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# Mitigating Climate Change Through Green Buildings and Smart Growth

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**Abstract.** Energy-efficient buildings are seen by climate change experts as one of the least-cost approaches to mitigating greenhouse gas emissions. This paper summarizes a study done for the Pew Center on Global Climate Change that takes a broader look at the potential role of a climate-friendly built environment including not only considerations of how buildings are constructed and used, but also how they interface with the electric grid and where they are located in terms of urban densities and access to employment and services. In addition to summarizing mechanisms of change (barriers and drivers), the paper reviews a set of policies that could bring carbon emissions in the building sector in 2025 back almost to 2004 levels. By mid-century, the combination of green buildings and smart growth could deliver the deeper reductions that many believe are needed to mitigate climate change.

## 1 Introduction

Green buildings and smart growth strategies are key to reducing global greenhouse gas (GHG) emissions in the future. In the United States as in most developed countries, the energy requirements of buildings account for more than one-third of GHG emissions. Approximately 43% of U.S. carbon dioxide ($CO_2$) emissions result from the energy services required by residential, commercial, and industrial buildings, while transportation accounts for 32%, and industry accounts for 25% (Brown et al., 2005). Thus, assessments of GHG reduction have itemized the many ways that building services could be provided in a more energy efficient manner. It's also important, however, to consider other GHG impacts affiliated with the built environment, including: the effects of alternative urban designs; the use of on-site power generation; and the life-cycle GHG emissions from building construction, materials, and equipment. This broader perspective leads to climate change strategies that address 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 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 following the 1973–74 OPEC oil embargo. Since 1972, primary energy use in buildings overall has increased at less than half the rate of growth of the nation's gross domestic product (GDP). Since the late 1970s, when detailed energy use data first became available through the Energy Information Administration's (EIA) Residential and Commercial Building Energy Consumption Surveys, residential energy use per capita has declined by 27%, while energy use per square foot of commercial building space has declined by 25% (Brown et al., 2005, p. 2). These energy intensities have decreased despite the fact that the size of homes has increased and the range of electric equipment provided in buildings has expanded, especially air conditioning in the South as well as electronic equipment, televisions, and other "plug loads" in buildings nationwide.

**Figure 1. Declining Energy Consumption per Household**

Examples of technology improvements during the past 30 years help document this progress. Compact fluorescent lamps, now in common use, are 70% more efficient than are incandescent lamps; refrigerators use 75% less energy; and new horizontal-axis clothes washers are 50% more efficient than current minimum standards. The typical level of insulation in walls, ceilings and attics has increased significantly, and the market penetration of high-efficiency low-emissivity (low-E) coated windows in homes has grown to almost 30% (U.S. Climate Change Technology Program, 2003; NAHB, 2000).

Yet many opportunities exist for further curtailing GHG emissions from the U.S. building sector. Current homes, stores, offices, and factory buildings rarely incorporate the full complement of cost-effective, energy-efficient technologies and design strategies that 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. 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 urban sprawl suggest the need for an integrated approach to GHG reductions.

The magnitude of the problem is compounded by the fact that the U.S. population, economy, and building stock are projected to continue to grow. The U.S. population is expected to expand from 295 million in 2005 to 378 million by 2035 (U.S. Census Bureau, 2004). Over the same period, the built environment in the United States is expected to increase by an amount roughly equal to 70% of today's existing building stock (Nelson, 2004), and the explosion of new energy services in buildings is forecast to continue. Even more compelling are the high rates of growth of energy consumption anticipated for the residential and service sectors of the developing world. Between 1971 and 1995, the average annual growth rate of primary energy use for residential and commercial buildings in developed countries averaged 1.8%; in contrast, developing countries in Latin America averaged 4.7%, in the Asia-Pacific region they averaged 5.5%, in Africa 5.9% and in the Middle East 10.3% (Metz, et a., 2001, p. 176).

This paper describes the short- and long-term potential for reducing GHG emissions from the U.S. built environment. It draws extensively from a much longer report published by the Pew Center on Global Climate Change (Brown, 2005). After describing the nature and sources of GHG emissions from the building sector, we describe the obstacles and drivers of change. Next we summarize the potential for technologies and consumer actions to reduce GHG emissions in buildings, including 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. We then discuss the policy options that could translate these various opportunities into reality. The paper ends with a summary of its findings and recommendations.

## 2 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, fluorine-containing substances from industrial sources). Based on overall emission levels and global warming potential, $CO_2$ is by far the most important GHG, accounting for 85% of total U.S. GHG emissions in 2002, and residential, commercial, and industrial buildings are responsible for 43% of these $CO_2$ emissions (EIA, 2003b, EPA, 2004). Among the other two principal GHGs (methane and nitrous oxide), buildings are responsible for an estimated 7 to 8%. For methane, the buildings sources are landfill debris, fireplaces and cookstoves, and for nitrous oxide the sources are primarily fireplaces and woodstoves. The “other gases” account for less than 2% of total U.S. GHG emissions when weighted by their 100-year global warming potential (EIA, 2003b). Among these "other gases," only HFCs are significantly related to buildings – they are used as refrigerants and as blowing agents in insulation.

Figure 2 shows a breakdown of the $CO_2$ emissions attributable to the U.S. building sector, by energy source. Emissions from electricity consumption dominate in the residential sector (where it accounts for 76% of $CO_2$ emissions) and in the commercial sector (where in accounts for 67%). The dominance of electric services in this sector underscores the important role that low-carbon electricity generation could play as an additional means of reducing $CO_2$ emissions from the energy used in buildings. Direct combustion of natural gas (e.g., in furnaces and water heaters) accounts for about 23% of emissions in residential buildings, while it emits slightly less $CO_2$ in commercial buildings (17% 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% of residential building emissions) than in the commercial sector (where it represents only 5% of commercial building emissions).

**Figure 2. $CO_2$ Emissions from U.S. Residential and Commercial Buildings, by Energy Source, 2002**

GHG emissions from the U.S. building sector have been increasing at about 2% per year since 1990, and the EIA forecasts that they will continue to increase at approximately 1.4% 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% 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.

## 2.1 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% of the U.S. total. Energy consumption is directly tied to GHG emissions—every quad of energy consumed in the building sector results in approximately 40 million metric tons of carbon (MMTC) emissions (and costs almost $8 billion in 2001$) (EERE, 2003).

**Figure 3. Primary Energy Consumption in Residential and Commercial Buildings, 2002**

Most of the energy consumed by residential buildings is for space heating (30%) and air conditioning (11%); both of these uses are geared to maintaining occupant comfort in response to climatic conditions. An additional 12% is used for water heating, and a further 12% is for lighting. The remainder of the energy consumed in homes goes for appliances, electronics, and other purposes (EIA, 2004a). Nearly 63% of all housing units are single-family detached homes, and they account for 73% 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.

In the commercial sector a great deal of energy is used for lighting (21%) and office equipment (8%). Air conditioning (9%) requires almost as much energy as space heating (12%), 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 that vary by type of enterprise, e.g., automated teller machines, telecommunications equipment, medical equipment, pumps, and emergency electric generators (EIA, 2004a). Commercial buildings range widely in size, energy intensity, function, and ownership. Offices dominate, both in terms of square footage (21%) and energy consumption (22%), followed by retail services, education, and health care.

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.

### 2.2 New construction versus renovation

It is also important to distinguish between new versus 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% 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% of U.S. GDP. New buildings construction represents almost half of this total ($562 billion), and building renovation was valued at $265 billion (EERE, 2003). 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 of their heating, ventilation, and air-conditioning (HVAC) 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.

**2.3 Technical and economic potential for GHG reductions**

Based on current levels of use of building products and practices, most owners and occupants have significant potential to improve the energy efficiency of their buildings. HVAC equipment, appliances, and lighting systems currently on the market vary from 20% to more than 100% efficient (heat pumps can exceed this level by using “free” thermal energy drawn from the air, water, and ground, although their system efficiency is penalized by the use of electricity from inefficient central power plants). Only 40% of residences are well insulated, and less than 40% of new window sales are of advanced types (e.g., low-E). In commercial buildings, only 17% of all windows are advanced types. Only 30% of commercial buildings have roof insulation and somewhat fewer have insulated walls. Nationally, reflective roofing materials still comprise less than 10% of the roofing market; asphalt comprises 95% of urban pavements despite its high heat absorption (compared with concrete), which also contributes to the urban “heat island” effect. Design tools for energy efficiency are used by fewer than 2% of the professionals involved in the design, construction, and operation of commercial buildings in the United States (U.S. Climate Change Technology Program, 2003).

Some improvements in energy efficiency are forecast by the EIA through the operation of market forces in response to fuel price increases.  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% of costs per year (Newell et al., 1999).

The actual market uptake of energy efficiency improvements depends on many factors. The market success of most new equipment and appliance technologies is virtually ensured if the efficiency improvement has a three-year payback or better and if 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) (U.S. Climate Change Technology Program, 2003).

The result is a forecasted annual increase in energy consumption over the next decade of 1.3% 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% annually in the residential sector and 1.9% annually in the commercial sector—or an overall annual rate of increase of 1.4% (EIA, 2004a).

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 (Brown et al., 2001; OTA, 1991; National Academy of Sciences, 1992; and Tellus Institute, 1998). 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% (Brown, et al., 2001). 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%. Similar conclusions are reported in *Technology Opportunities to Reduce U.S. Greenhouse Gas Emissions* (the “11-Lab Study”) (DOE National Laboratory Directors, 1998).

On the other hand, critics claim that the existence of cost-effective energy-efficiency opportunities has not been justified on the basis of market inefficiencies (Jaffe and Stavins, 1994). They argue that there is no energy efficiency gap (i.e., there is no 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). 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 (Sutherland, 1996). 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) (Braithwait and Caves, 1994).

## 3 Mechanisms of change

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.

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 reward subsequent users. 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.

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).

## 4 Green building and smart community approaches

Applying currently available technologies can cost-effectively save 30 to 40% of energy use and GHG emissions in new buildings, when evaluated on a life-cycle basis. Some of the numerous promising off-the-shelf technologies and practices 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. Emerging building technologies, especially new lighting systems and integrated thermal and electric power systems, could lead to further low-cost energy savings. For instance, in the 2025 timeframe, newly constructed net-zero-energy homes and climate-friendly designs for large facilities could deploy 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 as well as 80 – 90% efficient integrated energy systems that provide on-site power, heating, cooling and dehumidification from thermal energy that would otherwise be wasted.

In the long run, evidence suggests that higher-density, more spatially compact and mixed-use building developments can also 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. A recent review of the locational efficiency literature concluded that approximately 45-50% of the reduction in GHG emissions from more compact spatial development would come from efficiencies brought about by district heating of residential and service buildings, 45-50% would come from reduced passenger travel, and 3%-5% would result from the reduced need for supporting municipal infrastructures (Brown, et al, 2005). A Center for Clean Air Policy study found a direct relationship between the number of dwellings per acre and the level of GHG releases. At a fairly common suburban density of 4 homes per acre, CO2 emissions per household were estimated to be 25% higher than in an urban neighborhood with 20 homes per acre (Benfield, et al, 1999). A National Research Council study of urban sprawl in the U.S. concluded that planned, spatially compact growth consumes not only 45% less land area but also costs 25% less for roads, 20% less for utilities, and 5% less for schools, than the more common sprawling form of growth we have been used to (Burchell, et al., 1998). Locational efficiency research by Hotlzclaw et al (2002), based on detailed spatial data for the San Francisco Bay Area, Los Angeles, and Chicago, also 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. They concluded that differences in density and access to public transit are significant predictors of per household vehicle miles of travel. Figure 4 shows the hypothesized impact of residential density on travel-related $CO_2$ emissions (San Francisco League of Conservation Voters, 2005).

**Figure 4. Impact of Residential Density on Travel-Related $CO_2$ Emissions**

The ecological footprint studies by Wackernagel and Rees (1995), Walker and Rees (1997), Merkel (2003) and others (see Gilson and Gelb, 2004) are especially useful because they provide breakdowns in the resource requirements of different dwelling types. The Walker and Rees study indicates that 53% of the ecological footprint of a detached house is related directly to the type of housing, while 44% is related to its associated travel requirements, with an additional 3% associated with the need for municipal infrastructure. Caution is warranted in placing too fine a breakdown on such savings, however, as ecological footprints vary in composition depending on how specific consumption categories are defined, as well as on the specific coefficients used (e.g. average miles per gallon). And transportation savings are often under-represented by focusing solely on passenger movements, sometimes subsuming possible freight transportation savings to goods and services. Even so, a consistent pattern is recent land use-based resource studies is one of significant additive environmental benefits from combined "housing" and “transport” efficiencies. The recent example of trying to compute these combined GHG emissions savings is a Finnish study (Harmaajarvi, et al 2002), in which 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. The study suggests that 48% 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, while 48% would come from reduced passenger travel within each commuting region, with an additional 4% savings due to a reduced need for supporting municipal infrastructures.

However, bringing about change through land use planning requires sufficient lead times, on the order of years, to produce significant results. A number of past studies have concluded conservatively that changes in land-use patterns may reduce vehicle miles traveled by 5 to 12% by mid-century (Southworth and Jones, 1996), with similar levels of GHG reduction. These savings are subject to the near-term enactment of progressive land-use planning policies (Brown et al., 2005). Success in reducing travel related GHG emissions through smarter growth will require not only better coordination of local, citywide and statewide planning, but also an ability to overcome “not in my back yard” (NIMBY) responses within the general public. Positive signs include a growing involvement by States in land use planning over the last decade (U.S. Department of Transportation, 1998); while growing traffic congestion along with rising gasoline prices are two additional “unplanned” factors that may serve to limit automobile vehicle miles of travel (VMT) to some degree. This situation suggests that study of different combinations of travel and urban land use pricing policies is worth further attention, recognizing that consideration of these broader travel reduction issues moves us outside the traditional realm of buildings-related research per se. And whether incentive/pricing-based policies or more direct interventions through travel limiting or land use control strategies are attempted, all of the potential benefits are contingent upon policy interventions that successfully overcome current attitudinal as well institutional barriers to change.

## 5 Policy options

The mosaic of current policies affecting greenhouse gas emissions from 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 across the U.S. and around the globe.

### 5.1 Regulation

Regulatory policies include building energy codes, appliance standards, interconnection standards for distributed generation equipment, and land-use zoning to promote smart growth. The past and potential future role of building codes and appliance standards are particularly relevant to the discussion of accelerating the market penetration of green 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. 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 (*The Building Codes Assistance Project Bimonthly Newsletter*, 2004; Business Council for Sustainable Energy, 2004). In addition, many states lack consistent enforcement and support programs, resulting in a shortfall in energy performance.

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. 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 (EERE, 2000). This estimate assumes that roughly half of the potential energy savings are actually achieved. 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% 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 as more buildings are constructed and more jurisdictions adopt state-of-the-art codes.

Jones and coauthors (1998) estimate the nationwide energy savings potential from residential building codes to be 3.25 quads over 30 years, or 0.11 quads annually, if all states adopted the 1998 or more recent International Energy Conservation Code® (IECC) or International Residential Code® (IRC) (Jones et al., 1998). The 2000 and 2003 versions of the IECC residential code created a new provision for homes in hotter climates, setting solar heat gain standards for windows, thereby reducing cooling energy use. This standard, if adopted in 10 southern states, would save another 2 quads over 30 years, or 0.07 quads annually (Tribble et al., 2002). This would result in a total potential for annual savings of 0.59 quads. While this estimate assumes complete code compliance, it does not take into account technological innovations and cost reductions that will fuel the continued tightening of building codes and greater energy savings.

**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 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%, primary energy consumption by 1.3% (1.2 quads), and U.S. carbon emissions from fossil fuel use by 1.7% (25 MMTC) (Geller et al., 2001). The cumulative cost for establishing and implementing appliance standards between 1987 and 2000 were $200 to $250 million. The cumulative net benefit to consumers and businesses over this same period is estimated to be $17 billion (in 2001$) (Meyers et al., 2003).

The federal standards covering clothes washers, water heaters, central air conditioners, heat pumps, and fluorescent lighting ballasts are set to be updated by 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. In addition, consumers and businesses are projected to save billions of dollars in reduced utility costs, as previous rounds of standards have accomplished (Geller et al., 2001). 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 (Nadel, 2003; Rosenquist et al., 2004). 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.  For instance, they can create increased demand by reducing the effective cost of energy services. 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. And any impacts on low-income households can be addressed as part of a larger package that includes progressive elements such as adding home insulation, caulking air leakages, and providing other such weatherization assistance to the income-qualified.

**Land Use Controls.** Policy actions that have been proposed to curtail the worst effects of sprawl include a variety of land use controls including 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; and the use of green areas such as small urban parks and tree-lined streets to act as carbon sinks, as well as to help break up the well documented "heat island" effect that often accompanies asphalt, concrete and other heat absorbing surfaces (Southworth and Jones, 1996; Jack Faucett Associates and Sierra Research, Inc., 1999).

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 (National Governors Association Center of best Practices, 2002; Lyons, W.M., S. Petersen, and K. Noerager, 2003).

### 5.2 Financial incentives

Financial incentives such as tax credits, rebates, low-interest loans, energy-efficiency mortgages, and innovative financing,  such as 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 (Prindle et al., 2003). State and local governments have also experimented with developer-based incentives (such as New Jersey's Smart Growth Tax Credit) (Bryk and Henry, 2004) 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. 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 (Gillingham et al., 2004). Despite strong evidence of the cost effectiveness of these programs, more work is needed to fully account for costs and benefits (Joskow and Marron, 1993).

**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% of their income for energy needs, compared with the 3.5% 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 105,000 homes weatherized in 2002, this amounts to energy savings of 3.05 TBtu (Berry and Schweitzer, 2003). 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 per weatherized home, the total carbon emission reduction in 2002 is estimated to be 0.523 MMTC.

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, growing numbers of workers must commute long distances because of the lack of affordable housing in the communities where they work (NAHB, 2000). Both zoning restrictions and financial incentives have been promoted as a means of creating a better jobs-to-housing balance within specific suburbs in an effort to reduce work trip lengths and therefore reduce regional VMT. 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, leading to travel-related GHG penalties. With nearly 28 million households federally eligible for weatherization assistance, this program could continue to deliver GHG benefits well into the next century.

**Smart Growth Tax Credits.** A variety of financial incentives to promote smart growth have also been tried, including the use of developer impact fees, local and regional business tax incentives, and subsidies to home buyers through locationally efficient mortgages (LEMs), all geared towards more compact energy and travel efficient land use arrangements. LEMs are currently available in Chicago, Seattle, San Francisco, and Los Angeles, where banks allow increases in the amount of money homebuyers 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. A recent variant on this idea is the Smart Growth Tax Credit (SGTC), meant as a legislative tool recently developed for State use by the Natural Resources Defense Council (Bryk and Henry, 2004). The idea grew out of the Green Building Tax Credit signed into law in New York State in May 2002.

The SGTC legislation, introduced into 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% of the developer's project costs (excluding the cost of the land), with additional credits up to 11% 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 to automobile parking, encourages public transit use, and includes green buildings that are certified by the Leadership in Energy and Environmental Design (LEED®) (see below).

### 5.3 Information and education

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 policies and programs can improve the knowledge of the public and key decision-makers about carbon-reduction opportunities and providing technical assistance with their implementation. Information and education policies include:

- GHG reduction targets or goals, and registries for reporting and tracking GHG emission reduction activities;
- energy labels and ratings of products and buildings (such as Energy Star® and LEED),
- mandatory disclosure of energy use information at time of sale of a building;
- audit and other decision tools such as the PLACE$^3$S sustainable community design software;
- 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 production builders).

The economic rationale for these policies lies primarily in the public goods nature of knowledge and information. 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. 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 allied programs to leverage national resources and maximize impacts.

Since its labeling of energy-efficient computers in 1992, the ENERGY STAR program 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% 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 (National Awareness of ENERGY STAR®, 2003). Market penetration statistics suggest that considerable progress has been made (Air and Radiation Office, 2004). The ENERGY STAR label has been earned by more than 200,000 new U.S. homes and it 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% of the market in new commercial buildings, and over 12 billion square feet of building space.

Through the end of 2002, EPA estimates that the ENERGY STAR program saved 105 billion kWh (equivalent to 1.08 quads) and 21.5 MMTC in its commercial and residential buildings (Webber et al., 2003). 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 (DeCanio, 1998; DeCanio and Watkins, 1998). 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.

**LEED® for Neighborhood Development.** The U.S. Green Building Council originally developed LEED to help commercial building developers evaluate green building designs. 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. Recent research on locational efficiency has led to the LEED® for Neighborhood Development (LEED-ND) concept that takes into account location, density, and proximity to transit, as well as green building practices, i.e., combining green and smart growth practices based on comparable measures of energy savings. It has been noted, however, 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) (Bryk and Henry, 2004).

### 5.4 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 construct 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% reduction (from the 1990 levels) by 2020. The cities of Seattle, Salt Lake City, and Austin have set similar goals (Prindle et al., 2003; Pew Center on Global Climate Change, 2005). 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." (http://www.eere.energy.gov/femp/about/about.cfm). FEMP's goal is to reduce energy intensity in federal buildings by 30% in 2005 and 35% in 2010 (relative to a 1985 statutory baseline).

FEMP manages a portfolio of deployment activities, including alternative financing, direct technical assistance, training and information, publication of an annual report to Congress, and procurement recommendations. In addition, it has set stringent energy intensity and GHG reduction goals for federal facilities.

DOE reports that, based on information from 29 federal agencies, the total primary energy consumed by the federal government in 2002 was 1.4 quads, a reduction of 9.6% or 0.065 quads relative to 1985 (EERE, 2004a). The energy intensity of its standard buildings dropped by 26% in 2002 compared with the FY 1985 baseline year, putting the government generally on track to meet its target for 2005 (EERE, 2004b). Although not all energy savings can be directly attributable to FEMP's portfolio of deployment activities (DOE assesses that 50% of savings are due to FEMP's leadership), over the past 20 years of activities, FEMP's annual investment of approximately $25 million in 2002 saved 0.58 quads of energy and 11.5 MMTC.

### 5.5 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 advances are incremental and have a high probability of commercial success over the next decade (such as low-cost compact fluorescents and greater building automation). Other 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 (Stringer and Horton, 2003).

The fragmented and highly competitive structure of the building sector and the small size of most builders and A/E firms discourage 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% of revenues on R&D, compared with 3.5% for the overall U.S. economy (Business Week, 1995). 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 (Dooley, 1998). 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 numerous groups conclude that federal R&D programs play a critical a role in financially supporting and coordinating building research among the various participants (OTA, 1992; SEAB, 1995).

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 (National Research Council, 2001). This study concludes that energy efficiency research at DOE has produced significant 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: advanced refrigerator/freezer compressors, electronic ballast for fluorescent lamps, and low-E glass, which saved 4.7 quads of energy and 80 MMTC. On an annual basis (over a 23-year period), these impacts amount to 0.20 quads and 3.48 MMTC. These three technology development efforts account for a small fraction of the $2 billion (averaging $46.3 million annually, in 1999$) 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 produce a greater return, it is not possible to determine if there would be an increasing or decreasing rate of return on the investment. R&D into more efficient community designs and urban forms is also warranted, targeting 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.

Emerging energy-efficient technologies have been identified in past studies by the American Council for an Energy-Efficient Economy (Sachs et al., 2004). Five such technologies were recently evaluated in detail by Oak Ridge National Laboratory scientists (Hadley et al., 2004):

- **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, hot water, dehumidification—and packaged combined heat and power technologies that integrate multiple energy services into single pieces of equipment to lower cost and increase efficiency)
- **Efficient operations technologies** (information 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% of the forecasted energy consumption and carbon emissions forecasted for the building sector in that year. 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.

### 5.6 The potential for reduced emissions

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 and potential impacts of these policies (Table 1). It also characterizes the benefits that could be achieved by extending and expanding these policies into the future.

In summing the estimates in Table 1, consider that to some extent, the R&D and six deployment policies overlap, causing total savings to be lower. This double counting results from the fact that several of the programs address overlapping markets and technologies (e.g., some utility-based financial incentive programs subsidize appliances that are also labeled and promoted by the ENERGY STAR® Program.) The amount of overlap is limited by the generally distinct nature of the programs—e.g., addressing new homes with building codes versus existing homes with weatherization assistance; eliminating the worst-performing appliances from the market with performance standards vs. improving the efficiency of available products through R&D). In addition, supplemental funding could substantially improve the effects of many of these programs, causing total savings to be greater than the sum of the experiences to date. For example, the Weatherization Assistance Program is currently only able each year to retrofit the homes of a small fraction of eligible households. 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 3.9 quads and 75 MMTC, representing 13% of U.S. $CO_2$ emissions 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 210 MMTC avoided, representing 23% of the forecasted energy consumption and carbon emissions of buildings in the United States in 2025. 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) (Brown et al., 2001; Koomey et al., 2001). However, the carbon reductions (238 MMTC) are almost identical. The 25-year 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 comparable carbon reduction estimates (Brown et al., 2001; Koomey et al., 2001).

## 6 Conclusions

The analysis presented in this paper leads to several conclusions that can be summarized by 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. R&D on advanced building technologies 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.  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 could begin to displace the GHG-intensive structures that embody today’s standard practices. 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. 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.

By mid-century, green building practices and smart growth policies could transform the built environment. At that time, locationally efficient communities and urban systems could have as large an impact on GHG emissions as improving the design, construction, and operation of individual structures by using ultra-low GHG technologies.

The temporal phasing of possible impacts (from retrofitting the existing building stock, to constructing net zero-energy buildings, and ultimately to improving the locational efficiency of communities and urban systems) does not mean that retrofit versus new construction and land-use policies should be staged. To achieve significant GHG reductions by mid century, all three elements of an integrated policy approach must be strengthened in the near term.

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**Table 1. 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 [b]** |
|---|---|---|---|---|---|
| ***Regulation*** | | | | | |
| Building codes | 0.154 (1998) | 3.55 | $8 (1998$) | 0.59 (2016) | 13.6 |
| Appliance and equipment efficiency standards | 1.2 (2000) | 25 | $14–$18 (2002$) | 5.27 (2020) | 88 |
| | | | | | |
| ***Financial incentives*** | | | | | |
| Utility-based financial incentive programs | 0.626 (2000) | 10.2 | NA | 0.626 (2020) | 10.2 |
| Low-income weatherization assistance | 0.061 (2002) | 0.52 | $141 (2002$) | 0.061 (2020) | 0.52 |
| | | | | | |
| ***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 | 0.58 (2002) | 11.5[2] | $25 (2002$) | 0.58 (2020) | 11.5[2] |
| | | | | | |
| ***Research and Development*** | | | | | |
| Federal funding for buildings energy R&D | 0.20 (1978–2000) | 3.28 | $46.3 (1999$) | 4.2 (2025) | 71 |
| | | | | | |
| **Totals** | 3.9 (variable) | 75 | | 12 (variable) | 212 |

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., 2016 is the midpoint of a 30-year range.
[b] Preliminarily based on the carbon content of the energy saved by the ENERGY STAR Program.

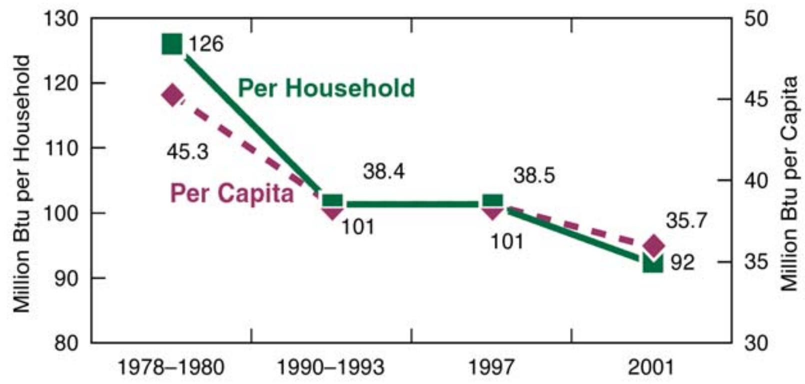



**Figure 1. Declining Primary Energy Consumption per Household**

Sources: Rawlings and Saluter, 1995; 2. U.S. Census Bureau, 2002; 3. U.S. Census Bureau, 2004;

EIA, 2003a; EIA, 2004b

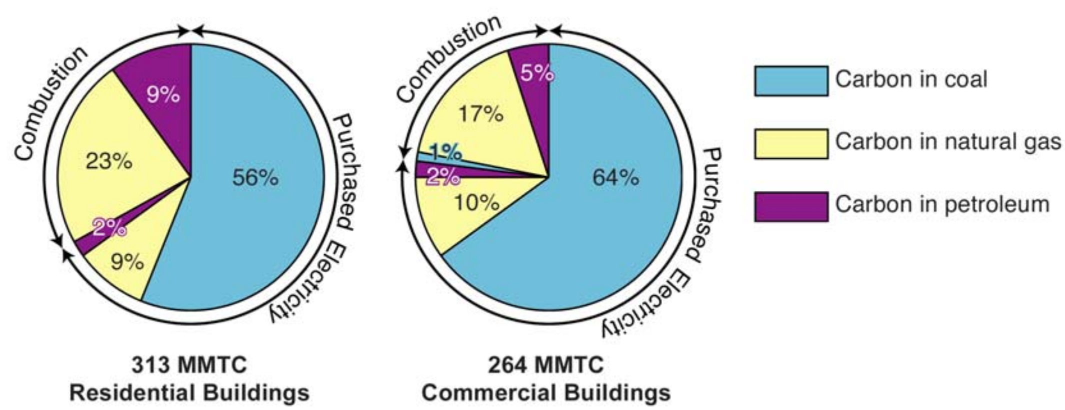
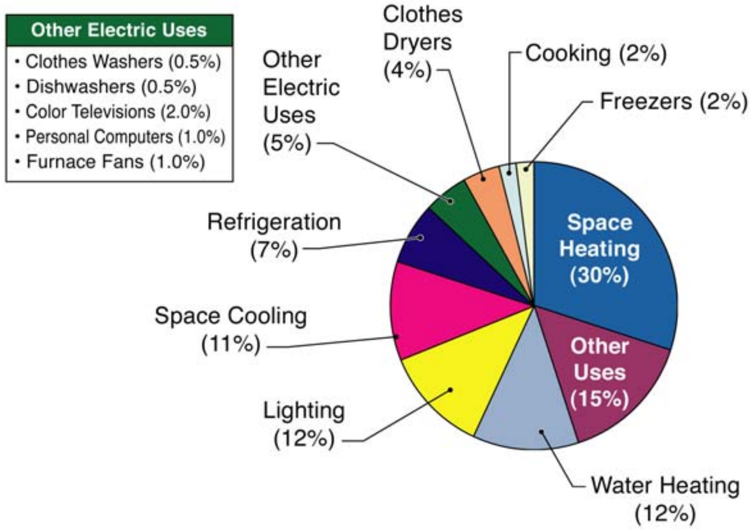



**Figure 2. $CO_2$ Emissions from U.S. Residential and Commercial Buildings,**

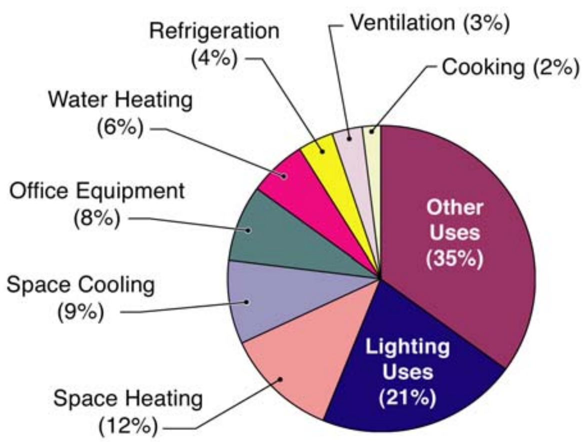
**by Energy Source, 2002**

Source: Based on U.S. EPA. 2004, p. 3-4, 3-7, and 3-17, tables 3-3, 3-6, and 3-10.




**Residential Buildings (Total Quads: 20.9)**

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.




**Commercial Buildings (Total Quads: 17.4)**

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

**Figure 3. Primary Energy Consumption in Residential and Commercial Buildings, 2002**

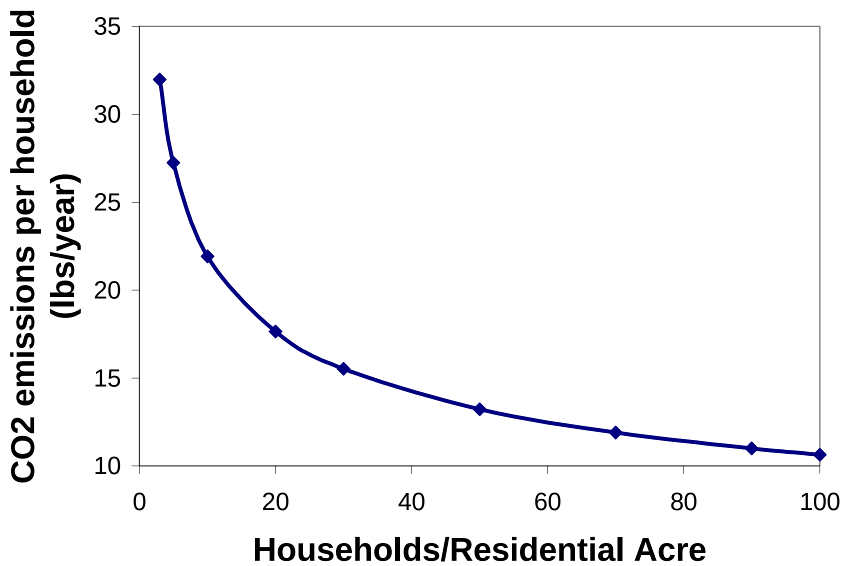



**Figure 3. Impact of Residential Density on Travel-Related $CO_2$ Emissions**

Source: Computed using the calculator found at http://www.sflcv.org/density/index.html

(San Francisco League of Conservation Voters website) (assumes 28 lbs/gal of gasoline)