EXECUTIVE SUMMARY

ENERGY FUTURE

Think Efficiency™

HOW AMERICA CAN LOOK WITHIN TO ACHIEVE ENERGY SECURITY AND REDUCE GLOBAL WARMING

2010 2020 2030 2040 2050

APS physics

ENERGY = FUTURE

Think Efficiency

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Founded in 1899, the American Physical Society (APS) is the largest organization of professional physicists in the United States. Its 46,000 members are drawn from universities, industry and national laboratories. The APS is one of the premier publishers of international physics research, maintaining print and on-line publications, as well as electronically searchable archives dating back to 1893.

For more than forty years, APS has also devoted resources and expertise to a number of public policy areas, including education, energy, innovation and competitiveness, national security, and science research programs. As part of its policy work, APS periodically prepares technical analyses on subjects of significant public interest. This report follows in the tradition of past APS studies and represents a fresh look at the subject of energy efficiency, which the Society first examined in 1975.

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Making major gains in energy efficiency is one of the most economical and effective ways our nation can wean itself off its dependence on foreign oil and reduce its emissions of greenhouse gases. Transportation and buildings, which account for two-thirds of American energy usage, consume far more than they need to, but even though there are many affordable energy efficient technologies that can save consumers money, market imperfections inhibit their adoption. To overcome the barriers, the federal government must adopt policies that will transform the investments into economic and societal benefit. And the federal government must invest in research and development programs that target energy efficiency. Energy efficiency is one of America's great hidden energy reserves. We should begin tapping it now.

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 35 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.

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

The American Physical Society set up its Energy Efficiency Study Group to do just that for the transportation and buildings sectors of our economy. 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 those goals. The opportunities are huge and the costs are small.

Some of the targets we identify could be easy to achieve within the next few years using existing technologies. Some of them will be more difficult to realize and might take a decade or two to attain. Some are extremely challenging and lie in the more distant future. But whatever their ease or difficulty, whatever their time horizon, achieving them will require intelligent public policy and serious public commitment. They are worth pursuing not only because they will provide greater energy security and reduce global warming, but also because they will provide significant economic benefits.

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 energy efficiency in the transportation and buildings sectors, we need to clarify two issues: (1) What we mean by "energy efficiency" and (2) 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. This may seem an intuitively reasonable definition, but in some cases it is too simplistic. Consider two homes both heated with furnaces rated at 80-percent efficiency, one home well insulated and the other so badly insulated that it takes twice as much energy to keep it warm. The furnaces are both 80 percent efficient, but, considered as a system, one home clearly should only receive a 40 percent rating for heating efficiency. This example demonstrates that what matters is how much primary energy it takes to accomplish a particular task, rather than simply how one element of an integrated system performs. As another example, consider the case of an electric heater. It might receive a 100 percent rating as a single element, but the production and transmission of the electricity it uses comes at a great energy cost: only about 30 percent of the primary energy from the fuel (coal, natural gas, nuclear, etc.) used in a power plant finds its way to the heater.

Ideally we would like to know the ratio of the minimum energy required to do the job to the energy actually used. That is sometimes hard to do, but it is always 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 also seem like a simple task, but it isn't. Consider the case of plug-in hybrid cars. They have the potential for reducing gasoline consumption and our dependence on foreign oil. But plug-in hybrids need electricity for recharging their batteries, and in most cases the electricity will have to be generated centrally and distributed through the power grid. The efficiency of electricity generation and transmission must be counted in determining the overall energy efficiency, since our definition of efficiency requires starting with the primary energy source. For very large market penetration of plug-in hybrids, electrical generation capacity will have to be increased and the grid will have to be upgraded. A parallel argument applies to hydrogen fuel cell vehicles, which will probably require centralized production of hydrogen and development of a major distribution and delivery infrastructure.

Despite their connection with energy production and distribution, we elected to include plug-in hybrids and fuel cell vehicles in our discussion of energy efficiency, because they have an extraordinary potential for decreasing carbon emissions and increasing our energy security. Some biofuels can replace foreign oil and decrease carbon emissions, as well, but their use has little to do with energy efficiency, and therefore we did not consider them. These examples illustrate the principles we applied to circumscribe the energy end-use applications we considered.

By adopting sensible end-use energy efficiency policies now, we can begin to cut our dependence on foreign oil, strengthen our economy and reduce global warming. In the balance of the Executive Summary, we highlight the near-term, medium-term and long-term opportunities for improving energy efficiency and the actions that are required to realize the objectives.

In the Near Term

For Transportation Objectives

- The fuel economy of conventional gasoline-powered light-duty vehicles, which include cars, sport utility vehicles and pickup trucks, can be increased to at least 35 miles per gallon by 2020 through steady improvements in internal combustion engines, transmissions, aerodynamics and other technologies. This can be done with technology that is available today or in the pipeline, with minimal changes in the performance of current vehicles. Widespread deployment of hybrid or diesel technology can improve mpg further.

- The federal government's current research, development and demonstration program should have a broader focus. A more balanced portfolio is needed now across the full range to enable the deployment of potential medium- and long-range advances in automotive technologies. Increased research is needed in batteries for conventional hybrids, plug-in hybrids and battery electric vehicles, and in various types of fuel cells. This more balanced portfolio is likely to bring significant benefits sooner than the current program through the development of a more diverse range of efficient modes of transportation, and will aid federal agencies in setting successive standards for reduced emissions per mile for vehicles.

- Although this report does not examine energy efficiency issues for tractor-trailers and other large trucks, we note that a comprehensive study of the subject recently completed by the National Academy of Sciences, "Review of the 21st Century Truck Partnership," concludes that the Department of Energy funding for the program does not match its goals or needs and that the program needs restructuring.

For Buildings Objectives

- The goal of achieving significant levels of construction of cost-effective residential zero energy buildings (ZEB) — buildings that use no fossil fuels — by 2020 is feasible, except in hot, humid climates. Most of the required technology to compete with traditional housing is available, but inadequately demonstrated. To achieve this goal in hot, humid climates will require increased R&D to develop low-energy dehumidification and cooling technologies and strategies.

- More generally, the federal government should raise its R&D spending for next-generation building technologies, for training building scientists and for supporting the associated national laboratory, university and private sector research programs. The current investment of somewhat more than $100 million per year is considerably less than the $250 million invested in 1980 (in inflation adjusted dollars), which led to important innovations. Funding for building R&D should be restored to the $250 million level during the next 3 to 5 years. The existing demonstration program for construction of low-energy residential buildings, along with associated research, should also be expanded. These steps are necessary to achieve the zero energy building goals of 2020 for all residential buildings and of 2030 for commercial buildings.

- Federal and state governments should adopt policies to address the wide range of market barriers and market failures that discourage investment in energy-efficient technologies, especially in the highly fragmented buildings sector, where barriers are especially prevalent. A number of policies have proven effective on a large scale in promoting or requiring investment in energy efficiency in buildings, among them (1) For whole buildings: building energy codes, labeling, audit programs and financial incentives for purchase of efficient technology; (2) For appliances, heating and cooling equipment, and lighting: (a) Mandatory efficiency standards in the case of appliances and (b) Voluntary standards, such as industry consensus guidelines in the case of lighting usage and federally promoted labels (Energy Star, for example) to highlight exceptional efficiency performance in the case of appliances.

- The Department of Energy should develop and promulgate appliance efficiency standards at levels that are cost-effective and technically achievable, as required by the federal legislation enabling the standards. DOE should promulgate standards for all products for which it has been granted authority to do so. A streamlined procedure is needed to avoid delays in releasing the standards.

- Demand-side management (DSM) programs in which a central agency, often a utility company, invests money to assist customers in becoming more energy efficient have proven very effective. Yet, many states have hesitated to create such programs. Where DSM programs do not exist, the federal government should encourage states to initiate them through utility companies. The federal role could be to provide rewards to states that have significant and effective DSM programs and disincentives to those that do not.

- California has been a leader in developing its own building energy standards, which have proven very effective. Standards, such as those promulgated in California, should be implemented nationwide. States should be strongly encouraged to set standards for residential buildings and require localities to enforce them. For commercial buildings, performance-based standards that rely on computer software to compare a building design with a reference building are implemented only in California. The federal government should develop a computer software tool much like that used in California to enable states to adopt performance standards for commercial buildings. States should set standards tight enough to spur innovation in their building industries.

- Reducing energy consumption and the carbon footprint is one of the most important goals for green buildings. Any green building rating system, such as the Leadership in Energy and Environmental Design (LEED) Green Building Rating System, should give energy efficiency the highest priority and require reporting of energy consumption data.

For Crosscutting Objectives

- The Department of Energy's Office of Science has a broad energy-related mission. Through energy authorization legislation enacted in 2005 and 2007, Congress and the administration have asserted that the DOE Office of Science requires significant funding increases to carry out its basic research mission. Congress should appropriate and the White House should approve for the DOE Office of Science funds that are consistent with the spending profiles specified in the 2005 Energy Policy Act and the 2007 America COMPETES Act. Congress should periodically review the Energy Frontiers Research Centers program to ensure that basic research related to energy efficiency receives adequate attention.

- DOE should fully comply with the 2005 Energy Policy Act mandate to improve the coordination between its basic and applied research activities. Congressional oversight committees should ensure that DOE fulfills its obligation. Historically, coordination among basic and applied research programs within the Department of Energy has been far from ideal.

- Within DOE, indeed within the federal government as a whole, long-term applied research, whether it is general or strategic in nature, often is the orphan child of science and technology programming. To meet the out-year technology goals we have proposed for energy efficiency, DOE must take steps now to fold long-term applied research into its science and technology programming in a more serious way than it currently does. The department has several options. It can charge the Office of Science with the responsibility and provide the necessary budget, but if it does so, it must protect the culture and budgets of its current basic research programs. It can designate the Energy Efficiency and Renewable Energy Office (EERE) with the responsibility and augment its budget for that purpose, but in that case, DOE must be careful not to allow short-term activities to continue to diminish long-term opportunities. The department can also create a new structure to support long-term applied research or adapt the Advanced Research Projects Agency – Energy (ARPA-E), which was established by the America COMPETES Act.

- ARPA-E's program mission is to facilitate bringing to market the fruits of high-risk, high-payoff research in the energy sector, but its modus operandi and the nature of its portfolio depend on clarification of its role. For example, if ARPA-E is to function as a venture capital firm, as some advocates believe it should, it needs a venture capital (VC) perspective. If its investments are in partnership with the private sector, as some successful DOE R&D programs have been, it needs to adopt an appropriately different point of view. But whether it invests on its own or functions as a technology bridge between the DOE laboratories and the private sector, ARPA-E would greatly benefit from a group of outside advisors who can bring the competitive private sector's perspective to bear. We note that ARPA-E is modeled after the Department of Defense's highly successful DARPA program, but unlike DARPA, ARPA-E's customers are principally in the private sector and not within the agency that oversees its activities. If ARPA-E is to be successful, it needs to have its purposes better defined, its time horizons clarified and the couplings to its ultimate customer, the private sector, put in better focus.

In the Medium Term

For Transportation Objectives

- The federal government should establish policies to ensure that new light-duty vehicles average 50 miles per gallon or more by 2030. The specific policies are beyond the scope of this study but could include more aggressive Corporate Average Fuel Economy (CAFE) standards, financial incentives such as "feebates" (fees for not meeting the standard and rebates for surpassing it) and carbon taxes. Technologies are available to move beyond the 35 mpg CAFE standard mandated in law by the year 2020. They include further improvements in internal combustion engines; vehicle weight reductions while maintaining vehicle dimensions; and a reasonable mix of vehicles powered by efficient internal combustion engines, diesel engines and improved hybrid technology.

- The weight of vehicles can be significantly reduced without compromising safety through design and new materials. Vehicle weight reductions of 20 percent, for example, achieved by greater use of high-strength steel, aluminum and composite materials, would improve fuel economy by approximately 14 percent while reducing traffic injuries and fatalities. Greater reductions in weight, such as the 50 percent goal of the FreedomCAR program (See, for example, "Review of the Research Program of the FreedomCAR and Fuel Parnership: First Report," National Academy of Sciences, 2005), if achieved by means of advanced light-weight materials, would lead to even greater improvements in fuel economy.

- Plug-in hybrid electric vehicles (PHEVs), which charge their batteries from the electric grid, could reduce gasoline consumption by more than 60 percent assuming a full fleet of PHEVs with a range on batteries alone of at least 40 miles. However, plug-in hybrids require more efficient and more durable batteries, able to withstand deep discharges, that are not yet in commercial large-scale production. Given the technical difficulties faced in developing the batteries, it cannot be assumed that plug-in hybrids to replace the standard American family car will be available at affordable prices in the near term.

- "Time of use" electric-power metering is needed to make nighttime charging of batteries the preferred mode. Improvements in the electric grid must be made in order to handle charging of electric vehicles if daytime charging is to occur on a large scale or when the market penetration of electric vehicles becomes significant.

For Buildings Objectives

- If current and emerging cost-effective energy-efficiency measures are employed in new buildings and in existing buildings as heating, cooling, lighting and other equipment systems are replaced, the growth in energy demand by the building sector could be reduced from the projected 30 percent increase to zero between now and 2030. Therefore, the federal government should set a goal for the U.S. building sector — to be revisited every five years in light of available technologies — to use no more primary energy in 2030 than it did in 2008.

- A zero energy building (ZEB) — one that uses no fossil fuels — would typically have an efficient grid connection to a renewable energy generator that could produce as much energy as the building consumed annually. As a practical matter, the ZEB target will require the building's energy consumption to decline by 70 percent relative to the amount a conventional building would use. Worthy as it is, the goal of achieving significant construction levels of cost-effective new commercial ZEBs by 2030, already mandated by Congress for federal buildings, is not attainable without significant advances in building technology and without the development and widespread adoption of integrated building design and operation practices. To achieve the 2030 ZEB goal for commercial buildings, the federal government should create a research, development and demonstration program that makes integrated design and operation of buildings standard practice. The federal government, state governments and electric utilities should carry out the program co-operatively, with funding from all three entities.

In the Long Term

For Transportation Objectives

- An all-electric battery-powered vehicle would reduce to zero the use of petroleum as a fuel for light-duty vehicles. However, achieving the same range as a gasoline-powered car — 300 miles is the government target — requires batteries with much larger capacity than is needed for plug-in hybrid electric vehicles (PHEVs). For the standard mid-priced American family vehicle, batteries with the needed energy storage per unit weight and per unit volume do not exist. A long-term R&D program will be required to develop them.

- Hydrogen fuel cell vehicles (FCVs) are not a short-term solution to our oil needs, but rather a long-term option requiring fundamental science and engineering breakthroughs in several areas. Without such breakthroughs, FCVs are unlikely to be more than a niche product. The main challenges are durability and costs of fuel cells, including their catalysts, cost-effective onboard storage of hydrogen, hydrogen production, and deployment of a hydrogen-refueling infrastructure.

- There are many areas of long-term basic and applied research that offer unusually promising opportunities for meeting energy efficiency objectives. Among the most notable specifically related to transportation are batteries and energy storage, catalysts, fuel cells, and thermoelectric devices. These areas of opportunity require close coordination between basic and applied research, a management gap that DOE must address more effectively, as we noted earlier in the section on Near Term Crosscutting Objectives.

For Buildings Objectives

- Long-range applied R&D in the buildings sector has been neglected for many years, in part due to the fragmented nature of the industry. We note that the Department of Energy's focus on near-term research and demonstration programs within the Office of Energy Efficiency and Renewable Energy (EERE) has exacerbated the problem — an issue we draw attention to further in the following section on Crosscutting Objectives. Among the critical longer-term applied research opportunities specifically related to buildings are advanced ventilation, advanced windows, thermodynamic cycles and ultra-thin insulators.

For Crosscutting Objectives

- There are many long-term basic and applied research challenges and opportunities in the area of energy efficiency that transcend the boundaries of the specific transportation and buildings objectives. We call attention to just a few of the most prominent ones: lightweight materials, solid-state lighting and behavioral research.

We conclude by emphasizing, as we did earlier, that technology alone will not lead to the potential gains in energy efficiency we identify in this report. Crafting and implementing wise policies are key to any success.

Summary of Recommendations

1. The federal government should establish policies to ensure that new light-duty vehicles average 50 miles per gallon or more by 2030.

2. The federal government's current transportation R&D program should have a broader focus. A more balanced portfolio is needed across the full range of potential medium- and long-range advances in automotive technologies. Increased research is needed in batteries for conventional hybrids, plug-in hybrids and battery electric vehicles, and in various types of fuel cells. This more balanced portfolio is likely to bring significant benefits sooner than the current program through the development of a more diverse range of efficient modes of transportation, and will aid federal agencies in setting successive standards for reduced emissions per mile for vehicles.

3. "Time of use" electric-power metering is needed to make nighttime charging of electric vehicle batteries or plug-in hybrid vehicle (PHEV) batteries the preferred mode. Improvements in the electric grid must be made in order to handle charging of electric vehicles if daytime charging is to occur on a large scale or when the market penetration of electric vehicles becomes significant.

4. Federally funded social science research is needed to determine how land-use and transportation infrastructure can reduce vehicle miles traveled. Studies of consumer behavior as it relates to transportation should be conducted, as should policy and market-force studies on how to reduce vehicle miles traveled. Estimation of the long-term effects of transportation infrastructure on transportation demand should become a required component of the transportation planning process.

5. The federal government should set a goal for the U.S. building sector to use no more primary energy in 2030 than it did in 2008. The goal should be revisited at 5-year intervals in light of the available technology and revised to reflect even more aggressive goals if they are justified by technological improvements.

6. To achieve the 2030 zero energy building (ZEB) goal for commercial buildings — replacing fossil fuels with renewables and reducing energy consumption by 70 percent relative to conventional building usage — the federal government should create a research, development and demonstration program that makes integrated design and operation of buildings standard practice. The federal government, state governments and electric utilities should carry out the program co-operatively, with funding coming from all three entities.

7. Any green building rating system, such as the Leadership in Energy and Environmental Design (LEED) Green Building Rating System, should give energy efficiency the highest priority and require reporting of energy consumption data.

8. The federal government should sharply increase its R&D spending for next-generation building technologies, for training building scientists, and for supporting the associated national laboratory, university and private sector research programs. Specifically, funding for building R&D should be restored to its 1980 level — $250 million in 2008 dollars — during the next 3 to 5 years from the current level of $100 million. At the end of that period the buildings program should be reviewed carefully to determine (1) how much continued federal funding will be needed for the program to reach its goals; and (2) which parts of the program are ready to be shifted to the private sector.

9. The existing demonstration program for construction of low-energy residential buildings, along with associated research, should be expanded.

10. The Department of Energy should develop and promulgate appliance efficiency standards at levels that are cost-effective and technically achievable, as required by the federal legislation enabling the standards. The department should use a streamlined procedure to promulgate the standards for all products for which it has been granted authority to do so.

11. The federal government should encourage states to initiate demand-side management (DSM) programs through utility companies, where such programs do not exist. Such programs, in which a central agency (often a utility company) assists customers in becoming more energy efficient, have proven cost-effective. The federal government could provide rewards to states that have significant and effective DSM programs and disincentives to those that don't.

12. Energy standards for buildings, such as the standards promulgated in California, should be implemented nationwide. States should be strongly encouraged to set standards for residential buildings and require localities to enforce them. The federal government should develop a computer software tool much like that used in California to enable states to adopt performance standards for commercial buildings. States should set standards tight enough to spur innovation in their building industries.

13. Congress should appropriate and the White House should approve for the DOE Office of Science funds that are consistent with the spending profiles specified in the 2005 Energy Policy Act and the 2007 America COMPETES Act. Congress should exercise its oversight responsibility to ensure that basic research related to energy efficiency receives adequate attention in the selection of Energy Frontiers Research Centers.

14. To meet the out-year technology goals this report sets for energy efficiency, DOE must take steps to fold long-term applied research into its scientific programming in a more serious way than it currently does. The department has several options. It can charge the Office of Science with the responsibility and provide the necessary budget, but if it does so, it must protect the culture and budgets of its current basic research programs. It can designate the Energy Efficiency and Renewable Energy Office (EERE) with the responsibility and augment its budget for that purpose, but in that case, DOE must be careful not to allow short-term activities to continue to diminish long-term opportunities. The department can also create a new structure to support long-term applied research or adapt Advanced Research Projects Agency – Energy (ARPA-E), which was established by the America COMPETES Act.

15. The Department of Energy should fully comply with the 2005 Energy Policy Act mandate to improve the coordination between its basic and applied research activities. Congressional oversight committees should ensure that DOE fulfills its obligation.

16. ARPA-E, if funded, needs to have its purposes better defined. Its time horizon must be clarified, and the coupling to its ultimate customer, the private sector, needs better focus. This report takes no position on whether ARPA-E should be funded.

17. Long-term basic and applied research in energy efficiency should be pursued aggressively. In the case of transportation, the opportunities often point up the close connections between basic and applied research and underscore the need for close coordination of the two activities. In the case of buildings, the fragmented nature of the industry and EERE's focus on near-term research and demonstration programs have led to a serious lack of long-range applied R&D, a deficiency that needs to be rectified.

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