Chapter 4

BUILDINGS SECTOR[1]

4.1 INTRODUCTION AND BACKGROUND

This chapter describes our detailed assessment of the achievable potential for reducing building sector carbon dioxide emissions in 2010 and 2020. We calculate dollar, energy, and carbon savings associated with adoption of more energy-efficient technologies, and explicitly define a set of policies and programs that would lead to this outcome. This chapter also assesses the potential role of research and development (R&D) in providing advanced building technologies and practices that will enable continued reduction in energy use and greenhouse gas emissions.

4.1.1 Overview of Sector

Energy is used in buildings to provide a variety of services such as space heating, space cooling, water heating, lighting, refrigeration, and electricity for electronics and other equipment. In the U.S., building energy consumption accounts for a little more than one-third of total primary energy consumption and related greenhouse gas emissions. The cost of delivering all energy services in buildings (such as cold food, lighted offices, and warm houses) was about $240 billion in 1997 (US DOE, 1999).

About two-thirds of building sector primary energy use is electricity, and this sector uses about two-thirds of all electricity generated nationally. Natural gas accounts for about one quarter of total primary energy in this sector, and electricity and natural gas account together for about 90% of building sector primary energy use. Oil consumption is only 4% of the total, although it is a significant heating fuel in the Northeast.

4.1.2 Buildings Sector Primary Energy Use in 1997

Fig. 4.1 shows the percentage breakdown of primary energy use by end-use in residential and commercial buildings. The breakdown of carbon emissions by end-use tracks the primary energy breakdown closely. Space heating is by far the largest identified end-use in the residential sector, accounting for just over one-third of the primary energy. Water heating is next, followed by refrigerator/freezers space cooling, and lighting. The “miscellaneous uses” category contains a variety of smaller end-uses, including clothes washers, dishwashers, home electronics, and all the other unidentified energy end-uses[2].

In the commercial sector, lighting accounts for about one quarter of total primary energy use, and is far and away the largest identified end-use in this sector. Space heating is next, followed by office equipment, cooling, and water heating. The “miscellaneous uses” category contains cooking, transformers, traffic lights, exit signs, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses. It also includes an adjustment term to ensure that the total commercial sector energy use adds up to the totals reported in EIA’s State Energy Data Report.

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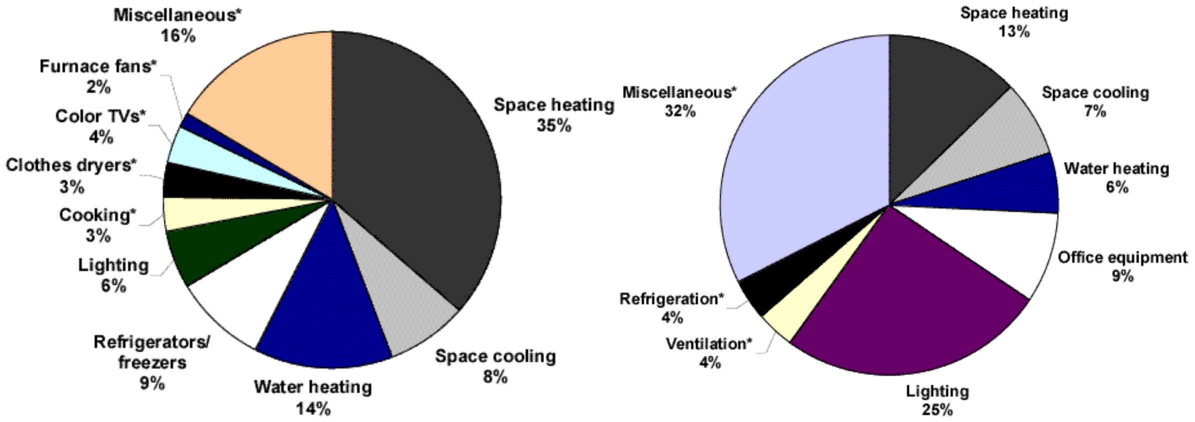
[2] More details on the constituents of the “all other” category (as used in Tables 4.8 and 4.9) and “miscellaneous uses” category can be gleaned from tables in Appendices B-1, C-1, and D-1.

Fig. 4.1 Primary Energy Consumption in the Buildings Sector by End Use, in 1997



Residential Buildings Total Primary Energy Use in 1997 = 19.0 quads	**Commercial Buildings** Total Primary Energy Use in 1997 = 15.2 quads
Constituents of the "All other" category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include clothes washers, dishwashers, other home electronics, ceiling fans, pool pumps, and other unidentified end-uses.	Constituents of the "All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. "Miscellaneous uses " include transformers, traffic lights, exit signs, cooking, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses.

This energy portrait in 1997 will of course not remain static in the next two decades, and that has important implications for energy policy design. EIA projects in its Reference Case Forecast, for example, that demand for personal computing and office equipment services in the commercial sector will result in energy increases of over 2% per year. By contrast, EIA also projects sharp *decreases* in home energy use for refrigeration and freezers, due to implementation of standards and technological improvements. These projected shifts mean that by 2020 energy demand for refrigeration will have fallen to 4% of total use (versus 9% now), while energy use for commercial office equipment will increase its share from 9 to 12% of that sector by 2020.

4.1.3 Technology Opportunity Examples

The fundamental insight driving the analysis in this report is that people don’t demand energy, per se. Instead, they demand warm rooms, cold beer, clean dishes, and hot food. It is widely known that technology can vastly decrease energy use, while still delivering these same services (or even better services) and saving consumers money. More recently, it has become clear that that systematic implementation of programs and policies (like ENERGY STAR® programs, Green Lights, Building America, Rebuild America, government procurement, and minimum efficiency standards) can help cost-effective efficiency technologies to be purchased when they would not have been implemented otherwise (ACEEE, 1998; Koomey et al., 1996 Koomey et al., 1998a; Webber and Brown, 1998).

4.2 BUSINESS-AS-USUAL CASE

The building sector uses the AEO99 reference case (US DOE, 1998a) as our business-as-usual (BAU) case, which is summarized in Tables 4.6 and 4.7 below. By 2020 in the BAU case, primary energy use in buildings grows by 37% and carbon emissions grow by 48% over 1990 levels. Compared to 1997 levels, primary energy use grows by 20%, and carbon emissions grow by 31%. The greater growth in carbon emissions is caused by a shift towards more carbon intensive electricity end-uses by the end of the forecast.

The AEO99 reference case contains assumptions about the effect of current policies. Minimum efficiency standards now on the books are included in the reference case, but no additional standards beyond those already enacted are assumed. The standards in the AEO99 case include the refrigerator, freezer, and room air conditioner (RAC) standards for which DOE has enacted final rules. Their date of implementation is October 1, 2000 (for RAC) or July 1, 2001 (for refrigerators and freezers), although in the AEO99 forecast they are modeled for convenience as being effective on January 1, 2001 and 2002, respectively.

The residential sector forecast includes significant increases in the thermal integrity of new homes caused by improvements in building codes and technology. This assumption is one that EIA is revisiting for the AEO2000 forecast.

The AEO99 case also includes EIA's estimates of the effects of the Clinton Administration's Climate Change Action Plan and the 1992 Energy Policy Act (EPACT). These two policies are projected to promote building code adoption, consumer labeling of efficient products, efficiency standards for equipment, energy-efficient mortgages, restructuring of the electric utility industry (which affects electricity prices for buildings), and voluntary programs that promote energy efficiency.

4.3 POLICY IMPLEMENTATION PATHWAYS

Students of end-use markets have long been puzzled by the lack of adoption of ostensibly cost-effective energy efficiency technologies. A rich literature has developed around this question, and analyses of various barriers to adoption of efficiency technologies are widespread (DeCanio, 1993; DeCanio, 1998; Fisher and Rothkopf, 1989; Golove and Eto, 1996; Hirst and Brown, 1990; Howarth and Andersson, 1993; Jaffe and Stavins, 1994; Koomey, 1990; Koomey et al., 1996; Lovins, 1992; NPPC, 1989; Oster and Quigley, 1977; Sanstad and Howarth, 1994; Sanstad et al., 1993). Various policies have been implemented over the past twenty years to ameliorate or sidestep these barriers, and we develop our policy pathways based on that program experience supplemented by professional judgment. We develop both moderate and advanced pathways, as discussed below.

4.3.1 Barriers to Adoption of Cost-Effective Efficiency Technologies

The barriers that inhibit adoption of cost-effective technologies can be broken down into those faced by users, and those faced by manufacturers, builders, designers and suppliers of efficient products.

4.3.1.1 Barriers faced by energy users

Organizations and individuals face a variety of complex barriers to choosing the most cost-effective efficiency option, which vary by user, technology, and end-use[3]. The list below is not comprehensive but illustrative of the kinds of constraints that users face. Each particular transaction is affected by different barriers, and this complexity has made it difficult for researchers to assess the effect of these barriers in a comprehensive way.

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[3] For a review of many of these reasons, see Stephen DeCanio, "Why do profitable energy-saving investment projects languish?" *Journal of General Management*, Vol. 20, No. 1 (Autumn 1994):62-71, and "Barriers within firms to energy-efficient investments," *Energy Policy* (September 1993): 906-914 .

Not knowing. It is impossible for a utility customer, even one who carefully reads her bills, to determine the contribution of various appliances to the total bill (the bills do not separate the cost for lighting from that for refrigeration or cooking). Attaching individual electricity meters to particular appliances is extremely rare, so that the consumer finds herself in a "supermarket without prices:" the user collects all the purchases in their shopping cart and gets one lump-sum bill to pay at the end of the month, with no separate accounting. No consumer can optimize when she doesn't know the price of purchasing a service.

Universal metering by appliance is unlikely to come about any time soon, but the ENERGY STAR label and wide distribution of energy information can help ameliorate this problem. Efficiency standards also mitigate this problem to some degree. As information and metering technologies become more widespread, this problem will become less important, but it will be many years before these technologies will have a significant effect on ameliorating this barrier.

Not caring. In most cases, energy is a small part of the cost of owning and operating a device or building, so the potential energy savings will not "make or break" the firm or make a family rich[4]. For example, before the advent of the ENERGY STAR television (TV) program, typical TVs with remote controls used 5 to 7 watts when turned off because a small amount of standby power is necessary to turn the TV on. TVs that qualify for ENERGY STAR must achieve standby power of three watts or less, a savings of roughly 50%. About ten major manufacturers now offer such TVs. When Sony examined their TV models, the company was able to reduce their standby power from 7-8 watts to about 0.6 watts. While a large savings in percentage terms, even this 90+% reduction will only save about $5 per year per TV. If implemented for all TVs across the U.S., the total savings would be hundreds of millions of dollars per year, but the cost per TV is so low that it would be hard to imagine consumers lobbying TV manufacturers to reduce the standby power of their units.

Since energy costs are typically small on an individual basis, it is easy (and rational) for consumers to ignore them in the face of information gathering and transaction costs. However, the potential energy, dollar, and emissions savings can be important when summed across all consumers, which is why government agencies like EPA and DOE work directly with manufacturers to improve the efficiency of their products. A little work to influence the source of mass-produced products can pay off in significant efficiency improvements and emissions reduction that rapidly propagate through the economy due to mass production and distribution. These programs eliminate the information and transaction costs that impede adoption of efficiency technologies without the program.

Unable to find out. Wise purchases are based on reliable and easily accessible information. Determining which energy efficient products are cost-effective and reliable is not a trivial task. Consumers and managers have limited time and attention, and they are not generally energy experts, so it's difficult for them to separate the winners from the losers. While these costs are a normal part of markets, they can be reduced or eliminated by centralized information collection and dissemination by a credible source (such as EPA, DOE, non-profit organizations, state energy offices, *Consumer Reports*, or electric utilities).

Can't raise the money. Many consumers and industries face capital constraints in pursuing those energy efficiency improvements that require additional incremental investment. These constraints surface as short payback time requirements for investments (2-3 years), or an inability to even consider investing due to lack of money. Creating attractive financing options that improve the consumer's monthly cash flow is one strategy that has proven successful in promoting the EPA's ENERGY STAR new homes program to builders and consumers.

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[4] Of course, for low-income families, the cost of energy can be a very significant part of their income. In this case capital constraints and information are more important barriers to promoting energy efficiency than "not caring".

Split incentives. Whenever the purchaser or operator of an appliance is not the same person who pays for the electricity, the incentive for considering efficiency can be diluted or eliminated. Landlords who pay the energy bills have no control over their tenants' energy use. Alternatively, if tenants pay the bills, then landlords will likely invest in improving energy efficiency only if it will improve tenant retention, justify higher rents, or increase the value of the property upon resale. For these latter conditions to hold there needs to be an objective way to measure the energy efficiency of a building, a situation that only exists in the few jurisdictions where home energy ratings are commonplace, and is rarer still in commercial buildings. Split incentives are particularly difficult to ameliorate, but minimum efficiency standards have been effective in counteracting them.

In residential buildings, about one-third of all households rent. About 90% of all multifamily households rent, which makes this barrier particularly important in this segment of the market.

4.3.1.2 Barriers faced by manufacturers, builders, designers, and suppliers

Energy-aware consumers may never even be offered energy-efficient products if manufacturers choose not to produce them, so it's important to understand the barriers manufacturers face in producing such goods. By the same token, a lack of consumer demand can also inhibit manufacturers from incorporating more efficiency into their products (If the customers don't ask for it, why deliver it?). This lack of demand can be a direct result of the long list of consumer barriers reviewed above. This "chicken and egg" problem is one that can be influenced by policies.

Reluctance to change. An important barrier is inertia. If a TV's power supply has worked well for ten or twenty years, why "rock the boat" with a new design, especially when the public is not clamoring for change? The introduction of ENERGY STAR, however, created a different dynamic. The marketing advantage of having a "green" product is brought to the attention of the marketing branch of the corporation, and these marketers become the advocates within that company for design changes that will make their jobs easier. As long as the new technology is at least as reliable and capable as that it replaces (and there's no reason why it shouldn't be) then the ENERGY STAR method for removing barriers can work well. In fact, reexamining time-honored choices about product design usually leads to increased product functionality and cost savings as well.

Inability to capture all benefits of research and development. If a company spends money on research and development (R&D) to create new products, they can reap some, but not all of the benefits from such innovation. As soon as the company creates a new product, competitors can copy those designs, without having to spend their own money on R&D. This situation leads to under-investment in R&D from society's perspective, which is the main justification for government sponsored R&D. This problem afflicts all sectors of the economy, and it is widely recognized by economists and public policy analysts around the world.

The problem is especially pronounced when an industry is as fragmented as the design and construction industries (Brambley et al. 1988). Oster and Quigley (1977), discussing R&D in the residential construction industry, state that

> "Small scale may be particularly problematic if many of the potential innovations in the industry are in organization, systems design, and in the integration of housing components. Here the minimum efficient scale for R&D activity is presumably rather large, and, more importantly, the returns to R&D are not easily captured by a single firm."

Fragmentation of the industry is also a problem in the commercial buildings sector, with the design and engineering of buildings split between many small design firms.

In addition, there is a longer-term public-purpose aspect to R&D. Certain kinds of long-term basic and applied research is unlikely to be funded by industry, because the payoff will be so far into the future. Government R&D can and does focus on many technologies that will not be cost effective for years, yet may be strategically important decades hence. Historical support for fuel cells and photovoltaics falls into this category.

Design and production cycles. Product design cycles can also slow the pace of innovation. Until a product has "run its course" and repaid the initial investment, most manufacturers are justifiably reluctant to modify production lines. These cycles have become shorter and shorter in recent years due to the growing impact of information technology, but they can be important in particular instances. By working with manufacturers to accommodate their design cycles, EPA has successfully encouraged dozens of them to incorporate efficiency into their next product cycle, while minimizing any transition costs for altering products.

Perverse fee structures. Lovins (1992) describes how typical fee structures for engineers and architects penalize efficiency. Lovins interviewed more than fifty design professionals and analysts of the design process, and documented a market rife with inefficiency and "perverse" incentives. These inefficiencies are driven mainly by the difficulty of creating optimized, custom-built buildings systems in the face of persistent institutional failures.

Lovins analyzes the prevailing fee structures of building design engineers, which are explicitly or implicitly based on a percentage of the capital cost of the project. The reason why fee structures like this one are pernicious is because good design for heating, ventilation, and air-conditioning (HVAC) systems will allow substantial reductions in capital costs *and* operating costs. Such design requires additional expenditures beyond the typical "rule-of-thumb" equipment sizing that most engineers do, which results in a net penalty for designers of efficient systems:

> "Designers who do extra work to design and size innovative HVAC systems exactly right, thereby cutting their client's capital and operating costs, are directly penalized by lower fees and profits as a result, in two different ways: they are getting the same percentage of a smaller cost, and they are doing more work for that smaller fee, hence incurring higher costs and retaining less profit (Lovins, 1992)."

The innovation stifling effects of such fee structures are reinforced by the obligations of professionals, as codified in law. Burnette (1979a, 1979b) points out that the judgement of a particular professional "need not be infallible, just reasonable within the norms established by the judgements and practices of other qualified professionals." Such a standard (and associated litigation) "leads to defensive design and institutionalized conformity" (Lovins, 1992). Use of inaccurate rules of thumb regarding equipment sizing[5], as well as those related to setting fees, are both expressions of that conformity.

Lovins shows how, even though this type of fee structure has been strongly discouraged in the U.S. since the early 1970s (through the threat of anti-trust action against the professional associations), the practice has been eliminated in name only: "both the designer and procurer of design services still generally base their fee *negotiation* on percentage-of-cost curves, just as if nothing had changed. In low-rise office

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[5] Since HVAC systems are typically oversized by factors of two and three, these rules of thumb (coincidentally or not) increase the designers profits because of fee structures based on the capital costs of the project.

projects, for example, 70% of U.S. designers estimate their fees as a percentage of project cost, even though only 15% bid them in that form; for low-rise hotels, 100% vs. 50%; for apartments, 50% vs. 5%."

4.3.2 Policies to Remove Barriers

Policies to remove barriers and reduce energy costs, energy use, and carbon emissions in buildings fall into nine general categories: voluntary programs, building efficiency standards, equipment efficiency standards, state market transformation programs, financing, government procurement, tax credits, accelerated R&D, and carbon trading systems. Each policy may affect residential buildings, commercial buildings or both, and each ameliorates specific market barriers that inhibit the adoption of cost-effective efficiency improvements. Tables 4.1 and 4.2 (below) summarize which barriers and end-uses (respectively) can be affected by each policy. The specific policies we consider are described in detail in Appendix B-1. Not all policies discussed here are used in our scenarios.

Table 4.1 Carbon Mitigation Policies and Which Barriers They Can Affect

Barrier	Policy Type								
	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Domestic Carbon Trading
SCENARIO	B	B	B	B	B	B	B	B	A
Barriers faced by users									
Not knowing	X	X	X	X			X		
Not caring	X	X	X	X					
Unable to find out	X	X	X	X			X		
Can't raise the money				X	X		X		
Split incentives		X	X						
Barriers faced by manufacturers, builders, designers, & product suppliers									
Reluctance to change	X	X	X			X			X
Inability to capture all benefits of R&D								X	
Design and production cycles	X							X	
Perverse fee structures					X		X		

(1) "B" under scenario signifies "both," "M" signifies Moderate Scenario only, "A" signifies Advanced Scenario only.

Voluntary Programs. Major voluntary buildings-sector programs in the U.S. include the ENERGY STAR programs operated by EPA and DOE, and the Building America and Rebuild America programs run by DOE. Programs exist for both residential and commercial products and buildings. The ENERGY STAR product programs are structured as labeling programs. Identifying high efficiency products for consumers is only one aspect of the program, however. The programs has also been effective in working with manufacturers to convince them to promote existing and develop new energy-efficient products.

Table 4.2 Carbon Mitigation Policies and Which End-Uses and Technologies They Can Affect

End-Use/Technology	Policy Type								
	Voluntary Programs	Building Codes	Equipment Standards	State Market Transformation Programs	Financing	Government Procurement	Tax Credits	Accelerated R&D	Domestic Carbon Trading
SCENARIO	B	B	B	B	B	B	B	B	A
Thermal Shell-Res. Retrofits	X	X		X	X	X	X	X	X
Thermal Shell-Res. New	X	X		X	X		X	X	X
Thermal Shell-Comml Retrofits	X	X			X		X	X	X
Thermal Shell-Comml New	X	X			X		X	X	X
Residential HVAC equipment	X		X	X	X		X	X	X
Commercial HVAC equipment	X	X	X	X	X	X	X	X	X
Residential Ducts				X	X		X	X	X
Commercial Ducts					X		X	X	X
Residential Water Heating	X		X	X	X		X	X	X
Commercial Water Heating	X	X	X		X	X	X	X	X
Residential Refrigeration	X		X	X				X	X
Commercial Refrigeration	X	X		X		X		X	X
Cooking Equipment			X					X	X
Laundry	X		X	X				X	X
Dishwashers	X		X					X	X
Residential Lighting	X			X				X	X
Commercial Lighting	X	X	X	X		X		X	X
Televisions	X								X
PCs	X					X			X
Office Equipment (not PCs)	X					X			X
Motors	X	X	X	X		X		X	X
Transformers	X		X					X	X
Water Conservation Measures		X	X				X		X
Residential Miscellaneous	X			X				X	X
Commercial Miscellaneous	X		X	X		X		X	X
District Energy Systems with Combined Heat and Power				X		X	X	X	X
Fuel cells				X		X	X	X	X

(1) "B" under scenario signifies "both", "M" signifies Moderate Scenario only, "A" signifies Advanced Scenario only.
(2) Fuel cells, district energy systems, shell retrofits, and state market transformation programs for new residential shells are not included in current scenarios.

ENERGY STAR's residential programs are all structured as labeling programs, even the ENERGY STAR new homes program for residential buildings. In this program, EPA works with builders to increase the construction of high efficiency homes, which can then be marketed using the ENERGY STAR label. Residential products covered by ENERGY STAR programs include residential HVAC equipment, insulation, windows, residential lighting fixtures, clothes washers, dishwashers, room air conditioners, refrigerators, televisions, VCRs, home audio equipment, and home computers. Future product programs may include other consumer electronics and water heaters. Also in development is a program aimed at existing homes.

Commercial products covered by the ENERGY STAR labeling programs include PCs, monitors, copiers, printers, fax machines, multi-function devices, exit signs and transformers.

Some commercial sector ENERGY STAR programs operate differently from equipment labeling programs, relying on high level corporate commitments and public recognition of participating corporations to promote cost-effective efficiency investments. The commitment of the chief executive of a company to these programs allows program champions within the organization to beat back institutional inertia and cut through red tape to make these investments happen. ENERGY STAR's commercial buildings programs are the ENERGY STAR Building program and the ENERGY STAR Small Business program, which focus on improving the energy efficiency of existing buildings by working with and educating building managers and business owners.

The DOE's Building America program is a private/public partnership that applies a systems-engineering approach to the design and construction of production housing. The goals of the partnership include producing homes on a community scale that use 30% to 50% less energy than those built to code at no incremental cost, reducing construction time and waste by as much as 50%, and improving builder productivity. The systems engineering approach considers the interaction between the building site, envelope, and mechanical systems, as well as other factors. It recognizes that features of one component in the house can greatly affect others and it enables the teams to incorporate energy-saving strategies at no extra first cost.

Rebuild America is a voluntary program that stimulates energy efficiency upgrades in existing commercial buildings, new education buildings, and existing high rise residential buildings. DOE supplies technical support and State Energy Offices supply limited financial support. Its goal is to reduce energy use and bills in such buildings by 20-30%.

Building Codes. The most important efficiency code for new low-rise residential buildings is the International Code Council's Model Energy Code, which is periodically reviewed and updated. In residential buildings, the focus is primarily on the building shell, although codes may also affect HVAC equipment and lighting.

The most important energy conservation standard for new high-rise residential and commercial buildings is that issued by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and by the Illuminating Engineering Society of North America (IESNA). In the summer and fall of 1999, these organizations approved a new standard for commercial and high-rise residential buildings, ASHRAE/IESNA Standard 90.1-1999. This standard, which will be published in February 2000, will then be available for adoption by federal, state and local government agencies into building codes. Standard 90.1-1999 is an update of the previous Standard, ASHRAE/IESNA Standard 90.1-1989, (issued in 1989), and will produce substantial savings relative to it, according to ASHRAE.

In our analysis, however, our "baseline" energy standard is the 1989 version, the operative commercial building standard available to us while this report was being written. (ASHRAE issued final approval of the 1999 version in late October 1999). The 1989 standard is referenced in the Energy Policy Act of 1992, which directs the states to demonstrate that its commercial energy codes meet or exceed ASHRAE Standard 90.1-1989.

For the Moderate and Advanced scenarios, we developed an altogether different commercial standard to capture the energy savings potential inherent in commercial building standards. We didn't use ASHRAE/IESNA 90.1-1999, because most of its energy savings potential, which is in lighting, will be captured first by another policy instrument, namely the promulgation of minimum efficiency standards for fluorescent ballasts in 2004 (as we assume in our Moderate and Advanced scenarios).[6] Instead, we assume in our Moderate and Advanced scenarios that a new commercial standard is developed and adopted that features a 15% “whole building” reduction target. This standard, by design, is not prescriptive, and allows builders and designers maximum flexibility in reaching the target. Advances in handheld computer technology will facilitate adoption of and compliance with this new standard.

Equipment Standards. Equipment standards require that all new equipment sold meet minimum energy-efficiency standards. Water conservation measures, such as low-flow showerheads and faucets, are also considered since they reduce water-heating energy. The appliance standards considered here are based on three pieces of legislation: the National Appliance Energy Conservation Act of 1987 (NAECA), which addresses primarily residential appliances, the 1988 amendments to NAECA, which address magnetic fluorescent ballasts, and the Energy Policy Act of 1992 (EPACT), which primarily addresses commercial products.

In the residential sector, NAECA standards are currently in place for residential refrigerators and freezers, water heaters (gas, oil and electric), clothes washers, clothes dryers, dishwashers, heat pumps, central air conditioners, room air conditioners, furnaces (gas and oil), and boilers (gas and oil). EPACT set water conservation standards for showerheads and faucets that reduce residential hot water use. DOE periodically updates NAECA standards. Tighter standards are anticipated for residential clothes washers, water heaters, heat pumps and central air conditioners between 2000 and 2006, with some updates to follow in 2010.

In the commercial sector, EPACT set standards for lamps (4- and 8-foot fluorescent lamps and incandescent reflector lamps), motors (1-200 horsepower), and commercial heating and cooling, including packaged air-cooled air conditioners and heat pumps, packaged water-cooled air conditioners and heat pumps, packaged terminal air conditioners and heat pumps, water heaters, furnaces and boilers. The showerhead and faucet standard also affects commercial hot water use. The only commercial products covered under NAECA, fluorescent lamp ballasts, currently are subject to a standard that prevents sales of the lower efficiency core-coil magnetic ballasts (high-efficiency magnetic ballasts can still be sold). We assume in our scenarios that DOE will enact a revised standard for ballasts that takes effect in 2004.

State Market Transformation Programs Funded Through “Public Benefits (Line or pipe) Charges.” State Market Transformation programs are quite diverse. As implemented in states that are experimenting with deregulation, they involve a small charge (1-2%) on every kWh that is transmitted across the grid (they could also in principle be applied to natural gas as well). Payment of the charge would be a precondition for interconnecting with the grid. This money then goes into a fund to pay for energy efficiency and renewable technology implementation programs.

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[6] In Fall 1999 (after the analysis for this study had been completed), efficiency advocates and ballast manufacturers negotiated an agreement that would result in an efficiency standard eliminating most U.S. magnetic ballast manufacturing by April 1, 2005 (except for ballasts manufactured as replacements for existing equipment), and eliminating all such manufacturing by July 1, 2010. The U.S. Department of Energy accepted this negotiated agreement in its Congressionally mandated standards-setting process.

Such programs can focus on new construction or on retrofits and replacements. State new construction programs can affect the thermal shell, HVAC, water heating and lighting, and may influence fuel choice for HVAC, water heating, cooking, and dryers. For existing homes, utilities have weatherization programs focusing on the building shell, rebates for high-efficiency HVAC, appliances and lighting. Rebates may also be used to subsidize fuel switching for hot water heating or conversion from electric resistance central furnaces to heat pumps.

Financing. An important subset of State Market Transformation Programs and some ENERGY STAR programs is special financing to spread the incremental investment costs over time and reduce the first cost impediment to adoption of energy efficient technologies. The ENERGY STAR new homes program, for example, already offers preferential financing that improves monthly cash-flow for purchasers of ENERGY STAR homes. These financing packages can apply to those end-uses that are structural parts of the building, like HVAC, thermal shell, and water heating.

In commercial buildings, Energy Savings Performance Contracting (ESPC) is another way to use creative financing to promote efficiency investments. In such contracts, an energy service company guarantees a fixed amount of energy cost savings throughout the life of the contract (typically 5 to 12 years, and up to 25 years for Federal government contracts) and is paid directly from those cost savings. The organization that owns the facility retains the remainder of the energy cost savings for itself.

Government Procurement. Procurement policies have the potential to accelerate the adoption of new technologies, and also directly save money for the government. Procurement can reduce costs for new technologies by allowing manufacturers to acquire production experience with them and hence “move down the learning curve”. In 1997 the Federal Acquisition Regulations were amended, directing that “agencies shall implement cost-effective contracting preference programs favoring the acquisition of...products that are in the upper 25 percent of energy efficiency for all similar products” (FAR, sec. 23.704). In addition, EPA and DOE are currently working to encourage state and local governments to reform their own purchasing practices to encourage adoption of more energy efficient devices. Another program that falls under this general category is the Federal Low Income Weatherization Program, which improves the energy efficiency of qualifying residences. We treat procurement policies as a key enabling program (particularly for ENERGY STAR) that are implicit in the Moderate and Advanced Scenarios, but we do not explicitly estimate their effects.

Tax Credits. We consider the effect of tax credits for high-efficiency equipment, as described in President Clinton’s Climate Change Technology Initiative. This initiative, first laid out in January 1998 and updated in Spring 1999, proposed tax incentives for efficient natural gas water heaters, electric central air conditioners, electric heat pumps, residential-sized heat-pump water heaters, and natural gas heat pumps. It also proposed tax credits for fuel cells, new homes with efficiencies that significantly exceed current building standards, rooftop photovoltaic systems, and solar water heating systems.

Accelerated R&D. R&D is an important enabling policy. The effect of accelerated R&D on the costs and potentials for efficiency improvements has been included in a schematic way in our analysis. This policy measure applies to all end-uses where public-private R&D partnerships can be effective in improving the rate of technological change associated with the energy efficiency of these products. We exclude office equipment, televisions, and other electronic equipment from this policy, because these technologies change at such a rapid rate, and because this industry's lifeblood is R&D and innovation. Some longer-term basic research in semiconductor physics may assist this industry, but such basic research is not included in our scenarios.

We assessed roughly twenty different key R&D technologies for buildings (see the following box), and of those chose five to represent whatever technologies are likely to be successful in a well designed R&D portfolio (whole buildings R&D for residential buildings, whole buildings R&D for commercial buildings, mini-HID lamps for residences, CFL torchiere lamps, and heat pump water heaters). It is impossible to say whether these particular options are the ones that will be successful, but we believe that these five are a good proxy for those that would be successful. The details of how we modeled the effects of this policy are contained in the appendices, but in summary, we lowered costs for these technologies and assessed the additional market penetration associated with such cost reductions.

R&D Options for the Buildings Sector

*Systems integration in new construction (including community scale)
Improved industrialized housing methods
Fully integrated service module development
Phase change thermal storage
Integrated photovoltaic construction
Superinsulating materials
Electrochromic and other efficient window technologies
*“Smart Buildings” (advanced sensors, energy control and monitoring systems
Health impacts identification and mitigation
Characterization of energy efficiency - worker productivity interactions
PEM fuel cell adaptation for buildings
Small gas turbine applications for combined heat and power production
Advanced refrigeration components, refrigerants, lubricants and materials
Improved understanding and characterization of combustion processes
Advanced desiccants
Large commercial chiller improvements
*Residential heat pump water heater development
Residential absorption heat pump
VHF light sources
*Mini HID lamps
*Improved compact fluorescent lamp (CFL) torchieres
Improved lighting distribution systems
Building commissioning

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* indicates that R&D for this technology was included in the CEF building sector scenarios.

Carbon Trading System. This cross-cutting policy is implemented for all sectors in the Advanced Scenario. It reduces carbon emissions by promoting energy efficiency and fuel switching to less carbon intensive fuels.

4.3.3 Definition of Pathways

Our policy pathways combine many (but not all) of the policies discussed above in both Moderate and Advanced Scenarios. The Moderate Scenario presumes modest progress in implementing those policies and programs. The Advanced Scenario assumes that significant implementation effort beyond the Moderate case. In addition, the Advanced Scenario contains a \$50/t carbon permit trading fee that reflects the adoption of an emissions trading system for carbon and other greenhouse gases. The content of these scenarios is summarized in Table 4.3. Appendices B-1 and C-1 contained detailed information about policies and technologies in each scenario.

Creating scenarios entails judgment. No one can forecast the future with certainty, and many of the relevant parameters are simply not known. We made judgments that we felt were plausible, based on the analysis teams' considerable experience in this area. Penetration rates in particular were usually developed in this manner, after reviewing the literature on experience with related programs and policies. We documented our assumptions in the appendices.

4.4 METHODOLOGY FOR ANALYZING IMPACTS

We rely on a three-step process for creating our analysis: first, we assess the potential impact of individual policies on energy demand in detailed spreadsheets. Then we change hurdle rates (implicit discount rates) and other parameters inside the buildings sector modules of CEF-NEMS (our version of the National Energy Modeling System)[7] so that the model mimics the energy savings calculated from the spreadsheets when these modules are run in stand-alone mode (equipment efficiency standards were implemented directly in the CEF-NEMS modules). Finally (for the Advanced Scenario only) we add a carbon permit trading fee of \$50/t and the CEF-NEMS modules respond to that fee using the modified hurdle rates, reflecting a policy and market environment that is working towards substantial carbon reductions. This procedure follows that used in the earlier study by Koomey et al. (1998b).

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[7] As in other parts of this report, we use the term “CEF-NEMS” to refer to the NEMS model as modified for our policy analyses, and use the term “NEMS” whenever we discuss issues generic to the NEMS model in all its incarnations. The complete list is as follows: (AHAM, 1997; Anderson, 1999; Appliance, 1996; Appliance, 1998; Atkinson, 1996; Auten, 1999; Barbour, 1998; Barnes et al., 1996; Barnes et al., 1997; BCAP, 1999; BEA 1998; Berry, 1991; Berry, 1993; Berry, 1996; Berry et al., 1997; Brinch, 1996; Brown, 1993; Brown et al., 1998; Calwell, 1999; Davis Energy Group, 1994; ELPN et al., 1998; Energy Center of Wisconsin, 1997; EPRI, 1987; Eto et al., 1994; Eto et al., 1995; Geller et al., 1998, Geller et al. 1987; Gregerson, 1994; Haasl and Sharp, 1999; Hughes and Shonder, 1998; Jakob et al., 1994; Johnson et al., 1994; Katz and Warren, 1996; Kinney et al., 1997; Koomey et al., 1991; Koomey et al., 1994; Koomey et al., 1999a; Koomey et al., 1999b; Krause et al., 1989; LBNL, 1996; LBNL, 1997; Levine et al., 1995; Meier et al., 1993; Mills, 1991; Mr. Cool, 1998; Nadel, 1991; Nadel, 1992; Nadel et al., 1998; Nadel and Ticknor, 1992; Parker et al., 1999; Petrie and Childs, 1998; Richey, 1999; Richey and Koomey, 1998; Sanchez et al., 1998; Sezgen et al., 1995; Stern et al., 1985; Su and Zambrano, 1999; Suozzo and Nadel, 1998; Tomlinson and Rizy, 1998; Train et al., 1985; US Bureau of the Census, 1997; US Bureau of the Census, 1998; US DOE, 1990; US DOE, 1993a; US DOE, 1993b; US DOE, 1995a; US DOE, 1995b; US DOE, 1998b; US DOT, 1999; US EPA, 1999a; US EPA, 1999b; US EPA, 1999c; Vine and Harris, 1988; Vineyard et al., 1997; Vorsatz and Koomey, 1999; Wenzel et al., 1997; Westphalen et al., 1996; XENERGY, 1996).

Table 4.3 Buildings Sector Policies, By Scenario

Moderate Scenario	Advanced Scenario
➢ Expand voluntary labeling and deployment programs such as ENERGY STAR, Building America, PATH, Rebuild America to increase the penetration of efficient technologies in the market and to raise the efficiency level for certain programs.	➢ Enhanced programs more penetration, more covered end-uses
➢ Increase enforcement and adoption of current building codes	➢ Same, but adding a new more stringent residential building code in 2009 that is gradually adopted by states in preference to the less stringent codes that already exist.
➢ Implement new efficiency standards for equipment beyond those already planned.	➢ More end-uses covered. Another round of standards for some products.
➢ Line charges for states implementing electricity restructuring (full national utility restructuring by 2008)	➢ Higher line charges for states implementing electricity restructuring (full national utility restructuring by 2)
➢ Government procurement assumed to increase in scope over current efforts. Increase DOE's Federal Energy management Program (FEMP) efficiency goals by executive order. Adopt renewable power purchase requirement for Federal facilities. (1)	➢ Significant efforts beyond moderate case, including more rapid implementation of FEMP efficiency goals and faster expansion of ENERGY STAR purchasing to state and local governments as well as large corporations. Adopt more stringent renewable power purchase requirement for Federal facilities. (1)
➢ Implement tax credits as proposed by Clinton Administration	➢ Same credits but with longer time periods before phase out. Size of tax credit increased for heat pump water heaters as well.
➢ Expand cost-shared federal R&D expenditures by 50%.	➢ Double cost-shared federal R&D expenditures, leading to greater cost reductions, more advanced technologies, more penetration associated with R&D.
	➢ Domestic carbon trading system with assumed permit price of $50 per metric ton of carbon, announced in 2002 and implemented in 2005

(1) Unlike other policies enumerated here, we do not explicitly model government procurement policy in this analysis. However, we recognize it here as an important and strategic enabling policy that is essential for the voluntary programs to achieve their estimated penetration levels.

4.4.1 Overall Approach

The most challenging part of this analysis is estimating the impact of policies on the market penetration of technologies under our Moderate and Advanced scenarios over the next two decades. To accomplish this difficult task, we use our best qualitative judgement, based on our collective experience with buildings efficiency programs, because there is simply no "scientific" means for predicting the precise impacts of most policy measures.

With respect to research and development, for example, the predictive challenge is aptly captured by the President's Committee of Advisors on Science and Technology (PCAST) in their report, *Federal Energy Research and Development for the Challenges of the Twenty-First Century* (PCAST 1997). PCAST frames the challenges as follows:

> "how much can energy R&D contribute to (national goals)…as a function of time and in relation to the sums invested? It is difficult, indeed impossible, to offer any precise answers to this question, not least because the answers depend strongly on the outcomes of R&D (by the nature of such activity) which cannot be predicted in detail." (page 1-16)

But while the precise prediction is not possible, the basic relationship between resources and outcomes is evident: "The evidence from all of these historical approaches supports the proposition that the leverage of R&D, against the challenges facing the energy system, is likely to be large." (PCAST, page 1-17) And the empirical record of Federal buildings energy efficiency research is compelling, with development of a number of high-performance technologies, including low-emissivity window coatings, high-efficiency refrigerator compressors, and fluorescent lamp electronic ballasts, all of which are widespread products in today's marketplace.

With respect to predicting the future impacts of voluntary information programs on consumer choice, there is also great uncertainty. As a recent U.S. DOE report observes of information and education policies:

> "…the ability of information programs to induce actual changes…depends on three factors: the extent to which the information is applicable to the decisions at hand and considered reliable, the extent to which the information identifies previously unknown cost-effective opportunities or positive product attributes, and the extent to which it is acted upon." (US DOE 1996, p. 3-17).

Establishing robust parameters for any one of those factors is challenging, but it is especially daunting to establish a firm causal link between the information provided, "and the extent to which it is acted upon."

Nonetheless, to illustrate the potential impacts of policies in the year 2015 such as advanced technology tax credits for heat pump water heaters, ENERGY STAR buildings, and accelerated research and development, one must make transparent, well-documented, and defensible assumptions about program impacts, and that is what we did.

4.4.2 Details of the Analysis of Policies Outside of CEF-NEMS

Our spreadsheet analysis of the buildings sector relies for its basic structure on the spreadsheet analysis documented in the study *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy Technologies by 2010 and Beyond* (Interlaboratory Working Group 1997). We updated the spreadsheets to reflect some of the improvements in the NEMS Annual Energy Outlook forecast since that study was published, including detailed breakdowns of the residential and commercial miscellaneous end-uses, explicit accounting for halogen torchieres in lighting, and extension of the analysis period to 2020.

The spreadsheets rely on careful stock accounting for buildings and equipment, and detailed characterizations of the technoeconomic potential for efficiency improvements by end-use, based on the latest technology data. Efficiency improvements are characterized in terms of the percentage savings that are cost effective relative to typical new equipment purchased in 2000, and a cost of conserved energy ($/kWh or $/Mbtu) for purchasing those efficiency options.

The technology and program effectiveness data for the building sector relies on a huge variety of sources. We combine information from these sources with experience and judgment to create the policy scenarios.

The calculations are carried through for each technology at a low level of disaggregation. Estimated energy savings per unit for each appliance are multiplied by the number of efficient units expected to be shipped in a given year, accounting for expected program penetrations and retirements and growth in the number of households and floor area of commercial buildings. These savings are then aggregated over all the end-uses to estimate the total savings for a given fuel type in each scenario. Details on the assumptions and calculation methods are contained in Appendices B-1 and C-1. Because of their importance to the overall results, we summarize equipment efficiency standards included in our scenarios in Table 4.4.

In the real world, only some fraction of this technoeconomic potential can be captured with real programs and policies. The original interlaboratory analysis of buildings used overall achievable fractions of 35% and 65% for the efficiency and high-efficiency/low carbon cases, respectively, implying that 35% or 65% of the technoeconomic potential could be captured in practice by 2010. In this analysis, we derive these implementation fractions by end-use by explicitly characterizing the pathways for specific policies. We also derive a program implementation cost, based on recent program experience. These key data are summarized in Table 4.5. The details of these calculations are contained in Appendices B-1 and C-1, and an end-use by end-use breakdown of these results is shown in Appendix D-1.

The achievable fractions in 2010 for residential and commercial buildings are about one-quarter in the Moderate Scenario, and around one-third in the Advanced Scenario. By 2020, as a result of stock turnover and advances in technology brought about by policies and programs, these achievable fractions go up to around forty percent in the Moderate Scenario and to over fifty percent in the Advanced Scenario. While the aggregate achievable fractions in this study never reach the 65 percent used in the advanced case for the interlaboratory analysis, the CEF analysis surpasses the 35 percent achievable fraction assumed in that study's efficiency scenario by 2020 in both the Moderate and Advanced Scenarios.

Table 4.4 Summary of New Equipment Efficiency Standards by Scenario

Sector	*Equipment type*	*Year*	*Efficiency/ Energy units*	*Baseline efficiency*	*Standard efficiency*	*Scenario*
Residential	CAC	2006	SEER	10.42	12	M,A
	ASHP heating	2006	HSPF	7.17	7.4	M,A
	ASHP cooling	2006	SEER	10.89	12	M,A
	RAC	2001	EER	9.1	9.7	M,A
	RAC	2010	EER	9.7	10.5	M,A
	Refrigerator/freezer	2010	kWh/year	665	495	M,A
	Refrigerator/freezer	2010	kWh/year	495	421	A
	Freezers	2010	kWh/year	455	391	M,A
	Freezers	2010	kWh/year	391	290	A
	Gas water heater	2004	EF	0.54	0.62	M,A
	Dishwasher	2010	kWh/year	496	431	A
	Televisions	2010	kWh/year	184	146	A
	Clothes washer	2004	Modified EF	0.817	0.961	M
	Clothes washer	2007	Modified EF	0.961	1.362	M
	Clothes washer	2004	Modified EF	0.817	1.362	A
Commercial	Packaged AC	2005	EER	9.4	10.3	M
	Packaged AC	2005	EER	9.4	10.3	A
	Packaged AC	2010	EER	10.3	11	A
	Fluorescent Ballasts	2004		Typical in 2000	Electronic	M,A

(1) CAC = Central Air Conditioner, ASHP = Air Source Heat Pump, RAC = Room Air Conditioner, AC = Air Conditioner, SEER = Seasonal Energy Efficiency Ratio, HSPF = Heating Seasonal Performance Factor, EF = Energy Factor.

(2) The baseline efficiency shown above is the average efficiency of new units in 2000, except for the 2010 standards for RACs, Refrigerator/freezers, and Freezers, where the baseline efficiency is the previous standard level. The projected efficiency of average new units in the year a particular standard comes into force is correctly analyzed in our scenario calculations, but for simplicity's sake, we show the year 2000 new unit efficiency in this table.

(3) Standard for televisions affects standby power only, reducing it to 3W.

(4) In Scenario column, 'M' stands for Moderate and 'A' stands for Advanced.

(5) The standard levels and timing of equipment efficiency standards shown in this table represent the authors' best judgment of feasible and cost effective standards for the two main scenarios considered in the study. They should in no way be construed to represent the position of the U.S. DOE on these standards, which will only be officially determined after appropriate rulemaking procedures are followed.

Table 4.5 Summary of Buildings Sector Program Effectiveness and Costs, by Scenario and Fuel

	Technoeconomic potential % savings relative to business as usual case		*Achievable percentage of technoeconomic potential*		*Technology cost*	
Sector & fuel	***2010***	***2020***	***2010***	***2020***	***$/MBtu 2010***	***$/MBtu 2020***
Residential--Moderate						
Electricity	28%	37%	28%	45%	6.00	5.46
Natural gas	5%	12%	21%	22%	2.11	2.27
Oil	6%	13%	0%	0%	N/A	N/A
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	21%	24%	36%	5.23	4.88
Residential--Advanced						
Electricity	28%	37%	34%	65%	5.43	4.31
Natural gas	5%	12%	28%	36%	2.48	1.95
Oil	6%	13%	0%	18%	N/A	1.88
LPG	6%	13%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	14%	21%	31%	55%	5.13	4.00
Commercial--Moderate						
Electricity	19%	26%	37%	54%	7.45	7.53
Natural gas	16%	26%	22%	25%	1.60	1.43
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	27%	37%	6.13	6.19
Commercial--Advanced						
Electricity	19%	26%	42%	62%	7.14	7.13
Natural gas	16%	26%	29%	40%	1.59	1.57
Oil	16%	26%	0%	0%	N/A	N/A
Other	0%	0%	N/A	N/A	N/A	N/A
Total	17%	25%	33%	48%	5.43	5.32

(1) Technology cost is the total incremental investment cost for the more efficient option, annualized and expressed as a Cost of Conserved Energy (CCE). CCEs are calculated using a real discount rate of 7% and lifetimes as shown in Appendix C-1.

(2) Technoeconomic potential savings and CCEs for electricity are expressed in terms of site energy at 3412 Btus/kWh, so no electricity supply side effects are included.

(3) All costs are in 1997 dollars.

(4) Program implementation costs of $0.6/MBtu of fuel and $1.7/Mbtu of site electricity are used (corresponding to $0.6/Mbtu of primary energy for electricity), as described in Chapter 1.

4.4.3 Modeling the Scenarios in CEF-NEMS

The revised analysis spreadsheets incorporate these parameters, and then yield energy savings by end-use in 2010 and 2020 for residential and commercial buildings in the Moderate and Advanced Scenarios. To match the CEF-NEMS projection in our scenarios to our detailed spreadsheet forecasts of energy savings by end-use and technology, we changed hurdle rates, technology costs, and growth trends for each end-use. We directly input the equipment efficiency standards to the CEF-NEMS buildings sector modules. These changes reflect the effect of a variety of non-energy-price policies that eliminate many of the barriers to investing in cost-effective efficiency technologies.

We match the CEF-NEMS run for each building sector module run in “stand-alone” mode against the spreadsheet results. The fuel price interactions in the integrated runs would make it difficult to exactly match against the spreadsheets. Running the CEF-NEMS modules in stand-alone mode eliminates this complexity. Appendix A-1 contains information on how we modified the CEF-NEMS input files and code to reproduce the energy savings from the spreadsheets.

On the demand side, NEMS interprets a series of “hurdle rates” (sometimes referred to as “implicit discount rates”) as a proxy for all the various reasons why people don't purchase apparently cost-effective efficiency technologies in the building sector. They include constraints for both the consumer (purchasing) and for the supplier (product manufacturing and distribution). Among the constraints are transaction costs, manufacturer aversion to innovation, information-gathering costs, hassle costs, misinformation, and information processing costs. The hurdle rates embody the consumers’ time value of money, plus all of the other factors that prevent the purchase of the more efficient technologies. In this regard, the NEMS modeling framework follows a long and rich history in the economics of energy efficient technology adoption (DeCanio 1998, Howarth and Andersson 1993, Howarth and Sanstad 1995, Koomey et al. 1996, Meier and Whittier 1983, Ruderman et al. 1987, Sanstad et al. 1993, Train 1985).

In the residential and commercial sectors, for example, the financial component of the reference case hurdle rate is about 15 percent (in real terms) with the other institutional and market factors pushing such rates to well above 100 percent for some end-uses. In our scenarios, we reduce the hurdle rates as appropriate for many end-uses to reflect the policies described above. When we reduce the hurdle rates in the CEF-NEMS model, we are increasing the responsiveness of the model to changes in energy prices. This change accurately (though indirectly) reflects a world in which aggressive programs and policies remove barriers to adoption of energy-efficient technologies.

In the advanced scenario, the $50/t carbon permit trading fee is modeled directly in the CEF-NEMS model, and the building sector modules respond using the revised hurdle rates that we input to those modules. The $50/t fee corresponds to about a 10% increase in base year electricity prices, and a 15% increase in natural gas prices, not accounting for price effects from fuel switching caused by the fee.

4.5 POLICY SCENARIO RESULTS

4.5.1 Overview

The results for our two policy scenarios are summarized in Tables 4.6-4.11 and in more detail in Appendix D-1. Energy and carbon emissions savings are dominated by those from electric end-uses. Carbon savings reflect savings in primary energy as well as the savings from fuel switching and other effects on the electricity supply side (which are driven by the carbon permit trading fee and other policies). Relative to the BAU case, absolute savings in primary energy are larger in the residential sector than in commercial buildings, for both Moderate and Advanced Scenarios. In percentage terms, the largest primary energy savings accrue in lighting (both residential and commercial), in residential “all other”, and in residential space cooling.

In the Moderate Scenario in 2020, primary energy savings in buildings sector electricity are about one-fifth lower than site energy savings in percentage terms, indicating that the changes on the electricity supply side actually decrease the conversion efficiency of power generation. In the Advanced scenario in 2020, primary energy savings in buildings sector electricity are roughly nine percent higher than site energy savings in percentage terms, indicating a small improvement in conversion efficiency on the electricity supply side.

We can also decompose the carbon savings in electricity in the Advanced Scenario in 2020. About half of total buildings electricity-related carbon savings in 2020 in this scenario is attributable to demand-side efficiency improvements, while the other half is attributable to fuel switching and efficiency improvements on the electricity supply-side. Supply side fuel switching is about ten times more important than supply side efficiency improvements in reducing carbon emissions in this scenario.

4.5.2 Moderate Scenario

By 2010, total primary energy use in the building sector grows about 9% in the Moderate Scenario compared to 1997 levels, and grows to about 11% over 1997 levels by 2020, compared to growth of about 12% in the BAU case in 2010 and 20% by 2020. Carbon emissions are reduced compared to the BAU case, but without the effect of the carbon permit trading and other supply-side policies on the electricity sector fuel mix, carbon emissions in the building sector still increase after 2010. The total cost of delivering energy services, accounting for bill savings and the costs of efficiency programs and investments, is reduced by about one tenth relative to the BAU case in both 2010 and 2020.

4.5.3 Advanced Scenario

In the Advanced Scenario, primary energy use in 2010 is just above 1997 levels, and by 2020 it declines a bit relative to 2010. This result reflects the significantly greater commitment to carbon reductions in the Advanced Scenario. Carbon emissions decline significantly, and are below 1990 levels by 2010, and well below 1990 levels by 2020. A large fraction of this decline is the result of the electricity supply-side policies discussed in Chapter 7, but the remainder is attributable to the set of programs and policies described in detail in Appendices B-1 and C-1. The total cost of delivering energy services, accounting for bill savings and the costs of efficiency programs and investments, goes up by 2% relative to the BAU case in 2010, and down by 4% in 2020. In 2010, the carbon permit fee increases overall energy prices more than the efficiency programs reduce energy use, while in 2020, the energy savings are large enough to more than offset the increase in prices associated with the carbon permit fee.

Table 4.6 Primary Energy Use by Scenario and Fuel in the Buildings Sector

			2010					**2020**				
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	Q	**Q**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**
Residential												
Primary Electricity	10.2	11.7	13.8	13.1	-5.1%	12.1	-12.3%	15.4	13.3	-13.3%	11.2	-27.4%
Natural gas	4.5	5.2	5.5	5.5	-0.5%	5.2	-5.2%	6.0	5.9	-1.7%	5.5	-8.0%
Oil	0.8	0.9	0.7	0.7	0.0%	0.7	-4.1%	0.7	0.7	1.5%	0.6	-6.2%
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	-4.7%	0.4	0.4	0.0%	0.4	-2.6%
Other	0.7	0.8	0.7	0.7	0.0%	0.7	0.0%	0.8	0.8	1.3%	0.8	-1.3%
Total primary	16.7	19.0	21.2	20.5	-3.4%	19.2	-9.6%	23.2	21.1	-9.2%	18.5	-20.5%
Commercial												
Primary Electricity	9.3	11.0	12.8	12.3	-4.4%	11.4	-11.2%	13.8	12.3	-10.8%	10.8	-22.1%
Natural gas	2.8	3.4	3.9	3.8	-2.6%	3.7	-4.9%	4.0	3.8	-6.5%	3.7	-8.4%
Oil	0.5	0.5	0.3	0.4	5.9%	0.3	-5.9%	0.3	0.3	9.7%	0.3	-16.1%
Other	0.4	0.3	0.3	0.3	0.0%	0.3	0.0%	0.3	0.3	0.0%	0.3	0.0%
Total primary	13.0	15.2	17.3	16.7	-3.7%	15.7	-9.5%	18.5	16.8	-9.4%	15.1	-18.6%
Total Buildings												
Primary Electricity	19.6	22.8	26.6	25.3	-4.7%	23.5	-11.7%	29.2	25.7	-12.1%	22.0	-24.9%
Natural gas	7.4	8.5	9.4	9.3	-1.4%	8.9	-5.1%	10.0	9.7	-3.6%	9.2	-8.2%
Oil	1.3	1.4	1.1	1.1	1.9%	1.0	-4.7%	1.0	1.0	4.2%	0.9	-9.4%
LPG	0.4	0.4	0.4	0.4	0.0%	0.4	-4.7%	0.4	0.4	0.0%	0.4	-2.6%
Other	1.1	1.1	1.1	1.1	0.0%	1.1	0.0%	1.1	1.1	0.9%	1.1	-0.9%
Total primary	29.8	34.2	38.5	37.1	-3.6%	34.8	-9.5%	41.7	37.8	-9.3%	33.5	-19.7%
Site Electricity												
Residential	3.15	3.65	4.58	4.27	-6.8%	4.07	-11.1%	5.28	4.44	-15.9%	3.94	-25.4%
Commercial	2.88	3.45	4.27	4.02	-5.9%	3.84	-10.1%	4.76	4.10	-13.9%	3.80	-20.2%
Total	6.03	7.10	8.85	8.29	-6.3%	7.91	-10.6%	10.04	8.54	-14.9%	7.74	-22.9%

(1) BAU = Business-As-Usual Scenario; Q = quadrillion Btus of primary energy.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ (change) is relative to the BAU scenario in that year.

(4) Electricity primary energy savings include both demand-side efficiency and supply side effects. For example, in the Advanced scenario in 2020, primary energy savings in buildings sector electricity are roughly nine percent higher than site energy savings in percentage terms, indicating a small improvement in conversion efficiency on the electricity supply side.

Table 4.7 Carbon Emissions by Scenario and Fuel in the Buildings Sector

				2010						*2020*		
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	MtC	**MtC**	**MtC**	**MtC**	**% Δ**	**MtC**	**% Δ**	**MtC**	**MtC**	**% Δ**	**MtC**	**% Δ**
Residential												
Primary Electricity	162	182	226	203	-10.0%	159	-29.5%	255	212	-16.5%	128	-49.6%
Natural gas	66	74	80	79	-0.6%	76	-5.0%	86	85	-1.5%	79	-8.1%
Oil	17	20	15	15	0.0%	15	-3.3%	14	14	0.5%	13	-6.0%
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	-1.0%	7	-2.4%
Other	3	1	1	1	0.0%	1	0.0%	1	1	0.0%	1	0.0%
Total primary	253	286	330	307	-7.0%	258	-21.6%	363	320	-12.0%	229	-37.0%
Commercial												
Primary Electricity	148	172	210	191	-9.4%	150	-28.5%	228	196	-14.0%	123	-46.0%
Natural gas	41	49	55	54	-2.3%	53	-4.5%	58	54	-6.6%	53	-8.4%
Oil	10	14	11	12	3.6%	11	-5.4%	11	11	4.7%	10	-8.5%
Other	7	2	3	3	0.0%	2	-4.0%	3	3	0.0%	3	-3.8%
Total primary	206	237	279	259	-7.4%	216	-22.6%	300	264	-11.8%	189	-37.0%
Total Buildings												
Primary Electricity	311	354	436	394	-9.7%	310	-29.0%	483	409	-15.3%	252	-47.9%
Natural gas	107	123	135	133	-1.3%	129	-4.8%	144	139	-3.5%	132	-8.2%
Oil	26	34	26	27	1.5%	25	-4.2%	25	25	2.3%	23	-7.1%
LPG	6	8	8	8	0.0%	7	-3.8%	7	7	-1.0%	7	-2.4%
Other	10	4	4	4	0.0%	4	-2.6%	4	4	0.0%	4	-2.6%
Total primary	460	522	609	565	-7.2%	475	-22.1%	663	584	-11.9%	418	-37.0%

(1) BAU = Business-As-Usual case. MtC = Million metric tons of carbon emitted per year.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ (change) is relative to the BAU scenario in that year.

(4) Electricity carbon savings include both demand-side efficiency and supply side effects. For example, in the Advanced Scenario in 2020, about half of total buildings electricity-related carbon savings in 2020 is attributable to demand-side efficiency improvements, while the other half is attributable to fuel switching and efficiency improvements on the electricity supply-side.

Table 4.8 Primary Energy Use by Scenario and End-Use in the Buildings Sector

			2010					*2020*				
Sector & fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	Q	**Q**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**	**Q**	**Q**	**% Δ**	**Q**	**% Δ**
Residential												
Space heating	5.1	6.9	6.9	7.0	1.1%	6.7	-3.7%	7.2	7.3	0.8%	6.7	-7.1%
Space cooling	1.7	1.5	1.7	1.6	-3.8%	1.4	-15.7%	1.8	1.5	-14.0%	1.3	-26.8%
Water heating	2.4	2.6	2.7	2.5	-4.6%	2.4	-11.4%	2.8	2.5	-10.4%	2.3	-18.5%
Refrigerators/ freezers	2.2	1.6	1.1	1.0	-3.9%	1.0	-6.8%	1.0	0.9	-8.7%	0.8	-19.3%
Lighting	1.0	1.1	1.2	1.2	-3.3%	1.0	-13.6%	1.3	1.2	-12.6%	0.9	-30.2%
All other	4.4	5.3	7.7	7.1	-7.0%	6.7	-12.7%	9.0	7.6	-15.4%	6.4	-29.3%
Total	16.7	19.0	21.2	20.5	-3.4%	19.2	-9.6%	23.2	21.1	-9.2%	18.5	-20.5%
Commercial												
Space heating	1.9	1.9	1.9	1.9	-0.7%	1.8	-7.4%	1.9	1.9	-3.5%	1.7	-10.9%
Space cooling	1.8	1.1	1.1	1.0	-12.2%	0.9	-17.2%	1.1	0.9	-15.2%	0.8	-22.5%
Water heating	1.1	0.9	1.0	0.9	-6.0%	0.9	-8.7%	0.9	0.9	-6.8%	0.9	-9.8%
Office equipment	0.6	1.3	1.9	1.9	3.2%	1.8	-1.2%	2.2	2.3	4.8%	2.2	-3.7%
Lighting	3.7	3.9	3.9	3.7	-3.9%	3.4	-11.9%	3.9	3.4	-12.8%	2.9	-25.2%
All other	3.8	6.1	7.6	7.3	-4.5%	6.9	-9.7%	8.4	7.4	-12.4%	6.6	-21.9%
Total	13.0	15.2	17.3	16.7	-3.7%	15.7	-9.5%	18.5	16.8	-9.4%	15.1	-18.6%

(1) BAU = Business-As-Usual Scenario. Q = Quadrillion Btus of primary energy.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ is relative to the BAU Scenario in that year.

(4) Electricity carbon savings include both demand-side efficiency and supply-side effects, as discussed in the notes to Table 4.6.

(5) “All other” in residential includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans. It also includes the CEF-NEMS residential “other uses” category, which consists of unidentified uses.

(6) “All other” in commercial includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration. It also includes the CEF-NEMS commercial “other uses” category, which consists of unidentified uses and other miscellaneous energy use.

Table 4.9 Carbon Emissions by Scenario and End-Use in the Buildings Sector

			2010					*2020*				
Sector & Fuel	***1990***	***1997***	***BAU***	***Moderate***		***Advanced***		***BAU***	***Moderate***		***Advanced***	
	MtC	***MtC***	***MtC***	***MtC***	***% Δ***	***MtC***	***% Δ***	***MtC***	***MtC***	***% Δ***	***MtC***	***% Δ***
Residential												
Space heating	79	99	98	98	-0.1%	90	-8.3%	103	102	-0.2%	88	-14.3%
Space cooling	27	23	27	25	-8.7%	18	-32.2%	29	24	-17.2%	15	-49.1%
Water heating	36	39	41	39	-6.8%	34	-18.5%	44	39	-11.8%	32	-28.6%
Refrigerators/ freezers	35	25	18	16	-8.8%	13	-25.0%	17	15	-12.1%	9	-44.1%
Lighting	15	17	20	18	-8.3%	14	-30.5%	22	19	-15.9%	11	-51.6%
All other	60	82	125	111	-11.7%	89	-29.0%	148	121	-18.5%	74	-49.8%
Total	253	286	330	307	-7.0%	258	-21.6%	363	320	-12.0%	229	-37.0%
Commercial												
Space heating	30	32	32	32	-0.6%	29	-10.0%	32	31	-3.4%	28	-14.9%
Space cooling	29	17	18	15	-16.7%	12	-32.9%	18	14	-18.3%	10	-45.4%
Water heating	17	14	15	14	-7.0%	13	-11.8%	15	14	-7.7%	13	-13.5%
Office equipment	10	20	31	30	-2.2%	24	-20.5%	37	37	1.1%	25	-33.2%
Lighting	59	61	64	58	-9.0%	45	-29.1%	64	54	-15.9%	33	-48.1%
All other	61	93	120	110	-8.3%	92	-22.9%	134	114	-15.0%	81	-39.6%
Total	206	237	279	259	-7.4%	216	-22.6%	300	264	-11.8%	189	-37.0%

(1) BAU = Business-As-Usual Scenario. MtC = Million metric tons of carbon emitted per year.

(2) Buildings in the industrial sector are not included in these results.

(3) % Δ is relative to the BAU Scenario in that year.

(4) Electricity carbon savings include both demand-side efficiency and supply-side effects, as discussed in the notes to Table 4.6.

(5) "All other" in residential includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans. It also includes the CEF-NEMS residential "other uses" category, which consists of unidentified uses.

(6) "All other" in commercial includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation, cooking, and refrigeration. It also includes the CEF-NEMS commercial "other uses" category, which consists of unidentified uses and other miscellaneous energy use.

Table 4.10 Penetration Rates by Scenario for Selected Technologies in the Buildings Sector

Sector & technology	*Scenario*	*2000*	*2005*	*2010*	*2015*	*2020*
		% of New Shipments				
Residential						
Heat pump WH	Moderate	0%	5%	7%	11%	15%
	Advanced	0%	5%	10%	21%	31%
Dedicated CFL Lighting Fixtures	Moderate	2%	4%	6%	7%	9%
	Advanced	2%	5%	9%	15%	23%
Horizontal Axis Clothes Washer	Moderate	7%	14%	100%	100%	100%
	Advanced	7%	100%	100%	100%	100%
Commercial						
Electronic ballasts	Moderate	53%	100%	100%	100%	100%
	Advanced	54%	100%	100%	100%	100%
High Efficiency Transformers	Moderate	25%	41%	56%	64%	71%
	Advanced	25%	100%	100%	100%	100%
		% of Equipment Stock				
Residential						
Heat pump WH	Moderate	0%	1%	2%	5%	8%
	Advanced	0%	1%	5%	12%	21%
Dedicated CFL Lighting Fixtures	Moderate	1%	2%	3%	5%	7%
	Advanced	1%	2%	5%	9%	15%
Horizontal Axis Clothes Washer	Moderate	3%	6%	34%	67%	91%
	Advanced	3%	18%	52%	83%	98%
Commercial						
Electronic ballasts	Moderate	30%	55%	82%	98%	100%
	Advanced	31%	58%	84%	100%	100%
High Efficiency Transformers	Moderate	16%	19%	25%	32%	41%
	Advanced	16%	24%	41%	57%	74%

(1) WH = water heater; CFL = compact fluorescent lamp.

Table 4.11 Annual Total Costs of Energy Services by Scenario in the Buildings Sector (B 1997$/year)

		2010					***2020***				
	1997	***BAU/ B$/yr***	***Moderate B$/yr***	***% Δ***	***Advanced B$/yr***	***% Δ***	***BAU/ B$/y***	***Moderate B$/yr***	***% Δ***	***Advanced B$/yr***	***% Δ***
Residential											
Annual fuel cost	137	146	133	-9%	143	-2%	151	132	-13%	132	-13%
Annualized incremental technology cost of energy efficiency	0	0	1.9	N/A	3.8	N/A	0	5.8	N/A	9.1	N/A
Annual program costs to promote energy efficiency	0	0	0.5	N/A	1.0	N/A	0	1.5	N/A	2.7	N/A
Annual total cost of energy services	137	146	136	-7%	148	1%	151	139	-8%	144	-5%
Commercial											
Annual fuel cost	98	103	89	-14%	102	-1%	103	84	-18%	92	-11%
Annualized incremental technology cost of energy efficiency	0	0	2.0	N/A	2.7	N/A	0	4.6	N/A	5.8	N/A
Annual program costs to promote energy efficiency	0	0	0.5	N/A	0.8	N/A	0	1.1	N/A	1.6	N/A
Annual total cost of energy services	98	103	92	-11%	106	2%	103	90	-12%	99	-4%
Total Buildings											
Annual fuel cost	236	249	222	-11%	245	-2%	254	216	-15%	224	-12%
Annualized incremental technology cost of energy efficiency	0	0	4.0	N/A	6.5	N/A	0	10.4	N/A	15.0	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	1.8	N/A	0	2.7	N/A	4.3	N/A
Annual total cost of energy services	236	249	227	-9%	253	2%	254	229	-10%	243	-4%

(1) BAU = Business-As-Usual case.

(2) Buildings in the industrial sector are not included in these results.

(3) Costs for R&D are not included in these sector results, but are included in the aggregate all-sector cost calculations in the summary results chapter.

(4) % Δ (change) is relative to the BAU scenario in that year.

(5) Energy service costs include cost of purchased fuels and electricity (which in the advanced case includes the cost of the carbon permit trading fee), program costs, and the annualized costs of incremental efficiency improvements.

4.6 DISCUSSION OF RESULTS

In this section, we focus on the results in the Advanced Scenario in 2020. The relative comparisons generally apply also to the Moderate Scenario, but where there are salient differences between moderate and Advanced Scenarios (or between 2010 and 2020 results), we note them parenthetically.

4.6.1 Key Technologies

Penetration rates and stock saturations for selected technologies in the two scenarios are shown in Table 4.10. Penetration rates of 100% reflect the imposition of a minimum efficiency standard. For horizontal clothes washers, for example, the efficiency standard mandating their use is assumed to come into force in 2007 in the Moderate Scenario, and in 2004 in the Advanced Scenario.

Each of the technologies in Table 4.10 plays a key role in the scenarios, with the high efficiency electronic ballasts, commercial transformers, and heat pump water heaters being particularly important.

A number of technologies offer the potential to fundamentally alter the current upward trend of buildings energy use over the next several decades, if they are commercialized and widely adopted in the market. The technologies described below illustrate important “breakthrough” potential, but this list is not exhaustive (see the following box), just illustrative (for a more complete inventory, see Nadel et al. (1998). Many of these technologies serve multiple end-uses simultaneously, and are thus difficult to model. They were not explicitly included in the results presented in this chapter (the one exception is that of photovoltaics, which were assessed independently in the electricity sector analysis).

4.6.2 Key Policies

Minimum equipment efficiency standards, voluntary programs, and R&D are the three most important contributors to energy savings, with building codes, tax credits, and incentive programs generally playing a supporting role. (See Table 4.12 below.) Typically, 90 to 95% of the energy savings is attributable to these three types of programs. For electronics end-uses, where rapid technological innovation and proven success of voluntary efforts hold sway, the voluntary programs capture most of the savings. As we expect, R&D grows in importance over time, and has its most significant effects after 2010.

For the residential sector, equipment standards account for between 35 and 50% of projected savings, and for the commercial sector, equipment standards account for about one-third of the savings. Voluntary programs capture about half of the savings in the commercial sector by 2010, but by 2020, this percentage declines to 25 to 35%, in the face of the increases in the effectiveness of whole buildings R&D. Voluntary programs account for roughly 40% of savings in the residential sector for 2010 and 2020 in both scenarios.

The results in Table 4.12 should be used with caution. The effects shown for R&D, for example, are only the direct effects modeled for our five representative technologies. In fact, R&D plays a key enabling role, and the success of other programs and policies in the Moderate and Advanced Scenarios would not be possible without it. In addition, the exact division of savings by policy type is dependent on assumptions and conventions that are arbitrary in some ways. For example, our assumption that equipment standards are implemented before voluntary and incentive programs leads to equipment standards claiming a larger fraction of the savings than they might if we made another (equally arbitrary) assumption about the order of implementation.

Breakthrough Buildings Technologies

- **Fuel cells** convert the chemical energy of a fuel into electricity without the use of a thermal cycle or rotating equipment. The preferred fuel is hydrogen, and fossil fuels must generally be converted to hydrogen before being used. Electric conversion efficiency is about 35-40% and can double in combined heat and power applications. Fuel cells can range in size from 50 watts to 250 kilowatts. Promising technologies include proton exchange membrane, phosphoric acid, and molten carbonate fuel cells.
- **Photovoltaic** cells convert light energy into electricity at the atomic level, at an efficiency of 7%-17%. *Building Integrated Photovoltaics systems* (BIPV) can be combined with roof tiles or other parts of building structures to supplement grid-supplied power, reduce energy costs, and provide emergency back-up power during utility power outages.
- **Microturbines** in the 10-500 kW range are scaled-down versions of the gas turbines that utilities have been using to serve peak loads. Electrical efficiencies could approach 35% under optimum conditions, and, as with fuel cells, those efficiencies roughly double in combined heat and power applications.
- **District Energy Systems with Combined Heat and Power** produce both electricity and usable heat, which results in significant reductions in energy use and emissions. Many existing district energy systems do not now generate electricity, but the potential electricity generation from such combined systems in the U.S. building sector totals about 19 GW by 2010 and 50 GW by 2020. Total primary energy savings for these potentials are 0.3 and 0.8 quads/year, respectively (Spurr 1999).
- **Thermally-Activated Heat Pumps** represent a new generation of advanced absorption cycle heat pumps and chillers for residential and commercial space conditioning. They enable highly efficient heat pump cycles to replace the best natural gas furnaces, reducing energy use by as much as 50%, while also providing gas-fired air conditioning (and lowering summer peaking electric loads).
- **Integrated Electric Multi-Function Heat Pumps** capture the waste heat from space cooling to provide “free” water heating. Savings approach 20-25% relative to an electric resistance water heater and electric heat pump system.
- **Electrochromic Glazing** is currently considered to be the most suitable technology for active energy control in building windows. A multi-layer coating deposited on the glass alters its optical properties depending on the magnitude of the voltage applied to it. Windows can thereby be “switched” on demand from clear to dark – thereby reducing cooling loads and allowing for integration of glazing and lighting systems.

Further reading:

1) *Emerging Energy-Saving Technologies and Practices for the Buildings Sector* (Nadel et al. 1998).
2) *PEM Fuel Cells for Commercial Buildings* (Brown 1998).
3) *Photovoltaics and Commercial Buildings – A Natural Match* (NREL 1998).
4) *District Energy Systems Integrated with Combined Heat and Power* (Spurr 1999) and *Combined Heat and Power: Capturing Wasted Energy* (Elliott and Spurr 1999)
5) Web site for the DOE's Electrochromics initiative: http://windows.lbl.gov/doeeci/

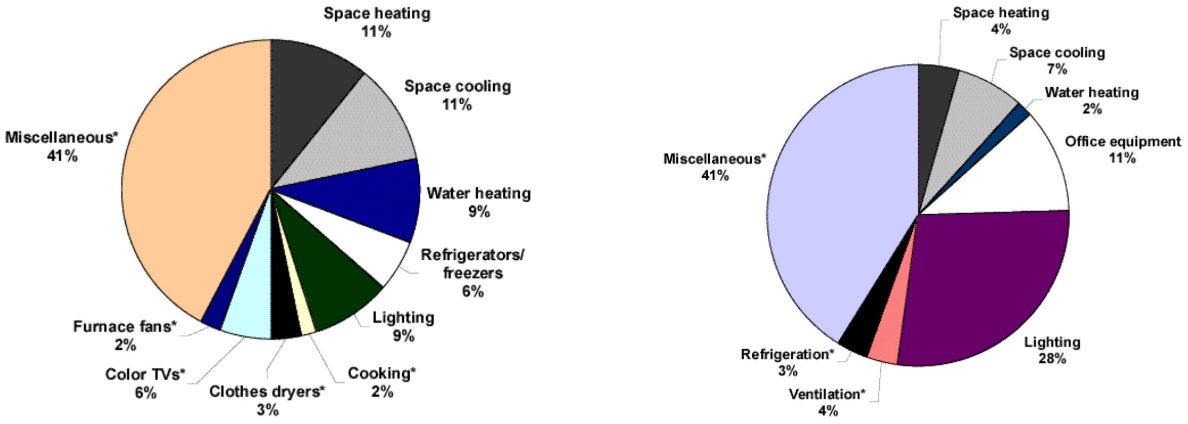
4.6.3 Key End-Uses

In residential buildings by 2020, by far the largest primary energy and carbon savings in absolute terms (relative to the BAU case) occur in the category “all other” uses (see the sum of end-uses with asterisks in Fig. 4.2). Next in rank order are space cooling, space heating, water heating, and lighting. In percentage terms, the largest primary energy and carbon savings occur in lighting, space cooling, and in “all other” end-uses. Recall that “all other” in the residential sector includes many smaller end-uses that are explicitly represented in CEF-NEMS, including cooking, clothes dryers, clothes washers, dishwashers, color TVs, personal computers, and furnace fans, as well as other unidentified uses.

In commercial buildings, lighting and “all other” end-uses dominate the energy and carbon savings in absolute terms, and lighting, cooling, and “all other” end-uses dominate the energy and carbon savings on a percentage basis. “All other” in the commercial sector includes smaller end-uses that are explicitly represented in CEF-NEMS, including ventilation and refrigeration, as well as other unidentified uses.

Even among the end-uses that are not explicitly identified in the CEF-NEMS framework (e.g., “miscellaneous uses”), we analyze potential savings for specific technologies (such as ceiling fans, pool pumps, and home electronics in residential buildings, and transformers, traffic lights, and exit signs in commercial buildings). Savings from reducing standby losses in home electronics are particularly important in residential “miscellaneous uses,” and transformers and exit signs are particularly important in the commercial “miscellaneous uses.” The details of these calculations are contained in Appendices B-1 and C-1.

Fig. 4.2 Carbon Emission Reductions in the Advanced Scenario in 2020, by Buildings End Use
(Reductions are Relative to the Business-as-Usual Forecast)



Residential Buildings

Constituents of the “All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include clothes washers, dishwashers, other home electronics, ceiling fans, pool pumps, and other unidentified end-uses.

Commercial Buildings

Constituents of the “All other” category shown in Tables 4.8 and 4.9 are marked with asterisks above. “Miscellaneous uses” include transformers, traffic lights, exit signs, cooking, district services, automated teller machines, telecommunications equipment, medical equipment, and other unidentified end-uses.

Note: Carbon savings from electrical end-uses include both demand-side efficiency and supply-side effects.

Table 4.12 Share of U.S. Energy Savings by End-use Sector and Policy Type

Year	*Scenario*	*Sector*	*Equipment Standards*	*Building Codes*	*Voluntary Programs*	*State/ Utility Programs*	*Tax Credits*	*R&D (Direct Effects Only)*	*Total*
2010	Moderate	Residential	53%	2%	38%	1%	3%	3%	100%
		Commercial	31%	0%	52%	0%	0%	17%	100%
	Advanced	Residential	45%	3%	38%	1%	9%	5%	100%
		Commercial	28%	2%	49%	0%	0%	20%	100%
2020	Moderate	Residential	47%	4%	38%	1%	1%	9%	100%
		Commercial	29%	2%	34%	0%	0%	35%	100%
	Advanced	Residential	36%	4%	44%	1%	2%	12%	100%
		Commercial	36%	3%	26%	0%	0%	35%	100%

(1) Sector totals weighted by site energy.

(2) Tax credits were not considered for commercial buildings.

4.6.4 High Discount Rate Sensitivity Case

What effect would a higher real discount rate have on the energy savings results reported here? As stated above, we used a 7% real discount rate in the calculations for the building sector. This discount rate reflects typical real interest rates for home mortgages and loans for other major purchases. It also corresponds to the typical rate of return for natural gas and electricity supply side investments over the past few decades, thus making the calculation of costs for energy efficiency options comparable to the costs of the supply-side options that they displace.

As a sensitivity case, we estimated the costs of conserved energy using a 15% real discount rate (a rate which is consistent with purchasing energy-efficient products at credit card interest rates) and recalculated the savings. In this case, total building sector energy savings (expressed either in site or primary energy) are reduced by no more than twenty percent by 2020 in our CEF-NEMS Advanced Scenario. The effect is relatively modest because many of the energy-efficient technologies have CCEs that are significantly lower than the cost of avoided fuels and electricity. The higher discount rate is not enough to push the CCE over the cost of avoided energy in many cases.

4.7 REMAINING ANALYSIS NEEDS

Because of time and resource constraints, many simplifications were necessary in conducting this analysis.

- No savings have been included for commercial building shell measures. Windows strongly influence heating, cooling, and lighting loads in all commercial buildings, and insulation can be important for smaller commercial buildings.
- No savings have been included for residential building shell measures in existing buildings.

- No savings have been included for the advanced cooking technology from Turbochef and Maytag, which reduces oven cooking times by two thirds to three quarters. This device combines microwave and convection oven technologies, and it is expected to become available for both residential and commercial applications by the year 2000.
- No savings have been included for the advanced heat exchanger technology currently being commercialized by Modine, which reduces air conditioner and heat pump energy use by 15-25% and *reduces* the cost of the heat exchanger.
- No savings have been included for distributed generation technologies like fuel cells and micro-turbines, which are likely to be important technologies in buildings in the next twenty years.
- No savings have been included for integrated systems that combine heating and water heating, or heating, cooling, and water heating.
- No savings have been included for large-scale district heating and cooling systems with combined heat and power. Recent analysis (Elliott and Spurr 1999, Spurr 1999) indicates that there is on the order of 20 GW of potential electricity generation for such systems in the U.S. These systems can result in significant carbon savings compared to conventional electricity generation (Krause et al. 1994).
- No savings have been included for large-scale tree planting. More data are needed on the effects of this policy on energy use.
- No savings have been estimated for commercial office equipment beyond the Business-As-Usual case, but opportunities may arise to use additional voluntary programs (similar to the highly successful current ENERGY STAR office equipment program) to promote efficiency as this end-use evolves over the next decade.
- No savings have been included for passive or active solar heating and water heating systems. Such systems have the potential to contribute significant carbon savings by 2020, particularly in the Advanced Scenario.
- No attempt has been made to correct for changes in internal gains associated with energy savings for appliances located within conditioned spaces. Recent work in U.S. commercial buildings (Sezgen and Koomey 1998) indicates that the heating penalties roughly offset the cooling benefits in both primary energy and dollar terms (when averaged across the entire commercial sector). There is no comparable analysis for average residences in the U.S., but an analysis for Europe (Krause et al. 1995) finds that this effect leads to small net energy penalties in residences.
- No attempt has been made to incorporate R&D on building commissioning, which has the potential to reduce operation and maintenance costs for buildings, and significantly improve energy performance.
- Because energy savings from miscellaneous electricity use are so important to the results of the buildings sector, it is crucial that more research be carried out, both to characterize how energy is used in the miscellaneous category and to identify technologies for improving the efficiency of sub-categories within the miscellaneous category of electricity use. The analysis presented here embodies significant improvements in data and analysis from even a few years ago, but more work is urgently needed here.
- The Annual Energy Outlook 1999 progress in new and existing residential shells needs to be investigated. The large increases in the efficiency of residential building shells that exist in the AEO99 reference case are probably too big in a scenario where fuel and electricity prices are flat or declining.

On balance, we believe that adding these items to the analysis would increase savings and decrease costs.

4.8 SUMMARY & CONCLUSIONS

This chapter summarizes the results of two policy scenarios (Moderate and Advanced). The analysis specifies in detail the policies and programs that would be needed to capture the projected energy savings by 2010 and 2020 in these scenarios.

The buildings sector contributes significant energy and carbon savings in the Moderate and Advanced cases. Primary energy savings for the building sector totals about 18% in the advanced case in 2020 relative to the business-as-usual case. Total carbon savings in that year, including both demand and supply-side effects, are almost 40% of business-as-usual emissions. These savings reduce carbon emissions from this sector to below 1990 levels in 2020.

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