National Science Board

August 3, 2009

MEMORANDUM FROM THE CHAIRMAN OF THE NATIONAL SCIENCE BOARD

SUBJECT: *Building a Sustainable Energy Future: U.S. Actions for an Effective Energy Economy Transformation*

The United States is facing a critical challenge to its future prosperity, environmental well-being, and national security rooted in its current dependence on fossil fuel for energy. The National Science Board (Board) is pleased to present its recommendations for national actions to fundamentally transform our current fossil fuel energy economy to a sustainable energy economy.

The Board initiated a study in October 2007 to examine current activities in sustainable energy and the science and engineering challenges related to the development of sustainable energy. The study, lead by the Board's Task Force on Sustainable Energy, includes recommendations for a nationally coordinated science and engineering research and education initiative, including explicit guidance on the role of the National Science Foundation. The Board's report draws on the findings from three public roundtable discussions held in Washington, DC; Golden, Colorado; and Berkeley, California, which were organized by the Task Force in 2008 to receive insight from energy stakeholders throughout the country.

Transformation of our current fossil fuel economy to a sustainable energy economy requires national leadership and coordination; a new U.S. energy policy framework; and robust support for sustainable energy research, development, demonstration, deployment, and education. The scope and urgency of the sustainable energy challenge requires immediate and broad-based U.S. and global commitment. Such a transformation will promote economic prosperity, national security, and stewardship for continued vitality of the environment. It is time to join together with resolve and determination to build a successful energy future.

Steven C. Beering
Chairman
National Science Board

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Executive Summary

The United States faces a critical challenge to transform our current fossil fuel based energy economy to a stable and sustainable energy economy. This transformation must be achieved in a timely manner to increase U.S. energy independence, enhance environmental stewardship and reduce energy and carbon intensity, and generate continued economic growth. In this report, the National Science Board (Board) offers key findings, recommendations to the U.S. Government, and guidance to the National Science Foundation (NSF). Collectively, these actions will initiate and sustain a transformation to a sustainable energy economy. The following six topics of key findings support and form the basis of the Board's recommendations and guidance:

Finding 1: *U.S. Government leadership and coordination*: A comprehensive coordinated Federal strategy is required for sustainable energy initiatives.

Finding 2: *R&D investment*: Private and Federal support for sustainable energy R&D is inadequate.

Finding 3: *Policy development*: The U.S. energy economy is carbon-intensive and does not adequately value the environment as a public good.

Finding 4: *Energy education and workforce*: Human capital development in the sustainable energy sector is vital.

Finding 5: *Global cooperation*: Limited international engagement and collaboration inhibits progress on sustainable energy solutions.

Finding 6: *Energy awareness and action*: Strong public consensus and support for sustainable energy actions are needed to achieve a national transformation to a sustainable energy economy.

The Board makes the following overarching priority recommendation and six component recommendations to the U.S. Government:

Priority Recommendation

The U.S. Government should develop, clearly define, and lead a nationally coordinated research, development, demonstration, deployment, and education (RD3E) strategy to transform the U.S. energy system to a sustainable energy economy that is far less carbon intensive.

Recommendation 1: Lead a Coordinated RD3E Strategy in Sustainable Energy

- Establish a leadership body to coordinate all Federal activities in sustainable energy
- Provide a leading example by adopting sustainable energy measures and analyses throughout the U.S. Government
- Organize and coordinate energy RD3E activities across the United States to link fundamental scientific discoveries with technological innovation

Recommendation 2: Boost Research and Development (R&D) Investment

- Increase Federal investment in sustainable energy R&D
- Facilitate innovation by encouraging investment in research and commercialization of sustainable energy technologies across all economic sectors

Recommendation 3: Facilitate Essential Policies

- Consider stable policies that facilitate discovery, development, deployment, and commercialization of sustainable energy technologies
- Accelerate adoption and commercialization of sustainable energy technologies

Recommendation 4: Support Education and Workforce Development

- Bolster science and technology education related to sustainable energy at all levels
- Bolster workforce training in sustainable energy-related fields

Recommendation 5: Lead Globally

- Engage in global cooperation for sustainable energy strategies
- Reduce barriers to cross-national collaboration in sustainable energy-related research

Recommendation 6: Promote Public Awareness and Action

- Inform consumers and motivate the public to actively seek out, invest in, and implement energy-saving practices and technologies

In support of a nationally coordinated sustainable energy RD3E strategy, the Board offers the following primary and component guidance to NSF:

Priority Guidance for NSF

The National Science Foundation (NSF) should continue to increase emphasis on innovation in sustainable energy technologies and education as a top priority.

Guidance 1: Coordinate and enhance sustainable energy activities with other Federal agencies and throughout NSF headquarters

Guidance 2: Strengthen systems approaches in research programs that focus on issues for a sustainable energy economy

Guidance 3: Strengthen science and engineering partnerships among states, universities, the private sector, and international entities

Guidance 4: Support education and workforce development to train students, researchers, teachers, and technicians for a sustainable energy economy

Guidance 5: Collaborate internationally through the NSF Office of International Science and Engineering and in partnership with the U.S. Agency for International Development

Guidance 6: Promote public awareness and action through programs for students, NSF-funded researchers, and the public

The United States can promote a sustainable energy economy through creation of a nationally coordinated sustainable energy RD3E strategy. This strategy would provide Federal leadership and coordination, boost public and private investment in sustainable energy RD3E, construct essential policies to facilitate innovation in sustainable energy, build human capital, engage in international cooperation, and promote public awareness and action. With resolve and invigorated initiative, the United States is positioned to successfully build and support a sustainable energy future.

Introduction

Transformation of the U.S. fossil fuel-based energy economy to a sustainable energy economy is a critical grand challenge facing the Nation today. This transformation will require national leadership and coordination, a new U.S. energy policy framework, and robust support for sustainable energy RD3E. Together, these approaches will promote our national security through increasing U.S. energy independence, ensure environmental stewardship and reduce energy and carbon intensity,[1] and generate continued economic growth through innovation in energy technologies and expansion of green jobs.

Sustainability is defined as meeting present needs without compromising the ability of future generations to meet their own needs.[2] Within the context of sustainability, the term "sustainable energy" is broadly defined in this report. Sustainable energy includes a wide range of clean, equitable, reliable, renewable, secure, and economically viable energy strategies and solutions that value environmental and ecosystem stewardship. Sustainable and clean energy sources also have significantly lower total and per unit greenhouse gas emissions, reduce U.S. dependence on imported energy sources, and are affordable and available in sufficient quantity to enable continued economic and social development.

Achieving a sustainable energy economy requires both near- and long-term actions. Urgent near-term actions include: developing mechanisms for conserving energy; encouraging and implementing energy efficiency improvements; and identifying, developing, demonstrating, and deploying both existing and emerging sustainable energy technologies. The near-term, multi-pronged actions should be capable of supporting continued economic growth, manifesting proper stewardship of the environment, and adapting to future environmental conditions as necessary. Long-term needs include: understanding and applying the basic science related to climate and the carbon cycle, accelerating innovation in sustainable energy technologies and facilitating their transfer into the marketplace, exploring the potential of new materials for better energy storage and conversion from one form to another, and educating and training a workforce with the skills needed in the new energy economy. These efforts require robust support for science and engineering research related to sustainable energy, as well as significant attention to the economic, social, and environmental impacts of energy technologies.

U.S. Energy Supply

U.S. energy supply has varied throughout the Nation's history. During the Nation's formative years, wood was the primary energy source used. Around 1885, coal surpassed wood as the preeminent energy supply produced in the United States, and coal was in turn replaced by petroleum in the middle of the 20th century. The United States produced its own energy supply until the late 1950s, when energy consumption began to outpace domestic production.[3] Over the past 40 years, imports of crude oil and refined petroleum products have constituted an increasing share of the growing supply of petroleum required to meet U.S. demand.

Today, 85 percent of the U.S. energy supply comes from the combustion of fossil fuels (e.g., oil, natural gas, and coal).[4] Nuclear electric power provides 8 percent of the U.S. energy supply,[5] and energy derived from water (hydroelectric), geothermal, wind, sun (solar), and biomass account

for the remaining 7 percent of the energy supply.[6] Dramatic advances and investment in the production, storage, and distribution of U.S. sustainable energy sources are needed to increase the level of sustainable energy supplies.[7]

U.S. Energy Consumption

U.S. energy consumption varies by economic sector and by energy source. About one-third of energy delivered in the United States is consumed by the industrial sector, and one-half of that amount is consumed by three industries (bulk chemicals, petroleum refining, and paper products). The transportation sector accounts for the second highest share of total end-use consumption at 29 percent, followed by the residential sector at 21 percent and the commercial sector at 18 percent.[8]

Across all sectors, petroleum is the largest primary energy source at around 40 percent, followed by natural gas (23 percent), coal (22 percent), nuclear electric power (8 percent), and renewable energy (7 percent).[9] The transportation sector has historically consumed the most petroleum, with its petroleum consumption dramatically increasing over the past few decades. In 2007, petroleum accounted for 95 percent of the transportation sector's energy consumption.[10,11]

Vision for a Sustainable Energy Future

The imperative to build a sustainable energy future is primarily based on three urgent priorities that should collectively drive the transformation toward a sustainable energy future. The three priorities are to:

- promote national and economic security by increasing U.S. energy independence,
- enhance environmental stewardship and reduce energy and carbon intensity, and
- generate continued economic growth through innovation in energy technologies and expansion of green jobs.

One priority for a sustainable energy economy is to promote national and economic security by increasing U.S. energy independence. The United States imported about 58 percent of the petroleum it consumed during 2007.[12] U.S. reliance on foreign oil sources places the national transportation sector and economy at risk of supply disruptions. Increasing U.S. energy independence will help to ensure a reliable supply of energy resources and more control over price volatility.

Equally important, there is an urgent imperative to enhance environmental stewardship and reduce energy and carbon intensity in a new sustainable energy economy. Global atmospheric concentrations of greenhouse gases (e.g., carbon dioxide, methane, and nitrous oxide) have increased since 1750.[13] Global increases in atmospheric carbon dioxide concentrations are due primarily to fossil fuel use; energy-related carbon dioxide emissions accounted for more than 80 percent of total U.S. greenhouse gas emissions in 2007.[14] The Summary for Policy Makers of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) notes that most of the observed increase in global average temperatures since the mid-20th century is very likely[15] due to the observed increase in anthropogenic greenhouse gas concentrations. Utilizing sustainable energy sources, deploying energy-efficient technologies, and reducing energy consumption[16] will help reduce both greenhouse gas emissions and the impact of climate changes.

Third, investment in a sustainable energy future will enable economic growth and spur job creation in the United States and in other countries. Ensuring continued economic growth requires identifying and developing sustainable energy sources and efficient storage and delivery systems, while paying close attention to environmental impacts and climate change. Also, investments in human capital must be increased throughout the sustainable energy economy, from educational institutions to the private sector.

Process for Producing the Report

In October 2007, the Board established the Task Force on Sustainable Energy (Task Force) to examine ways that the U.S. Government could address the science and engineering (S&E) challenges related to building a sustainable energy economy in the United States. The Board charged the Task Force with developing recommendations for stakeholders on a national research and education initiative on sustainable energy, with a specific emphasis on defining NSF's role in carrying out the initiative.

To accomplish the Board's goals, the Task Force organized three public roundtable discussions in 2008 in Washington, DC; Golden, Colorado; and Berkeley, California. Participants included Board Members; representatives from the scientific community, NSF, and other pertinent Federal agencies involved in energy-related research; and stakeholders from academia, industry, and non-governmental organizations. The Task Force examined current activities in sustainable energy and explored possibilities for developing a long-term, coordinated, inter-agency strategy to achieve a sustainable energy future for the United States.[17]

This report contains key findings, recommendations to the U.S. Government, and guidance to NSF, based on the work of the Task Force. Collectively, these recommendations and NSF guidance build a RD3E strategy in sustainable energy that, if implemented, would catalyze the transformation to a secure, environmentally responsible, and sustainable U.S. energy economy. This national RD3E strategy must include U.S. Government leadership and commitment, strong enabling policies to promote favorable market conditions, robust and long-term stability for sustainable energy research, support for education and workforce development, international engagement, and public awareness and action.

Key Findings

The U.S. Government should lead a coordinated effort to substantially increase and leverage Federal and private sector investment in sustainable energy research and development (R&D). This effort must establish policies that enable market conditions favorable for the development and widespread deployment of sustainable energy sources and technologies, educate and train a workforce to address energy challenges, and advocate energy efficiency and energy conservation measures both in the marketplace and among private citizens. These actions, taken together in a coordinated effort, will foster the transformation to a sustainable energy economy that values and rewards sustainable and clean energy solutions. U.S. Government leadership must be coupled with active cooperation among the public and private sectors.

Six key findings informed the recommendations to the U.S. Government and guidance to NSF offered in this report.

Finding 1: U.S. Government Leadership and Coordination

Current Status: Currently, there is no comprehensive coordinated strategy for sustainable energy initiatives at the Federal level, and energy RD3E activities are not well coordinated across the country. Federal agencies also have not made significant progress in adopting energy efficiency and conservation measures in their own operations.

Goal: **A forward-looking, long-term, coordinated strategy for achieving a stable, sustainable, and clean energy future.** The strategy must substantially increase investment in sustainable energy RD3E, establish appropriate policies to facilitate development and widespread deployment of sustainable energy sources and technologies, educate and train a workforce to address energy challenges, advocate energy efficiency and energy conservation measures, and upgrade national energy infrastructure (e.g., modernizing the national electricity grid and ground transportation system). The national strategy must include and readily adopt opportunities for efficient energy usage, storage and distribution. The national sustainable energy strategy should benefit from lessons learned from individual states' experiences in sustainable energy efforts. For example, California estimates that it reduced annual electricity use by 15 percent in 2003 through adopting efficiency measures for utilities and standards for buildings and appliances.[18]

Finding 2: R&D Investment

Current Status: Within the current policy environment, the level of Federal support for sustainable energy R&D is inadequate to meet the scale, scope, and urgency of the challenges of achieving sustainable energy solutions. Historically, U.S. energy policies and the level of investment in sustainable energy R&D have not resulted in the scale of market development and deployment of sustainable energy sources and technologies needed to address the energy challenges faced by the Nation. The unique circumstances of the energy problem – attempting to transform an already established sector and market – would require active attention to all stages along the R&D spectrum: basic research, applied research, development, and market commercialization and deployment.

As demonstrated by Yoichi Kaya[19] and adopted by the IPCC,[20] the "Kaya Identity" relates carbon emissions to gross domestic product (GDP), energy intensity (energy per unit GDP), and carbon intensity (carbon emissions per unit energy).[21] Nations have aspired to reduce carbon emissions by reducing energy intensity and/or carbon intensity through changes in policy, but a balanced portfolio of policies and R&D is needed to minimize the likely negative impacts on GDP characteristic of either approach alone.

Goal: **Substantial and continuous investment in sustainable energy R&D.** Such investment requires attention to both basic and applied research – to facilitate basic discovery and development of new processes and materials[22] – and to bring sustainable energy technologies to the marketplace. This approach is absolutely critical to achieving innovation and widespread deployment of sustainable energy technologies.

Federal investment in energy research should be substantially increased and applied to a wide range of energy sources and solutions, in order to have informed decision-making. Areas of research that require immediate attention include, but are not limited to: energy efficiency; energy storage; ecosystem impacts of energy technologies; established sustainable energy sources, such as wind, solar, hydro, and biomass; enhanced geothermal systems; cellulosic biofuel production; smart transmission grids; and ocean/kinetic power. These research areas all have tremendous potential, but are currently in various stages of technical maturity.

Finding 3: Policy Development

Current Status: The U.S. energy economy is carbon-intensive and does not adequately value the environment as a public good. Capital-intensive energy infrastructure technologies have long lifetimes, ranging from 20 to 100 years, making them subject to both technological and institutional "lock-in" (i.e., conditions that favor existing technologies over new technologies).

Goal: **Energy policies that facilitate the development and deployment of sustainable energy technologies and are established and evaluated through the use of social and behavioral research.** These measures should encourage long-term commitment to substantial private sector investment in sustainable energy R&D, facilitate widespread adoption of new energy technologies, and value the attributes of sustainable energy usage. Adoption of new energy technologies should be facilitated, not restrained, by effective energy policy.

Finding 4: Energy Education and Workforce

Current Status: As part of a broader national crisis in science and math education, institutions of higher education and the public and private sectors are struggling to train and retain talented specialists in energy research and skilled technicians in energy-related specialties.[23] This need will only grow as more energy professionals and technicians are required and as new professions emerge as a result of investment in sustainable energy.

Goal: **Human capital development in the sustainable energy sector that is vital to the discovery of sustainable energy solutions, as well as to the achievement and maintenance of a sustainable energy economy.** Increased efforts are needed in education and workforce development related to sustainable energy RD3E. These efforts include ensuring the U.S. education system addresses the technologies of today and the skills required in the future.

Finding 5: Global Cooperation

Current Status: Currently, no coordinated strategy exists among U.S. Federal agencies for international involvement in sustainable energy research, development, and deployment. This limited international engagement and collaboration inhibits progress toward critical multilateral and bilateral actions to cooperate on sustainable energy solutions. Further, the experiences of foreign countries engaged in sustainable energy initiatives can offer important guidance to the United States,[24] and it is vital for the Nation to actively collaborate with those other countries in sustainable energy RD3E where possible.

Goal: **A coordinated strategy for international involvement in sustainable energy research, development, and deployment involving active engagement and collaboration with industry in both developed and developing countries.** Early engagement, direct involvement, and active dialogue are essential for ensuring international cooperation, mutual innovation, and progress in sustainable energy. It is particularly important to encourage stakeholders in developing countries to advocate for sustainable energy, to lead in developing and deploying technologies, and to create pathways for global deployment.

Finding 6: Energy Awareness and Action

Current Status: Strong public consensus and support for sustainable energy actions are needed to achieve a national transformation to a sustainable energy economy.[25] While there is much publicly accessible information about energy issues, greater public awareness and recognition of the urgent need for sustainable energy solutions are essential to appropriately inform and motivate environmentally responsible consumer decisions and behaviors.

Goal: **National public awareness of sustainable energy solutions and education regarding energy consumption, and energy efficiency are needed along with strategic engagement with the public to motivate appropriate individual consumer action.** Such a goal would include widespread dissemination of accurate information and guidance on various energy issues, such as the importance of transitioning from using fossil fuels to using sustainable energy sources, as well as innovative efforts to engage the public in ways that will effectively motivate action.

Recommendations to the U.S. Government

The future prosperity and economic progress of the United States depend significantly on developing a nationally coordinated long-term strategy to transform toward a stable and sustainable energy economy. This transformation must be achieved in a sufficiently timely manner to reduce prospective greenhouse gas impacts and U.S. dependence on foreign sources of energy. The Board makes the following overarching priority recommendation:

Priority Recommendation

The U.S. Government should develop, clearly define, and lead a nationally coordinated research, development, demonstration, deployment, and education (RD3E) strategy to transform the U.S. energy system to a sustainable energy economy that is far less carbon intensive.

This strategy must include clearly defined science and engineering research and education objectives that prioritize national security, economic growth, and environmental stewardship. Enacting this strategy requires U.S. Government action on the following recommendations:

Recommendation 1: *Lead a Coordinated RD3E Strategy in Sustainable Energy*

Establish a leadership body to coordinate all Federal activities in sustainable energy

- Establish a Presidential Sustainable Energy Council to champion the transformation of the national energy economy and lead an interagency working group to implement sustainable energy goals. This Council should be under the direction of the Executive Office of the President.
- Set, through this new council, a clear national strategy and objectives in sustainable energy, and require cross-agency coordination in all related activities. Federal agency coordination is demonstrated in a new collaborative initiative by NSF and the U.S. Department of Energy (DOE), Regaining our Energy Science and Engineering Edge (RE-ENERGYSE), which focuses on preparing students for careers related to research and education on clean energy.
- Conduct, through this new council, "systems-level" analyses of U.S. energy systems (e.g., next-generation ground transportation, next-generation utility studies).[26]

Provide a leading example by adopting sustainable energy measures and analyses throughout the U.S. Government

- Encourage all Federal agencies to become exemplars for deploying sustainable energy technologies. These practices should be adopted throughout the U.S. Government supply chain. Increased use of sustainable energy technologies (e.g., in heating and lighting, industrial power, transportation, and information and communications technologies) that can displace technologies with greater energy consumption by Federal agencies and government contractors will generate significant demand and stimulate increased commercial development and deployment.
- Support implementation of Federal and state efficiency policies, including the support of national efficiency standards for buildings, equipment, and appliances.

- Incorporate life cycle and cost-benefit analyses into Federal agency program planning and evaluation of their energy usage. These analyses should consider all energy technologies, applications, and systems, as well as take into account key sustainability metrics in areas, such as greenhouse gas emissions, water consumption, and soil fertility.

Organize and coordinate energy RD3E activities across the country to link fundamental scientific discoveries with technological innovation

- Accelerate critical knowledge transfer between stakeholders (e.g., Federal and state governments, academic institutions, industry, and national laboratories) for the invention and commercialization of new sustainable energy technologies, applications, and processes. Interdisciplinary, multi-institutional, university-industry collaborative research centers can help to successfully promote technology transfer.
- Foster public and private partnerships to pursue transformative, applications-oriented research among multiple stakeholders and communities. These public-private partnerships will collaboratively demonstrate the commercial viability of sustainable energy technologies and work to encourage deployment of new technologies in markets.

Recommendation 2: *Boost R&D Investment*

Increase Federal investment in sustainable energy R&D

- Define and support a national sustainable energy R&D program at a greatly increased and appropriate scale to meet sustainable energy technological and deployment challenges necessary to reduce energy intensity and carbon intensity in a timely manner. The R&D program should address system resiliency to energy supply and transmission disruptions, accommodate base-load demands through energy supply and storage systems, support a balance of centralized and distributed energy generation systems, and favor long-term strategies that demonstrate significant return on investment.
- Ensure long-term stability for Federal energy research, development, demonstration, and deployment by creating a Clean Energy Fund. This funding mechanism must be administered in a manner that facilitates transformative market concepts and does not simply reinforce the status quo. The Clean Energy Fund should guarantee long-term funding and commitment to support the rapid commercialization of competitive and innovative sustainable energy technologies, applications, and systems. The Clean Energy Fund will be particularly useful in supporting large-scale, long-term development and demonstration initiatives.
- Support a range of sustainable energy alternatives, their enabling infrastructure, and their effective demonstration and deployment. Funding should support investigation into a wide range of sustainable energy RD3E topics, including, but not limited to:
  - Advanced, sustainable nuclear power (fission and fusion);
  - Alternative vehicles and transportation technologies;
  - Basic science and engineering research that feeds into applied energy technologies;
  - Behavioral sciences related to energy consumption;
  - Carbon capture, sequestration, and utilization;
  - Economic models and assessments related to sustainable energy;
  - Energy efficiency technologies at all levels of generation, transmission, distribution and consumption;
  - Energy storage;

  - Information and communications technologies that can help conserve energy and/or use it more efficiently, such as broadband cyberinfrastructure;
  - Renewable energy supply technologies (e.g., solar, wind, geothermal, hydroelectric, biomass/biofuels, kinetic, tidal, wave, ocean thermal technologies);
  - Smart grid;
  - "Systems" approaches to large-scale sustainability solutions, including full life cycle analyses of energy systems (e.g., advanced fossil-fuel technologies and biomass-derived fuels); and
  - Zero-energy buildings.
- Support and apply basic science research related to the climate system, climate change, and the carbon cycle.

Facilitate innovation by encouraging investment in research and commercialization of sustainable energy technologies across all economic sectors

- Encourage strategic public-private partnerships in sustainable energy basic and applied research. These partnerships should involve Federal and state governments, science and technology centers, academic institutions, industry, and other energy stakeholders.
- Understand the perspectives of non-Federal stakeholders (e.g., state and local governments, public utilities, and industry), and actively strengthen their involvement in a nationally coordinated sustainable energy RD3E strategy.

Recommendation 3: *Facilitate Essential Policies*

Consider stable policies that facilitate discovery, development, deployment, and commercialization of sustainable energy technologies

- Adopt national targets for reducing carbon dioxide and other greenhouse gas emissions based upon scientific findings about carbon-intensity reduction strategies.
- Encourage all states to create a goal-oriented renewable portfolio standard (RPS) and work with states that are already implementing such standards to consider them in the national strategy. Consider implementing a national RPS that focuses on the goals for a sustainable energy future, in order to encourage the development and commercialization of a broad range of sustainable energy technologies and solutions, instead of one that selects energy technologies and sources.
- Encourage the establishment of aggressive Corporate Average Fuel Economy standards for vehicles.[27]
- Encourage the establishment of national energy-efficiency standards for buildings, equipment, and appliances.[28] These standards should be periodically updated as new energy efficient technologies are developed and deployed from basic and applied research.
- Create incentives for U.S. businesses and state and local governments to adopt sustainable business practices. For example, programs analogous to the Malcolm Baldrige National Quality Award managed by the National Institute of Standards and Technology should be considered to recognize businesses and states that demonstrate leadership in sustainability.
- Establish clear guidelines and policies that accelerate the retirement of older infrastructure that does not meet current environmental standards. These U.S. government-wide guidelines should reflect science and engineering research outcomes.
- Work with states to harmonize state and Federal Renewable Fuels Standard (RFS) rules[29] and understand the implications of life cycle analyses for qualifying fuels.

- Establish financial mechanisms and/or incentives that appropriately reflect the impact of greenhouse gas emissions (e.g., carbon dioxide) and are informed by basic and applied research.
- Understand the explicit and implicit subsidies of current energy technologies that impede conversion to the use of sustainable energy sources. Actively work to establish research-based strategies that encourage greater market deployment of sustainable energy technologies.

Accelerate adoption and commercialization of sustainable energy technologies

- Stimulate the investment environment for sustainable energy technologies with incentives that are predictable over time (e.g., Investment Tax Credit,[30] Production Tax Credit).
- Fast-track establishment of a "Clean Energy Fund," as described in Recommendation 2.

Recommendation 4: *Support Education and Workforce Development*

Bolster science and technology education related to sustainable energy at all levels

- Support efforts to include sustainable energy as an area of focus in science standards, assessments, and instructional materials in grades K-12.
- Support efforts to prepare and enhance teachers in grades K-12 in sustainable energy topics.
- Create new and strengthen existing programs in sustainable energy research and education at the undergraduate, graduate, and doctoral levels.

Bolster workforce training in sustainable energy-related fields

- Create and strengthen Federal government programs to develop, and train a sustainable energy workforce capable of functioning in interdisciplinary energy fields.[31]
- Support technical training programs in energy-related fields at national laboratories, community colleges, and undergraduate institutions.

Recommendation 5: *Lead Globally*

Engage in global cooperation for sustainable energy strategies

- Actively participate in international efforts to strengthen global environmental stewardship, and to develop and deploy sustainable energy technologies.[32] For example, the United States should collaborate with other countries, especially developing countries, to encourage the adoption of sustainable energy technologies with low/zero carbon dioxide emissions. The United States should also learn from ideas and technologies developed in other countries that are further advanced in areas of sustainable energy RD3E as part of its global collaborative efforts.
- Provide leadership in defining and implementing policy, technology cooperation, and fiscal mechanisms to adequately address the magnitude of the global energy challenge.

Reduce barriers to cross-national collaboration in sustainable energy-related research

- Promote policies with other countries that protect intellectual property rights while stimulating sustainable innovation.
- Foster greater opportunities for international exchanges of scientists and engineers. In part, more collaboration could occur if certain constraints can be overcome in issuing foreign-national (H-1B) visas.[33]

- Work with developing countries to facilitate knowledge transfer in energy technologies and adoption of advanced energy technologies suited to local environments.

Recommendation 6: *Promote Public Awareness and Action*

Inform consumers and motivate the public to actively seek out, invest in, and implement energy-saving practices and technologies

- Create and support a multi-pronged, integrated energy efficiency and conservation strategy to encourage consumer adoption of available, cost-effective, and energy-efficient technologies. This integrated strategy should build on social, behavioral, and educational research to promote informed and timely consumer action; an effective strategy will require a combination of science-based policies, institutional changes, and improved communication and information quality.
- Provide accurate, easily accessible information on the life cycle impacts of energy choices to consumers to inform and motivate the public to actively seek out, invest in, and implement energy-saving practices and technologies.[34]

Guidance for the National Science Foundation

In support of a nationally coordinated sustainable energy RD3E strategy, the Board offers the following primary guidance for NSF:

Priority Guidance for NSF

The National Science Foundation (NSF) should continue to increase emphasis on innovation in sustainable energy technologies and education as a top priority.

As components of this overarching NSF guidance, the Board offers the following specific guidance to NSF:

Guidance 1: *Coordinate and Enhance Sustainable Energy Activities*

- Collaborate with other Federal agencies through a newly formed interagency working group on sustainable energy under the aegis of the Presidential Sustainable Energy Council, in accordance with Recommendation 1. The new NSF and DOE collaborative initiative RE-ENERGYSE is an example of cross-agency collaboration.[35]
- Contribute to the entire range of national sustainable energy RD3E investment areas through NSF-supported research, education, and infrastructure programs.
- Integrate energy efficiency measures throughout NSF headquarters to serve as an exemplar of building efficiency. NSF headquarters should demonstrate the U.S. Government's commitment to sustainability and the environment.

Guidance 2: *Strengthen Systems Approaches in Research Programs*

- Develop and strengthen interdisciplinary "systems" approaches for research programs that focus on basic science, environmental, social, and economic issues in a sustainable energy economy. Examples of systems approaches that could be applied to the sustainable energy economy include the use of ecosystem life cycle and whole-system analyses; consumer behavior information; and economic net value of technologies, applications, and systems.
- Enhance interdisciplinary research programs that develop environmental accounting techniques that can utilize both biophysical and economic values in parallel.
- Fund innovative science and engineering research on reducing energy and carbon intensity while minimizing the negative effects on GDP.

Guidance 3: *Strengthen Science and Engineering Partnerships*

- Support science and engineering partnerships for building clean and sustainable energy initiatives among states, universities, and the private sector. International entities should be an essential part of many of these partnerships.
- Consider expanding NSF centers programs that focus on energy topics and foster successful public-private partnerships.

Guidance 4: *Support Education and Workforce Development*

- Create new and strengthen existing programs to prepare and enhance students, researchers, and technicians for a sustainable energy workforce. These programs should involve multidisciplinary and interdisciplinary curricula and experiences, for example:
  - Special training grants for beginning researchers in sustainable energy fields within the existing NSF Faculty Early Career Development Program; and
  - Special emphasis on sustainable energy for programs within the Research Experience for Undergraduates program; Integrative Graduate Education and Research Traineeship program; Advanced Technological Education program; or Course, Curriculum, and Laboratory Improvement program.
- Promote interest in science and energy fields during K–12 education by supporting the development and dissemination of programs and curricula designed to teach students about energy, the environment, and related economic issues.
- Support, in conjunction with other Federal agencies, technical education programs in community colleges and undergraduate institutions that include support for science and engineering teachers, technicians, and professional development activities.

Guidance 5: *Collaborate Internationally*

- Encourage international collaboration in sustainable energy RD3E through the NSF Office of International Science and Engineering and through partnerships with the U.S. Agency for International Development.

Guidance 6: *Promote Public Awareness and Action*

- Foster societal literacy and encourage efficient and effective use of energy by enhancing existing programs and by developing new sustainable energy education programs for students, NSF-funded researchers, and the public. Examples of NSF programs that could be enhanced to include a focus on sustainable energy are Innovative Technology Experiences for Students and Teachers, Informal Science Education, and Discovery Research K-12.

Conclusion

The scope and urgency of the sustainable energy challenge requires immediate and robust U.S. and global commitment. This commitment is necessary to effectively transform the current U.S. economy to a sustainable energy economy. Such a transformation will help promote energy independence, foster future economic prosperity and ensure stewardship and continued vitality of the environment. The United States can promote a sustainable energy economy through creation of a nationally coordinated sustainable energy RD3E strategy. This strategy would provide Federal leadership and coordination, boost public and private investment in sustainable energy RD3E, construct essential policies to facilitate innovation in sustainable energy, build human capital, engage in international cooperation, and promote public awareness and action.

This report reflects a concerted effort by the Board, colleagues, and stakeholders throughout the Federal, private, academic, and nonprofit sectors to address the challenges and opportunities for sustainable energy in the 21st century. The recommendations offered to the U.S. Government strive to promote leadership and coordinated efforts to move toward a sustainable energy economy. In addition, the Board offers guidance for NSF that aims to prioritize innovation in sustainable energy, by supporting sustainable energy RD3E that leads to the development and deployment of viable sustainable energy technologies. With resolve and invigorated initiative, the United States is positioned to successfully build and support a sustainable energy future.

Endnotes

[1] The Energy Information Administration defines carbon intensity as: "The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per British thermal unit (Btu) of energy. When there is only one fossil fuel under consideration, the carbon intensity and the emissions coefficient are identical. When there are several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels." Available online at: *http://www.eia.doe.gov/glossary/glossary_c.htm*. Energy intensity is the energy per unit of gross domestic product. Reductions in energy and carbon intensity factor into reducing carbon emissions.

[2] The definition of "sustainability" used in this report is derived from the definition of "sustainable development" in the 1987 report of the United Nations World Commission on Environment and Development.

[3] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*, DOE/EIA-0384(2007). (Washington, DC: U.S. Department of Energy, June 2008).

[4] U.S. Department of Energy, Basic Energy Sciences Advisory Committee. *New Science for a Secure and Sustainable Energy Future*. (Washington, DC: U.S. Department of Energy, December 2008).

[5] U.S. Department of Energy, Energy Information Administration. *Annual Energy Review 2007*, DOE/EIA-0384(2007). (Washington, DC: U.S. Department of Energy, June 2008).

[6] U.S. Department of Energy, Energy Information Administration. *Renewable Energy Consumption and Electricity Preliminary 2007 Statistics*. (Washington, DC: U.S. Department of Energy, May 2008). Available online at: *http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html*.

[7] For further information about U.S. energy supply, see Appendix A.

[8] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*, DOE/EIA-0384(2007). (Washington, DC: U.S. Department of Energy, June 2008).

[9] Ibid.

[10] For further information about U.S. energy consumption, see Appendix A.

[11] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*, DOE/EIA-0384(2007). (Washington, DC: U.S. Department of Energy, June 2008).

[12] U.S. Department of Energy, Energy Information Administration. *How Dependent is the United States on Foreign Oil?* (Washington, DC: U.S. Department of Energy). Available online at: *http://tonto.eia.doe.gov/ask/crudeoil_faqs.asp*.

[13] R.K. Pachauri and A. Reisinger, eds. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (Geneva, Switzerland: IPCC, November 2007). Available online at: *http://www.ipcc.ch/ipccreports/ar4-syr.htm*.

[14] U.S. Department of Energy, Energy Information Administration. *Emissions of Greenhouse Gases in the United States 2007*. (Washington, DC: U.S. Department of Energy, 2008). Available online at: *http://www.eia.doe.gov/oiaf/1605/ggrpt/*.

[15] The term "very likely" indicates a probability of occurrence greater than 90 percent. R.K. Pachauri and A. Reisinger, eds. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (Geneva, Switzerland: IPCC, November 2007). Available online at: *http://www.ipcc.ch/ipccreports/ar4-syr.htm*.

[16] The Climate Group. *Smart2020: Enabling the Low Carbon Economy in the Information Age*. (London: The Climate Group, 2008).

[17] Background information about the history and context of sustainable energy is included in Appendix A. Appendix B includes the charge to the Task Force. Appendixes C, D, and E describe the key topics discussed at each roundtable discussion and provide a complete list of roundtable participants.

[18] Mark D. Levine. "What Roles Can Federal and State Governments Play in Promoting Sustainable Energy?" Presentation to the National Science Board. (Berkeley, CA: September 4, 2008).

[19] Y. Kaya and K. Yokoboi. *Environment, Energy, and Economy: Strategies for Sustainability*, presentation to the Tokyo Conference on Global Environment. (Tokyo, Japan: 1993).

[20] For more information, see: *http://www.ipcc.ch/*.

[21] The Kaya Identity, developed in 1993 by Yorchi Kaya, is a mathematical equation used to calculate carbon dioxide emissions and is useful in evaluating the proposed and actual performance of decarbonization policies.

[22] For example, increased investment in basic research should include high-performing materials that orchestrate the seamless conversion of energy between light, electrons, and chemical bonds. U.S. Department of Energy, Basic Energy Sciences Advisory Committee. *New Science for a Secure and Sustainable Energy Future*. (Washington, DC: U.S. Department of Energy, December 2008).

[23] There is currently a lack of sufficient engineers to plan for future transmission infrastructure needs or to perform environmental impact analyses on new transmission lines. In Colorado, there is a 4 percent set-aside for residential solar panel installations, which people have been quick to take advantage. But once the photovoltaic arrays are installed, there is typically a considerable delay – on the order of months – before the utility can send a trained worker to convert the meter for the arrays to become operational.

[24] For example, the Danish government has set ambitious goals to reduce national dependence on foreign sources of energy, including pledging to double the fraction of energy consumption from renewable sources by 2025 and to reduce total energy consumption by 4 percent by 2020. Denmark has doubled the capacity of combined heat and power plants in the past 25 years, and electricity generation from renewable sources satisfied 13 percent of the total electricity demand in 2007, which is up from 3 percent in 1990. The Danish government also invests heavily in sustainable energy R&D, fostering effective partnerships with public and private research institutions. As a result, exports of energy technology increased 18 percent in 2006. Denmark, Ministry of Climate and Energy. *The Danish Example—Towards an Energy Efficient and Climate Friendly Economy*. (Copenhagen, Denmark: Ministry of Climate and Energy, April 2008). Available online at: *http://www.ens.dk/sw12333.asp*.

[25] Corresponds to Conclusion 9, "The S&T community—together with the general public—has a critical role to play in advancing sustainable energy solutions and must be effectively engaged." .InterAcademy Council. *Lighting the Way: Toward a Sustainable Energy Future*. (Amsterdam, the Netherlands: InterAcademy Council, October 2007). Available online at: *http://www.interacademycouncil.net/?id=12161*.

[26] All sustainable energy solutions need to be evaluated according to a systems-level approach in order to enable transparent and well-informed policy decisions about the use of energy sources and technologies. This approach must look across multiple technologies and across multiple end-use sectors, integrating technical feasibility with potential environmental impacts (i.e., life cycle impacts of a particular energy source or technology). In addition, this approach must consider energy consumer behavior – from businesses and institutions to private citizens – and policy feasibility from local to global levels.

[27] Recently, President Obama announced a new national fuel efficiency policy that requires an average fuel economy standard of 35.5 miles per gallon in 2016. This policy would surpass the Corporate Average Fuel Economy law passed by Congress in 2007 that required an average fuel economy of 35 miles per gallon by the year 2020.

[28] This should be accomplished in collaboration with the U.S. Green Building Council, the U.S. Environmental Protection Agency, and the U.S. Department of Energy.

[29] The Energy Independence and Security Act of 2007 (P.L. No: 110-140) requires an increase in the production of renewable fuels from 4 billion gallons to 36 billion gallons by 2022.

[30] An investment tax credit is important to enable the market for an emerging industry, and with the current financial situation, it is important that the issue of tax credit monetization also be addressed.

[31] For example, the Energy Independence and Security Act of 2007 (P.L. No: 110-140) established the Energy Efficiency and Renewable Energy Worker Training Program. This program provides training to veterans, unemployed individuals, and workers impacted by energy and environmental policies.

[32] These efforts should be coordinated with industry stakeholders and the Overseas Private Investment Corporation.

[33] H-1B visas allow employers to hire foreigners with specific skills, as well as allow foreigners to receive graduate degrees from American universities. The Board has expressed concern that "ready availability of outstanding science and engineering talent from other countries is no longer assured," due in part to constraints on employment of foreign nationals in its 2003 report, *The Science and Engineering Workforce: Realizing America's Potential* (NSB-03-69). Many business leaders recommend that Congress raise the cap on H-1B visas.

[34] The creation of a national, centralized, easily accessible Website to promote information on the life cycle impacts of energy choices may have a tremendous impact.

[35] This initiative focuses on preparing students for careers related to research and education on clean energy. NSF, working with DOE, will leverage existing programs and partnerships to train scientists and technicians, educate K-12 and undergraduate students, and inform the public.