

# Executive Summary

## Overview

**A**n abundant supply of clean and affordable energy is vital to the economic growth, quality of life, and security of the United States. Energy provides essential services for many aspects of modern life. In recent years, however, economic and political factors have stressed the global supply of oil and natural gas, driving the prices of these commodities to new highs and increasing the risk of a damaging energy shock. Meanwhile, increases in greenhouse gas emissions, in part resulting from fossil fuel combustion, are linked by many scientists to global climate change. Combined, these issues create an imperative for change in the Nation's energy systems and infrastructure in order to ensure national energy security while protecting the environment.

Technology innovation opens up new opportunities to overcome these challenges. U.S. universities and national laboratories lead the world in research that generates technology breakthroughs, while the Nation's industrial sector and its entrepreneurs are leaders in creating innovative commercial products. Emerging technologies from the private sector and the research community could enable cleaner and more efficient use of energy throughout the economy.

In recent years, entrepreneurs have begun to focus on technologies that could significantly increase the efficiency of the Nation's energy use and reduce carbon emissions. In fact, over a hundred companies founded in the last decade — many of them within the last five years — are commercializing energy innovations. Most of this entrepreneurial activity has been in solar energy, biofuels, fuel cells, and energy storage devices. Venture capital investment in the U.S. energy sector totaled nearly \$1B in 2005 and is on track to more than double that amount in 2006. The President's Council of Advisors on Science and Technology (PCAST) members believe that these efforts, combined with technology development funded by the Federal Government, private equity sources, and large corporations, could lead to substantial improvements in the Nation's energy infrastructure.

Electric power is the fastest growing energy sector. U.S. demand for electricity is expected to increase by about 50% over the next 25 years (EIA-DOE 2006a). Continuing current trends, a substantial portion of this increase in demand will be supplied by natural gas power plants, leading to a sharp increase in imports of natural gas from suppliers outside of North America. Meanwhile, the transportation sector accounts for two-thirds of U.S. oil consumption. Oil imports, which supply roughly 60% of U.S. demand, are a major energy security concern. PCAST analysis suggests that national and global energy challenges in the electric power and transportation sectors could be met in large part by a combination of diverse approaches, including renewable energy, nuclear energy, biofuels, advanced vehicles, and energy efficiency technologies.

Renewable energy sources such as solar and wind energy, for example, are expected to become increasingly competitive with fossil-fuel-based electricity generation. While renewable sources are unlikely to completely replace conventional power plants in the foreseeable future, the share of non-hydroelectric renewable electricity generation in the U.S. could grow to 10% or more by 2030 and to over 20% by midcentury.

Meanwhile, energy-efficient building and industrial technologies could help reduce the projected need to build hundreds of new power plants in the United States by 2030.

Nuclear energy is a proven alternative to fossil fuels, which some analysts regard as the least expensive option for expanding U.S. electricity generation capacity. Further, because it produces virtually no atmospheric emissions, PCAST members believe that nuclear power is the best large-scale option available today to reduce CO<sub>2</sub> emissions in the electric power sector. Coal gasification plants with carbon capture and storage could also provide large amounts of new generating capacity with near-zero atmospheric emissions. In sum, improving energy security and substantially reducing the growth of emissions in the electric power sector will likely require aggressive deployment of nuclear, coal gasification, and renewable energy technologies.

Biofuels offer a clear, near-term opportunity to reduce the Nation's dependence on oil. Biomass — raw plant matter that can be converted into biofuels — can be produced from crop residues, wood waste, forest industry by-products, and perennial grasses. With potential improvements in crop production and biorefineries, cellulosic biofuels could replace a significant percentage of the Nation's gasoline use by 2030. Biofuels could also reduce greenhouse gas emissions compared to fossil fuels, because most of the carbon released in the processing and use of biofuels is absorbed during plant growth. Furthermore, development of a large biofuels industry would offer vast potential for wealth creation in rural America.

An alternative path to reducing dependence on oil for transportation is through greater use of electricity to power vehicles or mass transit systems. With expected cost reductions in energy storage, “plug-in hybrid” vehicles with large battery packs could become widely available. In concept, these vehicles operate on electricity alone for most trips but use a gasoline engine for longer drives. Ultimately, all-electric vehicles or hydrogen fuel-cell vehicles may compete with conventional, gasoline-fueled cars and trucks. Efficient vehicle technologies such as lightweight materials could also reduce transportation fuel use. Considered together, alternative fuels and advanced vehicle technologies offer the potential to dramatically reduce the projected amount of oil imports by 2030.

Energy efficiency technologies for buildings, the electric grid, and industrial processes could substantially reduce energy consumption in these sectors. Besides benefiting consumers, reduced energy use avoids the generation and distribution losses that would otherwise be incurred to supply that power. Including related power generation losses, the building sector accounts for 40 percent of primary U.S. energy consumption, and the industrial sector accounts for an additional one-third. A comprehensive analysis suggests that less than half of this energy is actually converted to useful energy for consumers. Innovations in lighting, appliances, heating and cooling systems, and industrial processes could moderate the projected growth in electricity demand over the next two decades, providing economic, environmental, and energy benefits.

This report describes an array of technologies that by 2030 could help achieve energy security and a more economical and environmentally sound energy infrastructure, both in the United States and globally. The report focuses on entrepreneurial activity. Yet entrepreneurs and the private sector represent just one component of the “innovation ecosystem.” In many cases, commercial innovation emerges from Federally funded basic research conducted at universities or national laboratories. Basic research is vital to overcoming fundamental hurdles to commercialization of new technologies. In general, successful market adoption of breakthrough innovations results from complex interactions among the private sector, the Federal Government, State governments, universities, and the marketplace.

Therefore, this report suggests that innovations currently in commercial development by entrepreneurs and energy companies could lead the way to dramatic changes in the Nation's energy infrastructure. PCAST offers the following recommendations, grouped by category, as early steps that the Federal Government could take to accelerate this process and consolidate near-term gains.

## Recommendations for Federal Energy Policy

### Overarching Recommendations

- 1. Increase Federal support for science and technology research and development.** Many of the advanced energy technologies described in this report have originated, at least in part, from Federally funded research. The President's American Competitiveness Initiative supports future innovation by proposing to double funding for the National Science Foundation (NSF), the National Institute of Standards and Technology (NIST) in the Department of Commerce (DOC), and the Department of Energy (DOE) Office of Science. Meanwhile, in order to accelerate the near-term commercialization of energy technologies, the President's Advanced Energy Initiative proposes a 22% increase in clean energy research and development (R&D) funding in DOE in FY 2007. PCAST recommends that Congress fully fund these initiatives and consider funding for an expanded Advanced Energy Initiative research effort in future years, including at the U.S. Department of Agriculture (USDA).
- 2. Promote EAct 2005 incentives.** Financial support measures targeted to assist commercialization — low-interest loans, tax incentives, capital contributions, and price subsidies, among others — are in many cases vital to bringing new energy technologies to market. The Energy Policy Act of 2005 (EAct) established incentives for virtually every area of energy technology (see Table IV-2). DOE, USDA, and other agencies have taken significant steps to implement these provisions. PCAST recommends that DOE and USDA promote these incentives as currently targeted and report back on whether they are having the desired effect or whether modifications are necessary. If ongoing monitoring shows that goals are being reached sooner than the Act anticipated, PCAST recommends moving up the timelines and making the goals more aggressive. Also, some of the EAct incentives expire in 2007 and 2008; those that have proven to be successful should be extended.
- 3. Support State initiatives.** Individual States are funding many programs to improve the competitiveness and availability of renewable energy resources for their businesses and residents. These programs tend to focus on resources that are most readily available in each State, such as hydroelectric, geothermal, biomass, wind, wave, or solar energy. Because States and their public utility commissions have the ultimate authority for most decisions related to the electric power infrastructure, the Federal Government should work with the States to expand successful programs and encourage the States to cooperate with each other on "best practices" developed through these projects.
- 4. Position the Federal Government as an early adopter of new technology.** The Federal Government is both a large producer and a large user of the Nation's energy resources. Therefore, the Federal Government should expand its role as an early adopter in order to demonstrate the commercial feasibility of advanced energy technologies. PCAST suggests that the Federal Government redouble its efforts to implement EAct provisions of this type.

## Electric Power Generation

As stated earlier, domestic electricity demand is expected to rise by 50% over the next quarter-century. This has two policy implications. First, the overall energy efficiency of the electric power sector must be improved. In an earlier report (PCAST 2003), this Council recommended policy actions, several of which have been implemented, to reduce inefficiencies in the Nation's electricity generation and transmission infrastructure. Complementing this, the present report includes a discussion of the need to improve the energy efficiency of end-use applications. Even with improved efficiency, however, a substantial increase in electricity generation capacity will be needed. Non-hydroelectric renewable energy can be an important contributor to U.S. power generation by 2030, but more new capacity will likely be supplied by fossil fuel and nuclear power plants. Thus it is crucial to accelerate deployment of next-generation nuclear and coal gasification plants, which can help achieve both economic and environmental goals.

5. **Expand nuclear energy as a clean, base-load power source.** Nuclear energy has the potential to be the lowest-cost source of electric power (OECD/IEA 2005), and it produces very low life-cycle emissions. The EAct legislation provides incentives to encourage utilities to work with the Federal Government to reinvigorate the domestic nuclear industry. PCAST recommends that the Federal Government use its best efforts to ensure that the risk insurance and other incentives outlined in the EAct are taken up by utilities so that new nuclear plants can contribute to the electric grid beginning in 2015, as the first step in a significant expansion in nuclear power capacity. PCAST further recommends that Congress increase the scope of the production tax credit for advanced nuclear power plants beyond the EAct-specified 6,000 megawatt capacity limit. The goal for the Nation should be to add at least 36,000 megawatts of new nuclear generation capacity by 2030.<sup>1</sup>
6. **Resolve the nuclear waste containment issue.** New reactor designs and reprocessing technologies that are under consideration could reduce the amount of high-level waste generated by nuclear plants, but they will not eliminate it. In order to expand nuclear energy capacity, the nuclear industry needs assurance that a permanent waste disposal site exists. All stakeholders need to work together to ensure that the proposed underground waste facility at Yucca Mountain, NV, is established as soon as possible.
7. **Build coal gasification plants instead of natural gas facilities.** The EAct provides incentives for the construction of high-efficiency, low-emission coal gasification power plants. PCAST recommends that the Federal Government use its best efforts to maximize the value of these incentives for public utilities. States should be encouraged to establish energy policies that support national energy security objectives rather than depending solely on "least cost" parameters. Based on existing trends, most new electric power capacity will be supplied by natural gas plants and conventional coal plants, leading to an increase in overseas natural gas imports and greenhouse gas emissions. Through its higher generating efficiency, coal gasification technology could make better use of the Nation's huge domestic coal reserves while reducing energy losses and carbon emissions compared to conventional coal plants. This technology also enables relatively low-cost carbon capture. With the benefit of several commercial-scale demonstrations over the next decade, next-generation coal gasification plants could become competitive with conventional power plants, reducing the need for new natural gas plants to supply clean base load power (NRC 2003). Thus, the Federal Government should work with the States, taking full advantage of the EAct incentives, to encourage deployment of coal gasification power plants.

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<sup>1</sup>This figure is based on maintaining a constant proportion of U.S. electricity generation from nuclear energy (EIA-DOE 2006d, Table 73).



8. **Improve the efficiency of legacy electric power plants.** Current regulations inhibit utilities from making needed improvements to old power plants. These regulations should be modified to allow utilities to improve the efficiency and environmental performance of legacy coal plants without incurring an onerous economic penalty, as long as the upgraded power plants will produce fewer emissions per megawatt of generation capacity than they would without the upgrades.
9. **Support renewable energy plans.** Many States have incentive programs to increase the percentage of their grid power requirements supplied by renewable sources. These programs focus on utility-scale projects (defined as 1 megawatt output or more); to date, over \$475M has been obligated for some 18 different projects, mostly involving wind energy. These programs, together with State renewable portfolio standards, could help increase the level of renewable electricity generation substantially over the next two decades. The DOE should be tasked to track these programs and to encourage broader use of those approaches that are showing the most promise. Additionally, the Federal Government should aggressively pursue, and consider increasing, the EAct goal for at least 10,000 megawatts of non-hydroelectric renewable generation capacity to be approved for siting on Federal lands by 2015.
10. **Reduce regulatory barriers to installation of renewable distributed generation technologies.** Today, grid interconnection and net metering rules vary by State, and even by utility or other electric service provider within a State, resulting in a patchwork of requirements across the United States. Some States do not even have regulatory interconnection standards. This inconsistency creates high barriers to penetration of renewable distributed generation technologies (such as solar photovoltaic cells) into the U.S. market. Therefore, the Federal Government should work with State governments and utility regulators to facilitate the broad adoption of consistent interconnection and net metering standards, which would create a more predictable and consistent business environment for technology suppliers and project developers. The Federal Government should also examine access to transmission lines for new renewable electricity providers, especially in rural areas.

## Transportation

Increasing concerns about energy security provide a strong motivation for the United States to reduce its requirement for imported oil. This goal can be achieved by developing new domestic oil fields, competitive alternative fuels, and vehicles with higher fuel efficiency. Currently, most entrepreneurial activity in this area is aimed at biofuels or efficient vehicle propulsion systems. The following recommendations could facilitate commercialization of these technologies.

11. **Encourage industry to expand the availability of biofuels and flex-fuel vehicles.** The Administration should convene a roundtable of stakeholders, including automakers, energy companies, fuel distributors, and fleet managers, to develop a private-sector roadmap with specific commitments to increase the nationwide availability of biofuels and the percentage of flex-fuel vehicles (FFVs) among new car offerings. The stakeholders should also collaborate on fuel and vehicle standards that maximize market efficiencies and biofuel flexibility.
12. **Increase the supply of E10 and other biofuel blends.** The EAct established or extended several incentives for the production of ethanol. E10, which contains 10% ethanol and 90% gasoline, helps reduce smog formation and has provided a major market for ethanol producers. PCAST suggests that the Administration encourage broader use of E10, as well as higher-percentage blends of ethanol (or other biofuels), in order to surpass the EAct goal of 7.5 billion gallons of ethanol by 2012. For example, use

of 10% ethanol in all transportation fuel would equate to 12–14 billion gallons of biofuels. Widespread use of richer biofuel blends could increase ethanol use far beyond this level.

13. **Eliminate the ethanol import tariff for E85 applications.** The EPAAct provides incentives for distributors of E85, a fuel containing 85% ethanol and 15% gasoline. Some private companies considering distribution of E85 are hindered by the current lack of a reliable and cost-competitive supply of ethanol. Thus, PCAST supports opening the biofuels market so that the import of foreign sources of ethanol (primarily from Brazil) for E85 would be permitted without a tariff. This should be viewed as part of an integrated industrial development and trade strategy.
14. **Modify the Volumetric Ethanol Excise Tax Credit (VEETC) to match competitive realities.** Currently, blenders of E10 and E85 fuels are granted tax incentives based on the amount of ethanol they bring to market. This incentive effectively reduces the cost of producing these fuels. Competitive considerations, however, would suggest that as the price of oil rises, the need for a tax incentive decreases; conversely, as the price for oil decreases, the need for a subsidy increases. PCAST recommends that these realities be placed into the regulations such that the VEETC slides from high to low as the price of oil moves from low to high. If set at appropriate levels, this change in the VEETC would help lower the price at which biofuels are competitive with gasoline. Additionally, States should consider taxing fuels on the basis of energy content rather than volume; most States currently tax fuels by volume, which effectively penalizes E85, because it contains only about 75% of the energy per gallon as in gasoline. PCAST recognizes that the timing of these types of changes is critically important and should be weighed with long-term investment horizons in mind. The current ethanol industry has only recently experienced strong growth, compared to the decades of profitability for the petrochemical industry with its multiple historical subsidies. Over the next several decades, the Nation — and the world — may be similarly building out a new biofuels industry; therefore, changes to the current tax structure should be carefully phased in.
15. **Identify lands suitable for energy crop production.** Several different crops capable of yielding in excess of 10 tons of biomass per acre are under consideration for use as energy feedstocks. Suitable lands for perennial grasses — potentially the largest source of biomass — could come from the Conservation Reserve Program or other Federally managed lands. An inventory of Federal lands suitable for conversion to energy crops would help expedite the shift to large-scale production of biomass for energy. PCAST recommends that USDA be tasked to specifically identify lands most suitable for energy crop production.
16. **Support cellulosic biomass conversion technologies.** PCAST endorses the recently announced roadmap for developing cellulosic ethanol (USDOE-SCI/EERE 2006) and encourages the DOE and USDA to also consider the potential of other biofuels such as butanol, methanol, and others, as well as the suite of biobased products. Given recent progress in developing cost-effective enzymes and improved biomass yields, large-scale production of cellulosic biofuels appears feasible by 2015.
17. **Encourage production of FFVs.** For many years, automobile manufacturers in the United States have been providing flex-fuel capability for a small percentage of their new cars and light trucks, enabling these vehicles to operate on either E85 or gasoline. To enhance future flexibility, PCAST suggests that the Federal Government use its influence to encourage vehicle manufacturers to rapidly provide flex-fuel capability in as many models as possible. FFVs give consumers a choice of fuels and create much-needed competition in transportation fuels. This recommendation could be implemented in part through the industry roundtable described in recommendation #11.

18. **Expand use of E85 in Federal Government vehicles.** The Energy Policy Act of 1992 requires Federal agencies, with certain exceptions, to purchase alternative fuel vehicles for 75% of their fleet vehicles. Many agencies purchase FFVs to comply with this requirement, but E85 has often not been available for their use. Last year, the EPAct instituted a requirement that Federal agencies use E85 in all FFVs unless a waiver is granted by DOE. PCAST recommends that this provision be applied aggressively in order to expand ethanol availability by providing a growing market.
19. **Review CAFE standards regularly and make needed reforms.** Corporate Average Fleet Economy (CAFE) standards on passenger cars have not been updated for more than 15 years, even though many efficient vehicle technologies have become available. Therefore, PCAST recommends that Congress pass legislation to give the U.S. Department of Transportation (DOT) the flexibility both to set passenger car fuel economy regulations and to structure the program to be consistent with the revised light truck CAFE program. DOT should also be made responsible for reviewing the standards at least every three years in order to assess the feasibility of further increases in the CAFE standards.
20. **Modify CAFE regulations to encourage non-fossil-fuel use.** The CAFE program should be modified to further encourage deployment of FFVs. Although FFVs currently receive CAFE credits, these incentives are capped at a relatively low percentage of new vehicle production. Therefore, the CAFE incentives should be restructured to encourage a larger percentage of the fleet to have flex-fuel capability. Additionally, plug-in hybrids, which are expected to be commercially available in the next few years, should be granted targeted CAFE credits to encourage their manufacture.

## Energy Storage

It is difficult to overstate the importance of energy storage. The efficiency and cost-competitiveness of renewable electricity generation and alternative-fuel vehicles could be significantly improved by the availability of low-cost, high-capacity storage. For example, because solar and wind power generation is intermittent — the sun and the wind are not constantly available — these systems require energy storage if they are to serve as a reliable supply of electricity throughout the day. In the transportation sector, advanced energy storage technology could enable affordable family-sized vehicles that travel 200 miles or more on a single, rapid battery charge. Low-cost energy storage could also improve the commercial feasibility of hydrogen fuel cell vehicles. Therefore, PCAST makes the following recommendations.

21. **Support research on nanomaterials for energy storage applications.** The National Nanotechnology Initiative is to be commended for supporting research that is advancing understanding of nanomaterials broadly, including for energy storage applications. Progress toward improved energy storage systems will depend on continued strong support for research on novel nanoscale and nanostructured materials. Promising technologies should be identified and targeted to receive support for further development and prototyping in order to expedite technology transfer to and application by the private sector.
22. **Encourage the manufacture of energy storage products in the United States.** The manufacture of most batteries has moved offshore. Energy storage should be considered a key sector for the Federal Government to target with domestic manufacturing incentives. Such incentives could encourage the growth of an energy storage “ecosystem” spanning from materials development to the manufacture of finished products, helping to ensure that the United States leads in this core area of energy technology.
23. **Initiate a basic research initiative on next-generation energy storage technology.** The Federal Government should initiate significant funding for basic research to investigate radically new chemistries

and concepts for electrochemical or electric storage, with the goal of achieving an order-of-magnitude improvement in cost and energy density compared to today's lithium battery technology.

## End-Use Energy Efficiency

While several recommendations above relate to improving the efficiency of the electric power and transportation sectors, there are also significant opportunities to improve "end-use" efficiency in the residential, commercial, and, on a national scale, industrial sectors. Building and appliance efficiency improvements can reduce consumer costs and yield a substantial reduction in primary energy input (e.g., coal, natural gas, and nuclear energy), including energy used for power generation and transmission.

24. **Expand the Energy Star program as broadly as possible.** The Energy Star program, managed by the U.S. Environmental Protection Agency (EPA), helps to raise public awareness of the "after purchase" costs of energy for many products. To the degree possible, all products that impact energy, from kitchen appliances to windows to automobiles, should carry an Energy Star rating. The EPA should update each standard regularly to ensure that it is stretching the private sector to integrate the latest energy efficiency technologies that can provide economic benefits to consumers.
25. **Encourage mainstream use of energy-efficient and renewable energy technologies in buildings.** Consumers and businesses are increasingly interested in owning their own distributed energy systems, which often use photovoltaic (PV) solar cell or fuel cell technology. The EAct offers incentives to consumers and businesses to install solar and other efficient systems, but these products are often not available as an integrated option for new homes or commercial buildings. Thus, in order to expand adoption of economically attractive and energy-efficient systems for homes and commercial office space, the Administration should encourage greater collaboration between stakeholders in this sector, including builders, trade associations, labor unions, State and local regulators, realtors, lenders, investment bankers, pension funds, appraisers, insurers, consumer groups, and utilities. A strong collaboration among these stakeholders could help overcome the market barriers — including a lack of information, outdated codes and standards, high transaction costs, and fragmented procedures and regulations — that inhibit the use of commercially available technologies that provide financial, energy, and environmental benefits.
26. **Establish programs to install efficient lighting.** Dramatic improvements have been made in the efficiency of household and commercial lighting. The transition to these new technologies, however, has been uneven — moving quickly in some applications such as traffic lights, but more slowly, for example, in the residential market. Besides assigning Energy Star ratings to all lighting products, the Federal Government (as mandated in the EAct) should lead the way by switching most of its lighting to efficient bulbs, in order to demonstrate their value while helping to reduce manufacturing costs by increasing the volume of these products. Consumer incentives for installing high-efficiency lighting should be retained and, if appropriate, expanded.
27. **Set standards to improve motor-driven appliance efficiency.** Mandatory Federal standards for the efficiency of residential heating, ventilation, and air conditioning (HVAC) units increased by 30% in January 2006, as part of the National Appliance Energy Conservation Act. Additionally, the EAct establishes an HVAC maintenance consumer education program and mandates an increase in the efficiency of commercial HVAC units by 2010, in addition to new standards for 14 other product categories. Still, some appliance efficiency standards in Europe and Japan remain stricter than those of



the United States, suggesting that further increases in the minimum efficiency requirements may be economically feasible. The Federal Government should consider raising appliance efficiency standards based on the availability of improved technologies, such as low-cost brushless DC motors for efficient HVAC units.

Each stage of the energy infrastructure — the production, storage, transportation or transmission, conversion, and use of energy — involves many unique technologies. Clearly, no single silver bullet can meet all the Nation’s energy needs in a cost-effective and environmentally responsible way. Rather, all of the technologies mentioned in these recommendations and in the balance of this report must be considered as potential contributors to a long-term shift from heavy dependence on fossil fuels to more efficient, clean, and domestically available technologies such as renewable energy and nuclear power. This report seeks to highlight new ideas stirring in universities, government laboratories, and private enterprises that could dramatically change the Nation’s energy infrastructure and systems by 2030. PCAST’s recommendations consist of near-term opportunities for the Federal Government to encourage development of these technologies in order to advance national and global energy goals.

