Introduction

CHAPTER 1

Whether you want the United States to achieve greater energy security by weaning itself off foreign oil, sustain strong economic growth in the face of worldwide competition or reduce global warming by decreasing carbon emissions, energy efficiency is where you need to start. Thirty-five years ago the U.S. adopted national strategies, implemented policies and developed technologies that significantly improved energy efficiency. More than three decades have passed since then, and science and technology have progressed considerably, but U.S. energy policy has not. It is time to revisit the issue.

In this report we examine the scientific and technological opportunities and policy actions that can make the United States more energy efficient, increase its security and reduce its impact on global warming. We believe the findings and recommendations will help Congress and the next administration to realize these goals. Our focus is on the transportation and buildings sectors of the economy. The opportunities are huge and the costs are small.

Nowhere in the world does energy affect the lives of people more than in the United States, one of the world's largest per capita consumers of that commodity. Nowhere is the standard of living more rooted in energy than in the United States, and, with its defense forces deployed in the most distant regions around the world, nowhere is the security of a nation more dependent on energy.

Yet only in times of extreme turbulence—the OPEC (the Organization of Petroleum Exporting Countries) oil embargo in 1973, the overthrow of the shah of Iran in 1979 and the Persian Gulf War in 1991—when public frustration became politically intolerable did American officials devote serious attention to energy policy. Although some of the policy initiatives yielded significant benefits, others were left on the drafting board, as the nation reverted to a business-as-usual energy routine, once the turbulence passed and public dissatisfaction dissipated.

Today the American public is again demanding that its elected officials take action. Gasoline prices are soaring, increased transportation costs are driving up the costs of goods, and home-heating oil is becoming prohibitively expensive. The people feel as if they are under siege.

In contrast to previous market instabilities, however, this one may be more enduring. Thirty-five years ago, when OPEC imposed its oil embargo, the United States was importing 6.3 million barrels a day; today it imports 13.5 million barrels a day, two-thirds of the nation's consumption. Thirty-five years ago, the world's two most populous countries, China and India, were poor agrarian societies that had minimal need for oil; today they are rapidly developing industrial economies with a greatly increasing demand for energy. Thirty-five years ago, unfriendly nation states posed the greatest risk to oil security; today terrorist groups have added substantially to potential interruptions of global supplies.

By enacting Public Law 110-140, the Energy Independence and Security Act of 2007, Congress and the administration explicitly recognized the national security threat created by our unwholesome dependence on foreign sources of oil. Titles I, III and IV of the act deal specifically with energy efficiency policies in the transportation and buildings sector. Generally this report neither criticizes nor endorses particular portions of those titles, but instead focuses on the scientific and technological opportunities and challenges associated with improving energy efficiency in the transportation and buildings sectors.

Without question, the United States faces a greater energy risk today than it has at any time in its history. But the nation and the world face another risk that was barely recognized thirty-five years ago. Global warming and the potential it has for causing major disruptions to Earth's climate are scientific realities. The precise extent of the human contribution to global warming still needs deeper understanding, but there is virtually no disagreement among scientists that it is real and substantial.

The physics and chemistry of the greenhouse gas effect are well understood and beyond dispute. Science has also achieved an overwhelming consensus that the increase in greenhouse gases is largely of human origin, tracing back to the Industrial Revolution and accelerating in recent years, as carbon dioxide and methane—the products of fossil fuel use—have entered the atmosphere in increasing quantities.

Modeling the climate has proven to be a complex scientific task. But although the models are far from perfect, many of their predictions are so alarming that conservative, risk-averse policymaking requires that they be considered with extraordinary gravity.

Energy is necessary for almost all facets of human existence: oil and gas for cooking and heating; electricity for cooling, lighting, appliances and machines; gasoline and diesel fuel for transportation; and a mix of energy supplies for myriad other purposes. Energy is necessary for every society at every level of development, but as a general rule, energy consumption increases as societies become more developed and their standard of living rises. The United States, for example, which boasts the highest per capita gross domestic product (GDP) among nations of 10 million people or more, has approximately 5 percent of the world's population but consumes almost 25 percent of the world's energy supply each year.

Just as the per capita GDP delineates have and have-not nations, so do primary energy reserves. Oil, natural gas and coal are not distributed uniformly around the world. The United States, for example, is coal rich, possessing far more recoverable reserves than any other nation—about 275 billion tons, or 25 percent of the world's total. But in the case of oil, the United States has less than 2.5 percent of the world's known reserves, and at the current rate of domestic production that percentage is shrinking rapidly.

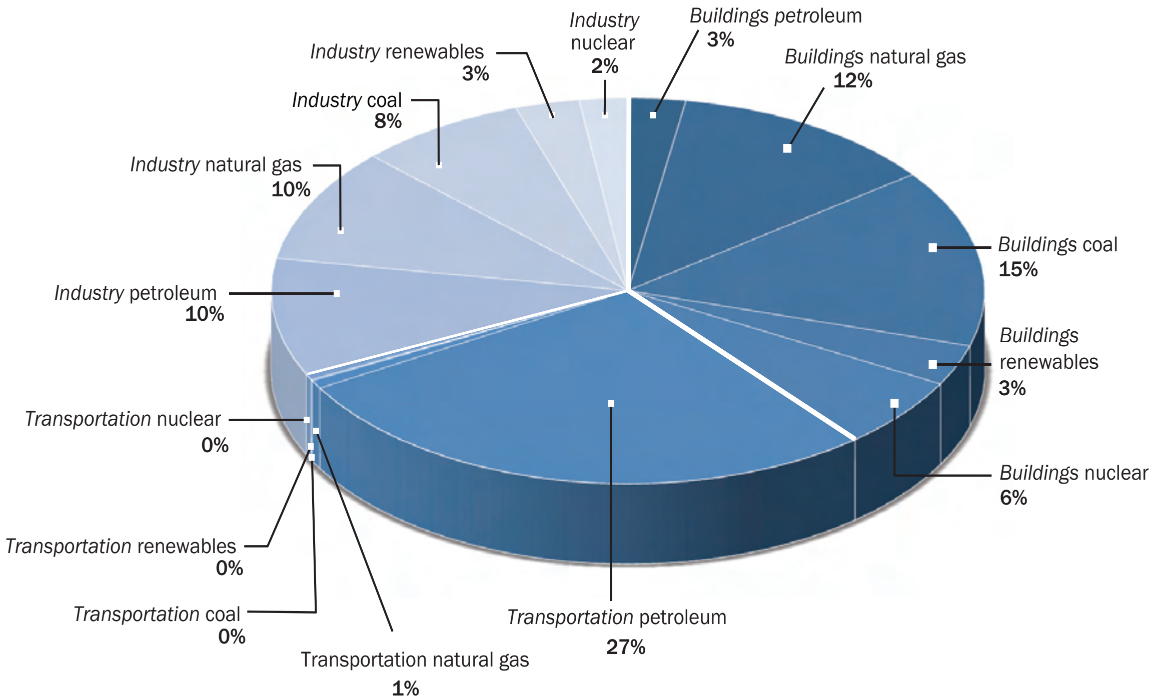
Relying on foreign oil is particularly dangerous for our nation, since two-thirds of the world's known reserves are in non-democratic countries, some of them overtly hostile to American interests. Replacing oil with other sources of energy and reducing energy consumption are clearly in the best interests of national security.

U.S. policymakers therefore face the challenge of keeping the American economy humming while simultaneously reducing the emission of greenhouse gases and diminishing the nation's dependence on uncertain and insecure sources of foreign oil. The challenge may seem daunting, but the twin goals are achievable if the nation adopts wise policies and makes prudent investments in research and development. A strong industry commitment to short-term applied research and development, sustained federal government investment in long-term basic and applied research and the adoption of state and federal policies that stimulate the market for greater energy efficiency can re-

Figure 1

Energy usage in the U.S.

Distribution of U.S. energy usage in 2006, grouped by end-use sector (transportation, buildings and industry). Annual consumption for 2007 was 101.6 quads (10^{15} BTU).



duce greenhouse gas emissions, achieve energy security and enable the American economy to remain robust and competitive. The greatest impact at the least cost can come from improving the energy efficiency in key sectors of our economy.

Reducing global carbon emissions while the world's economies continue to grow will not be easy. Science and technology, coupled with intelligent policymaking, provide the United States with the tools needed to achieve the goal at home and stimulate success in other parts of the world.

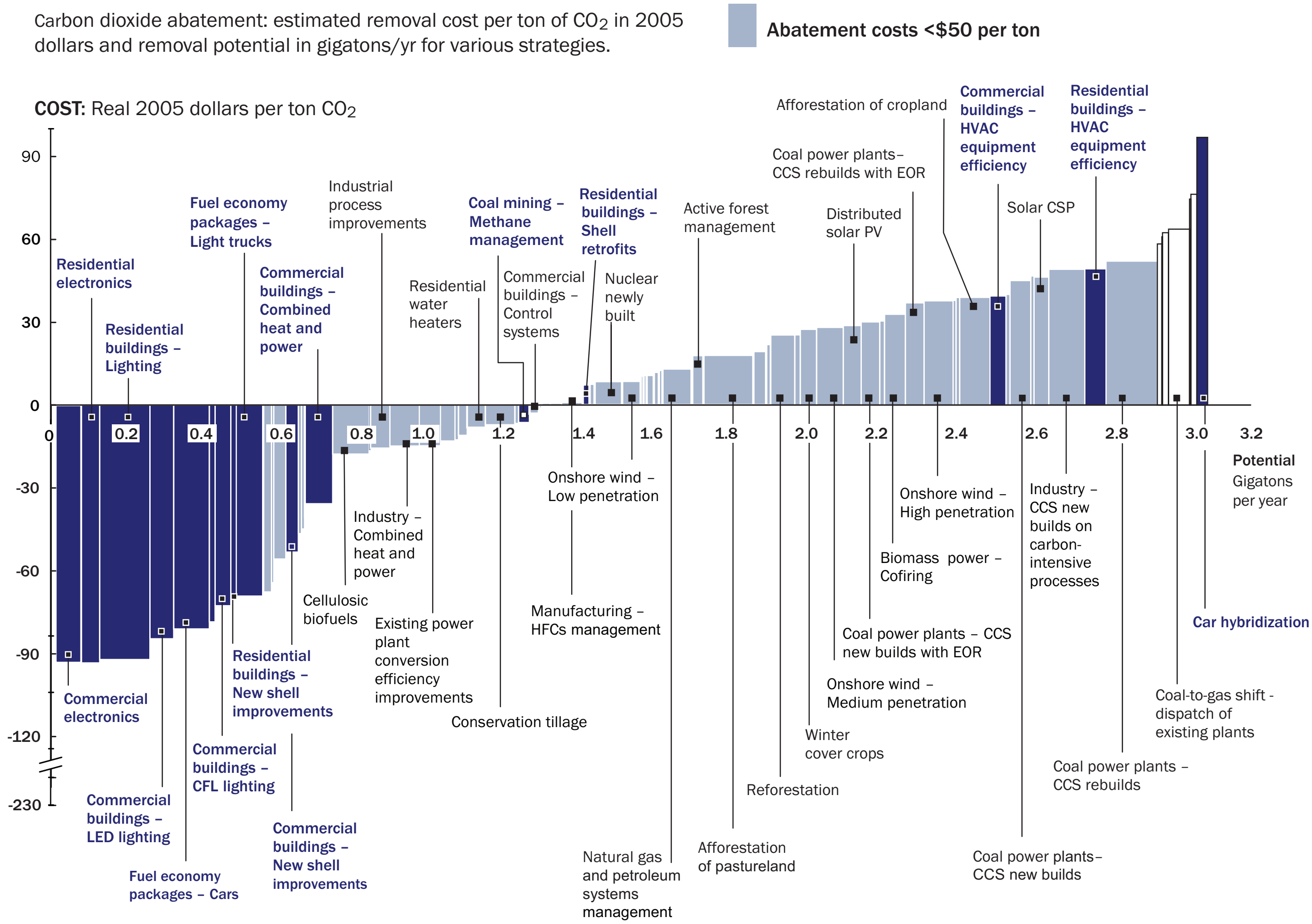
Of all policy and technology options, the one that has the greatest potential in the next two decades is improving energy efficiency, particularly end-use efficiency in buildings and transportation. These two sectors together account for almost 70% of total domestic carbon emissions. However, elected officials, policymakers, industrial leaders and the public have paid scant attention to energy efficiency in the past. But with oil and gasoline prices skyrocketing, foreign supplies increasingly insecure and global warming widely accepted as a scientific reality, energy efficiency is gaining currency as a policy issue, an economic issue and a research and development issue.

The American Physical Society (APS) is not new to the issue of energy efficiency. It first addressed the question in 1975 [W. Carnahan *et al.,* 1975], and the results of that APS study helped provide the intellectual underpinnings for achieving major efficiency gains, particularly in appliances, heating systems and air conditioning. The current APS study focuses on end-use efficiency in two of the three end-use sectors: transportation and buildings. It does not address industrial energy usage, because the problems there are industry specific and it was not feasible to assemble a set of generalized findings and recommendations. Nor does this study address the efficiency issues associated with the generation and transmission of electricity, in which 50 percent to 70 percent of the energy created

Figure 2

U.S. mid-range abatement curve - 2030

Carbon dioxide abatement: estimated removal cost per ton of CO_2 in 2005 dollars and removal potential in gigatons/yr for various strategies.



Source: *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?,* Executive Report, McKinsey & Company, December 2007

is lost depending on the generating technology.

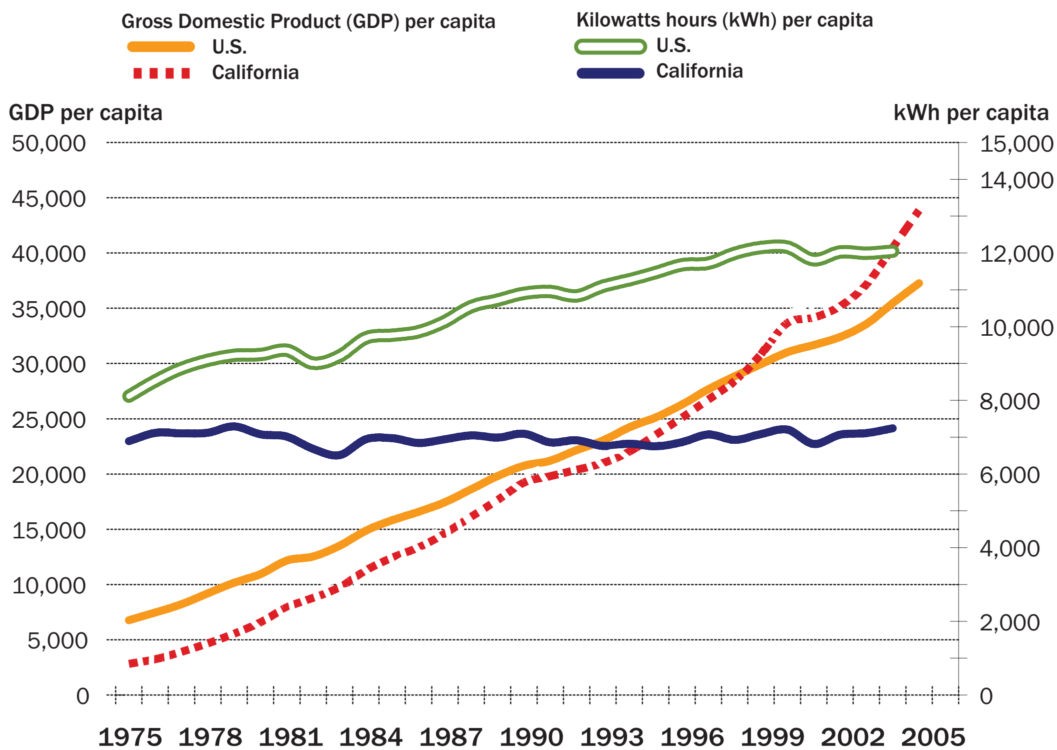
To put the three sectors—end-use buildings, transportation and industry—in the context of energy security and carbon emissions, we begin by summarizing the amount of U.S. primary energy (petroleum, natural gas, coal, renewables and nuclear) each sector uses. As *Figure 1* illustrates, transportation accounts for 68 percent of U.S. petroleum consumption. Therefore, improving efficiencies and trimming the use of petroleum in transportation—including greater reliance on rechargeable batteries or fuel cells in the years ahead—provides the greatest potential for reducing America's dependence on foreign oil and for increasing America's energy security.

Converting the sector data shown in *Figure 1* into proportional shares of carbon emissions requires taking into account how much carbon each of the three fossil fuels—petroleum, natural gas and coal—contains. Including the carbon emissions from the generation of the electricity used in each sector, the analysis shows that each is responsible for about a third of the emissions: buildings, 36 percent; transportation, 32 percent; and industry, 32 percent. Significant improvements in building and transportation efficiency, which this report will demonstrate are within reach, provide an extraordinary potential for making major reductions in greenhouse gas emissions. Improving energy efficiency is therefore, in a real sense, equivalent to replacing fossil fuels with non-polluting sources of energy.

Reducing carbon emissions will have economic ramifications, and, contrary to common lore, many of them are beneficial, as noted by McKinsey and Company, a private research firm, in its

Figure 3

Electricity usage and economic growth for California and the United States



Source: California Energy Commission

2007 report, "Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?" Although we have not examined the data used in the McKinsey analysis, we find the U.S. Mid-Range Abatement Curve—2030, shown in *Figure 2,* at least qualitatively instructive. Replacing carbon-emitting fossil fuels with most alternative energy sources, including clean-coal (with carbon sequestration), nuclear power, biomass, wind, solar photovoltaics (PV) and concentrated solar power (CSP), costs the economy money (positive bars, expressed in 2005 dollars per ton of CO_2 removed from the emission inventory). But, improving energy efficiency in transportation and buildings generally saves the economy money (negative bars).

Despite the projected savings, some critics argue that reducing per capita energy use through improved efficiency could depress economic growth. But the California experience suggests otherwise. In 1975 California instituted a program to improve electrical energy efficiency—in part as a response to the APS study. California's policies, including regulations and incentives, have helped hold the state's per capita electricity use constant for the past 30 years while allowing its economy to flourish. Some of the reduction in energy consumption is attributable to changes in California's economic mix, but a significant fraction is associated with efficiency gains. During the same 30-year period, electricity use per capita in the United States rose by 50 percent, and GDP growth nationally did not even keep pace with California's GDP increase. *Figure 3* summarizes the results graphically.

Notwithstanding the positive California experience, in which the state intervened with regulations and incentives to achieve energy efficiencies, some analysts argue that markets ultimately are efficient and will provide the most beneficial outcomes if left unregulated. Government intervention, they say, is unnecessary and potentially harmful. But in the case of energy efficiency, market imperfections exist and must be remedied if progress is to occur. We highlight a few instances, beginning with support for long-term research.

Achieving the maximum efficiencies possible in both transportation and buildings will require making significant scientific advances, many of them taking ten, twenty or more years to achieve. Experience of the past few decades has shown that such time horizons are incompatible with the parameters established by financial markets, which require companies to demonstrate performance every quarter or every year. Money may be patient to some degree, but certainly not for a decade or more.

Long-term research, either basic or applied, is simply not well suited to the abbreviated time frames of the private sector, nor are many of the risks associated with such research generally acceptable to most financial investors. As a result, over the past thirty years, the United States has evolved toward a system in which funding of long-term basic research has become the province of the federal government and investment in short-term applied research and development has remained largely in the domain of private industry. Although the hand-off from public-sector science to private-sector innovation is not perfect, the U.S. model has shown great efficacy and resilience and is now emulated by many other countries.

Even when technologies exist, the market does not always react efficiently. In the case of buildings, for example, tenants are often responsible for paying for utilities and maintenance. Therefore, builders and landlords have little incentive to spend extra money to achieve energy efficiencies in lighting, heating, cooling and structural design. Few residential consumers have the knowledge or the time to seek energy efficient products. Absent government energy labels, codes and standards, market forces alone will not encourage such investments.

In the case of transportation, especially in the light-vehicle sector, manufacturers in recent years have optimized their profits by building vehicles of ever increasing size and horsepower. While gas prices were low, power and size provided the greatest appeal to consumers and the greatest profits for manufacturers. Absent a penalty for carbon emissions, neither sellers nor buyers had any incentive to favor more efficient and less carbon-polluting vehicles. We note that consumer preference for power and size has changed dramatically in the last year as rapidly rising gasoline prices have driven buyers away from sport-utility vehicles and pick-up trucks. But if gasoline prices fall, the prior pattern of sales could easily resume.

The building and transportation sectors also have significant inertia built into them by the associated lifecycle times. When the costs of energy rise rapidly and unexpectedly or the potential interruption of oil supplies suddenly looms large—both of which we have witnessed over the past year—a market that functions on much longer lifecycle times often cannot react rapidly enough to avoid the adverse societal and economic consequences. Incandescent lamps, which typically burn out after a year, are an exception. But the development of energy-efficient replacement lamps required government-funded R&D that took place over many years. Appliances generally last 7 to 20 years; cars, 10 to 15 years; heating and cooling systems in commercial buildings, 20 years or more; and building structures, 50 to 100 years.

With such relatively long lifecycles affecting the buildings and transportation sectors, and with energy costs and occasional supply interruptions mostly unpredictable, market forces alone cannot drive the adoption of energy-efficiency technologies in a beneficially sustained manner within the timeframe imposed by the challenges of global warming. Stimulating the markets to behave efficiently, given the external realities, requires carefully crafted policies. These could involve selective mandates, such as CAFE (Corporate Average Fuel Efficiency) standards for cars and light trucks, building codes and appliance standards. They could involve taxes, such as those applied to the weight of a vehicle or an engine displacement. They could include incentives such as those that have been applied to hybrid cars or solar panels. Or they could require energy labeling of products or energy audits of buildings that would permit consumers to make choices based on better information.

Identifying which set of policies is likely to have the greatest influence on implementing the recommendations of our study sometimes lies beyond the scope of our report. Indeed, in a number of cases the choice of policies might require additional social science research into how people evaluate risk, how they integrate long-term and short-term benefits and costs, how they react to economic triggers and how they understand and value the energy security and global warming issues. While this report focuses on the physical sciences and was written largely by experts in that field, the panel strongly believes that progress in energy policy will be inadequate without additional social science research and without implementing what social science can already teach us about policies to use energy more efficiently. Even when we refrain from prescribing specific policy choices, we are resolute in our view that appropriate policies must be adopted for technological developments to have the greatest benefit.

Before we address the specifics of energy efficiency in the transportation and buildings sectors, we pause to clarify two issues: what we mean by "energy efficiency" and what criteria we use to circumscribe "energy end use."

In common parlance "energy efficiency" denotes the ratio of useful energy or work a device produces to the energy the device consumes. For example, a furnace that burns its fuel completely but loses 20 percent of the heat it produces to flue gases escaping up the chimney is said to be 80 percent efficient because it converts 80 percent of the fuel's energy into usable heat. Similarly, an internal combustion engine that transforms 20 percent of the chemical energy contained in gasoline into a car's energy of motion (kinetic energy) but loses 80 percent of the gasoline's energy to waste heat is said to be 20 percent efficient.

The ratio of useful energy output to total energy input may seem an intuitively reasonable definition of energy efficiency, but in some cases it is too simplistic. Consider two homes, for example, both heated with 80 percent efficiency furnaces. One of the homes is well insulated and the other one has little or no insulation. We would certainly view the well insulated home, which might use one-fifth as much energy, as far more energy-efficient, even though the furnaces of both homes carry the same efficiency rating. Similarly, if we could use a "thermoelectric" device to convert some of the waste heat of a car's engine into electricity to power accessories or recharge a hybrid car's battery, we could increase the overall efficiency of the car without ever increasing the efficiency of its internal combustion engine.

Another definition of energy efficiency has greater utility: the ratio of the minimum amount of energy needed for accomplishing a task to the energy actually used. Although it may not always be possible to determine the minimum amount of primary energy required for a task, it is still possible to compare the relative efficiencies of two methods for accomplishing the same task. In this report, we implicitly apply such logic when we conclude that one strategy is more energy efficient than another.

Separating energy end use from energy production and delivery may seem like a simple task, but it isn't, particularly in the case of energy efficiency. For example, the use of plug-in hybrid cars or trucks for transportation will reduce oil consumption and in that respect make vehicles more carbon efficient and less dependent on foreign sources of energy. But plug-in hybrids will also need electricity for recharging their onboard batteries, and in most cases the electricity will have to be generated centrally and distributed through the power grid. The efficiency of electricity generation has to be counted in determining the overall energy efficiency. If plug-in hybrids become ubiquitous, their widespread use will almost certainly require increasing electrical generation capacity and upgrading the grid. Many of the same things can be said about fuel cell vehicles.

Despite their impact on energy production and distribution, we elected to include plug-in hybrids and fuel cell vehicles in our discussion of energy efficiency in the transportation sector, because we believe they have an extraordinary potential for decreasing carbon emissions and increasing our energy security. By contrast, we elected not to discuss biofuels, including ethanol and biodiesel, because they have minimal impact on energy efficiency.

We recognize that some of our choices regarding which science and technologies to emphasize in this study may seem arbitrary, but we believe they represent the areas that have the greatest potential for increasing our nation's energy security, decreasing our dependence on foreign sources of oil, reducing the nation's contribution to greenhouse gas emissions and sustaining our economy. In the following three chapters, we examine the possibilities for improving energy efficiency in two principal energy sectors: transportation and buildings. We also highlight the research and development opportunities and the public policies that we believe to be most effective in achieving the twin goals of improved energy security and reduced greenhouse gas emissions.

Attaining these objectives may seem like a formidable challenge. But in answer to the question, "Can we do it?" We note that in a speech to the nation during the oil shock of 1973, President Richard Nixon unveiled "Project Independence 1980" [*New York Times,* 1973]. It was "a series of plans and goals," he said, "set to insure by the end of this decade Americans will not have to rely on any source of energy beyond our own." President Nixon resigned from office eight months later, and although the our nation never achieved the energy independence he and his successor Gerald Ford sought, the energy efficiency measures the United States adopted cut energy consumption dramatically even as our economy continued to thrive. The Project Independence report [Federal Energy Administration, 1974] had predicted that American energy needs would double from 75 quads at that time to 150 quads by the turn of century. In fact, by the year 2000, American energy consumption had not yet reached 100 quads, an increase of less than a third, even though the real U.S. gross domestic product (GDP) had more than doubled. The movement from manufacturing to services, perhaps not sufficiently foreseen in 1975, played a role in reducing the number of quads consumed per unit of GDP, but so too did major improvements in energy efficiency.

There is no reason why we cannot use gains in efficiency once again to curb our energy consumption. Reducing our dependence on foreign oil is at least as important today as it was in 1974, and restricting greenhouse gas emissions, which was not on the scientific radar screen three decades ago, is now a recognized global necessity. As this report shows, we are not remotely near any physical limitations on efficiency improvement. What we need are the innovations, policies and will to achieve the goal.

Chapter 1 References

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