oak Ridge, TN.

79. Khudhair, A.M., M.M. Farid. 2004. "A review of energy conservation in building applications with thermal storage by latent heat using phase change materials." *Energy Conversion and Management* 45(2): 263–275, January.

80. The NAHB estimates the current annual market potential for the five vacuum insulation panel applications selected as most promising in the near term are manufactured housing floor panels (489 million square feet), exterior doors (100 million square feet), garage doors (33 million square feet), manufactured housing ceiling panels (489 million square feet), acoustical ceiling panels (potentially large commercial building market), and attic access panels/stairway insulation (approximately 1 million access panels). Source: NAHB Research Center, Inc. 2002. *Accelerating the Adoption of Vacuum Insulation Technology in Home Construction, Renovation, and Remodeling.* National Association of Home Builders, Upper Marlboro, MD, December.

81. Lippke, Bruce, Jim Wilson, John Perez-Garcia, Jim Bowyer, and Jamie Meil. 2004."CORRIM: life-cycle environmental performance of renewable building materials." *Forest Products Journal* 54(6): 8–19, June. http://www.corrim.org/reports/pdfs/FPJ_Sept2004.pdf, February 4, 2005.

82. Mumma, Tracy. 1995. "Reducing the embodied energy of buildings." *Home Energy Magazine Online* January/February, http://hem.dis.anl.gov/eehem/95/950109.html#95010901.

83. Lippke, op cit. 2004.

84. For example, the *Sustainable Design Resource Guide* reports that wood contained a very low level of embodied energy, while the embodied energy of concrete was about 3 kWh/lb, and metal represented the highest embodied energy of all, with up to 13 times more embodied energy than wood framing. (Source: *Sustainable Design Resource Guide.* 1997. AIA Committee on the Environment, Denver, CO.) A study of total embodied and operating energy for 20 years for three framing materials was commissioned by the Canadian Wood Council and published on the Internet in May 2004 (Canadian Wood Council. 2004. *Energy and the Environment in Residential Construction.* Sustainable Building Series no. 1, http://www.cwc.ca/pdfs/EnergyAndEnvironment.pdf, February 4, 2005). The overall results of the report conclude: "Summing the total embodied and operating energy for twenty years for each design and then comparing these overall results relative to the wood design, indicates that both the steel and concrete design: (1) embody 12 percent and 20 percent more energy, (2) emit 15 percent and 29 percent more greenhouse gas, (3) release 10 percent and 12 percent more air pollution … respectively."

85. Thermal comfort zones in buildings have been defined for occupants (at various levels of activity) based on the indoor air temperature and relative humidity. For example, sedentary occupants in the summer will be equally comfortable at a temperature of 80ºF with a relative humidity of 30 percent as they are at 73ºF with a relative humidity of 70 percent (American Society of Heating, Refrigerating, and Air Conditioning Engineers. 2001. “Thermal comfort.” In 2001 *ASHRAE Handbook—Fundamentals.* Atlanta, GA).

86. Duct energy losses can be reduced by a combination of testing for leaks and then sealing the leaks. The tests are performed using a fan to pressurize the duct system and measure the leak rate. Sealing the leaks can be challenging. Some duct leaks are accessible, such as those around room registers, but others are hidden inside walls or are otherwise difficult to reach. A system has been developed to spray an aerosol sealant into the duct system that seals these hard-to-reach places (Berkeley Lab “Research News,” May 16, 2003, http://www.lbl.gov/Science-Articles/Archive/EETD-aerosol-injection.html, February 4, 2005).

87. American Council for an Energy Efficient Economy, “Top-Rated Energy-Efficient Appliances: Central Air Conditioners,” http://www.aceee.org/consumerguide/topcac.htm, February 4, 2005.

88. Hadley et al., 2004, op cit.

89. Central forced-air furnaces have a lifetime of 10 to 25 years; the lifetime of hydronic heating systems is 20 to 30 years. The replacement market for oil-fired systems would therefore be approximately 5 percent of the existing inventory (EIA. 2003. *The Assumptions to the Annual Energy Outlook 2003, Residential Demand Module.* DOE/EIA-0554(2003), U.S. Department of Energy, http://www.eia.doe.gov/oiaf/archive/aeo03/assumption/residential.html, February 4, 2005). Approximately eight million homes heat with fuel oil, or about 7.5 percent of U.S. households. (EIA. 2001. *Residential Energy Consumption Survey.* U.S. Department of Energy, http://www.eia.doe.gov/emeu/recs/recs2001/detail_tables.html#space, Februray 4, 2005). At a replacement rate of 5 percent per year, about 400,000 oil-fired units will be purchased as replacement units for existing houses each year. Considering that most of these units are located in colder climates (more than half of these units are located in climates with more than 5,000 heating degree days), the energy saving potential of newer and more efficient technology is substantial.

90. The AFUE rating is determined by specific test procedures to give a comparable indication of furnace efficiency. This figure reflects both the steady-state thermal efficiency and the thermal losses that occur when the unit is cycled on and off throughout the season.

91. HUD PATH, 2003, op cit.

92. A heat transfer coefficient is an experimentally measured value that enables calculation of the amount of energy that will travel from one location to another, based on the temperatures of the two locations. Within a heat exchanger, a higher heat transfer coefficient means that more energy will be removed from the hotter fluid, even if the inlet temperatures of the two fluids are not changed. For example, in a gas furnace the hotter fluids would be the hot gases, and the cooler fluid would be the return air from the duct system. If more energy is taken from the hot gas and transferred to the cooler air, the furnace is more efficient and won’t need to run as long to heat the house.

93. HUD PATH, 2001, op cit.

94. U.S. Department of Energy. 2004. Letter to ENERGY STAR partners from R.H. Karney, Manager, ENERGY STAR Program, January 6], http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/DOE_water-heaterletter_final_1.6.04.pdf, February 4, 2005.

95. Tomlinson, J.J. 2002. “All pumped up.” *Home Energy* 19(6):30–35, November/December.

96. The estimated retail cost of the water heating dehumidifier is approximately $500. In comparison, a 30-pint dehumidifier, typically adequate for a 1600-ft^2 area over 24 hours, costs about $160; a 65-pint dehumidifier costs about $250; and a standard 40- to 50-gallon electric water heater costs around $200 or $300.

97. Waste heat is used to pre-heat the water in the HPWH. The waste heat source varies depending on whether the space heat pump is set for heating or cooling mode. When it is in cooling mode, a series of motorized dampers direct the warm air from behind the refrigerator into the HPWH closet to be used by the HPWH evaporator. The outlet air stream from the HPWH is then cooled, dehumidified, and directed back into the kitchen to help air-condition the house. When the space heat pump is in heating mode, air is pulled from the crawl space by the HPWH fans, directed to the HPWH evaporator, and then exhausted outside the house. The result is an annual water heating bill of less than $100 (Oak Ridge National Laboratory. 2004. ORNL’s EERE Program…“In hot water.” *Science and Technology Highlights* 2:10–11, http://www.ornl.gov/eere).

98. Solar Electric Association. 2003. *Zero-Energy Homes, A Report on the Zero Energy Homes—Utility Benefits Workshop.* Solar Energy Power Association, Washington, DC.

99. Million Solar Roofs is a DOE initiative to facilitate the installation of solar energy systems on one million U.S. buildings by 2010. The initiative does not provide funding to design, purchase, or install solar energy systems. Instead, the Million Solar Roofs Initiative brings together the capabilities of the federal government with key national businesses and organizations and focuses them on building a strong market for solar energy applications on buildings (http://millionsolarroofs.org/about_initiative/, February 4, 2005).

100. Stringer and Horton, op cit., 2003.

101. Rogol, M., S. Doi, and A. Wilkinson. 2004. *Solar Power: Sector Outlook,* CLSA Asia-Pacific Markets, July, http://www.solarworld.de/pdf-global/solar-power-2004-07.pdf, February 4, 2005.

102. Tulley, G. 2000. "Bringing big builders to efficiency." *Home Energy Magazine Online* March/April, http://hem.dis.anl.gov/eehem/00/000307.html; February 4, 2005 Wee, H. 2001. Buildings with built-in energy savings, BusinessWeek Online August 27, http://www.businessweek.com/magazine/content/01_35/b3746614.htm February 4, 2005.

103. Wee, 2001, op cit.

104. Zero Energy Homes brochure, NAHB Research Center, Upper Marlboro, MD, http://www.toolbase.org/docs/MainNav/Energy/4339_ZEH_Brochure-final-screen.pdf, December 6, 2004.

105. Stringer and Horton, op cit., 2003.

106. Commissioning is a quality assurance process that ensures that HVAC, controls, and electrical systems operate efficiently in a new building. Recommissioning involves revisiting these systems at regular intervals to check and retest them to ensure that they continue to operate efficiently. (For more information see: ENERGY STAR® Building Manual, http://www.energystar.gov/index.cfm?c=business.bus_upgrade_manual, April 12, 2005).

107. Stringer and Horton, op cit,. 2003..

108. Navigant Consulting Inc. 2003. *Energy Savings Potential of Solid State Lighting in General Illumination Applications.* Prepared for U.S. Department of Energy by Navigant Consulting Inc., Washington, DC, November.

109. Ibid.

110. Muhs, J. 2004. "Up Ahead: Hybrid Lighting," *Architectural Lighting,* February 12.

111. Optoelectronics Industry Development Association. 2001. The Promise of Solid State Lighting for General Illumination: Light Emitting Diodes (LEDs) and Organic Light Emitting Diodes (OLEDs): Conclusions and Recommendations from OIDA Technology Roadmaps Co-sponsored by DOE (BTS) and OIDA. Optoelectronics Industry Development Association, Washington, DC. The total U.S. carbon emission estimate is from EIA. 2004. Annual Energy Outlook 2004 with Projections to 2025. DOE/EIA-0383(2004). Reference Case, p. 93, Figure 117. EIA, Washington, DC.

112. The improved LEDs are projected to have efficiency levels of 70 to 145 lumens per watt (lm/W) for high quality light (such as is now provided by incandescent or halogen fixtures at efficiencies ranging from 13 to 20 lm/W) and 95 to 183 lm/W for medium quality light (such as now provided by many fluorescent fixtures at efficiencies in the range of 70 to 80 lm/W) (Source: Hadley et al., 2004, op cit.). Carbon equivalent based on value of 19.29 MMTC per primary electricity generation quad in 2025 (Office of Energy Efficiency and Renewable Energy. 2004. 2004 *Buildings Energy Databook,* p. 6-6, table 6.4.1. U.S. Department of Energy, Washington, DC.

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115. Hadley et al., 2004, op cit.

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127. Walker, L., and W. Rees. 1997. "Urban density and ecological footprints: an analysis of Canadian households." In *Eco-City Dimensions: Healthy Communities, Healthy Planet.* Mark Roseland (ed.), New Society Publishers, Gabriola Island, BC, Canada. Taking a standard detached house as the baseline, the authors conclude that a small-lot house has, in comparison, only 92 percent of the standard house's footprint, and a townhouse about 78 percent, while walk-up apartments and high-rise buildings require only 64 percent and 60 percent of the detached house footprint respectively.

128. Harmaajarvi, I, A. Huhdanmaki, and P. Lahti. 2002. *Urban Form and Greenhouse Gas Emissions: Summary.* Finnish Ministry of the Environment, Helsinki, Finland.

129. Smart growth refers to community design that provides better access to places while requiring less auto use. However, the term also covers a wide range of other potential benefits of more compact, mixed use development. See, for example, Smart Growth America website, http://www.smartgrowthamerica.com, December 6, 2004.

130. See Southworth and Jones, 1996, op cit; Jack Faucett Associates and Sierra Research, Inc. 1999. *Granting Air Quality Credit for Land Use Measures: Policy Options.* EPA420-P-99-028. U.S. Environmental Protection Agency, http://www.epa.gov/otaq/transp/trancont/lupol.pdf, December 6, 2004.

131. Surfaces such as concrete and asphalt have greater heat absorption and get much hotter than do vegetated surfaces during the day. Energy stored in roads and rooftops can cause the surface temperature of urban structures to

become 10–21°C higher than the ambient air temperatures. This stored heat is then released at night, creating a dome of warmer air over the city that increases energy consumption through greater use of air conditioning. See, for example, Urban Climatology and Air Quality, "Heat Island," http://www.ghcc.msfc.nasa.gov/urban/urban_heat_island.html, December 6, 2004. Also see U.S. Climate Change Technology Program. 2003. *Technology Options for the Near and Long Term*. op cit, p. 28.

132. An infill site is a development site enclosed within an already developed urban area.

133. It is unclear, however, what the percentage or durability of within-neighborhood travel savings would be, given that the majority of U.S. commuters currently travel out of their home neighborhood (and often out of their home county) to get to work, with many households involved in two such inter-suburban or suburb-to-central city commutes. Nor is the preferred shopping center necessarily found in the same part of the city as the home site.

134. Miller, E.J., and A. Ibrahim. 1998. "Urban form and vehicular travel: some empirical findings." *Transportation Research Record* 1617: 18–27.

135. Garreau, J. 1991. *Edge City: Life on The New Frontier.* Anchor Books, New York, NY.

136. National Governors Association Center of Best Practices. 2002. *Growing Less with Greenhouse Gases: State Growth Management Policies That Reduce GHG Emissions.* National Governors Association, http://www.nga.org/cda/files/112002GHG.pdf, December 6, 2004; Lyons, W.M., S. Petersen, and K. Noerager. 2003. *Greenhouse Gas Reduction Through State and Local Transportation Planning.* DOT-VNTSC-RSPA-03-02. Volpe Transportation Center, U.S. Department of Transportation. National Technical Information Service, Springfield, VA, http://climate.volpe.dot.gov/docs/reduction.pdf, December 6, 2004. Concurrency requirements have been used by local and state governments to ensure that public services and facilities such as local and access roads, police services, fire protection services, schools, parks, mass-transit facilities, water services, sewer services, and solid waste removal are available at the time a residential or commercial development is completed. This is usually easier to ensure when such developments are built within existing urban boundaries. See, for an example, Snohomish County Public Works, Transportation Currency Requirements, Bulletin #59, http://www.co.snohomish.wa.us/publicwk/pwhome/59concurrency.pdf, December 6, 2004.

137. A Location Efficient Mortgage® increases the amount of money homebuyers in urban areas are able to borrow by taking into account the money they save by living in neighborhoods where they can shop at nearby stores and use public transit, rather than driving to work and to the mall. See http://www.nrdc.org/cities/smartGrowth/qlem.asp#, February 4, 2005. LEMs are currently available in Chicago, Seattle, San Francisco, and Los Angeles. See Location Efficient Mortgage website, http://www.locationefficiency.com, December 6, 2004. A related goal is also supported by the Energy-Efficient Mortgage, which allows homeowners to finance the cost of adding energy-efficiency features to new or existing housing as part of their FHA-insured home purchase or refinancing mortgage. See FHA Loan Types, "FHA Energy Efficient Mortgages," http://www.fhaloan.com/energy_efficient.cfm., December 5, 2004.

138. See Bryk, D.S., and J. Henry. 2004. A new tool for greening buildings and neighborhoods: the "Smart Growth Tax Credit." In *Proceedings, 2004 ACEEE Summer Study on Energy Efficiency in Buildings.* American Council for an Energy-Efficient Economy, Washington, DC.

139. Bryk and Henry, 2004, op cit. However, in developing such a concept the authors note that (1) it is much more difficult to model where people are likely to live, work and send their children to school than it is to model the energy savings from improved lighting or HVAC technologies, and (2) conflicts between green and smart growth building projects can arise and need careful treatment (e.g., trying to prevent greener homes from being built because they are in greenfield rather than infill sites may not always lead to the best long term solution).

140. See Transit Oriented Development website, http://www.rtd-denver.com/Projects/TOD/, December 6, 2004, for links to city-specific transit-oriented development (TOD) projects. See also Dittmar, H., and G. Ohland. 2003. *The New Transit Town: Best Practices in Transit-Oriented Development.* Island Press, Washington, DC; Dumabugh, E. 2004. Overcoming financial and institutional barriers to TOD: Lindbergh Station case study. *Journal of Public Transportation* 7.3:43–69.

141. Service commercial vehicles are typically light-duty vehicles engaged in a wide range of professional visitation, pick-up, and delivery activities—such as plumbing, cleaning, and general repair services, as well as courier, small package, and document delivery services.

142. See U.S. Department of Transportation. 1998. *Transportation and Global Climate Change: A Review and Analysis of the Literature.* DOT-T-97-03. U.S. Department of Transportation, Federal Highway Administration, Washington, DC.

143. For a discussion, see Southworth, F. 2001. On the potential impacts of land-use change policies on automobile vehicle miles of travel. *Energy Policy Journal* 29:1271–1283.

144. Future travel pricing strategies are likely to benefit from real time traffic information (through, for example, data collected by in-the-pavement traffic sensors). This information can be used to charge travelers on the basis of when as well as where they travel, with higher fees charged for travel at congested times and in congested locations. For definitions and examples, see U.S. Environmental Protection Agency, "Congestion Pricing," http://yosemite.epa.gov/aa/tcmsitei.nsf/0/647e950797e1f217852565d90073f4e6?OpenDocument#rec, December 6, 2004.

145. Southworth and Jones, 1996, op cit. Also see Greene, D.L., and A. Schafer. 2003. *Reducing Greenhouse Gas Emissions from U.S. Transportation.* Pew Center on Global Climate Change, Arlington, VA.

146. Source: Prindle, W., N. Dietsch, R. Neal Elliott, M Kushler, T. Langer, and S. Nadel. 2003. *Energy Efficiency's Next Generation: Innovation at the State Level.* Report Number E031. American Council for an Energy-Efficient Economy, Washington, DC.

147. See Sterner, T. 2003. *Policy Instruments for Environmental and Natural Resource Management.* Resources for the Future Press, Washington, DC. This report provides a taxonomy of available policy instruments that include direct regulation, also sometimes termed command and control; quantity instruments such as tradable permits; price instruments such as tax incentives and subsidies for R&D; and information and education policies. Similar taxonomies are described in Brown, M.A., and D.W. Jones. 1989. *Policies and Measures for Reducing Energy Related Greenhouse Gas Emissions: Lessons from Recent Literature.* DOE/PO-0047. U.S. Department of Energy, Office of Policy and International Affairs, Washington, DC, pp. 3-1–3-51, July. See also Gillingham, K., R. Newell, and K. Palmer, 2004. "Retrospective Review of Energy-Efficiency Programs," RFF Discussion Paper 04-19rev. Washington, DC. Forthcoming, *Annual Review of Environment and Resources.*

148. Prindle et al., 2003, op cit. The California Title 24 standards are energy efficient standards for residential and non-residential buildings.

149. The Building Codes Assistance Project Bimonthly Newsletter. 2004. *The Building Codes Assistance Project Bimonthly Newsletter*, http://66.155.84.153/newsletters/BCAP_0904_Newsletter.htm, February 4, 2005.

150. Prindle et al., 2003, op cit. Jones, T., D. Norland, and W. Prindle. 1998. *Opportunity Lost: Better Energy Codes for Affordable Housing and a Cleaner Environment.* Alliance to Save Energy, Washington, DC, http://www.e-star.com/pdf/opplost.pdf, February 19, 2005.

151. Office of Energy Efficiency and Renewable Energy. 2000. *Clean Energy Partnerships: A Decade of Success.* DOE/EE-0213. U.S. Department of Energy, Washington, DC, March.

152. Rosenquist, G., M. McNeil, M. Iyer, S. Meyers, and J. McMahon. 2004. *Energy Efficiency Standards and Codes for Residential/Commercial Equipment and Buildings: Additional Opportunities.* National Commission on Energy Policy Washington, DC, http://www.energycommission.org, February 27, 2005.

153. For residential building codes, the analysis was conducted for each Census Division; each Division had a specific baseline construction practice with respect to insulation and glazing. Measures were selected in each Census Division that have a simple payback of less than 15 years. To obtain national averages, a weighted average was calculated to reflect the relevant shares of new housing construction in each Census Division. For commercial codes, construction practices for glazing were considered for "hot" and "cold" climate zones; for lighting, watts per square foot (i.e., lighting power densities) were considered for different building types. Lighting measures were selected that are cost-effective towards meeting the ASHRAE 90-1 2004 amendment for a standard that would become effective in 2015. For glazing, measures were selected that had a minimum life cycle cost for each building type. To obtain national estimates, a weighted average was calculated based on shares of new construction by building type. Source: Rosenquist, 2005, op cit.

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155. Geller, H., T. Kubo, and S. Nadel. 2001. *Overall Savings from Federal Appliance and Equipment Efficiency Standards.* American Council for an Energy-Efficient Economy, Washington, DC, http://www.standardsasap.org/stndsvgs.pdf, February 4, 2005.

156. Meyers, S., J.E. McMahon, M. McNeil, and X. Liu. 2003. "Impacts of U.S. federal energy efficiency standards for residential appliances." *Energy* 28:755–767.

157. Geller et al., 2001, op cit.

158. See S. Nadel. 2003. Appliance and equipment efficiency standards in the U.S.: accomplishments, next steps and lessons learned. In *ECEEE 2002 Summer Study Proceedings,* 1, 75–86, European Council for an Energy Efficient Economy, Stockholm, Sweden. See also Rosenquist, 2004, et al.

159. Prindle et al., 2003, op cit.

160. See Bryk and Henry, 2004, op cit.

161. Prindle et al., 2003, op cit.

162. Gillingham et al., 2004, op cit.

163. Joskow, P.L., and D.B. Marron. 1993. "What does a negawatt really cost? further thoughts and evidence." *The Electricity Journal* July, 14–26.

164. Berry, L., and M. Schweitzer. 2003. *Metaevaluation of National Weatherization Assistance Program Based on State Studies* 1993–2002. ORNL/CON-488. Oak Ridge National Laboratory, http://weatherization.ornl.gov/pdf/CON_488.pdf, February 4, 2005. A summary of the report and prior evaluation studies can be found at http://www.waptac.org/sp.asp?id=1437, February 4, 2005.

165. According to the Weatherization Assistance Program overview (http://www.waptac.org/sp.asp?id=1437, Februray 4 2005), weatherization avoids approximately 0.23 metric tons of carbon emissions per year in a home heated primarily with natural gas. For homes heated by electricity, the emission reductions are 0.475 metric tons of carbon annually. Because approximately 10 percent of the weatherized homes are heated by electricity, a weighted average of 0.25 metric tons is estimated.

166. NAHB, 2000, op cit, p. 33.

167. A GHG registry is a repository for reporting and tracking emissions and emission reduction and sequestration activities (Prindle et al., 2003, op cit).

168. With funding from DOE, the states of California, Oregon, and Washington have been involved in the development of the PLAnning for Community Energy, Environment and Economic Sustainability (PLACE3S) sustainable community design software. See California Energy Commission, "The Energy Yardstick: Using PLACE3S to Create More Sustainable Communities," http://www.energy.ca.gov/places/, December 6, 2004.

169. National Awareness of ENERGY STAR®, for 2003, *Analysis of CEE Household Survey,* pp. 4 and 14. http://www.energystar.gov/ia/news/downloads/E-STAR03Awareness.pdf, February 4, 2005.

170. Air and Radiation Office. 2004. *Protecting the Environment Together: ENERGY STAR® and Other Voluntary Programs,* 2003 Annual Report, EPA 430-R-04-011. U.S. Environmental Protection Agency, Washington, DC, September, http://www.epa.gov/chp/pdf/CPPD2003_web.pdf, February 4, 2005.

171. Webber, C.A., R.E. Brown, M. McWhinney, and J.G. Koomey. 2003. *2002 Status Report: Savings Estimates for the ENERGY STAR® Voluntary Labeling Program.* LBNL-51319. Lawrence Berkeley National Laboratory, Berkeley, CA, March. It is assumed that 10,346 Btu of fossil fuel energy are required to generate 1 kWh of electricity.

172. Supporting studies include DeCanio, S.J. 1998. "The efficiency paradox: bureaucratic organizational barriers to profitable energy-saving investments." *Energy Policy* 26(5):441–454; DeCanio, S.J., and W. Watkins. 1998. Investment in energy efficiency: do the characteristics of firms matter? *Review of Economics and Statistics* 80(1):95–107.

173. Prindle et al., 2003, op cit, pp. 58–61. Also, see the database maintained by the Pew Center on Global Climate Change for more information on state-level emission targets and other climate change activities, http://www.pewclimate.org/what_s_being_done/in_the_states/.

174. http://www.eere.energy.gov/femp/about/about.cfm, February 19, 2005.

175. Office of Energy Efficiency and Renewable Energy. 2004. *Federal Energy Management: Year in Review: 2003*. U.S. Department of Energy, Washington, DC, March, http://www.eere.energy.gov/femp/pdfs/yrinrview_2003.pdf, December 6, 2004.

176. Office of Energy Effieciency and renewable Energy. *Annual Report to Congress on Federal Government Energy Management and Conversion Progams Fiscal Year 2003.* Draft. U.S. Department of Energy, Washington DC, October. The conversion factor for calculating carbon reductions from energy savings is based on the total federal agency facility energy use and carbon emissions from Tables 3 and 6 (pp. 7 and 12).

177. Stringer and Horton, op cit., 2003.

178. Business Week. 1995. Blue-sky research comes down to Earth, July 3, p. 78.

179. Dooley, J. 1998. "Unintended consequences: energy R&D in a deregulated market." *Energy Policy* 26(7):547–555.

180. Office of Technology Assessment (OTA). 1992. *Building Energy Efficiency.* OTA-E-518. Office of Technology Assessment, Washington, DC, pp. 76–78, May; Building Energy Efficiency Program Review Group. 1992. *Achieving Greater Energy Efficiency in Buildings: The Role of DOE's Office of Building Technologies.* American Council for an Energy-Efficient Economy and Alliance to Save Energy, Washington, DC, July; Secretary of Energy Advisory Board (SEAB). 1995. *Energy R&D: Shaping our Nation's Future in a Competitive World.* U.S. Department of Energy, Washington, DC, p. 143, Annex 2, June.

181. National Research Council. 2001. *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research* 1978 to 2000. National Academy Press, Washington, DC, http://www.nap.edu/books/0309074487/html/, February 4, 2005.

182. R&D into more efficient community designs and urban forms is also warranted by the existing evidence, and for a number of complementary reasons including GHG reduction, energy savings, pollution reduction and travel time savings. Such efforts need to target both the potential GHG emission reductions of different land use arrangements and the potential for the more promising arrangements to be made attractive to the residents and businesses that will need to live in them. Given the longer term payoffs expected from this sort of R&D, a federal role would seem to be central to serious progress. Sophisticated software tools need to be developed to support this process.

183. Sachs, H., S. Nadel, J.T. Amann, M. Tauzon, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar. 2004. "Emerging Technologies/Practices: Finding the Next Generation." In *Proceedings, 2004 ACEEE Summer Study on Energy Efficiency in Buildings.* American Council for an Energy-Efficient Economy, Washington, DC, pp. 6.298–6.3009.

184. Hadley et al., 2004, op cit.

185. Brown et al., 2001, op cit; Koomey, J.G., C.A. Webber, C.S. Atkinson, and A. Nicholls. 2001. "Addressing energy-related challenges for the U.S. buildings sector: results from the Clean Energy Futures Study." *Energy Policy* 29(14): 1209–1221.

186. Brown et al., 2001, op cit; and Koomey et al., 2001, op cit.

187. EIA, 2004, op cit, p. 159, table A20.

This report discusses options for reducing greenhouse gas emissions from the U.S. buildings sector. The Pew Center on Global Climate Change was established by the Pew Charitable Trusts to bring a new cooperative approach and critical scientific, economic, and technological expertise to the global climate change debate. We intend to inform this debate through wide-ranging analyses that will add new facts and perspectives in four areas: policy (domestic and international), economics, environment, and solutions.

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