CHAPTER 3
ENERGY EFFICIENCY

The most urgent, long-term security requirement for the United States is to reduce our dependence on imported oil by developing clean, safe, renewable energy systems, and energy conservation programs.

Rear Admiral Eugene Carroll, U.S. Navy, Retired,
Deputy Director, Center for Defense Information [1]

R&D investments in energy efficiency are the most cost-effective way to simultaneously reduce the risks of climate change, oil import interruption and local air pollution, and to improve the productivity of the economy. Improvements in the use of energy have been a major factor in increasing the productivity of U.S. industry throughout the 1980s and early 1990's. Between 1973 and 1986, the nation's consumption of primary energy stayed at around 75 quads, whereas the GNP grew by more than 35 percent.

MOTIVATION AND CONTEXT

The decoupling of energy growth and economic growth is an important factor for the future: it shows that the nation can improve energy efficiency and increase economic productivity. The energy intensity of the economy, measured in terms of energy use per dollar of GDP, has dropped by almost a third since 1970 (Figure 3.1). If energy intensity had remained at the same level as in 1970, DOE estimates that the country would be spending $150 to $200 billion more on energy each year. Even so, consumers and businesses spend some $500 billion per year on energy, a significant fraction of which could be used more productively in other areas of the economy. And, although the economy continues to become more energy efficient, the decline in energy prices that began in 1986 has caused this trend to slow, so that energy demand grew considerably—to more than 91 quads—by 1995.

Between 1978 and 1996, the Federal government invested some $8 billion (1997 dollars) in research, development, and deployment of energy efficiency technologies. This work, in conjunction with other policies (such as standards and incentives), private R&D, and the pressure of high energy costs, helped spur a private sector investment achieving the $150 billion in annual savings—a

[1] Personal communication, elaborating on findings in the Defense Monitor (1993).

tremendous return on investment. Besides these financial savings, DOE-supported technologies have led to significant improvements in the environment and human health.

In recent years, however, energy consumption has begun to rise again, and with that rise comes greater oil imports, air pollution, and emissions of carbon dioxide (or carbon), the principal greenhouse gas, as well as other pollutants (Figure 3.2). But this trend is by no means inevitable: technological improvements in buildings, industry, and transportation could drastically cut energy consumption.

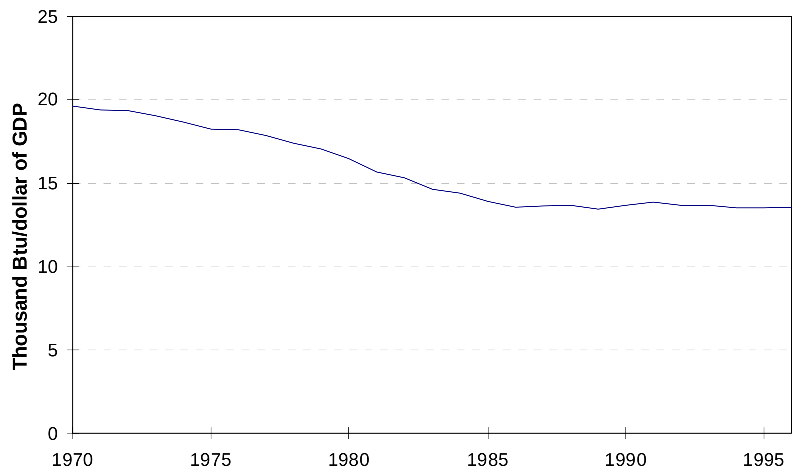

Figure 3.1: Energy intensity of the U.S. economy, 1970-1996. Source: EIA (1997, p. 15).

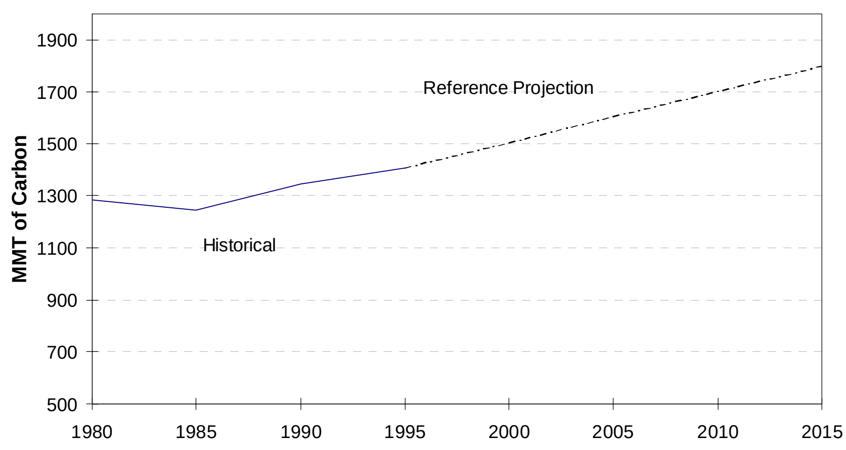

Figure 3.2: Actual and projected U.S. carbon emissions. Source: EIA (1997, p. 337).

Energy efficiency programs are aimed at three sectors: buildings (both residential and commercial); industry (manufacturing and nonmanufacturing); and transportation. Though total energy use in the three sectors is about equal, the transportation sector is expected to be the fastest growing of the three in the near future. There is vast potential for improving the productivity of energy use in these sectors of the U.S. economy (see Figure 3.3). Efficiency improvements simultaneously reduce carbon emissions, costs of energy services paid by consumers and industry, and the risk of oil interruption. The issues, problems, and solutions for energy efficiency are different for each of the three end-use sectors and are discussed separately in the following pages.

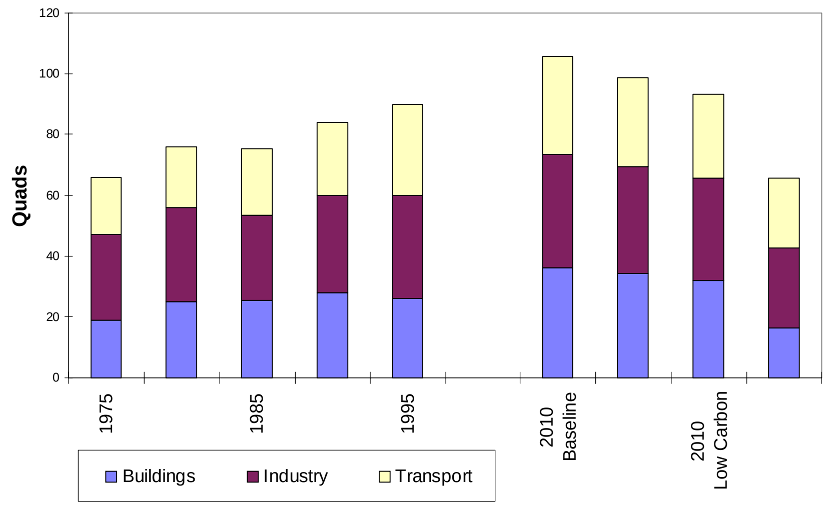

Figure 3.3: Energy efficiency potential. The baseline is the EIA Reference Forecast (EIA 1996). The five-lab Study scenarios depict two cases, one in which cost-effective efficiency technologies are deployed, and the other including these technologies and specifically low-carbon technologies (DOE 1997).

The **buildings sector**, which includes new construction and renovation as well as material and equipment suppliers, is large, valued at more than $800 billion per year—almost 13 percent of GDP. This sector alone employs more than 3.5 million workers.

Buildings consume one-third of total U.S. energy, and almost two-thirds of electricity. Even though energy prices are low, the average household spends almost $1,300 per year on energy, or 6 percent of gross annual income. Low-income households have a higher relative burden, spending up to 15 percent of gross income on energy.

Past building energy R&D focused on the major energy uses (Figure 3.4)—refrigeration, lighting, insulation, windows, and heating, ventilating and air conditioning (HVAC). These efforts have achieved extraordinary energy savings.[2] The best windows on the market, for example, insulate three times as well as their double-glazed predecessors. The next generation of technologies—such as advanced electronics and controls, advanced materials, integrated appliances, and advanced design and construction techniques—can accelerate this improvement and spread it throughout the building industry.

[2] LBL (1995), OP (1996).

The **industrial sector** is complex and heterogeneous. The manufacturing industries range from those that transform raw material into more refined forms (e.g., primary metals and petroleum refining industries) to those that produce highly finished products (e.g., the food processing, pharmaceuticals, and electronics industries). Hundreds of different processes are used to produce thousands of different products. The U.S. chemical industry alone produces more than 70,000 different products at more than 12,000 plants. Even within a manufacturing industry, individual firms vary greatly in the output they produce and their methods of production.

The DOE program focuses on seven material and process industries that consume about 20 percent of the nation's energy at a cost of about $100 billion per year (Figure 3.5). These are the chemical, petroleum-refining, forest products, steel, aluminum, metal-casting and glass industries. They account for 80 percent of the manufacturing sector's end-use energy consumption.

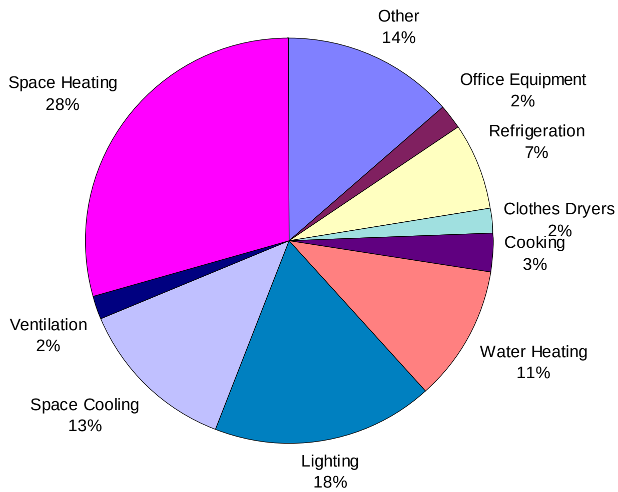

Figure 3.4: Percentage of consumption by end-use in buildings, 1995.
Source: EIA (1997).

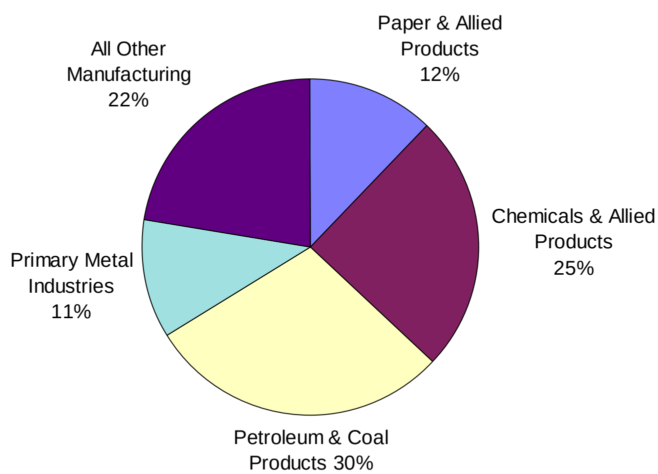

Figure 3.5: Percentage of primary energy used in the manufacturing sector by major industrial category, 1994. Source: EIA (1996, p. 43).

The materials and process industries are a large and critical component of the economy. In 1994, the chemical, forest products, and petroleum-refining industries shipped a total of $896 billion worth of products, i.e., they directly accounted for about 25 percent of all value added by manufacturing, and almost 5 percent of U.S. GDP.

Commensurate with their large physical size, the materials and process industries are a major source of jobs in the American economy. In 1994, total employment in these industries was about 2.9 million workers, about 16 percent of U.S. manufacturing employment and about 3 percent of the nation's total nonfarm, private sector employment. In addition to providing direct employment, it is important to recognize the multiplier effect of these jobs. The Economic Policy Institute estimates that each job in the materials and process industries supports four workers employed in supplier, equipment, repair, finance, engineering, sales, and even government occupations.

The materials and process industries also play a large role in the nation's trade picture. In 1994, they employed nearly 3 percent of the U.S. work force, produced nearly 5 percent of U.S. GDP, and accounted for more than 14 percent of our total merchandise trade. To maintain high trade levels, these industries must be extremely competitive, which in turn will require constant improvement in energy efficiency. Technology roadmaps (strategies for R&D and deployment of energy efficient and pollution prevention options), developed jointly by DOE and the respective industries, will make that possible.

The **transportation sector** poses the nation's greatest energy challenge. The U.S. transportation system is the dominant user of oil, accounting for more than 60 percent of the national oil demand and using more oil than can be domestically produced. Autos, trucks, and buses comprise one of the largest sources of local and regional air pollution, including NOx, particulate matter, and carbon monoxide. Transportation is also responsible for about a third of U.S. CO_2 emissions. Although the other demand sectors have managed to reduce dependence on oil, the transportation sector is still roughly 97 percent oil dependent (Figure 3.6) thereby making it vulnerable to oil price changes and supply interruptions. Because fuel expense is now a relatively minor part of the cost of driving, there is little incentive for consumers to demand more efficient vehicles.

Figure 3.6: Fuel used in the U.S. transportation sector, 1996. Source: EIA (1997, p. 41).

Transportation policy has been perennially contentious, making effective energy and pollution initiatives difficult and rare. Fuel efficiency standards doubled new car gas mileage between the mid-1970s and the mid-1980s, but these standards have been static since then. Further, because more and more consumers are switching to minivans and light trucks, fleet averages for new personal vehicles are dropping. In addition, vehicle miles traveled (VMT) have been increasing, putting additional pressure on oil consumption in this sector.

The Partnership for a New Generation of Vehicles (PNGV) was launched in 1993 to provide technologies to build sedan-type automobiles that are three times as efficient as today's cars — at competitive prices. This program has made some very promising strides, but the Panel believes that work needs to be supplemented by technology initiatives for larger vehicles, sport utility vehicles, light and heavy-duty trucks. Moreover, all of these efforts will require complementary policy changes to ensure that the new technologies fully penetrate the market.

Sector Issues

R&D alone does not ensure that technologies will be successful in the marketplace. The buildings, industry, and transportation sectors each have their own set of technology-introduction barriers. Collaborative government/industry investments in R&D are important, but they need to be supplemented by a diverse portfolio of options including standards, incentives, information, and education programs.

The buildings sector represents a classic case for government involvement in R&D and standard-setting. It is highly disaggregated, engaging hundreds of thousands of architects, developers, and contractors. Even the most innovative among them confront barriers such as local building codes, lack of private investment in R&D, lack of capital for lower income consumers, and the disconnect between the decision maker and the user. Combined, these barriers constitute formidable obstacles to the introduction of new energy efficiency technologies and practices. Too little R&D is being conducted on innovative technologies, and when new technologies and practices do become available it is difficult to get them into the hands of builders, the code books of local officials, or onto the shopping lists of consumers. Yet, there are many important energy efficiency and supply opportunities (see, for example, Box 3.1).

The industrial sector uses significant amounts of energy, but for the most part, energy does not constitute a large portion of operating costs. Although environmental drivers are motivating some industries to improve energy efficiency, unless there are significant price signals, industry will not generally make substantial improvements. However, if energy-efficient manufacturing technologies are available when industry is making capital investments, they will be incorporated if cost-effective.

In the transportation sector, consumer demand for larger and more powerful vehicles reduces energy efficiency improvement. With energy prices low, consumers' concern for fuel efficiency of automobiles is a low priority. The heavy-duty fleet is more price sensitive and therefore more energy efficient, but there are still significant gains to be made.

There is a clear case for an expanded DOE program, given the extraordinary potential of energy savings in the economy, the well-understood market barriers to obtaining such savings, and the profound benefits such savings would render in reduced imports, air pollution, and carbon emissions.

Other factors will hinder the future of technological innovation for energy. Changes in the nature of energy markets—particularly the move toward competitive markets for natural gas and electricity—have caused a significant downturn in R&D expenditures. As the electric sector is restructured, state-supported demand-side management programs are losing their funding (more than a $250 million drop so far), electric utilities are shutting down R&D programs (for example, PG&E is shutting down its $50 million per year operation), and major research organizations such as EPRI and GRI will lose more than $100 million in funding that would normally be used for energy efficiency research. Although some states will pick up some of the slack, states are unlikely to match pre-restructured levels and will not coordinate their efforts.

Industry R&D is becoming more and more focused on the short term. The utility sector in particular has "dimmed its headlights" in its R&D, leaving the medium and longer-term technology options stranded. The nation will ultimately lack a full menu of technology products unless the government builds and expands on a rigorous medium- and long-term agenda.

Box 3.1: Natural Gas and Efficiency Opportunities

Natural gas is widely used in the buildings and industrial sectors, and it has the potential for extensive use in transportation. There are significant opportunities for furthering the already high performance of natural gas systems in these sectors.

Residential and commercial buildings used about 8.7 quads of natural gas, 7.0 quads of electricity (not including losses in electricity generation) and 2.2 quads of oil in 1996; the industrial sector used about 10.3 quads of natural gas, 9.1 quads of oil, 3.5 quads of electricity (not including losses), and 2.4 quads of coal. The popularity of natural gas is due to its high performance, low emissions, relatively low cost,[a] and ease of use. It is identified by many as a key transition fuel to sustainable energy systems due to its low carbon content compared to coal and oil (see Chapter 4).

Natural gas can also provide important energy efficiency gains. For example, natural gas combined-cycle electricity generation is the cleanest, lowest cost, and highest efficiency fossil fueled system available today in the United States. Yet, even in this case, nearly half of the energy content of the natural gas is unavoidably lost as waste heat from the electricity generation process. This waste heat can potentially be made use of by using the natural gas to power a fuel cell or microturbine located in or near a building or industry and capturing the waste heat to heat the building, to heat water, or to heat an industrial or commercial process. In addition, by generating the electricity near where it will be used, the losses inherent in long distance transmission of electricity can be avoided and the capital costs of distribution transformers can be reduced, among other benefits. As these fuel cell and microturbine technologies are developed and commercialized, this can provide substantial cost, energy efficiency, and carbon savings.

Natural gas can also improve system efficiencies where it is used directly to power end use equipment. For example, using natural gas to directly power a heat pump or chiller has the potential to be more efficient than using natural gas to generate electricity at a central station plant—which loses nearly half the energy as waste heat; then transmitting it to the building—which typically loses 6-8 percent of the electricity; and then driving the motor used in the heat pump or chiller—which can also have large losses in the motor/compressor system. Alternatively, new technologies that use natural gas directly to power the heat pump or chiller could avoid these losses (but has certain other losses) and provide net system efficiency gains.

Natural gas may also offer substantial opportunities in the transportation sector, as compressed natural gas, through conversion to liquids with gas-to-liquids technology (Chapter 4), or through conversion to hydrogen (Chapter 4). Natural gas can be used either directly in internal combustion engines, in hybrid vehicles, or in fuel cell vehicles. Given its clean conversion, natural gas produces little pollution (additional work on NOx is important, however); its primary drawback is the emission of carbon into the atmosphere. Combined with hydrogen production and carbon sequestration, even this potentially serious problem may be resolvable (Chapter 4).

[a] The low cost of natural gas refers here to its highly competitive cost, not to a cost below historical commodity price levels.

In some cases, U.S. technology policy can help to spur technological innovations and research by international competitors. For example, PNGV and continued collaborative R&D on fuel cells may have convinced Daimler-Benz to invest almost $300 million in fuel cells and Toyota to invest an estimated $700 million per year on alternative-fuel cars.

In addition, there are export opportunities for U.S. energy efficiency technology and expertise (as an example, see Box 3.2.). As the world moves toward reducing greenhouse gas emissions (GHGs), technologies for improving the efficiency of energy use and the expertise for determining cost-effective energy improvements will be in demand. The United States can be a leader in many of these areas.

Box 3.2: Materials Compatibility and Lubricant Research:
A Government/Industry Success Story

DOE's Office of Building Technology, State and Community Programs participates in a grant administered by the Air Conditioning and Refrigeration Technology Institute to support R&D enabling U.S. manufacturers of heating, ventilation, air conditioning, and refrigeration (HVAC&R) equipment to move away from chlorinated refrigerants, the basis of nearly all air conditioning and refrigeration systems for 50 years. The HVAC&R industry consists of relatively small companies with limited R&D capabilities and funds. No single company could undertake the capital intensive and technically complex refrigerant research.

The materials compatibility and lubricant research (MCLR) program supports U.S. compliance with the Montreal Protocol to phase out the use of chlorofluorocarbons (CFC). It was initiated in 1991 with a DOE contribution of $10 million, with industry providing a direct cost-share of 7 percent and in-kind contributions estimated at $1.5 million. Private and national laboratories and universities conduct the R&D projects that address refrigerant and lubricant properties, materials compatibility, and ancillary systems-related issues, such as lubricant circulation, heat transfer enhancement, and fractionation of blends. The MCLR program terminates in 1999. Projects are selected competitively, and the program has stimulated industrywide precompetitive research.

As a direct result of this R&D program, the U.S. HVAC&R industry could support the White House initiative to advance the phaseout of CFCs from the year 2000 to 1996. By December 1995, the industry had alternative non-CFC products for all applications. In fact, many applications were totally CFC-free by mid-1993. These achievements gave the U.S. HVAC&R industry a large technologically competitive edge over foreign manufacturers. Beginning in 1991, the international balance of trade for the industry's products exploded, from a trade surplus of several hundred million dollars to a trade surplus of as much as $2.5 billion. The R&D program continues to seek better CFC-free refrigerants. Further, the HVAC&R industry has developed a research agenda to work cooperatively to improve energy efficiency and indoor environment.

Lessons Learned

1. It is appropriate for the government to participate in programs that stimulate precompetitive research by companies within an industry.

2. The government should support those energy R&D projects that can provide U.S. industries with an early entrant's advantage in international markets, especially when significant global environmental benefits can be achieved.

FINDINGS AND RECOMMENDATIONS

This and the following sections address the current programs and technologies for each sector (buildings, industry, and transportation); suggests operating goals for the programs; and outlines barriers, technologies, budgets, and programs that can help ensure success into the next century and achievement of the highest possible energy savings, pollution savings, and productivity improvements. A few recommendations are relevant for all three sectors:

- **Government investment in R&D is crucial, but needs to be supplemented by standards, incentives, information, and education programs.** Programs that have combined R&D, incentives, and standards—e.g., refrigerators—have achieved extraordinary energy savings and speedy market penetration.

- **The Administration should explore opportunities for multiyear funding for select programs, since the start/stop nature of many programs reduces their effectiveness**. Multiyear funding might take the form of two-year allocations coinciding with the congressional calender.

- **Federal agencies, in particular the General Services Administration (GSA) and Department of Defense (DOD), should purchase innovative and cost-effective technologies that reduce energy use and improve the environment. The Federal role is twofold. First, the government should be an early adopter of technologies with large long-term potential, such as electric vehicles and fuel cells. Second, the government, as a major purchaser, lessor and user of buildings, appliances, and vehicles, should purchase and operate buildings and equipment based on consideration of full life-cycle costs.** Future energy savings should be compared with capital costs whenever a building is built, purchased, or renovated. Agencies should be encouraged to use energy service performance contractors (ESCOs) to achieve savings, and DOE and GSA should be much more aggressive about using the new "super-ESCOs" toward this end.

- **Many technology initiatives—such as zero net energy buildings, advanced fuel cells, advanced sensors, and whole system optimization—require coordination across groups within energy efficiency and across other DOE programs such as renewables, fossil energy, and fundamental energy-linked science programs (including portions of Energy Research and Basic Energy Sciences). DOE should develop clearly articulated technology paths for initiatives that exploit and coordinate R&D resources as appropriate.**

THE BUILDING SECTOR

DOE's Office of Buildings Technologies, State and Community Programs (BTS) has achieved some remarkable successes in the past 20 years. The BTS programs have helped develop and disseminate a number of technologies—including low-E windows (Box 3.3), electronic ballasts for lighting, and high efficiency compressors and refrigeration systems—that have transformed their respective markets. These technologies have been complemented by energy efficiency standards for new appliances and equipment that have drastically reduced energy consumption—all at an extraordinary savings to consumers.

The DOE-2 buildings energy simulation program, which allows engineers to model and reduce energy consumption in buildings, is now used in some 15 percent of all new construction. These successes are already saving consumers billions of dollars per year and have more than paid for the Federal investment in energy efficiency programs. Even so, such efforts have only scratched the surface of the potential for efficiency improvements.

The Building America Consortia Program is designed to shape future R&D investments to the needs of real-world users, and then to disseminate R&D results effectively to the construction industry. These consortia are industry led and driven, with significant input from national laboratories and DOE. The program can have a tremendous impact on the future of building technology and application, presuming it is well managed, tightly focused, and adequately funded. (Examples of the technologies that may be used in buildings in the future are given in Box 3.4.)

The buildings program has managed such successes in spite of some organizational problems. These deficiencies are not news to DOE or to Congress; the Panel is pleased to report that DOE is working to correct them, in part through a long-term strategic planning process using a wide array of internal and external stakeholders. This process should help develop the strategic underpinning for future R&D prioritization. The Secretary has promised Congress a report on the strategic plan by the end of the year. Hopefully, the Panel's recommendations will help the program focus on the important items as the strategic planning process proceeds.

Box 3.3: Efficient Windows—A Technological Success

Twenty years ago, Lawrence Berkeley Laboratory launched a program to develop advanced, spectrally selective coatings for windows. The program, which cost some $3 million over the last two decades, has transformed the world's window industry. New windows are three times as efficient as double-glazed windows. "Low-E" glass now accounts for 35 percent of all windows sold in the United States.

Cumulative energy savings to date have exceeded $2.1 billion in the United States alone, and are projected to grow to $17 billion by 2015, yielding an R&D return on investment of 5700:1.

Operating Goals

The DOE buildings program can have a strong but not determinative influence over the buildings sector. New technologies permeate markets at various rates depending on their energy attributes, the cost of retooling, the dynamics in an equipment subsector, and general product line turnover. Buildings themselves are as much subject to state and local codes and builder practice as by any technological opportunity. Nonetheless, the DOE program, by creating enabling technologies and shepherding the standards process along, can significantly shape the country's buildings and lead to a more productive buildings industry.

Therefore, the goals identified by the Panel are as follows: By 2010, BTS R&D programs, outreach, and market transformation activities, working collaboratively with the private sector, universities and its research laboratories will lead to the deployment of 1 million zero net energy buildings,[3] and new buildings construction with an average 25 percent increase in energy efficiency as compared to new buildings in 1996.[4] Expanded renovations will average a 20 percent increase in energy efficiency as compared to the building's previous energy use. This increased efficiency will correspondingly reduce GHG (primarily CO_2) and air pollutant emissions. These measures will be achieved without increasing the life-cycle costs or lowering the level of service provided by the buildings. By 2030, all new construction will average a 70 percent GHG reduction, and all renovations will average 50 percent compared to new 1996 buildings.

Box 3.4. "Best-Practice" Home of the Year 2020

By the year 2020, a vigorous RD&D program could produce many advanced technologies that together will greatly reduce the average annual energy budgets of American families. The best practice house will use affordable, modular and flexible techniques, and new and innovative technologies.

These homes may utilize:

- sophisticated user-friendly computer design tools;
- manufactured wall systems with integrated superinsulation and "superwindows" optimized for orientation, external temperature, and internal needs;
- photovoltaic roof shingles with reflective roofing;
- low-cost, high-performance solar water heaters and other advanced solar heating and cooling technologies;
- advanced HVAC systems, where necessary;
- strategic positioning of trees to reduce cooling costs, fuel cells providing low-carbon energy, and energy storage;
- advanced high efficiency lighting systems actively operating with an array of daylighting and site/task strategies to optimize luminosity and reduce energy consumption;
- smart technology to closely match energy and water supply for multifunctional and integrated appliances and buildings control systems, and automatic load modulation of heating and cooling systems in response to varying weather, environment and occupant demands;
- improved sensors and controls, zoning and variable loading of the heating and cooling; and
- healthful house construction that is radon resistant, non-allergenic, and makes use of recycled materials.

Findings and Recommendations

This section outlines a series of recommendations for the buildings program which can help the office reorganize and continue to achieve significant success.

A Lead Individual

Some of the successes of public-private partnerships that can be attributed to PNGV and Industries of the Future are due to the direct involvement of high-profile political leadership. Vice President Gore has taken a personal interest and leadership in PNGV, and the former Under Secretary Mary Good at the Department of Commerce (DOC) was instrumental at keeping the partnership moving. Secretary O'Leary, the previous Secretary of Energy, took a personal role in Industries of the Future (IOF), helping to bring to the table the high-level industry executives required to make the program successful. The buildings program needs a similar boost. The political leadership does not have to come

---

[3] Zero net energy buildings are buildings that are efficient and, on average, produce enough energy (e.g. electricity via photovoltaics) to meet their internal needs and allow exports of energy sufficient to offset imports of fuels or power. DOE's programs should focus on low-GHG-emission net-zero homes.

[4] This number seems conservative, but note that it is difficult to achieve 100 percent penetration rates in new construction, which is, after all, governed by 50 state codes and thousands of local codes. If half the buildings had only nominal increases in efficiency, the other half would need to have a 50 percent increase to meet this goal.

from DOE. For example, although most of the PNGV research is in DOE, the political leadership came from the White House and Department of Commerce. The Vice President and the Secretary of Housing and Urban Development (HUD) might lead a residential R&D partnership. On the other hand, the Energy Secretary could provide the political leadership for Buildings for the 21st Century that would make it successful.

Recommendation: **The President should designate the Secretary of Energy or another high-level official to provide visible, ongoing support for Buildings for the 21st Century.**

Integrated R&D Strategy and Reorganization

Developing a central focus and an organizational structure that integrates the many elements in the building industry will be crucial for the long-term success of the program. Buildings for the 21st Century must provide that focus for the program, aimed at optimizing the "whole building" and stretching conventional efficiency goals. In the long-run, one can envision "zero net energy" buildings that are efficient and, on average, produce enough energy (e.g. using photovoltaics) to meet their internal needs and allow exports of energy sufficient to offset imports of fuels or power

There are significant barriers to technology introduction in the buildings sector, including the following:

- Fragmented and disparate markets include almost 500,000 builders, architects, and equipment and material suppliers.
- Neither builder/investor nor tenant/operator has a compelling interest in reducing overall building operating costs. The investor, who rarely occupies the building, is more concerned about minimizing the construction cost; the operator is willing to pay the operating costs, but cannot influence capital investments.
- When tenants do have a say in energy systems, often they expect to be in the building only a short time (residential, 7 to 10 years; commercial, 3 to 5 years) which discourages them from making energy efficiency investments.
- There are often local codes that impede the introduction of new technologies and practices.
- Low-income consumers, who are the most vulnerable to energy costs, do not have the up-front capital to invest in energy efficiency.
- There are few financial mechanisms offered to building owners and tenants that could assist them in spreading out potential initial cost increments associated with more energy efficiency and environmentally friendly buildings.
- Building appraisals generally do not reflect the energy and economic value of improved building performance and, in particular, of lower operating costs.
- There is a lack of credible information about the performance of energy-efficiency measures.

- Commercial buildings are complex, and there are insufficient systems and trained staff to address complex problems at low cost.

- Investment in construction R&D averaged less than 2 percent of total investment in the building industry (compared to an industry average of more than 3.5 percent); therefore medium- and high-risk R&D is generally not undertaken by the industry.

Because of these formidable obstacles, the DOE Office of Building Technology should be organized to integrate different systems. With the exception of some of the large architectural/engineering firms that build large structures, the buildings industry is made up of a diverse set of actors with a very unsophisticated integration process. DOE can work with industry to develop these necessary integration technologies and techniques.

An integrated vision of buildings that improves energy use—both in new construction and renovation—is needed. The type of vision that produced the PNGV could be useful in the buildings program. Operationally, the program could be organized around the models developed in the Office of Industrial Technologies, which are focused around "Industries of the Future" and are developed in partnership with the "clients," namely, the affected industries. Although the buildings sector is very different, this model concept would still be useful.

Recommendation: **The Office of Buildings Technology should maintain its traditional role in the areas of low-income weatherization, Federal Energy Management Program (FEMP), state and community programs, and codes and standards. However, these areas should be fully integrated with the general vision so that they implement technologies generated in the R&D programs and fully support the broader technology vision.**

The program should be focused around the Buildings for the 21st Century whole buildings concept, and implemented in partnership with industry consortia. It should function in cooperation with industry, national laboratories, and universities, as systems integrator for technologies, practices, and designs. It should also provide the outreach, education, and training necessary to ensure implementation of technologies by industry.

Recommendation: **BTS should be built around two basic programs: Residential and Commercial Crosscuts, each based on the Building America/Industries of the Future model. This integrating function should address the continuum from R&D through demonstration and technical assistance to market acceptance, while providing feedback to the R&D programs. When technologies are suited for both the residential and commercial markets, they should be managed in the R&D phase by one program and then distributed through both. The R&D programs should be organized around two major thrusts summarized in Table 3.1. This table includes the recommended thrusts, general technological themes, industry partners, and key technologies**.

Recommendation: **With these thrusts, DOE would bring together industry partners to develop technology road maps and integrating strategies. The partnership would develop focused R&D in new key technology areas based on the road maps.** Because the Panel believes these industry-led groups should define the technologies, details will not be specified. However, the program needs to limit the number and scope of these activities and, when possible, utilize technologies developed in other programs. For some of the themes, the technology might be developed primarily in other parts of DOE (e.g., fuels cells managed by a coordinating research function, or through the Office of Transportation Technologies or the Office of Utilities Technologies), with the buildings program applying its funds to develop specific applications and systems needed for the application. The thrusts would be directed by the residential and commercial sector crosscuts, establishing partnerships through industry subcommittees of the partnership members. The crosscuts would include industry participation from architects, builders, developers, financiers, and insurers.

It is clear that significantly more emphasis must be placed on whole buildings and systems integration. As PG&E demonstrated in its ACT-Squared demonstration program, optimizing many systems at once can cut energy use eight-fold or more. DOE has not paid sufficient attention to this potential.

Table 3.1: Organization of R&D Programs

Thrusts	Building System Design & Operations	Building Equipment and Materials
Technology Themes	On-site power generation	Integrated equipment systems performance
	Factory-built housing	Building materials and envelope performance
	System optimization	Insulation initiative
	Advanced sensors and smart controls	Incandescent replacement/ innovative lighting
	Energy design and diagnostic tools	Integrated/advanced appliances & water heating
Key Technologies	Fuel cells/ solar for buildings applications	Adaptive building materials and envelope systems
	Factory-built housing	Innovative thermal distribution networks
	Advanced sensor and smart controls	Development and testing of recycled materials
	Automated diagnostics	Water heating/ integrated multifunction appliances
	System interoperability controls/sensors	Innovative lighting
	Advanced electronics for lighting	New materials for appliances
Industry Partner Subgroups	Power generation industry	Wood products
	Controls and sensors	Steel
	Information systems	Concrete and masonry
	Software	Windows and glass
	Insurance	Insulation
	Finance	Heating and air conditioning appliances
	Electronics	Home appliance
		Lighting

Successful Programs, Outreach, and Reorganization

DOE's building program has had a string of outstanding successes, ranging from low-E windows, to electronic ballasts, to the DOE-2 design software. But the Panel thinks that program managers should look at their technological successes to determine whether the program should change focus, and whether increased effort needs to be made to educate and train builders, suppliers and consumers on the benefits and opportunities of the new technologies and practices, rather than expanding R&D in those areas. For example, the windows program should clearly map out the marginal changes possible in the windows market, and describe the technology required to get there. This work should inform code and standards-setting work, and should help structure the industry outreach program. All this should then be assessed against efforts to bring new technologies to market, so that maximum penetration of innovative technologies is achieved.

THE INDUSTRY SECTOR

Since 1976, the Office of Industrial Technologies (OIT), within the Office of Energy Efficiency and Renewable Energy has been helping industry to develop and adopt new energy-efficient and pollution prevention technologies (see, for example, box 3.5). OIT has a wide spectrum of programs—from basic energy and materials research through product and process development, demonstration, and technology transfer. The cumulative energy savings of more than 75 completed projects is approximately 886 trillion Btu, representing a net production saving of more than $1.8 billion. These savings have just begun and these technologies will continue to accumulate energy savings at no additional costs. The total OIT investment over this time was $1.23 billion for FY 1976 to FY 1995. The pollution reduction resulting from OIT programs is almost 70 million tons of carbon equivalent.

The seven material and process industries use about 25 quads of energy each year, at a cost of about $100 billion. Although industry's total energy expenditure is a large sum, it represents only 3 percent of total manufacturing costs. For material and process industries, the percentage of energy costs range from 7 percent to over 30 percent. For the processing of aluminum and cement, energy expenditures represent greater than 20 percent of manufacturing costs.

In the last 10 years, energy has become even less important as a driver of U.S. industry investment decisions because natural gas, electricity, and imported oil have been readily available at attractive prices and energy costs have been declining as a percentage of product selling price. Energy, however, is still an important consideration for investment and operating decisions for the materials and process industries. Concerns about generation of pollution and levels and types of industrial waste are increasing.

Box 3.5: Oxy-Fuel Firing—A Government/Industry Success

Oxy-fuel firing, the combustion of fuel using oxygen rather than air, is now widely used by the glass industry and is finding increasing use in the steel, aluminum, and metal-casting industries. Oxy-fuel combustion was first demonstrated in a large glass furnace under the sponsorship of DOE. Typically when fuel is burned in air, the nitrogen in the air is heated and carries away much of the energy in the exhaust. Oxy-fuel combustion is more efficient, transferring more of the energy released during combustion to the "load" being heated rather than to the nitrogen.

The technology reduces energy use and fuel expenses, with energy savings of up to 45 percent in small furnaces and more than 15 percent in large furnaces; improves product quality because improved melter control reduces defects in glass; meets environmental regulations because NOx emissions are reduced up to 90 percent, carbon monoxide by up to 96 percent, and particulates by up to 30 percent; and can increase productivity − in some cases furnace production rates improved by up to 25 percent.

The annual net energy savings attributed to oxy-fuel combustion systems used in the United States is greater than 2 trillion Btus per year. More than 100 oxy-fuel firing systems have been sold in the United States, with one-quarter of all conventional furnaces having been converted. The technology is beginning to be adopted by other industries.

The government rationale for funding energy R&D in industry can be summarized by the following: industry collectively utilizes one-third of the nation's energy; there are limited incentives for industry to invest in energy R&D technology, because within their own manufacturing facilities, energy costs are low (investments go into new products and process manufacturing); and, finally, many manufacturers buy equipment from suppliers who typically are small and conduct little R&D.

Program objectives have evolved and broadened over the past 20 years, responding to a changing energy situation and shifting national priorities. The current program has three major strategies: Industries of the Future (IOF), combined heat and power, and crosscutting technologies. The strategies, technologies, themes, and industry partners are summarized in Table 3.2.

Table 3.2: Major Program Strategies

Thrusts	Industries of the Future	Combined Heat & Power	Crosscutting Technologies
Themes	The 7 major energy-using process industries: Aluminum, Steel, Glass, Forest Products, Chemical, Metal Casting, and Petroleum Refining	Advanced turbines Gasification Microturbines Compined cycles	Combustion technologies Sensors & controls Advanced industrial materials Separation technologies
Key Tech-nologies	Recycling of steel Novel aluminum process cells Advanced paper drying Oxy-fuel firing	Turbines for industrial cogeneration Microturbines with advanced ceramic materials Adv. gasification for biomass	Enhanced intermetallic alloys Net shape materials processing Advanced industrial combustors Hi-temperature/harsh environment sensors
Industry Partner Subgroups	National Trade/Technical Assoc. Industrial partners Universities and Labs	Turbine developers Ceramic materials Forest products Energy service companies Fuel cell companies	7 major process industries Automotive/parts manufacturing Refractory industry Furnace & boiler manufacturing

Operating Goals

The Industrial Programs have significant opportunities to impact energy use and environmental impacts from industry. The IOF programs have successfully laid out technology road maps to be implemented by industry. Through R&D and the partnerships, the programs will by 2005 introduce a new family of sensors for harsh environment process industries to increase process efficiency up to 15 percent and reduce emissions up to 10 percent (Box 3.6), develop a combustor of the future to reduce emissions up to 40 percent, and increase efficiency up to 5 percent, and develop a greater than 40 percent efficient microturbine which will achieve a 50 percent reduction in CO_2 emissions.

By 2010, the programs will achieve a more than 25 percent reduction in emissions from the IOF Program industries, introduce wireless sensors that could improve efficiency by 10 percent, and introduce $200/kW 50 percent efficient microturbines.

By 2020, the programs will achieve a 20 percent improvement in energy efficiency and emissions from the next generation of industries.

Industries of the Future

The IOF thrust was created by Secretary O'Leary and implemented by OIT. It consists of the major energy consuming industries: forest products, steel, aluminum, metal-casting, chemicals, petroleum refining and glass. DOE has facilitated these industries in developing a vision of where they could be in the next 20 years. Industry has created the visions, developing pre-competitive technology road maps, and is implementing them with government collaboration.

Box 3.6: Advanced Process Controls for Industry

The Advanced Process Control Program was started by a cooperative agreement between DOE and the American Iron and Steel Institute. The program consists of six diverse sensor and control-system research tasks that focus on many aspects of steel making, with the common goals of on-line measurement of critical product properties. The successful development of sensor and control system technologies will increase the competitiveness of the domestic steel industry by reducing annual production costs approximately $146 million, which includes an annual energy savings potential of 6 trillion Btus.

Technical feasibility research and demonstration is ongoing in the following areas:

- Laser beam measurement of furnace off-gas carbon monoxide and carbon-dioxide – a gauge of completion of the conversion of iron to steel in the basic oxygen furnace.
- An on-line non-destructive system for the measurement of mechanical properties of low-carbon sheet steels to supplant traditional off-line testing.
- An on-line instrument to determine the microstructural distribution of iron and zinc phases present in galvanneal coating.

By its completion, this collaborative effort between DOE and the US steel industry will have provided significant new opportunities for the industry to increase the efficiency and productivity of its basic oxygen furnaces, its hot strip mills and its galvannealing lines.

In addition to facilitating the development and implementation of technology road maps, OIT cost-shares R&D in key areas that can have an impact on U.S. energy efficiency and emissions reduction. In general, industry provides guidance to DOE on what projects can be of greatest benefit, and can lead toward achieving the vision. The Panel found that industry is very positive about the IOF approach, and that DOE has been flexible in dealing with different industries. Although each of these major industries is organized differently and relates to OIT differently, they all follow the general trend of being engaged in projects that benefit the industry as a whole, while generating substantial public benefits. Two examples are presented below.

The metal-casting industry, through the Cast Metals Coalition (CMC), coordinates the proposal solicitation and review process for the IOF program of OIT. The CMC represents approximately 2800 metalcasters in the United States and has an open membership. Proposals are received from industry, academia, and DOE laboratories. Projects are reviewed in four stages:

- Technical review by a panel of experts and a DOE representative.
- Review by a nine-member panel from industry in open forum.
- Review by the CMC executive board.
- Final review and approval by DOE.

Criteria used by the reviewers include technical relevance to the vision and road maps, potential for energy and productivity savings, industrial participation, level of risk, cost realism and share, and prior performance of the researcher.

In the aluminum industry process, an open solicitation is held by DOE. Proposals are received from industry and universities, and reviewed by a technical merit board comprised of five industry members. DOE then performs a review and makes awards. Criteria include relevance to the aluminum road maps, 30 percent minimum cost-share by industry, and industrial participation in the R&D.

In each case, DOE has identified a “desk officer” to provide a link between the industry and other government agencies, such as the U.S. Environmental Protection Agency (EPA) and DOC. These officers have also helped create a link between the laboratories and industry. OIT has created a Laboratory Coordinating Council to help facilitate industry interaction with the laboratories. Some industry representatives found the laboratories too expensive. One factor adding to the cost is that DOE adds a fee on Work for Others (currently about 26 percent) at the laboratories. This fee is waived for the Metals Initiative by law. With private funding, the DOE Work for Others fee is automatically waived for small businesses, minority businesses, non-profit organizations and, for specific proposals, large businesses. The added cost is a disincentive for industry to sponsor work at a laboratory.

Recommendation: **Consideration should be given to a blanket waiver of the Work for Others fee**. Some IOF partners have initiated pre-negotiated agreements, e.g. the steel industry. The intent would be for all laboratories to sign a pre-negotiated agreement with industry trade associations. Specific task orders could then be sponsored at specific laboratories.

Recommendation: **Using the Laboratory Coordinating Council, DOE could assign coordinating laboratories for specific industries so that the research efforts are not fragmented across different labs**.

Recommendation: IOF is working well. The initiative has been successful because of high level support by government and industry (initiated by the Secretary of Energy with continual involvement by the Deputy Assistant Secretary for Industrial Programs and CEOs and CTOs); however, **the program is new and needs to be carefully monitored to ensure there is continued high level involvement by industry and government; that it gets results; and that it continues to be in the public's best interest. Industry and government are to collaborate, but industry should not control the program. The Panel finds that expanding the IOF program would have significant payoffs.**

Crosscutting and Combined Heat and Power

The crosscutting program addresses technologies that impact more than one of the seven major industries, such as materials, combustion, sensors, and cogeneration. For example, a sensor for the glass industry (high temperature and corrosion resistant) and one for the steel industry (same criteria) can have similar properties. Projects in this area often include multiple companies, particularly suppliers to multiple industries, and can start with a more generic activity and end in a specific demonstration in one or more of the seven industries. Crosscutting projects tend to be longer term than the IOF projects. The current Advanced Turbine System (ATS) program (whose goals are to improve current turbine efficiency 15 percent and reduce the emissions of small (less than 20 MW) gas turbines by 80 percent, while reducing the cost of electricity by 10 percent) is addressing major issues such as design and technology advance in cooling, materials, and coatings. The ATS program is an example of a successful collaboration between the Office of Fossil Energy and Energy Efficiency and Renewable Energy. A common program plan was formulated, and division was by size (small vs. large turbines), and utilization of common industry advisory group, etc. This model should be utilized more often, particularly in crosscutting areas such as materials (high-temperature ceramics), sensors, combustors, and new technology areas such as fuel cells and microturbines.

Recommendation: **The crosscutting programs are not adequately funded. The budget should be enhanced but not funded by the IOF budget** .

In both IOF and crosscutting technology programs, industry is involved throughout with cost-sharing; thus, commercialization will occur if industry criteria such as return on investment and capital availability are met.

Supplier involvement is key to commercialization of technologies from both areas. IOF is beginning to include supplier participation as part of the road map definition; crosscutting programs have also learned the importance of involving suppliers (e.g., nickel aluminide case study).

As in the other end user sectors, investments in pollution prevention through energy efficiency improvement are the most effective means to reduce carbon and other air pollutants, to reduce oil imports, and to maintain a strong economy. To ensure that industry continues to participate on a 50 percent cost-share basis, it is imperative that the government maintains its commitment to IOF projects. Crosscutting technologies are enablers for IOF, and the program should be expanded across the board in materials, sensors, and cogeneration. The program should remain focused on research projects whose primary objective is energy efficiency and pollution prevention technology—instead of research programs where energy and environmental savings are a minor, secondary benefit. As programs come to successful completion, such as ATS in the year 2000, other crosscutting energy efficiency programs should evolve to new areas, e.g., microturbines.

Suggested examples of specific new programs are the following:

IOF

- Agriculture industry. Activities could include increasing yields in an environmentally acceptable manner with energy-intensive inputs, crop genetics, management of the harvesting process using satellite imaging, advanced sensors and controls to access nutrients and manage moisture control, and other technologies. In food processing, processing, drying, and separation technologies are needed.. These activities need to be undertaken in close cooperation with the Department of Agriculture.

- Bio-based renewables. This should focus on replacement of oil by biomass feedstocks, including using modified genetics and advanced processes, with a goal of 10 percent of the petroleum feedstock replaced by 2010; 30 percent by 2030.

- Emerging energy-intensive industries. New industries such as information technology and its components, biotechnology, and advanced materials are generally not as energy intensive as the current major energy-intensive industries, but quality of energy is important; thus there will be an emphasis on technologies to ensure the availability of quality energy. This should be done in conjunction with the power quality work described in Chapter 6.

Crosscutting

- Microturbine (40 to 300 kilowatts; 40 percent efficiency goal).

- Fuel cell-gas turbine combined systems (70 percent efficiency goal).

- Biomass/black-liqueur gasification combined cycle (50 percent CO_2 reduction).

- Processing sensor needs for monitoring and control of manufacturing processes.

- Manufacturing technology for high-temperature materials—ceramics and composites.

THE TRANSPORTATION SECTOR

DOE transportation R&D is focused solely on vehicle technologies. The light-duty vehicle components are by far the largest effort, with a relatively small program devoted to heavy-duty transport. The transportation programs have a number of foci, including improving the energy efficiency of existing types of vehicles and promoting new engine technologies and alternative fuels (see Box 3.7).

The PNGV program[5] has been the primary focus of DOE efforts in transport over the past few years but significant progress on biomass-derived fuels, electric hybrids, and other motor systems has also been achieved. A mix of programs is important because the transportation sector has issues that are quite different, depending on the end-use, and there are large energy and environmental implications in all modes of transport.

The Federal government has addressed transportation policy sporadically. Post-World War II policies have promoted oil use and automobile proliferation. Transportation trends were set by Eisenhower's Interstate Highway System, which, together with mortgage interest deductions, supported sprawling settlement patterns. Oil depletion allowances and other favorable tax treatment helped create a strong domestic petroleum industry. And U.S. foreign policy has long held reliable access to low-cost foreign oil as a core goal.

In 1970, the Clean Air Act was passed, creating the early framework for environmental regulation of the automobile. The first oil crisis, in 1974, created complementary energy policy in the form of Corporate Average Fleet Economy (CAFE) standards, which ultimately doubled new car fuel mileage.

Box 3.7: *Zymomonas mobilis*—An R&D Success

Among the major barriers in the production of transportation fuels from plant biomass are capital and energy costs in fermentation. Different types of bacteria and fermentation equipment are required to process five- and six-carbon sugars.

Zymomonas mobilis is a genetically engineered organism capable of fermenting five- and six-carbon sugars to ethanol. The technology was developed by DOE's National Renewable Energy Laboratory and was the recipient of a 1995 R&D 100 award. It allows lignocellulosic biomass to be fermented in less time and with greater yields than conventional methods, substantially lowering the cost of producing ethanol for use as a transportation fuel, and thus improving its cost-competitiveness with gasoline.

This technology has the potential of reducing the cost of ethanol by as much as 10 cents per gallon. Using domestically produced ethanol from biomass reduces the nation's dependency on foreign oil, helps shrink the trade deficit, and reduces net greenhouse gas emissions.

---

5 PNGV (1996).

Since then, however, the Federal government has had only modest policies to steer the automobile sector toward greater efficiency. The strongest laws were perhaps the fleet purchase mandates in the Energy Policy Act of 1992, which aimed to get large fleet operators to introduce alternative fuels into their mix, but this law will have at best only a very modest impact on the makeup of the vehicle fleet.

In 1991, Federal R&D began to directly address the issues of energy efficiency, environmental degradation, and imported oil dependency. The Intermodal Surface Transportation Act (ISTEA) allocated some $2.9 billion for R&D at the Department of Transportation (DOT), ostensibly for the purpose of building a sustainable transportation system. In 1993, President Clinton and Vice President Gore launched the Partnership for a New Generation of Vehicles, (PNGV), aimed at building a high efficiency production prototype automobile by 2004.

This Panel has devoted most of its inquiry on the transportation system to three primary transportation R&D initiatives: PNGV, the Heavy Vehicle Technologies Program, and DOT's Intelligent Transportation Systems.

In addition to these initiatives, which are discussed below, the Panel believes that the alternative fuels program should be based on a long-term plan that considers fuel sources, infrastructure, and advanced conversion technologies (see, for example, Box 3.8). This work should be coordinated with fundamental energy-linked science and technology R&D at DOE, the fossil energy program (Chapter 4), and the renewable energy program (Chapter 6). Without such a plan, pursuits in this area are likely to be of less utility.

Box 3.8: Transportation Technology for the Future—Fuel Cells

The new millenium will witness the first fuel-flexible fuel cell vehicles capable of operating on any hydrogen-rich fuel, including fossil fuels such as gasoline and natural gas from the existing fuel infrastructure, and renewable fuels such as methanol, ethanol, and hydrogen.

DOE's fuel cell transportation R&D currently consists of efforts that will result in full size (50 kW), hydrogen-fueled laboratory proton-exchange-membrane (PEM) fuel cell power systems. Remaining barriers to development of the fuel processor include efficiency, fuel stream purity, compactness, and cost. Demonstration of a fully integrated system in a vehicle is another challenge.

Successful development will result in vehicles that achieve three times better fuel economy and emit practically no pollution. Acceleration, handling, and safety will equal or surpass today's cars — without additional cost to the consumer. Successful application of fuel cell technologies in automobiles will improve energy security and provide significant environmental benefits. A 10 percent market penetration could reduce US oil imports by 130 million barrels per year. Fuel cell vehicles will reduce urban air pollution and mitigate climate change. They will be 70 to 90 percent cleaner than conventional gasoline powered vehicles on a fuel cycle basis, and will produce 70 percent less carbon dioxide emissions.

Operating Goals

The Panel believes that the DOE transportation program needs to strengthen its goals, which are directed at a mixture of the various types of vehicles on the roads.

By 2004, develop with industry an 80-mile-per-gallon (mpg) production prototype passenger car (existing goal of the Partnership for a New Generation of Vehicles—PNGV). By 2005, introduce a 10-mpg heavy truck (Classes 7 and 8) with ultra low emissions and the ability to use different fuels (existing goal); and achieve 13 mpg by 2010. By 2010, have a production prototype of a 100-mpg passenger car with zero equivalent emissions. By 2010, achieve at least a tripling in the fuel economy of Class 1 to 2 trucks, and double the fuel economy of Class 3 to 6 trucks.

Table 3.3 summarizes DOE's transportation programs.

Table 3.3: Summary of DOE Transportation Programs

Thrusts	PNGV	Heavy Duty Vehicles	Materials	Alternative Fuels
Themes	Hybrid vehicles Diesel engines Electric vehicles Alternative fuels	Class 7-8 trucks Class 3-6 trucks Class 1-2 light trucks	Engine materials Chassis materials Body materials	Fuels development Automotive fuels Heavy vehicle fuels
Key Technologies	Direct injection diesel Fuel cells High power batteries Modular electronics Motors, controllers & sensors	Truck chassis Auxiliary systems Advanced materials Hybrid-electric propulsion Exhaust after-treatment	High temperature, high strength, lightweight Steel Aluminum Titanium	Biodiesel Gasification technologies Fermentative organisms On-board storage techs Fuel delivery systems Sensors Compressors
Industry Partner Subgroups	Big 3 automakers Product suppliers Component suppliers Electronic comps	Diesel engine Heavy truck manufacture Component suppliers Light truck manufacturing	Materials supplier Vehicle manufacturing Universities Labs	7 major process industries Automotive and parts manufacturing Refractory industry Furnace and boiler manufacturing

Partnership for a New Generation of Vehicles (PNGV)

PNGV constitutes the bulk of Federal research on vehicle fuel efficiency, and attracts the most attention. PNGV was initiated by President Clinton, Vice President Gore, and the CEOs of the Big Three automobile companies, and has three goals:

- To develop manufacturing techniques to reduce the time and cost of automotive development.
- To improve fuel efficiency and emission performance.
- To develop a vehicle with triple the fuel efficiency of today's mid-size cars while maintaining or improving safety, performance, emissions, and price.

Besides starting with these explicit goals, which were jointly developed by the automobile industry and the government, PNGV has several attributes that are rare or unique in Federal R&D:

- High-level attention, with the protocols signed by the President and the project regularly reviewed by the Vice President.

- Industry involvement in setting priorities and program management.
- Clear goals and a clear time frame for their achievement.
- Funds directed across the spectrum of R&D, from basic science to production prototypes.
- Outside review by the National Research Council of the National Academy of Sciences.

PNGV has been very successful in some regards, but needs some adjustment if it is to fulfill its potential to create public benefits. On the positive side, PNGV has developed a formal and continuing mechanism to link government priorities with those of industry. The program has focused automaker and government attention on the potential of hybrid technologies and has built stronger connections between national laboratories and the private sector, creating a path for bringing laboratory technologies to market. Moreover, as mentioned earlier, it has spurred activity in foreign competitors.

Although these achievements are laudable, the Panel has several reservations about, and recommendations for, PNGV, presented in the spirit of building on strength.

Issues and Recommendations

The PNGV time line is too short and filled with too many interim deadlines to effectively develop important medium- and long-term technologies. PNGV was launched in 1993; in 1997, finalist technologies are to be selected so that a production prototype can be built by 2003. As a consequence, the ten-year project has an effective research phase of only 4 years, leading to the predominance of conventional technologies, most obviously the direct injection diesel, which is already on the market in Europe. In addition, the PNGV program is insufficiently funded, increasing the risk of not meeting its goals.

Recommendation: **A PNGV-II, focused on mid-term and longer-term technologies should be created, and should receive the same level of attention and support as the shorter term goal; moreover, the overall program needs to be strengthened.**

The bulk of PNGV funding is directed by the Big Three automakers. Because of stagnant CAFE standards and low fuel prices, existing automakers have little incentive to promote long-term technologies; they therefore direct most of the research to incremental improvements in existing technology. The tension between building products that are usable in the near term, and thus highly relevant to automakers, and building products with longer term and more speculative returns has so far been largely resolved in favor of the nearer term. The PNGV program currently has direct injection diesel as a very likely technology for its “downselect” process.

Recommendation: **The PNGV technology program needs greater coordination with EPA and with the California Air Resources Board, which is a de facto national standard setter. PNGV also needs to give greater attention to air-quality issues, to ensure that technologies selected do not undermine national and state clean-air programs. And advanced vehicle development programs should be coordinated with alternative fuels programs to ensure they are complementary for transportation systems of the future.**

Recommendation: **The government should consider directing a greater portion of PNGV funds through other research consortia, auto suppliers, universities, and laboratories, with continued involvement with the automobile companies through project selection and monitoring. For very long term, high-risk technological issues, collaboration with international companies with U.S. manufacturing facilities should be considered.** Batteries could serve as an initial program. Lack of a real battery breakthrough has hindered electric vehicle development, and international collaboration might facilitate technological innovation.

The Administration has no policies for bringing PNGV technologies into the market. Absent clear policies to reduce fuel consumption in the automobile sector, the automobile industry will continue to produce, and customers will continue to demand and buy, relatively large and inefficient vehicles. Manufacturers currently have tremendous incentives to build large (and thereby profitable) automobiles and trucks, and to wring as much production from current technology as possible.

Recommendation**: The Administration and Congress should develop policies to help bring efficient, clean vehicles to market. Both market-based policies and standards should be considered. Otherwise, the Panel worries that many PNGV technologies could land on barren ground.**

The Heavy Vehicle Technologies Program

The Office of Heavy Vehicle Technologies (OHVT) supports research on light- and heavy-duty trucks, which together account for roughly half of U.S. highway transportation energy consumption. This portion is growing as sport-utility vehicles outpace sales of traditional automobiles.

Issues and Recommendations

OHVT has used a technology road map developed jointly with industry to build a light- and heavy-duty-truck program. The large truck projects are generally aimed at increasing the thermal efficiency of diesel engines and reducing parasitic drag from airflow, tires, and accessories on the truck.

The Panel finds that the choices are appropriate for short- and medium-term technologies, but also recommends the following :

- Funds allocated to the Office of Transportation Technologies for OHVT are insufficient for the problem to be adequately addressed and the opportunities at hand; **support should be increased**.

- OHVT has paid insufficient attention to long-term air quality problems. A major switch to diesel for light duty trucks would reduce energy consumption but would also probably significantly increase NOx and particulates. **This implicit contradiction and trade-off between OHVT goals and EPA goals must be recognized and explicitly resolved. DOE and EPA should work to see how to eliminate incentives for automakers to evade auto emissions targets by switching to diesel engines, attaining larger gross vehicle weights or by developing alternative fueled vehicles that are likely to run solely on gasoline.**

- **OHVT should have a long-term technology strategy that pursues fuel cells, turbines, and other hybrid technologies. This strategy should be coordinated with PNGV, but should consider the particular issues related to larger vehicles.**

Department of Transportation and Intelligent Transportation Systems

DOT conducts several substantial research programs, the most prominent of which is the Intelligent Transportation Systems (ITS) Program.[6] The total DOT research budget from FY 1992 to FY 1996 was $2.9 billion (some $600 million per year), of which $1.01 billion went to ITS. The bulk of DOT transportation funds ($2.1 billion) are spent by the Federal Highway Administration (FHWA) on programs ranging from pavement analysis to bridge design; from driver safety to communications technologies; from congestion management to automobile navigation. The ITS program is included in this total.

It is difficult to characterize either DOT research in general or ITS in particular in relation to public goals or technology paths. The recently drafted Transportation Science and Technology Strategy is a useful start, but it does not link its goals to DOT programs, leaving the Panel little basis to evaluate the programs.

DOT has a broader research mission than the DOE. Safety, congestion, and the viability of the infrastructure must be addressed, along with energy and the environment. But wider responsibility does not reduce in any way the need for cohesive strategies. Indeed, unconnected programs are likely to produce results for one sector that undermine goals in another.

The Panel therefore recommends the following:

- **DOT should revise its transportation, science, and technology strategy to include explicit interacting goals for safety, congestion, infrastructure, energy, and the environment. All existing research should be reorganized around those five goals. Programs that meet more than one goal should be explicitly recognized as such. Conversely, programs that would enhance one goal at the expense of another—and the Panel sees several that so threaten—should be weeded out, modified, or at least be explicit in describing the trade-offs.**

- **Energy and environment goals should mirror those goals recommended for DOE, namely, to reduce oil imports, to curb the growth in CO_2, and to develop technologies that steer the nation toward EPA's newly announced National Ambient Air Quality Standards**. The current DOT strategy, for example, mentions energy in a heading but not in any of the explicit goals or criteria.

- **DOT should increase its emphasis on multimodal research**. It is crucial, for example, that those who are trying to solve congestion problems also understand the role and needs of transit and intermodal problems.

- **DOT research should be managed by an Assistant Secretary, increasing the coordination and visibility of the programs and reducing the stovepiping now resulting from management by sector** (FHWA, FTA, FAA, etc.).

[6] ITS (1996a, 1996b, 1997).

- **Time frames for DOT research should be made explicit**.

- **Transit R&D is insufficient in scale and too modest in its goals. The nation's transit systems are all in some degree of crisis, yet little money is spent developing whole systems management, dispatch programming, multimodal linking, or labor-saving management models. Many soft technologies, such as computer programs that help municipal agencies better manage existing transit resources, could displace significant capital investments.**

- DOT, state departments of transportation, and metropolitan planning organizations rely on badly outdated and inaccurate models for transportation planning. Current models inadequately address the relationship between transportation, land-use, and air quality, leading to legal paralysis in some regions and to alternative model development in others. **DOT should focus resources on building new models as soon as possible to more accurately measure and reflect the above-mentioned three factors, and should do so quickly.**

- The Automated Highway System (AHS) program is very ambitious but is based on little explicit analysis of how AHS success could help meet national goals. Many analysts believe that AHS technologies could be at odds with efforts to reduce energy waste and pollution. **DOT should be explicit about the goals, describe the underlying assumptions, and then adjust the program according to a peer review of these considerations.**

BUDGET RECOMMENDATION

The Panel believes that the funding for energy efficiency R&D and implementation should be increased to a level to meet the goals identified and to be commensurate with the potential benefits that can accrue from a successful R&D program. The current funding for energy efficiency R&D requested by the President in FY 1998 is about $450 million . (This amount does not include low-income weatherization and state grant programs, which total $190 million; and FEMP, $31 million).

Given that the potential energy cost savings from energy efficiency across the buildings, industry, and transportation sectors could be more than $40 billion per year and potential carbon reductions more than 250 Million Metric tonnes of carbon per year (MMtcpy) by 2010[7], the budgets are not reflective of the potential benefits. With an annual budget of $450 million for R&D in efficiency, it is less likely that the technologies will be available to meet energy and environmental goals. Because the nature of these sectors requires technological advances in many small areas, the programs need to be funded at a level that would provide a critical mass of activities to achieve the technological improvements.

Energy efficiency has the potential for significantly reducing emissions (Figure 3.4), and investments in energy efficiency improvements are clearly the most cost-effective means to reduce carbon and other air pollutants. If the United States is to reduce the emission of GHGs at minimal costs and improve urban air quality, energy efficiency technologies in buildings, industry, and transportation will provide significant opportunities.

[7] DOE (1997).

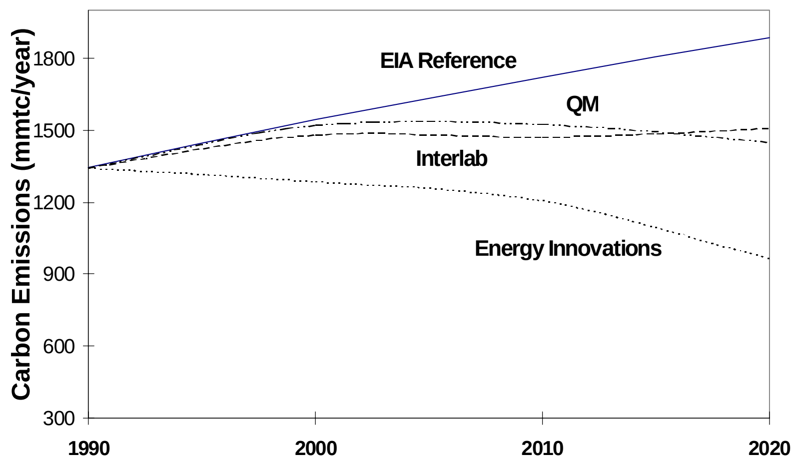

Figure 3.7: Carbon emission projections by alternative studies. Sources: for EIA Reference, EIA (1996); for QM (Quality Metrics), ADL (1997); for Interlab, DOE (1997); for Energy Innovations, ASE (1997).

After a careful analysis of budget needs, priorities, returns, opportunities, and potential**, the Panel recommends increases in the budget commensurate with the potential benefits, ramping up from $450 million in FY 1998 to $880 million in 2003.** After 2003, a new assessment of programs and prospects would be conducted to determine appropriate funding levels. This budget proposal would provide a critical mass of programs that would improve the probability of successful introduction of new technologies into the marketplace. The budget proposal assumes management would remain at current staffing levels even with increased budgets—forcing DOE to be more efficient. In addition, the Panel recommends that research be performed jointly by industry, national laboratories, and universities in partnership with DOE and that no more than 25 percent of the work be performed at national laboratories; i.e. laboratories should farm out significant amounts of work to universities and industry. Industry should cost-share technology R&D, providing at least a 20 percent cost share for high-risk technologies wherever possible[8] to more than 50 percent as risk is reduced. These increases have the potential of buying significant carbon reductions and consumer energy savings. The suggestions of management and technology foci in the report should help increase the probability of successfully achieving these savings. The budget summaries are included in Tables 3.5 to 3.7.

If potential benefits are realized, the return for this portion of the government investment would be on the order of 40 to 1—a cost to the government of about $5 per ton of carbon (of course the investment cost to consumers and industry is not included here, but these investments will be more than recovered from private sector energy savings). Table 3.4 summarizes potential impacts.

[8] In some cases, particularly for start-up companies, a 20 percent cost share may not be possible.

The recommended level of funding will not guarantee the successful introduction of energy efficiency technologies. As this report notes throughout, complementary policies and programs—most especially standards and incentives—are critical as well.

Table 3.4: Potential Benefits from Energy Efficiency Technologies [a]

Potential	**2005**	**2010**	**2020**	**2030**
Carbon reductions (mmtc)	40 – 60	60 – 150	90 – 200	150 – 300
Fuel cost savings (billion $)	15 –30	30 – 45	75 – 95	
Reductions in oil consumption (mmbd)	.5 - 1	1 – 5	2 – 8	4 – 10

[a] Sources: ADL (1997), ASE (1997), DOE (1997).

Table 3.5: Budget Summaries for Energy Efficiency R&D—Buildings (in Millions of Dollars)

Office of Building Technologies [a]	R&D Activities (new programs and those expanded beyond current baseline)	FY 1997	FY 1998 Request	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Residential & Commercial Crosscuts	The crosscut programs based on the IOF model will develop the technology visions road maps and facilitate the partnerships to steer the R&D programs and assist in the implementation of technologies.			20	25	30	35	35
Building System Design and Operations	Advanced sensors, smart controls, automated diagnostics, whole building optimization, and tools to use these technologies for measurement, analysis, and feedback throughout the building construction an operating lifecycle. Links to renewables such as building-integrated PV program), advanced manufacturing of factory-built housing to ensure energy efficiency, building energy models and advanced design tools (DOE III).	24	33	38	48	60	72	84
Building Equipment and Materials	Improved thermal distribution networks (including much expanded outreach), development and testing of innovative materials[b], advanced space-conditioning equipment[c], innovative lighting, better coatings on windows, window edge insulation, new designs for appliances (advanced electronics, better systems), energy-saving office equipment and other plug-loads, insulation initiative. [d]	27	37	57	72	85	98	111
Codes and Standards	Appliances: Standards for residential water heaters, furnaces, central air conditioners, clothes washers, lighting and transformers, commercial packaged HVAC equipment. Building standards: expanded technical assistance, expanded outreach to states, improvement of existing standards: identification of high-energy consuming troubled buildings.	12	21	25	25	25	25	25
Management and Planning		18	20	20	20	20	20	20
Subtotal		81	111	160	190	220	250	275

[a] This does not include weatherization and state and community programs.
[b] Electrochromics for windows; aerogels for insulation; roof reflection materials.
[c] Commercial chillers, gas heat pumps, advanced cycle chillers, gas chillers, building shell technology.
[d] Includes thermal conduction, visible and infrared transmission, absorption, and reflection.

Table 3.6: Budget Summaries for Energy Efficiency R&D—Industry (in Millions of Dollars)

Office of Industrial Technologies	R&D Activities (new programs and those expanded beyond current baseline)	FY 1997	FY 1998 Request	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Industries of the Future	Implement the technology road maps for metal-casting, glass, aluminum, forest products, steel, petroleum refining, chemicals, agriculture (including food processing), and emerging energy-intensive industries. This will help increase efficiency by over 25 percent and reduce emissions by 25 percent by 2010.	46	56	65	75	85	95	110
Crosscutting	Develop 40 percent efficiency microturbines at a target cost of less than $400/kw, develop family of sensors for high temperature harsh environments, aluminides, biomass/black liqueur gasification combined cycle, composites, manufacturing technology for high-temperature materials.	38	38	70	80	90	95	100
Technology Access	Innovations grants, industrial assessments, "Climate Wise" program, motors challenge	25	37	40	40	45	45	50
Management and Planning		7	8	10	10	10	10	10
Subtotal		116	139	185	205	230	245	270

Table 3.7: Budget Summaries for Energy Efficiency R&D—Transportation (in Millions of Dollars)

Office of Transportation Technologies	R&D Activities (new programs and those expanded beyond current baseline)	FY 1997	FY 1998 Request	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
Technology Deployment		11	17	20	20	20	20	20
Advanced Automotive								
-PNGV	Better emissions controls for light diesels; hybrid vehicles; whole vehicle system optimization; advanced vehicle energy and pollution modeling; CIDI engine technology; hybrid systems and emissions reductions to achieve 80 mpg vehicle.	105	129	100	100	100	100	75
-PNGV II	Fuel cells; micro turbines; advanced energy storage technologies; system optimization to achieve a 100 mpg vehicle			75	85	100	100	125
Advanced Heavy Vehicle Technology	Greater depth on engine efficiency; diesel pollution reduction; systems efficiency; intra-urban cycle efficiency; hybrids and other configurations; Class 1 and 2 Truck Initiative; chassis improvements; auxiliary systems improvements to achieve 10 to 20 mpg trucks	20	18	30	40	50	55	60
Transportation Material Program	Develop high temperature; high strength lightweight materials to achieve 25 percent weight reductions while minimizing costs; high temperature materials for engine components; membrane technology for fuel cells	33	31	35	40	40	40	45
Management		7	9	10	10	10	10	10
	Subtotal	176	204	270	295	320	325	335

Table 3.9: Budget Summary

Energy Efficiency	Sector	FY 1997	FY 1998 Request	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003
	Buildings	81	111	160	190	220	250	275
	Industry	116	139	185	205	230	245	270
	Transportation	176	204	270	295	320	325	335
TOTAL		373	454	615	690	770	820	880

REFERENCES

ADL 1997: Arthur D. Little, Inc., Peer Review of Office of Energy Efficiency and Renewable Energy Quality Metrics Estimates, 1997.

ASE 1997: Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Tellus Institute, Union of Concerned Scientists, *Energy Innovations, a Prosperous Path to a Clean Environment*, (Washington, DC: Alliance to Save Energy, 1997).

Defense Monitor 1993: "Defending America's Economic Interests", *The Defense Monitor* Vol. XXII, Number 6, 1993, p.7.

DOE 1997: U.S. Department of Energy, Interlaboratory Working Group on Energy-Efficient and Low-Carbon Technologies, *Scenarios of U.S. Carbon Reductions: Potential Impacts of Energy-Efficient and Low-Carbon Technologies to 2010 and Beyond*. (Washington, DC: DOE, 1997).

EIA 1996: Energy Information Administration, U.S. Department of Energy; *Annual Energy Outlook*, (Washington, DC: U.S. Government Printing Office, December 1996).

EIA 1997: Energy Information Administration, U.S. Department of Energy, *1996 Annual Energy Review*, (Washington, DC: U.S. Government Printing Office, July 1997).

ITS 1996: Federal Highway Administration, U.S. Department of Transportation, *Intelligent Transportation Infrastructure Benefits: Expected and Experiences*, (Washington, DC: U.S. DOT, January, 1996).

ITS 1996: Federal Highway Administration, U.S. Department of Transportation, *Key Findings from the Intelligent Transportation Systems (ITS) Program*, (Washington, DC: U.S. DOT, January, 1996).

ITS 1997: Federal Highway Administration, Intelligent Transportation Systems, U.S. Department of Transportation, Program Overview and Accomplishments, USDOT webpage, 1997.

LBL 1995: Lawrence Berkeley Laboratory, *From the Lab to the Marketplace, Making America's Buildings More Energy Efficient*, (Berkeley, CA: University of California, March 1995).

OP 1996: Office of Policy, U.S. Department of Energy, *Success Stories: The Energy Mission in the Marketplace, Part 2 of Department of Energy Report, Corporate R&D in Transition*, (Washington, DC: U.S. DOE, March 1996).

PNGV 1996: Partnership for a New Generation of Vehicles, *PNGV Technical Accomplishments*, (Washington, DC: U.S. Council for Automotive Research, 1996).