

The Energy Imperative: Report Update

President's Council of Advisors on Science and Technology

November 2008

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EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL ON ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

November 5, 2008

President George W. Bush
The White House
Washington, D.C. 20502

Dear Mr. President:

We are pleased to send you the attached update to our 2006 report, *The Energy Imperative: Technology and the Role of Emerging Companies*. The original report discussed entrepreneurial and private-sector innovation in clean and efficient energy technologies. It also outlined a set of policy recommendations to reduce our Nation's reliance on foreign oil and to decrease atmospheric emissions from energy production and use. While recent economic turmoil is leading to lower oil prices and may influence investments in new technologies, the fundamental long-term need for energy security and environmental sustainability is unchanged. In the present report, we update our previous findings to account for recent developments, particularly in the area of energy security, as well as progress in implementing the 2006 recommendations.

Over the past two years we have seen notable improvements in energy supply and demand trends. Since 2005, net oil imports in the United States have declined by almost 10 percent – from 12.5 million barrels per day (mbd) in 2005 to 11.3 mbd for the first eight months of 2008. There are also significant advances in the commercial viability of advanced energy technologies. Further, over the past two years, important new Federal energy policies have been enacted, including the renewable fuel standard and vehicle fuel economy standard that you proposed to Congress in January 2007 and signed into law in December 2007. For these reasons, the PCAST is optimistic that the Nation's imported oil demand will continue to decrease. Maintaining this progress, however, will depend on major improvements in technologies such as second-generation biofuels, energy storage for vehicles, and advanced nuclear reactors. Large-scale commercial viability of these technologies will require fundamental breakthroughs and technology innovation. To achieve this, Federal funding for energy research and development – following the significant progress made under your American Competitiveness Initiative and Advanced Energy Initiative – will need continued growth.

The full PCAST discussed and approved this update at its public meeting on September 16, 2008. We have been pleased with the number of recommendations from the 2006 report that have been implemented, and we hope that this update will also contribute to advancing our Nation's energy security and sustainability goals.

Sincerely,



John H. Marburger, III
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Overview and Key Observations

In November 2006, the President's Council of Advisors on Science and Technology (PCAST) published a report, *The Energy Imperative: Technology and the Role of Emerging Companies*, which discussed the potential for advanced energy technology to enhance U.S. energy security while protecting the environment. The report highlighted entrepreneurial and private-sector activity across an array of advanced energy technologies, and concluded that technology innovation offers the prospect of a cleaner, more efficient, and more economically sustainable future. In this document, PCAST updates its previous findings to account for recent developments in energy trends and energy policy, focusing in particular on energy security and the progress made in implementing the 2006 report recommendations.

Since the 2006 report, a number of domestic and international developments have affected the production and use of energy in the United States. The following observations relate to the current policy discussion on energy security:

- The recent turmoil in global markets has led to a drop in oil prices from mid-2008 highs, as well as a slowing of private investment in the development and deployment of new energy technologies. The clean-energy market will likely cool somewhat as the private sector is less able to invest in advanced technologies that increase up-front costs and risk. Nevertheless, from a long-term perspective, the fundamental need for national and global energy security and environmental sustainability remains unchanged. While an economic slowdown may temporarily ease the pressures associated with a rapid growth in demand, consistent government investment in this area remains essential, particularly in the area of basic research focused on breakthroughs that will enable broadly competitive clean and efficient energy technologies.
- Since 2005, net oil imports in the United States have *declined* by almost 10 percent – from 12.5 million barrels per day (mbd) in 2005 to 11.3 mbd for the first eight months of 2008 (EIA-DOE 2008d). Most of this reduction has been due to the following three factors:
 - increased availability of ethanol and biodiesel in motor fuel (from 0.25 mbd in 2005 to over 0.6 mbd today, or nearly 10 billion gallons per year and growing)
 - increased domestic oil production (from 8.3 mbd to 8.6 mbd)
 - a reduction in overall vehicle miles traveled.
- The growing demand for biodiesel and ethanol (which until recently has been priced well below gasoline), along with the Renewable Fuels Standard (RFS) mandated by the Energy Independence and Security Act of 2007 (EISA), have stimulated investment in advanced biofuels. Currently, six cellulosic ethanol refineries are in construction or planned, thereby increasing the likelihood that the EISA cellulosic biofuels production requirements will be achieved.
- Hybrid-electric vehicles have become popular with the public, and the demand for these products has grown rapidly. Automobile manufacturers have announced plans to introduce, in the next few years, plug-in hybrid electric vehicles (PHEVs) that can travel up to 40 miles on stored electricity before having to shift to gasoline. Energy storage technology has progressed, albeit slowly. Significant improvements in battery cost and performance are needed for PHEVs and electric vehicles (EVs) to become commercially

viable in the mainstream market. As the technology improves and these vehicles gain acceptance, however, electricity could become a cost-effective alternative to oil.

- While two-thirds of the Nation's oil supply is used for transportation (e.g., automobiles, trucks, and airplanes), about one-quarter of the total available oil is used in the industrial sector for the manufacture of some 300,000 products. There is evidence that some manufacturers are converting these petroleum-based products to bio-based substitutes, which should further reduce the demand for imported oil.

Overall, these developments indicate that we can be optimistic that the Nation's imported oil demand will continue to decrease in coming years. Additionally, the future transportation system may require a greater-than-expected increase in electricity demand.¹ The following observations relate to the future of the electricity grid.

- Rapid growth in the use of electricity for refining biofuels and charging PHEVs will eventually require a significant increase in the capacity of the U.S. electricity generation and transmission infrastructure. The growing use of desalinization for water supply will also place new demands on electricity supply. These factors, in addition to an increase in demand for electricity driven by economic and population growth, will especially impact base load demand, which today is supplied primarily by coal, natural gas, hydroelectric, and nuclear power plants.
- Energy efficiency measures, including efficient appliances, high-performance buildings, and smart grid technologies, offer highly cost-effective opportunities to reduce electricity demand and carbon emissions, but at best will reduce electricity demand by less than 20 percent compared to baseline projections for 2030.²
- Renewable power generation from solar, wind, biomass, and geothermal resources is growing rapidly, but these sources still supply only about two percent of the electricity consumed in the United States. In an optimistic scenario, non-hydro renewable sources could supply up to 20 percent of U.S. electricity by 2030. Enabling renewable energy to achieve its potential in the U.S. energy mix will require a long-term, consistent policy approach to address cost, regulatory, and transmission infrastructure challenges. For solar photovoltaic (PV) technology, basic research is particularly important to make the needed improvements in cost and performance.
- Solar power can help meet peak load electricity demand, and wind power offers relatively low-cost renewable electricity at the utility scale. These sources are, however, intermittent and thus cannot supply continuous, base load power for the electric grid without large-scale energy storage, which is not currently feasible. On the other hand, geothermal, biomass, and ocean-based systems can support base load demand. Thus these base load renewable energy technologies also merit increased funding for research and development (R&D) to drive down their cost. All of these technologies will benefit from the recently enacted extension of the renewable energy investment and production tax credits to encourage early deployment.

¹ The Energy Information Administration of the U.S. Department of Energy projects in its baseline scenario that U.S. electricity demand will grow by 29 percent from 2006 to 2030 (EIA-DOE 2008a).

² For example, a 2007 study by the Electric Power Research Institute estimated that accelerated energy efficiency measures could reduce electric power demand by 9 percent below baseline projections by 2030 (EPRI 2007).

- Concerns over global climate change are motivating reductions in greenhouse gas (GHG) emissions from the electric power sector. Significant emissions reductions will require not only increased renewable energy and energy efficiency, but also more nuclear power and cleaner coal-fired power plants in order to meet the demands of scale. The recent \$8-billion solicitation from the Department of Energy (DOE) to offer loan guarantees for new clean-coal plants is a step in the right direction. The successful development and demonstration of low-cost carbon capture and storage technology for fossil-fuel power plants would enable cost-effective carbon emissions reductions on a global scale. Even without carbon capture, high-efficiency coal power plant designs can significantly reduce CO₂ emissions and make more efficient use of mined coal. Coal gasification technology offers the potential for both improved plant efficiency and low-cost carbon capture.
- Applications for the construction of 11 new nuclear power plants have been submitted to the Nuclear Regulatory Commission (NRC), and utilities have announced plans to build 23 new nuclear plants. Although these announcements do not constitute commitments, they do indicate a strong interest in nuclear power from industry and the utilities; however, financial concerns persist and will in all likelihood require increased Federal loan guarantees to bring these facilities to completion.

Introduction

The need for dramatic improvements in the U.S. energy sector remains as apparent today as it did in 2006, when PCAST published *The Energy Imperative: Technology and the Role of Emerging Companies*. In the past year, fuel costs reached record levels. Meanwhile, global carbon emissions continue to increase and the Nation's transportation sector remains heavily dependent on oil. Despite these challenges, PCAST finds substantial grounds for optimism. Since the 2006 *Energy Imperative* report, both the Federal Government and the private sector have taken steps to move the U.S. transportation sector away from fossil fuels. For example, President Bush proposed (in January 2007) and signed into law (in December 2007) an ambitious renewable fuel standard as well as the largest increase in vehicle fuel economy standards in thirty years. Meanwhile, investments from U.S. technology companies have continued to grow. In the venture capital sector, clean energy technologies have garnered as much as 20 percent of all venture investments in recent quarters. Commercial products based on early investments in technologies such as energy storage, advanced biofuels, and solar power have begun to enter the market. Larger, established corporations and private equity funds in many industry sectors have also seen the market potential in the energy/climate sector and are increasingly investing to take advantage of industry opportunities. In the first three quarters of 2008, over \$5 billion worth of investments were made in clean energy technologies, a 50 percent increase over all of 2007 (Kho 2008). While this pace is likely to slow in coming months, clean energy technologies will continue to make significant contributions to the new electric power and transportation energy infrastructure.

The long-term prosperity of the United States depends on continued innovation in technologies for electric power generation, transportation, and industrial uses. The 2006 report highlighted entrepreneurial and private-sector activity in clean energy technologies and assessed some of the potential benefits of innovation in these areas. Given the importance of energy security and the pace of recent developments in this area, PCAST has decided to update the findings of its *Energy Imperative* report in order to recognize the progress being made toward implementing the report's recommendations.

Policy Developments

Since the publication of *The Energy Imperative*, there have been numerous developments in energy policy. PCAST applauds these developments and is pleased to have contributed to progress in this area.

EISA

EISA, signed by the President in December 2007, established a number of provisions that will contribute to cleaner and more efficient energy use. Several of these provisions are consistent with recommendations in the 2006 PCAST report. To address oil dependence and to respond to the President's "Twenty-in-Ten" plan, which was announced in his 2007 State of the Union address, EISA:

- Establishes a renewable fuel standard (RFS) with mandatory annual production volumes of biofuels, quadrupling the RFS of the Energy Policy Act of 2005. For the first time, EISA establishes separate mandatory targets for cellulosic ethanol, biodiesel, and other advanced biofuels, which can include just about any biofuel other than corn-starch ethanol. Today, biofuels production is approaching 10 billion gallons per year (mostly corn ethanol, but also including 0.5 billion gallons per year of biodiesel). The RFS requires the use of 36 billion gallons of biofuels per year by 2022, of which only 15 billion gallons can be corn ethanol. In effect, EISA establishes a price floor for cellulosic ethanol production. The legislation also requires that biofuels reduce life-cycle GHG emissions by amounts ranging from a 20 percent reduction for corn ethanol to a 60 percent reduction for cellulosic biofuels when compared to gasoline.
- Mandates a 40 percent increase in the corporate average fuel economy (CAFE) standard for cars and light trucks, from 25 miles per gallon (mpg) to 35 mpg, by 2020.

To address electricity use efficiency, EISA:

- Sets new energy efficiency standards for industrial electric motors, boilers, dehumidifiers, dishwashers, clothes washers, and other appliances.
- Requires a 28 percent reduction in energy used by incandescent light bulbs by 2012 and a 65 percent reduction by 2020. EISA also sets standards for fluorescent lights and metal halide lamp fixtures.
- Requires a 30 percent reduction in energy use in Federal buildings by 2015, which is in line with the President's Executive Order 13423 (January 2007) on sustainability requirements for Federal agencies.

Farm Bill

The 2008 Farm Bill provides a tax credit of \$1.01 per gallon for cellulosic ethanol, while reducing the existing tax credit for corn ethanol from \$0.51 to \$0.45 per gallon and setting an expiration date of December 31, 2010. Additionally, the Farm Bill provides several programs with mandatory and discretionary funding for grants, payments, and loan guarantees to encourage expanded domestic production of advanced biofuels and bio-based products. The

legislation also authorizes research, development, and demonstration activities related to improving these technologies.

Advanced Energy Initiative

The President announced the Advanced Energy Initiative (AEI) in his 2006 State of the Union address. Since then, funding for key areas of energy R&D has increased rapidly. Compared to fiscal year (FY) 2006, the President's proposed FY2009 budget includes 80 percent more R&D funding for the AEI technologies – increasing from \$1.8 billion to \$3.2 billion. For example, including basic and applied research from FY2006 to FY2009:

- Solar R&D funding has increased 103 percent from \$111 million to \$225 million;
- Biomass R&D funding has increased 188 percent from \$119 million to \$343 million;
- Clean coal R&D funding (now almost entirely carbon capture and sequestration R&D) has increased 87 percent from \$314 million to \$464 million;
- Nuclear R&D funding has increased 178 percent from \$251 million to \$697 million;
- Vehicle technology R&D funding (e.g., for PHEVs) has increased 21 percent from \$182 million to \$221 million.

American Competitiveness Initiative

The President's American Competitiveness Initiative (ACI) seeks to double basic research funding in the physical sciences over ten years at three Federal science agencies—the National Science Foundation (NSF), DOE Office of Science (SC), and the Department of Commerce's National Institute of Standards and Technology (NIST) laboratory research and facilities (Core). In year one of the initiative (FY2007), Congress provided about half of the President's \$1 billion requested increase for ACI research. The following year, less than one-third of the requested research increases were provided. In FY2009, year three of the ACI, President Bush's budget request has restored ACI to its original ten-year doubling path, proposing \$12.2 billion total for NSF, DOE SC, and NIST Core, a funding increase of \$1.6 billion, or 15 percent, above the 2008 enacted total of \$10.6 billion. This basic research funding, authorized in the bipartisan 2007 America COMPETES Act, is critical to enabling the innovation necessary to drive the Nation's long-term economic competitiveness.

Climate Technology Funding

Annual funding for climate technology R&D currently exceeds \$4 billion, and annual funding for climate science research and technology R&D combined has reached an estimated \$8.6 billion in the President's proposed FY2009 budget. That amount includes most of the AEI funding discussed above. U.S. Federal funding for climate and energy R&D, excluding nuclear energy R&D, far exceeds that of any other nation. Since 2001, the Bush Administration has devoted approximately \$45 billion for climate-related science, technology, observations, international assistance, and tax incentive programs.

Loan Guarantees

The FY2008 omnibus appropriations act included a two-year approval of the DOE loan-guarantee program, which provides \$20.5 billion specifically for nuclear energy – \$18.5 billion for up to 80 percent of construction costs for nuclear reactors and \$2 billion for uranium

enrichment – as well as \$10 billion for renewable energy and energy efficiency and \$8 billion for clean-coal technology. DOE is in the process of issuing solicitations for these loan guarantee authorities.

Climate Change Policy

In 2007, President Bush established the international Major Economies Meeting process, which led to an unprecedented summit of 17 leaders of major economies in July 2008. The summit produced a joint recognition of ambitious and achievable policy actions that will support ongoing negotiations under the UN Framework Convention on Climate Change. In April 2008, President Bush announced a national goal to stop the growth in U.S. GHG emissions by 2025. Enabled by the advanced technologies reviewed in PCAST *Energy Imperative* report, it is expected that the United States will be able to achieve dramatic reductions in emissions from 2025 onward.

Energy Projections

While the United States consumes about a quarter of the global energy supply – roughly the same as its share of global economic output – the growth of energy demand in developing nations in recent years has far outstripped that of developed nations. The Energy Information Administration (EIA) of the DOE projects that in the period 2005–2030, energy consumption in developed nations (i.e., members of the Organisation for Economic Co-operation and Development, OECD) will grow by 19 percent, while developing nations will increase their energy consumption by 85 percent (EIA-DOE 2008c). Altogether, world energy consumption is expected to grow by 50 percent over that 25 year period. Similarly, carbon emissions are projected to grow by 15 percent in developed nations, 85 percent in developing nations, and 50 percent overall during that same period.

Projected global trends in petroleum consumption are particularly instructive. The EIA expects that OECD nations will increase consumption of petroleum (and other fossil fuel liquids) from 49.3 mbd in 2005 to 53.3 mbd in 2030, which represents only an 8 percent increase. Non-OECD nations, on the other hand, are projected to increase their petroleum consumption by 73 percent, from 34.3 to 59.3 mbd, over the same period. Because crude oil is traded on a global market, the rapid growth of demand in developing nations could impact gasoline prices as much as if the increased demand was local. This suggests that technology innovation, which can alter consumption patterns on a global scale, is vital to addressing the energy challenges faced by the United States.

The geopolitical challenges associated with crude oil supplies – highlighted this summer by oil prices rising to well over \$100 per barrel – emphasize the need to displace oil with alternative fuels. This is especially important in the transportation sector, which accounts for over two-thirds of overall domestic oil consumption. An EIA paper (Kendell 1998) has outlined measures of energy security that can be used to interpret a degree of U.S. vulnerability as a result of oil imports. These include measures such as oil imports as a proportion of U.S. oil consumption, the net cost of oil imports, calculated U.S. oil intensity (consumption per dollar of gross domestic product), the Persian Gulf share of the world's oil exports, and global excess oil production capacity. For the past two decades, most of these measures have indicated that U.S. vulnerability is increasing. However, in the United States two of these indicators have improved since 2005: the volume of imported oil has actually decreased by approximately 10 percent from 12.5 mbd to 11.3 mbd, and oil intensity has decreased more rapidly than at any time in the past two decades. New, more efficient energy technologies are beginning to take hold.

Oil imports

From 1991 to 2005, oil imports in the United States increased from 40 to 60 percent of overall consumption. Since 2005, however, oil imports have been decreasing, both as a percentage of consumption and in absolute terms. In 2005, the United States imported an average 12.5 mbd (60.3 percent of total consumption), whereas in the first eight months of 2008, the United States imported just 11.3 mbd (56.6 percent of total consumption). Biofuels have contributed notably to this shift: domestic ethanol production has increased from 0.25 mbd in 2005 to over 0.6 mbd

today (EIA 2008a).³ At \$100 per barrel, this represents roughly a \$15-billion-per-year improvement in the U.S. balance of payments. Furthermore, the EIA has estimated that the increased fuel economy and biofuels mandates in EISA 2007 (described above) will result in an additional 2 mbd reduction in U.S. oil consumption by 2030 (EIA-DOE 2008a), compared to the 2030 baseline without the EISA 2007 provisions.

Oil Intensity

According to the EIA, from 1990 to 2004, U.S. oil intensity improved (i.e., consumption per dollar of gross domestic product decreased) by an average of 1.3 percent per year. Since 2005, oil intensity has been decreasing at a much faster rate – more than 2 percent per year. Thus today the U.S. economy consumes one-quarter less oil per dollar of gross domestic product than it did in 1990. This trend is expected to continue. From 2005 to 2030, the EIA projects that U.S. oil intensity will decrease by an additional 42 percent (1.6 percent per year), which will substantially reduce the impact of oil prices on the U.S. economy (EIA-DOE 2008b).

Alternative fuels, including cellulosic biofuels and electricity, can displace oil consumption in the transportation sector, reducing imports and oil intensity. Technology innovation is essential, however, to improve the cost and performance of these technologies so that they will be competitive in the mass market and yield benefits beyond those currently projected by the EIA. Recent progress in these technologies will be discussed in the next section.

Electricity

In the latest EIA baseline projections, U.S. electricity demand will grow by 29 percent by 2030, from 3,659 billion kilowatt-hours in 2006 to 4,705 billion in 2030 (EIA-DOE 2008a). If PHEVs and EVs become widely popular, however, the growth in electricity demand could end up being much greater. Initially, most of these vehicles would be charged during off-peak hours, when spare electricity generation capacity is available. Eventually, however, growing numbers of PHEVs and EVs in the U.S. fleet will require the construction of additional power plants to supply their daily charge. In this case, the electric power sector will become a key supplier of the Nation's transportation fuels. In addition, expanded uses for electricity such as water desalinization and railway electrification are being considered. In California alone, some twenty desalinization plants are either under construction or in the planning stage. Economic and population growth will also continue to require more "electricity security" even as "electricity intensity" is decreasing.

³ Table 11. The actual amount of oil displaced by ethanol depends on several factors, including the difference in energy density between gasoline and ethanol (i.e., a gallon of ethanol contains one-third less energy than a gallon of gasoline); the efficiency boost in some engines due to ethanol's higher octane level compared to gasoline; the amount of petroleum consumed in producing reformulated gasoline, especially the methyl tert-butyl ether (MTBE) oxygenate that has been replaced by ethanol, compared to the petroleum consumed in producing ethanol; and the baseline energy content of MTBE (about 15 percent lower than gasoline) compared to ethanol. Regarding the engine efficiency difference for ethanol, according to an EPA-DOE report, "There is no noticeable difference in vehicle performance when low-level ethanol blends are used. However, flex-fuel vehicles operating on E85 usually experience a 20–30 percent drop in miles per gallon due to ethanol's lower energy content." (EPA and DOE 2008) Regarding the calculation of petroleum balance, studies estimate that the petroleum consumed by corn ethanol production amounts to 5-10 percent of the output energy content of the ethanol fuel (Farrell et al. 2006), which is similar to the proportion of petroleum consumed in the gasoline refining process (Wang 2008).

Technology Developments

Advanced energy technologies can enable the United States and the world to meet the energy demands of a growing global economy while making progress toward environmental and other societal goals. For example, a transition to advanced biofuels produced from cellulosic feedstocks (i.e., not from grains) could substantially reduce U.S. oil consumption while having little or no impact on the food supply. PHEVs with cost-effective energy storage could shift a significant portion of their fuel source from oil to electricity. Nuclear power and other advanced technologies (e.g., clean coal, solar, and wind) could support the additional electricity demand for these vehicles. Ultimately, the Nation's energy infrastructure will have to be expanded and improved to accommodate the widespread use of an alternative fuel such as electricity or biofuels.⁴

Biofuels

Ethanol production has increased from 2.8 billion gallons in 2003 (1 percent of the U.S. petroleum supply) to a rate of over 9 billion gallons per year (3 percent of the petroleum supply) in the second half of 2008.

Challenges. As discussed in the 2006 PCAST report, one of DOE's primary goals in biofuels is to make cellulosic ethanol (or other advanced biofuels) practical and cost-competitive by 2012. A more challenging goal will be to enable cost-competitive biofuels at the large volumes specified by the new RFS. Barriers to large-scale biofuels production include the existing distribution and fueling infrastructure, limited flex-fuel vehicle capability, insufficient feedstock availability, unfavorable environmental impacts, and the cost and feasibility of technologies at each step in the production process (e.g., collection, pretreatment, hydrolysis, fermentation, and distillation for biochemical processes, and gasification, cleanup, and synthesis for thermal processes).

Technology progress. A number of companies have announced plans to build cellulosic ethanol refineries, often in collaboration with the Federal Government. DOE has announced plans to invest up to \$385 million, representing a total \$1.2 billion including private cost-share, for as many as six commercial-scale, cellulosic biorefinery projects over four years. A full-scale biorefinery typically produces 20-30 million gallons of fuel per year. DOE also plans to invest \$114 million in four pilot-scale biorefinery projects, which will be about 10 percent of the size of a commercial-scale facility, to test innovative processes for converting a variety of cellulosic feedstocks – sugarcane residues, wood product residues, other agricultural wastes, and dedicated energy crops – into ethanol. Meanwhile, DOE SC is investing \$375 million over five years to support Bioenergy Research Centers in Tennessee, Wisconsin, and California. These centers will conduct multidisciplinary research on microbes and plants to develop innovative biotechnology solutions. DOE is also investigating the potential for higher-level intermediate blends of ethanol (e.g., E15 and E20), biofuels pipelines, and optimized E85 alternative fuel vehicles.

⁴ The PCAST recognizes the potential for hydrogen fuel cell vehicles to capture a large portion of the market by 2050 (NAS 2008). In this memo, however, we focus on the potential benefits of PHEVs, which could be commercially feasible in the near term and could eventually lead to mainstream all-electric vehicles.

Benefits. Including the petroleum consumed in feedstock growth, harvesting, and transport, ethanol refining, and fuel delivery, over 90 percent net of the energy in corn ethanol effectively displaces petroleum (Farrell et al. 2006). On the other hand, the growth and conversion of corn currently requires a large amount of energy from natural gas or coal for fertilizer production and refinery process heating. On average, the net energy yield of corn ethanol is roughly 35 percent greater than the fossil energy input (Shapouri 2002), though new corn ethanol refineries can yield efficiencies of 70 percent greater energy out than energy in. In any case, ethanol refining has been an economically beneficial process for both producers and consumers – further assisted by the \$0.45-per-gallon Federal tax credit – as the price of natural gas per unit energy is about half that of crude oil, and coal provides an even cheaper energy source. Over the long term, however, the shift should be made to cellulosic ethanol technology, which does not require food grain feedstocks and can produce fuels with up to seven times more energy output than fossil energy input.

Food price impacts. The Chief Economist of the U.S. Department of Agriculture (USDA) estimates that corn ethanol accounts for a small portion of the food price increase (Glauber 2008). This impact is balanced by the advantages gained from the use of biofuels in place of oil. As already discussed, increased biofuels production has reduced oil imports and the U.S. trade deficit. Biofuels also help lower gasoline prices at the pump. A recent study estimated that the growth in ethanol production has reduced retail gasoline prices by \$0.29 to \$0.40 per gallon (Du and Hayes 2008).

Bio-based products. The manufacture of chemicals, plastics, hydraulic fluids, pharmaceuticals, and other industrial products accounts for fully 25 percent of domestic oil consumption (EIA-DOE 2008b, Table 5.13b). Biomass feedstocks can supply the raw materials for processes and products that replace petroleum. For example, corn starch can be used to produce bioplastics, while soybeans are used to produce a polymer for carpet backings. Research programs in DOE and USDA seek to expand the range of products derived from organic materials. A large market for these products could accelerate private investment in biorefineries and contribute significantly to rural jobs and income.

Plug-in Hybrid Electric Vehicles

Challenges. Energy storage is the major barrier to large-scale commercialization of EVs and PHEVs. Major improvements in vehicular energy storage will be needed if electric-powered transportation is to make a significant contribution to national energy security. Besides reduced costs, improvements in energy density (size and weight), power density, durability (average cycle life), reliability, safety, and charge time need to be realized for PHEVs and EVs to become commercially feasible.

Technological progress. In recent decades, substantial progress has been made in battery technology, largely due to the growth of the consumer electronics battery market. Battery cost and energy density factors are several times better than they were 25 years ago. The energy storage R&D effort in the DOE Office of Energy Efficiency and Renewable Energy (EERE), which has been allocated about \$50 million in the FY2009 budget, augments private-sector efforts to commercialize incremental improvements in batteries within the next few years. Long range improvements will also be needed. In order to achieve this, the President's last three

budgets (FY2007-FY2009) have provided funding for fundamental materials and chemistry research in DOE SC that could lead to breakthroughs in battery cost and performance. Thus far, however, Congress has not appropriated sufficient funds to begin this research effort, which is critical to moving the transportation sector away from fossil fuel use.

Benefits. A PHEV that can travel 40 miles on electricity alone could reduce annual oil consumption by 75 percent or more compared with a conventional fossil fuel vehicle. If PHEVs become widely competitive in the new-vehicle market by 2020, they could reduce oil imports by as much as 2 mbd by 2030. As battery costs come down, EVs will eventually become more economical than PHEVs, because an EV derives significant size and weight benefits from not carrying an internal combustion engine. Perhaps by 2025, researchers will have reduced battery cost and improved their performance sufficiently to justify a large-scale shift to EVs over the subsequent one or two decades.

Electricity Production and Efficiency

A shift to PHEVs and EVs will eventually require a large increase in electric generating capacity. The primary sources available for electric power generation include coal power plants (which supply 50 percent of the electricity generated in the United States), natural gas power plants (about 18 percent), nuclear power plants (20 percent), hydroelectric power plants (about 7 percent), and other renewable power sources (collectively about 2 percent). Most renewable energy sources are intermittent sources and thus cannot supply base load power. While the use of renewable energy sources such as solar and wind is growing at a very rapid rate, they will likely not exceed 20 percent of overall grid generation by 2030. Further, unless there is exceptional progress in energy storage technology, renewable sources will only account for a small portion of added base load capacity over the next two decades. Therefore, most new base load power generation will still need to come from coal, natural gas, or nuclear energy.

Nuclear Power. Modern nuclear power has a proven safety and reliability record. Unlike coal and natural gas plants, nuclear power plants produce virtually no atmospheric emissions. With regard to the issue of nuclear waste, in June 2008 DOE submitted to the NRC a license application for the Yucca Mountain repository. In September, the NRC formally docketed the license application for review, which is expected to take about four years. It is hoped that this licensing process will resolve the waste issue once and for all. With nuclear power, fuel costs comprise a relatively small portion of the cost of electricity. This is a notable difference from natural gas power plants, for which fuel costs can amount to 70 percent or more of the levelized cost of electricity (EIA 2008a), and for which new fuel supplies will eventually have to be imported from overseas; Russia, Iran, and Qatar possess about 60 percent of the world's natural gas reserves. Nevertheless, nuclear power faces some significant hurdles to expansion in the United States.

The greatest challenge for nuclear power is the capital costs for new construction. In a recent report, the Congressional Budget Office (CBO) estimated nuclear power capital costs in a high-capital-cost scenario to be about \$4800 per kilowatt capacity (CBO 2008), which is near the upper end of current industry estimates (NEI 2008). For this same case, CBO estimated the levelized cost of electricity from a new nuclear plant to be \$0.12 per kilowatt-hour (kWh), compared to \$0.08 per kWh for coal and \$0.07 per kWh for natural gas, assuming that these

sources are also subjected to the high-capital-cost condition. This presents a financial challenge for the industry. While future carbon regulation could narrow the cost gap between nuclear power and fossil fuel sources, these estimates suggest that construction of a 1 gigawatt (GW) nuclear power plant would require a utility to make perhaps a \$6 billion financial commitment, including the costs of financing. On the other hand, PCAST has heard inputs arguing that after a few initial installations, the total cost could be less than half that suggested by these estimates.

- Number of 1 GW nuclear plants that must be built by 2030 to maintain nuclear power's current share (20 percent) of U.S. electricity⁵: **22**
- EIA's current projection of the number of 1 GW nuclear plants that will be built by 2030: **12**
- Relative capital costs of building new generating capacity from a natural gas combined-cycle plant, compared to a nuclear power plant (according to the EIA): **1:4**
- Time required for planning, authorization, design, and construction of a new nuclear plant in the United States (typical industry estimate): **10 to 15 years**

In addition to the financial hurdles, utilities that are contemplating a new nuclear power plant must face the possibility of permitting delays, long-term waste storage problems, and high costs for uranium fuel. For these reasons, the industry believes that Federal loan guarantees and supportive State policies are essential for construction of new nuclear plants (NEI 2008). The FY2008 omnibus appropriations bill included a two-year approval of the DOE loan-guarantee program, providing \$18.5 billion in loan guarantees (for up to 80 percent of construction costs) for nuclear reactors. This would, however, support construction of only a few plants (and only if the two-year deadline is met or extended). In order to enable nuclear power to maintain its 20 percent share of electricity generation, it is estimated that 22 new nuclear plants must be built by 2030. To achieve this level of construction after a 30-year hiatus, further expansion and extension of the loan guarantees – and supportive rules implemented by DOE – will likely be needed for at least the first dozen new plants. This would enable the initial regulatory and cost hurdles to be overcome, demonstrating the commercial viability of a new generation of nuclear power plants.

Despite the challenges described above, there have been a number of positive developments in the nuclear field in the last three years. Provided that financing issues can be addressed, utilities have announced plans to build as many as thirty new nuclear plants over the next two decades – well beyond the EIA projections. Fourteen of these plants are anticipated to be AP1000 units from Westinghouse, eight from General Electric, and seven from the French firm, Areva. These companies say that, unlike the 104 existing nuclear plants in the United States, all power plants from a particular manufacturer will be essentially identical in design and fabrication. In fact, Westinghouse has announced plans to build a factory in Lake Charles, Louisiana, that will prefabricate major portions of their AP1000 units that will then be shipped to plant sites for assembly. The Louisiana facility is projected to have a capacity sufficient to supply materials for two reactors per year. In China, Westinghouse has committed to completing the first of several AP1000s in a three-year time frame. This movement to prefabricated, fully computer-aided-design methodology should dramatically reduce cycle times for nuclear construction.

⁵ Based on EIA 2008a, after accounting for EIA's projection of 2.7 GW of up-rates of existing plant capacity.

Renewable Energy. Over the past two years, more non-hydro renewable energy capacity has been added to the grid than ever before. Since mid-2006, wind energy capacity in the United States has doubled and solar PV capacity has increased by 50 percent. In the *Energy Imperative* report, PCAST recommended that the Federal Government track State-based renewable power programs and encourage broader use of best practices. To that end, the Environmental Protection Agency (EPA) has analyzed State-based renewable power programs and provided a list of best practices to encourage effective expansion of these incentives,⁶ Lawrence Berkeley National Laboratory has produced several reports on the effectiveness of State-based renewable power programs,⁷ and the DOE EERE Office has continued to fund the publicly available Database on State Incentives for Renewables & Efficiency.

Smart Grid. Intelligent management of energy in buildings, factories, and the electric grid can yield substantial energy and economic benefits by reducing inefficiencies and minimizing peak loads on the grid (PCAST 2003). Controls, monitoring, and communications technology can enable the grid, including all generators and user loads, to respond in real time to changes in market signals, power system conditions, or local faults. The DOE Office of Electricity Delivery and Energy Reliability is leading a "smart grid" initiative, which includes research funding, interagency coordination, and partnerships with industry, to support a transition to technologies and processes that will better support intelligent energy management as well as the interconnection of renewable energy sources to the grid. In its 2006 report, PCAST recommended that the Federal Government work with State governments and utility regulators to facilitate the broad adoption of consistent interconnection and net metering standards, and that it examine access to transmission lines for new renewable electricity providers. Substantial progress has been made toward these goals. For example, DOE has partnered with the Western Governors Association to develop regional transmission plans for renewable resources, to encourage more transmission and distribution of renewable power throughout the region, and to build interstate cooperation to address permitting and multi-state cost-allocation issues. NIST and the Federal Energy Regulatory Commission (FERC) are working with the private sector to develop new grid connection standards and regulations appropriate for 21st-century power generation. Additionally, FERC has recently taken action to improve interconnection backlogs for new generators, primarily involving the connection of wind power to the regional grid in the Midwest.

Energy Efficiency. Recognizing that energy-efficiency innovations offer highly cost-effective opportunities to reduce electricity demand and carbon emissions, in its 2006 report PCAST made four recommendations related to energy efficiency: (1) expand the Energy Star program as broadly as possible; (2) encourage mainstream use of energy-efficient and renewable energy technologies in buildings; (3) establish programs to install efficient lighting; and (4) set standards to improve motor-driven appliance efficiency. Progress has been made in each of these areas:

- 1) EPA has updated or expanded Energy Star specifications on many products, including appliances and windows, and the use of Energy Star compact fluorescent lights and Energy Star commercial building standards has increased significantly since 2006.⁸ Also,

⁶ See http://www.epa.gov/chp/state-policy/renewable_fs.html

⁷ See <http://eetd.lbl.gov/ea/EMS/re-pubs.html>

⁸ See http://www.energystar.gov/index.cfm?c=about.ab_milestones

EISA requires expansion of the Energy Star program to include labeling of consumer electronics products, including televisions, computers, video equipment, and set-top boxes.

- 2) The DOE High-Performance Buildings Initiative and the Solar America Initiative have begun to work with a broad array of stakeholders, including manufacturers, industry groups, investors, utilities, universities, non-governmental agencies, advocacy groups, public utility commissions, air quality offices, Federal, State, and city governments, and national labs, to overcome systemic barriers to deployment of cost-effective, energy-efficient and renewable technologies. For example, the DOE Buildings Initiative has funded demonstrations of the viability of net-zero-energy buildings that employ energy-efficient designs and appliances in conjunction with on-site renewable energy (e.g., rooftop solar PV). The Solar America Initiative has focused on optimization of the solar supply chain, development of improved solar materials and devices, and building-PV-to-grid integration issues.
- 3) EISA requires a 28 percent reduction in energy used by incandescent light bulbs by 2012 and a 65 percent reduction by 2020. Following the President's Executive Order 13423, issued in January 2007, EISA 2007 also requires a 30 percent reduction in energy use in Federal buildings by 2015, and requires that each public building constructed, altered, or acquired by GSA be equipped with energy-efficient lighting fixtures and bulbs to the maximum extent feasible.
- 4) EISA establishes new or increased efficiency standards on many appliances and electrical devices, including furnaces, air conditioners, heat pumps, battery chargers, clothes washers, dishwashers, humidifiers, refrigerators, freezers, incandescent lights, fluorescent lights, halide lights, and many types of electric motors.

Summary

The long-term prosperity of the Nation depends on continued innovation in technologies for electric power generation, transportation, and industry. Given the importance of energy security and the pace of recent technological and policy developments, PCAST has highlighted progress in energy policy and advanced energy technologies that could significantly enhance U.S. energy security over the next two decades. Overall, since publication of the 2006 report, PCAST has seen notable improvements in energy supply and demand trends, advanced energy technologies, and Federal policies related to energy security. These improvements warrant PCAST's optimism that the Nation's imported oil demand will continue to decrease in coming years. Continued increases in the Nation's R&D investments will be needed, however, to make clean and efficient energy technologies more cost-competitive. In particular, cellulosic biofuels and energy storage technologies for PHEVs and EVs represent key opportunities to displace a large portion of U.S. petroleum consumption. Also, even with energy-efficiency improvements on the grid, these and other new applications may lead to a much larger increase in electricity demand – especially in base load power demand – than currently projected. Therefore, policy makers should prepare for and help enable a large increase in nuclear power and renewable power generation over the next two decades.

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