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Building a Sustainable Energy Future

April 10, 2009

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Executive Summary

The fundamental transformation of the Nation's current extractive fossil fuel energy economy to a sustainable energy economy is a critical grand challenge facing the United States today. This transformation requires active U.S. Government leadership and coordination. It also requires robust support for sustainable energy research, development, demonstration, deployment, and education (RD3E) and a new U.S. energy policy framework that enables commercially attractive solutions. Together, these broad, science-driven approaches can help to promote our national security through increasing U.S. energy independence, enhance environmental stewardship and reduce energy and carbon intensity,[1] and generate continued economic growth through innovation in energy technologies and expansion of green jobs.

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 six key findings listed below support and form the basis of the Board's recommendations:

1. *U.S. Government leadership and coordination.* Achieving a secure and abundant supply of sustainable energy is a critical national goal. The U.S. Government must adopt a forward-looking, long-term, coordinated strategy for achieving a stable, sustainable, and clean energy future. This strategy must substantially increase investment in sustainable energy technology research; establish appropriate market conditions to facilitate development and widespread deployment of sustainable energy technologies; educate and train a workforce to address energy challenges; and advocate energy efficiency and energy conservation measures.
2. *R&D investment.* Within the current policy environment, the level of Federal support for sustainable energy research and development (R&D) is inadequate to meet the scale and scope of the challenges for achieving sustainable energy solutions. Federal support for sustainable energy R&D, which is not limited to direct financial assistance, should be substantially increased and applied to a wide range of energy technologies upon which the sustainable energy economy can be based. The unique circumstances of the energy challenge – attempting to transform an already established sector and market with legacy technologies – will require active Federal attention to all stages along the R&D spectrum: basic research, applied research, development, demonstration, market commercialization, and deployment. In addition, given the relationship between energy and environment, understanding and applying the basic science of the climate system, the carbon cycle, and climate change is essential.
3. *Policy development.* The current energy economy does not adequately value or reward the attributes of sustainable energy solutions relative to those for the use of non-sustainable energy. Commitment to sustainable energy policies will require development of methods to integrate scientific and technical information with social, economic, and environmental concerns.
4. *Energy education and workforce.* Human capital development in the sustainable energy sector is vital to the discovery of sustainable energy solutions, as well as to the achievement and maintenance of a sustainable energy economy. Institutions of higher

education and the private sector must train and retain talented specialists in energy research and skilled technicians in energy-related specialties. The U.S. must substantially increase efforts in education and workforce development related to sustainable energy research and technology development and deployment.

5. *Global cooperation.* Limited international engagement and collaboration on sustainable energy solutions are inhibiting progress toward critical multilateral and bilateral actions. The United States should develop and lead 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 with other nations are essential for ensuring international cooperation, mutual innovation, and progress in sustainable energy technologies.

6. *Energy awareness and action.* Strong public consensus and support for sustainable energy issues are needed to achieve a national transformation for a sustainable energy economy. The U.S. Government should promote national public awareness of sustainable energy solutions, energy consumption, and energy efficiency. In addition, it should strategically engage with the public to motivate sound consumer action.

In order to achieve a sustainable energy economy, the Board makes the following overarching priority recommendation 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.**

Enacting this strategy requires rapid U.S. Government action on the following recommendations:

1. *Lead a coordinated RD3E strategy in sustainable energy.* Establish a Presidential Sustainable Energy Council to coordinate all Federal activities in sustainable energy, and provide a leading example by adopting sustainable energy measures throughout the U.S. Government.
2. *Boost R&D investment.* Increase investment in sustainable energy R&D to achieve innovation and widespread deployment of sustainable energy technologies. Facilitate innovation by encouraging investment in research and commercialization of sustainable energy technologies across all economic sectors.
3. *Construct essential policies.* Consider stable policies that facilitate discovery, development, deployment, and commercialization of sustainable energy technologies. Develop policies that accelerate adoption and commercialization of sustainable energy technologies.
4. *Support education and workforce development.* Bolster science and technology education related to sustainable energy at all levels, and bolster workforce training in sustainable energy-related fields.
5. *Lead globally.* Engage in global cooperation in sustainable energy strategies,

and reduce barriers to cross-national collaboration in sustainable energy-related research.

6. *Promote public awareness and action.* Inform the public about how consumer behaviors affect energy usage and the environment. 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 guidance to NSF:

> ***Priority Guidance:* The National Science Foundation 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:

1. *Coordinate sustainable energy activities*. Collaborate with other Federal agencies through an interagency working group on sustainable energy that will work under a new Presidential Sustainable Energy Council.
2. *Strengthen systems approaches in research programs.* Develop and strengthen interdisciplinary "systems" approaches for research programs in the natural and social sciences that focus on environmental, social, and economic issues fundamental to the future energy economy. Examples of systems approaches that could be applied to the 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.
3. *Strengthen science and engineering partnerships*. Support partnerships for building clean and sustainable energy science and engineering initiatives among states, universities, and the private sector. International entities should be an essential part of many of these partnerships.
4. *Support education and workforce development.* Create new and strengthen existing programs to train students, researchers, and technicians for a sustainable energy workforce. Promote interest in the fields of science and energy in K–12 education by developing and disseminating programs designed to teach students about energy, the environment, and related technology and economic issues. Support, in conjunction with other Federal agencies, technical training programs in community colleges and undergraduate institutions that include support for science and engineering teachers, technicians, and professional development activities.
5. *Collaborate internationally.* Encourage international collaboration in sustainable energy RD3E, including through the NSF Office of International Science and Engineering and through partnerships with the U.S. Agency for International Development.

6. *Promote public awareness and action.* Foster societal literacy about energy-saving practices and technologies 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.

The United States can achieve a sustainable energy economy through creating a nationally coordinated RD3E strategy in sustainable energy: providing top-down Federal leadership; constructing essential policies to coordinate and facilitate innovation in sustainable energy; and boosting public and private investment in sustainable energy research, development, demonstration, deployment, and education. The United States is poised—in light of calls for positive change throughout the country—to build a sustainable energy future.

Introduction

The fundamental transformation of the current extractive U.S. fossil fuel energy economy to a sustainable energy economy is a critical grand challenge facing the Nation today. The current U.S. energy economy is carbon-intensive and does not adequately value the environment and sustainability as public goods. In contrast, a sustainable energy economy values environmental and ecosystem stewardship, as well as clean, equitable, reliable, renewable, safe, secure, and economically viable energy strategies and solutions. Transforming toward a sustainable energy economy requires national leadership and coordination, a new U.S. energy policy framework, and robust support for sustainable energy RD3E. Together, these approaches can help to promote our national security through increasing U.S. energy independence, ensure environmental stewardship and reduce energy and carbon intensity,[2] and generate continued economic growth through innovation in energy technologies and expansion of green jobs.

In this report, the term "sustainable energy" is broadly defined. Sustainable and clean energy sources have significantly lower total and per unit greenhouse gas emissions and reduce U.S. dependence on imported energy sources. Sustainable energy sources are affordable, safe, and available in sufficient quantity to enable continued economic and social development while promoting environmental stewardship.

Achieving a sustainable energy economy requires attention to both near- and long-term energy needs. Near-term needs include: developing mechanisms for conserving energy; encouraging energy efficiency; and identifying, developing, demonstrating, and deploying both existing and emerging sustainable energy technologies. The near-term solutions 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 to operate 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 amount of petroleum supplied 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] and nuclear electric power provides 8 percent.[5] Sustainable energy sources derived from water (hydroelectric), geothermal, wind, sun (solar), and biomass account for the remaining 7 percent of the U.S. 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. Appendix A further describes the current U.S. energy supply.

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 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.[7]

Across all sectors, petroleum is the highest 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).[8] 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.[9] Appendix A further describes current U.S. energy consumption.

Drivers for a Sustainable Energy Future

The imperative to build a sustainable energy future is primarily based on the following three urgent drivers 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.

The primary driver toward a sustainable energy economy is the critical need to promote national and economic security by increasing U.S. energy independence. The United States imported about 58 percent of the petroleum consumed during 2007.[10] 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.

Second, 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.[11] 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.[12] 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*[13] due to the observed increase in anthropogenic greenhouse gas concentrations. Utilizing sustainable energy sources, deploying energy-efficient technologies, and reducing energy consumption[14] 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 U.S. 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.

Task Force on Sustainable Energy

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 U.S. 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 stable, sustainable energy future for the United States. Background information about the history and context of sustainable energy is included in Appendix A. Appendices B, C, and D describe the key topics discussed at each roundtable discussion and provide a complete list of roundtable participants.

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 create 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 sustained 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 sustainable energy 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 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.[15]

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.

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; 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.

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[16] and adopted by the Intergovernmental Panel on Climate Change,[17] the "Kaya Identity" relates carbon emissions to GDP, Energy Intensity (energy per unit GDP), and Carbon Intensity (carbon emissions per unit energy).[18] Nations have aspired to reduce carbon emissions by reducing energy intensity and/or carbon intensity through changes in policy, but what is needed is a balanced portfolio of policies and technology improvements to minimize the likely negative impacts on GDP characteristic of either approach alone. Accordingly, it is important for the U.S. and other nations to fund innovation in energy technologies at levels reflecting the immense importance of climate change caused by anthropogenic carbon loading.

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[19] – and bringing sustainable energy technologies to the marketplace. This approach is absolutely critical to achieving innovation and widespread deployment of sustainable energy technologies.

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., a number of conditions that favor existing technologies over new technologies).

Goal: **Energy policies that facilitate the development and deployment of sustainable energy technologies and concomitantly address the science and engineering challenges related to the development of sustainable energy.** 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 rates 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.[20] This need will only grow as more energy professionals and technicians are required – new professions will 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 research, technology development, and deployment. 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,[21] and it is vital 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.[22] 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 issues related to energy consumption, and energy efficiency 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.

Recommendations to the U.S. Government

The future prosperity and economic progress of the United States depend largely 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.
- Through this new council, set clear national strategy and objectives in sustainable energy, and require cross-agency coordination in all related activities.
- The work of this council should include conducting "systems-level" analyses of U.S. energy systems (e.g., next-generation ground transportation, next-generation utility studies).[23]

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 energy technologies, applications, and processes.
- 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.
- Ensure long-term stability for Federal energy research, development, demonstration, and deployment by creating a "Clean Energy Fund." This funding mechanism should guarantee long-term funding and commitment to support the rapid, pro-competitive commercialization of 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;
    - Alternative vehicles and transportation technologies;
    - Basic S&E research that feeds into applied energy technologies;
    - Behavioral sciences as it relates to energy consumption;
    - Carbon capture and sequestration;
    - 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" approach 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.
- Understand the perspectives of non-Federal (e.g., state and local governments, public utilities, and industry) stakeholders, 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 to reflect advances in basic and applied research

- 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 an effective 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 reflects differences among states in resource conditions (e.g., wind, solar, biomass, geothermal).
- Encourage the establishment of aggressive Corporate Average Fuel Economy standards for vehicles.[24]
- Encourage the establishment of national energy-efficiency standards for buildings, equipment, and appliances.[25] 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.[26]
- Establish financial mechanisms and/or incentives that reflect appropriately the impact of greenhouse gas emissions (e.g., carbon dioxide) informed by basic and applied research.
- Understand the explicit and implicit subsidies of current energy sources that impede conversion to the use of sustainable energy sources, and 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 incentive polices that are predictable over time (e.g., Investment Tax Credit, [27] 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 curriculums in grades K-12.
- Support efforts to train 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.[28]
- 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.[29] For example, the United States should collaborate with countries, especially developing countries, to encourage the adoption of sustainable energy technologies with low/zero carbon dioxide emissions.
- 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 in-country collaboration could occur if certain constraints can be overcome in issuing foreign-national (H-1B) visas.[30]
- Work with other 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

- Create and strengthen consumer education programs that promote energy conservation and energy efficiency among consumers.[31] These consumer education programs should apply findings from social and behavioral research.

- Provide accurate, easily accessible information on the life-cycle impacts of energy choices to consumers to create an informed and motivated public that actively seeks out, invests in, and implements energy-saving practices and technologies.[32]

Guidance for the National Science Foundation

In support of a nationally coordinated sustainable energy RD3E strategy, the Board offers the following primary 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.**

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

Guidance 1: *Coordinate 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.

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 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 intensity and carbon intensity while minimizing the 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.

Guidance 4: *Support Education and Workforce Development*

- Create new and strengthen existing programs to train students, researchers, and technicians for a sustainable energy workforce. For example:
    - Special training grants for young 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 developing and disseminating programs designed to teach students about energy, the environment, and related economic issues.
- Support, in conjunction with other Federal agencies, technical training 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 to effectively transform to a sustainable energy economy. This transformation will help promote future economic prosperity and ensure stewardship and continued vitality of the environment. The United States can achieve a sustainable energy economy through creation of a nationally coordinated sustainable energy RD3E strategy. This strategy provides Federal leadership and coordination, boosts public and private investment in sustainable energy RD3E, constructs essential policies to facilitate innovation in sustainable energy, builds human capital, engages in international cooperation, and promotes public awareness and action.

This report marks a concerted effort by the Board to join with 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 made herein to the U.S. Government strive to promote leadership of harmonized efforts in moving 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.

[2] Energy intensity is the energy per unit of gross domestic product and carbon intensity is the carbon emissions per unit of energy. Reductions in energy and carbon intensity factor into reducing carbon emissions.

[3] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007). Released for printing: June 23, 2008.

[4] U.S. Department of Energy. Prepared by the Basic Energy Sciences Advisory Committee (BESAC) Subcommittee on Facing Our Energy Challenges in a New Era of Science. *New Science for a Secure and Sustainable Energy Future*. December 2008.

[5] Energy Information Administration. Annual Energy Review 2009.

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

[7] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007). Released for printing: June 23, 2008.

[8] Ibid.

[9] Ibid.

[10] U.S. Department of Energy, Energy Information Administration. *How dependent is the United States on foreign oil?* Retrieved August, 25, 2008. Available online at: *http://tonto.eia.doe.gov/ask/crudeoil_faqs.asp*.

[11] IPCC, 2007: 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 [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp. For more information, see: *http://www.ipcc.ch/ipccreports/ar4-syr.htm*.

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

[13] The term "very likely" indicates a greater than 90 percent probability of occurrence. Intergovernmental Panel on Climate Change, Fourth Assessment Report. Climate Change 2007:: Synthesis Report. (November 2007). For more information, see: *http://www.ipcc.ch/ipccreports/ar4-syr.htm*.

[14] The Climate Group on behalf of the Global e-Sustainability Initiative (GeSI). *Smart2020: Enabling the low carbon economy in the Information Age*. Creative Commons, 2008.

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

[16] Kaya, Y. and K. Yokoboi, Environment, Energy, and Economy: Strategies for Sustainability, Tokyo Conference on Global Environment, Tokyo, Japan, 1993.

[17] http://www.ipcc.ch/

[18] 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.

[19] 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. Prepared by the Basic Energy Sciences Advisory Committee (BESAC) Subcommittee on Facing Our Energy Challenges in a New Era of Science. *New Science for a Secure and Sustainable Energy Future*. December 2008.

[20] 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 of. 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.

[21] 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% 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.Ministry of Climate and Energy. "The Danish Example– Towards an Energy Efficient and Climate Friendly Economy." 22 April 2008. Available online at: *http://www.ens.dk/sw12333.asp*.

[22] 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*. October 2007. Available online at: *http://www.interacademycouncil.net/?id=12161*.

[23] 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). In addition, this approach must consider energy consumer behavior – from businesses and institutions to private citizens – and policy feasibility from local to global levels.

[24] Recently, Corporate Average Fuel Economy standards were increased to 35 miles per gallon by the year 2020. For more information, see section 102-104 in the Energy Independence and Security Act of 2007 (P.L. No: 110-140).

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

[26] 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. GovTrack.us. H.R. 6--110th Congress (2007): Energy Independence and Security Act of 2007, GovTrack.us (database of federal legislation). Available online at: http://www.govtrack.us/congress/bill.xpd?bill=h110-6. (. Accessed Feb 4, 2009).

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

[28] 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.

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

[30] H-1B visas allow employers to hire foreigners with specific skills, as well as allow foreigners to receive graduate degrees from American universities. Current U.S. limitations on H-1B visas may disrupt qualified science, technology, and engineering graduates from working at American companies in need of their specialized services. Many business leaders recommend that Congress raise the cap on H-1B visas.

[31] For example, the Energy Independence and Security Act of 2007 (P.L. No: 110-140) established a consumer education program regarding: (1) the benefits of alternative fuel in automobiles; and (2) fuel savings that would be recognized from the purchase of vehicles equipped with thermal management technologies. The scope of this consumer education program could be widened to include other sustainable energy issues.

[32] 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.

Appendix A: History and Context of Sustainable Energy

I. Selected Summary Descriptions of Sustainable Energy Investment Areas

The following sections highlight a limited number of sustainable energy investment areas that may be part of an RD3E strategy.

Advanced, Sustainable Nuclear Power

Nuclear power offers the possibility of providing continuous and dependable base-load electricity without the greenhouse gas emissions produced from fossil-fueled power plants. All commercial nuclear power plants currently operating in the United States (and most nuclear power plants operating worldwide) are light water reactors that use a "once-through" fuel cycle. Proposed advanced (generation IV) nuclear power plants aim to incorporate a suite of new technologies that will produce nuclear power in a manner that is sustainable, economical, safe, reliable, and proliferation-resistant.[1] Despite the potential advantages associated with reduced greenhouse gas emissions, additional research, development, and analysis of advanced nuclear power are needed. Specifically, further information and data are required to demonstrate the possibility of achieving enhanced safety, proliferation resistance, economical cost, and appropriate waste storage solutions. Twelve countries, including the United States, Russia, and China, as well as the European Atomic Energy Community, have agreed on a framework for international cooperation in research for Generation IV systems.[2]

Alternative Vehicles and Transportation Technologies

Transportation plays a vital role in the U.S. economy, allowing for timely and affordable movement of goods, services, and people. The U.S. transportation sector ranks high in both energy consumption and carbon dioxide emissions. A number of existing and emerging technologies can reduce energy consumption, carbon dioxide emissions, and dependence on foreign oil in the transportation sector. Technologies include hybrid and electric vehicles, smaller and more efficient cars, and advanced hydrogen fuel cell vehicles. There are also transportation infrastructure improvements that can reduce energy usage. Examples include improved public transit, congestion pricing, dedicated high-occupancy vehicle (HOV) lanes, and urban planning that encourages pedestrian and biking alternatives to driving. Transportation infrastructure improvements also address the relationship between land use and greenhouse gas emissions.

Basic Science and Engineering (S&E) Research

The objective of basic S&E research is to "gain more comprehensive knowledge or understanding of the subject under study without specific applications in mind."[3] Advances in basic S&E research are critical in driving applied research and innovation in sustainable energy. For example, basic S&E research of complex catalysts required for solar-powered hydrolysis may lead to the development of a carbon-neutral process for producing hydrogen.[4] The National Science Foundation is a leader in

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[1] U.S. DOE Nuclear Research Advisory Committee and the Generation IV International Forum. 2002. "A Technology Roadmap for Generation IV Nuclear Energy Systems."

[2] For more information about the Generation IV International Forum, see: http://www.gen-4.org/.

[3] National Science Board. 2008. *Science and Engineering Indicators 2008*. Two volumes. Arlington, VA: National Science Foundation (volume 1, NSB 08-01; volume 2, NSB 08-01A). Available online at: http://www.nsf.gov/statistics/seind08/c4/c4s.htm#c4sb1.

[4] Basic Energy Sciences Advisory Committee. U.S. Department of Energy. December 2008. *New Science for a Secure and Sustainable Energy Future*. Available online at: http://www.sc.doe.gov/BES/reports/files/NSSSEF_rpt.pdf.

supporting basic S&E research across all disciplines, and the agency has an important role in driving basic research that leads to sustainable energy innovation. The U.S. Department of Energy's Office of Science also supports basic S&E research that will help build a sustainable energy future.

Behavioral and Social Sciences Research

Behavioral and social sciences research builds knowledge of human behavior, human interactions, social and economic systems, and organizations and institutions.[5] Research in these fields is critical to understand the basis for human attitudes and actions toward sustainability, as well as to understand how to construct appropriate incentives for aligning human behavior with a sustainable energy future.[6] Behavioral and social sciences analyses are important components of life-cycle analyses and "systems" approaches to solving sustainability challenges.

Behavioral and social sciences research can be used to construct strategies to motivate appropriate individual consumer action. Consumer behavior related to sustainable energy includes decisions about driving and using public transit systems, buying and operating appliances, and energy conservation actions (e.g., turning off the lights when leaving a room). Decisions related to energy usage are a part of daily American life, and helping consumers make sustainable energy choices is an integral part of achieving a sustainable energy future. Economic incentives and education (both formal and informal) can influence consumer behavior; examples include real-time electricity pricing, the use of "smart appliances," and ad campaigns encouraging conservation. Specific areas of behavioral and social sciences research that could help to illuminate influences on consumer behavior include consumer response to incentives and information, attitudes and social interactions regarding energy, the effect of social values on consumption, social organization of energy pricing, micro-behavior in consumption environments, and macro-social patterning of consumption.[7,8,9]

Carbon Capture and Sequestration (CCS)

CCS involves the capture, transmission, and long-term storage of carbon dioxide from energy systems, especially power generation plants.[10] The captured carbon dioxide may be stored in locations such as deep saline aquifers or depleted oil and gas reservoirs. By capturing a waste stream of carbon dioxide, transporting and compressing the gas, and channeling the gas underground, CCS technology has the potential to reduce the amount of carbon dioxide released into the atmosphere.

Carbon-intensive fossil fuels are ubiquitous in the United States, largely because they are relatively

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[5] National Science Foundation. *Directorate for Social, Behavior, & Economic Sciences (SBE): About SBE*. For more information, see: http://www.nsf.gov/sbe/about.jsp.

[6] National Research Council. (2005). *Decision Making for the Environment: Social and Behavioral Science Research Priorities*. Panel on Social and Behavioral Science Research Priorities for Environmental Decision Making. G.D. Brewer and P.C. Stern, editors. Committee on the Human Dimensions of Global Change, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

[7] National Research Council. 1982. *Behavioral and Social Aspects of Energy Consumption and Production: Preliminary Report*. Committee on Behavioral and Social Aspects of Energy Consumption and Production, Assembly of Behavioral and Social Sciences. Washington, DC: The National Academies Press. Available online at: http://www.nap.edu/catalog/10458.html.

[8] Lutzenhiser, L. 1993. "Social and behavioral aspects of energy use." *Annual Review of Energy and Environment*, 18: 247-289.

[9] National Science and Technology Council, Subcommittee on Social, Behavioral and Economic Sciences. January 2009. *Social, Behavioral, and Economic Research in the Federal Context*. Available online at: http://www.ostp.gov/galleries/NSTC%20Reports/SBE%20in%20the%20Federal%20Context.pdf.

[10] Massachusetts Institute of Technology. 2007. "The Future of Coal: An Interdisciplinary MIT Study." Available online at: http://web.mit.edu/coal/

inexpensive energy sources for power generation. The use of fossil fuels depends on the level of required emissions control, especially with regard to carbon dioxide. Currently, about half of U.S. electricity comes from domestic coal supplies, which produce 69 percent of carbon dioxide emissions from the U.S. power generation sector. CCS technologies may help reduce carbon dioxide emissions from coal-fired power plants, but the long-term effects of CCS technologies and of storing carbon dioxide underground are unknown. Effective demonstration of CCS includes overcoming technological, economic, and safety challenges associated with effective transport and storage of compressed carbon dioxide. Many regulatory hurdles and risk management issues exist that must be considered prior to large-scale deployment of CCS technology. Despite these challenges, CCS may be an important component of the technology solutions required to achieve a sustainable energy future.

Economic Models and Assessments

Economic models and assessments for projecting environmental and economic effects of sustainable energy-related technologies and policies are important to arrive at a trans-disciplinary analysis of complex policy issues. Policies that benefit from the use of economic models and assessments include taxing carbon dioxide, renewable energy production tax credits, cap and trade systems, and renewable fuel standards. Some areas for improvement in economic assessments include refining the definition of underlying assumptions, simplifying model structures for faster computational times, and finding better ways to define model parameters.[11] Improved economic models and assessments could provide greater accessibility to policymakers.

Energy Efficiency

From a mechanistic perspective, increased energy efficiency means that "energy inputs are reduced for a given level of service, or there are increased or enhanced services for a given amount of energy inputs."[12] Increased energy efficiency may also refer to end-use energy conservation measures that reduce total energy consumption. Increases in energy efficiency may lead to decreased energy costs (for providers and consumers), as well as reduced levels of carbon dioxide emissions. Opportunities exist for improving the efficiency of energy generation (e.g., converting fuels into energy with less waste), transmission (e.g., transmitting electricity from power plant to load center with fewer losses), and distribution (e.g., use by U.S. infrastructure, buildings, and transportation vehicles). Consumers can reduce energy consumption and energy costs by making energy efficiency decisions such as weatherizing their homes and using Energy Star® appliances.

Energy Storage

Inexpensive, efficient, and safe methods to store electrical energy are critical elements of a sustainable energy economy. Electricity storage technologies include pumped hydropower, batteries, and compressed air, which all convert electricity to potential energy and retrieve it when demand for electricity is high. Research in thermal management will ensure a safe and reliable operating temperature for energy storage devices such as batteries. Another research challenge is to increase the number of life cycles for batteries. Emerging sustainable energy technologies that will benefit from advances in energy storage include fuel cells, hybrid electric vehicles, and plug-in electric vehicles.[13] Plug-in hybrid electric vehicle batteries provide a means of energy storage for the electric grid and

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[11] Ibid.

[12] Energy Information Agency. Energy Efficiency: Definition. Available online at: http://www.eia.doe.gov/emeu/efficiency/definition.htm.

[13] National Renewable Energy Laboratory. *Energy Storage: Research & Development*. For more information, see: http://www.nrel.gov/vehiclesandfuels/energystorage/research_development.html.

replace carbon-emitting internal combustion engines from many automobiles. Improvements in energy storage will also facilitate the incorporation of intermittent sources such as wind and solar to the electricity grid.

Information and Communication Technology (ICT)

The ICT sector is defined as "a combination of manufacturing and services industries that capture, transmit, and display data and information electronically."[14] Though ICT services are critical to our nation's productivity and economic well-being, they are large contributors to global greenhouse gas emissions.[15] The ICT sector can be made more efficient by renovating old data centers with new energy-efficient equipment, moving data centers near renewable energy sources, and putting data centers underground to utilize passive cooling potential. In addition to possible efficiency gains within the ICT sector, the use of advanced ICT services (e.g., Smart Motor Systems, Smart Logistics, Smart Buildings, and Smart Grids) has the potential to reduce energy consumption and carbon dioxide emissions in power generation and other end use sectors by as much as 15 percent by 2020.[16]

Renewable Energy Supply Technologies

The Energy Information Administration defines renewable energy as "energy sources that are naturally replenishing but flow limited."[17] Such energy sources are virtually inexhaustible, but often require advanced technologies to be efficiently captured and utilized. Renewable energy sources include solar technologies, wind, geothermal, biomass, and traditional (dams) and non-traditional (tidal, wave, and ocean thermal energy) hydropower. Renewable energy technologies produce little or no greenhouse gas emissions, but are often economically unattractive in the private sector and lack market investment incentives than traditional fossil energy technologies. Therefore, making R&D investments and establishing market conditions will help to make renewable energy cost-competitive with fossil fuels. The following summary descriptions are selected examples of renewable energy sources and technologies.

- **Biomass**
  Biomass is any plant-derived organic matter. Biomass available for sustainable energy includes herbaceous and woody energy crops, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, and other waste materials including some municipal wastes.[18] Biofuel is a liquid transportation fuel (e.g., ethanol and biodiesel) that can be produced from biomass.[19] First generation feedstocks for biofuel production include corn (for ethanol) and soybeans (for biodiesel).[20] Bioethanol and biodiesel are commercially available, and researchers are focused on improving crop yields. Second generation feedstocks include crop residues (e.g., corn stover), which are available but will

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[14] Organisation for Economic Co-Operation and Development. *Measuring the Information Economy*. 2002. Available online at: http://www.oecd.org/dataoecd/34/37/2771153.pdf.

[15] The Climate Group and the Global e-Sustainability Initiative. *Smart 2020: Enabling the low carbon economy in the Information Age*. 2008. Available online at: http://www.theclimategroup.org/assets/resources/publications/Smart2020Report.pdf.

[16] Ibid.

[17] Energy Information Administration. *Renewable Energy Consumption and Electricity Preliminary 2006 Statistics*. Available online at: http://www.eia.doe.gov/cneaf/solar.renewables/page/prelim_trends/rea_prereport.html#_ftn20. Accessed January 30, 2009.

[18] National Renewable Energy Laboratory. Glossary of Biomass Terms. Available online at: http://www.nrel.gov/biomass/glossary.html.

[19] National Renewable Energy Laboratory. *FAQs on biomass Basics*. Available online at: http://www.nrel.gov/biomass/faqs/topic.cfm/topic_id=4.

[20] Biomass Research and Development Board. "National Biofuels Action Plan." 2008.

require breakthroughs in cellulosic conversion technology or subsidies to become cost-competitive with corn ethanol and gasoline. Significant R&D gains will be required to commercialize biofuels from third generation feedstocks, which include algae and additional cellulosic feedstocks such as perennial grasses.

- **Geothermal**
  Geothermal energy utilizes heat beneath the earth's surface. Geothermal reservoirs of hot water and steam are used to spin turbine-generators to create electricity.[21] Additionally, geothermal heat pumps use the constant earth temperature just a few meters below ground to power a heat exchanger for building heating and cooling. These heat pumps provide an alternative to traditional home heating and air-conditioning systems. Accessing the very high temperature rock located hundreds of meters below the surface of the earth to use as a heat exchanger is a proposed second generation geothermal energy technology, but physical drilling limitations pose a barrier to implementation.[22]

- **Ocean Thermal Energy Conversion (OTEC)**
  OTEC technology takes advantage of the temperature difference between shallow and deep ocean water to produce electricity. The scientific principles behind OTEC have been demonstrated in prototypes, but the technology is not widely used.[23] Challenges to commercialization include substantial upfront capital investment, as well as practical implementation concerns (e.g., there are a limited number of sites where deep-ocean water is located close enough to shore to utilize OTEC technology).[24]

- **Solar**
  Renewable solar energy technologies capture energy from the sun in the form of light or heat, and use it for a variety of applications, such as electricity generation.[25] Photovoltaic (PV) cells capture energy from sunlight and convert the energy directly into electricity. First generation PV devices were made from silicon and were characterized by relatively high costs and moderate efficiency.[26] Second generation PV devices are built to reduce production costs by using thin film semiconductor materials. Although these devices have lower efficiency, they also have lower production costs. Third generation PV aims to combine lower cost with higher efficiency. "Concentrating PV technologies" use lenses or mirrors to concentrate sunlight onto high-efficiency solar cells; they are used in large-scale installations that require large amounts of energy to be harnessed from devices covering a relatively small area. In contrast to PV technologies, that convert sunlight to electricity, solar thermal technologies harness the heat energy from the sun to produce electricity. Concentrated solar thermal power technologies use mirrors in a variety of geometries in order to concentrate sunlight and transfer solar heat to be used in electricity generation.

- **Tidal power**
  Tidal power is generated by forcing water in tidal regions through turbines to generate

[21] National Renewable Energy Laboratory. *Geothermal Technologies*. For more information, see: http://www.nrel.gov/geothermal/.
[22] U.S. Department of Energy, Energy Efficiency and Renewable Energy. Available online at: http://www1.eere.energy.gov/geothermal/geothermal_basics.html.
[23] National Renewable Energy Laboratory. OTEC Homepage. Available at: www.nrel.gov/otec.
[24] U.S. Department of Energy, Energy Efficiency and Renewable Energy. Available at http://apps1.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50010.
[25] National Renewable Energy Laboratory. *Solar Research*. For more information, see: http://www.nrel.gov/solar/.
[26] Green, Martin A. Third Generation Photovoltaics: Advanced Solar Energy Conversion. Springer: Verlag. 2003.

electricity, typically through the use of a barrage or dam.[27] Tidal power generation is not widespread because of high capital costs and site difficulties, but there is potential for using this technology in the United States.

- **Traditional hydropower**
  Hydroelectric power plants convert the kinetic energy of flowing water to electricity by running the water through a turbine-generator.[28] Several types of hydropower plants exist; some simply divert running river water into a channel where the water flows through a turbine, while others use dams to store river water in a reservoir. Water stored in reservoirs can be released to flow over turbines and generate electricity when demand for electricity is high. Research and development in hydropower is required to improve energy efficiency, as well as to minimize the environmental impacts of the dams used in some hydroelectric power plants.

- **Wave power**
  There are multiple technological approaches to capturing the energy at or below the surface of ocean waves and converting it into electricity. The first commercial wave power plant (which opened in Portugal in 2008) uses the attenuation method of running a hydraulic motor by using the wave to create pressure differentials between sections.[29] Though wave power cannot be harnessed in all coastal areas, the Pacific Northwest is one region in the United States where the potential does exist. Upfront capital costs of building wave power plants are a significant barrier to making wave energy cost-competitive with other energy sources.[30]

- **Wind**
  The kinetic energy in wind can be harnessed and converted by wind turbines into mechanical power or electricity. Wind turbines can operate independently or can be connected to a utility power grid. Utility-scale wind energy generation requires a large number of wind turbines built close together to form a wind plant. Small wind systems can be used as distributed energy resources. Current research in wind technology involves working toward improved efficiency and materials for utility-scale wind turbines and smaller turbines used for distributed power generation.[31]

Smart Grid

A "Smart Grid" encompasses a system of technologies designed to make the electricity grid more efficient, reliable, and capable. Updating and improving the current antiquated electric grid involves many challenges because its critical infrastructure is deteriorating and is unable to handle increased electricity load to accommodate projected increases in U.S. energy demand. Failure to adequately address these challenges by developing an advanced Smart Grid could lead to severe economic disturbance from increasing interruption of electricity distribution and vulnerability from threats and natural disasters. Smart Grid technologies aim to reduce operating costs for both utilities and consumers by easing congestion and increasing capacity utilization through transmission corridors to accommodate the growing demand for electricity. In addition, Smart Grid technologies reduce the environmental impact of electricity production by reducing load during peak demand as well as

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[27] U.S. Department of Energy, Energy Efficiency and Renewable Energy. Available at http://apps1.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50008.
[28] U.S. Department of Energy, Energy Efficiency and Renewable Energy. Available at http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html
[29] Pelamis Wave Power. Available at: http://www.pelamiswave.com/.
[30] U.S. Department of Energy, Energy Efficiency and Renewable Energy. Available at http://apps1.eere.energy.gov/consumer/renewable_energy/ocean/index.cfm/mytopic=50009.
[31] National Renewable Energy Laboratory. *Wind Research*. For more information, see: http://www.nrel.gov/wind/

making it easier to integrate clean energy sources into the grid. Aspects of a Smart Grid include:

- Integration of digital, controls, and cyber-security technologies that allow the grid to perform more reliably and securely;
- Utilization of advanced storage technologies, including plug-in hybrid electric vehicles, to mitigate peak load and integrate intermittent energy sources, such as wind and solar; and
- Deployment of intelligent appliances in homes and offices, as well as smart meters that can communicate price signals and demand response from the power provider to consumers.

Achieving these measures will require new communication standards for appliances and grid-connected equipment, as well as the removal of barriers to adopt Smart Grid technologies and protocols.[32] Various technological components and protocols required to achieve a Smart Grid are currently under development in the public and private sectors. Technological areas requiring further development include sensing and measurement technologies, communication technologies, and energy storage.

Systems Approach to Sustainability Solutions

A "systems" approach to sustainability involves interdisciplinary work among technologists, behavioral scientists, regulatory experts, and policy analysts in addition to the development of life-cycle assessment tools, in order to understand the full environmental impact of sustainable energy solutions. Investment in systems approaches and life-cycle assessment tools will allow government and industry to consider economic, environmental and social costs of sustainable energy solutions in order to optimize their utilization. These approaches and analyses will ultimately help decision makers sift through conflicting benefits and consequences of sustainable energy technologies. For example, compact fluorescent light bulbs use less energy than incandescent light bulbs, but they also contain toxic chemicals (e.g., mercury), making disposal hazardous for humans and the environment. A systems approach would include incorporating environmental considerations into product design. Beyond evaluating specific sustainable energy technologies, using systems approaches would also benefit residential and commercial developments: investing in energy efficiency during the construction phase reduces energy costs throughout the operational life of buildings and infrastructure.

Zero-Energy Buildings

Buildings currently consume about one-third of the world's energy and account for 40 percent of primary energy use in the United States.[33] Projections indicate that buildings will be the primary consumer of energy worldwide by as early as 2025.[34] Most of the energy consumed in buildings is delivered in the form of electricity, which incurs heavy efficiency losses during generation and transmission. Support for zero-energy buildings can therefore have a substantial impact on global energy consumption and greenhouse gas emissions.

The term "net-zero energy" represents a vision for buildings that independently produce and fulfill their energy requirements, while minimizing greenhouse gas emissions. Zero-energy buildings utilize

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[32] Source: *Energy Independence and Security Act of 2007*, HR 6, 110th Congress, *Congressional Record 153* (December 19, 2007): P.L. 110-140. For more information, see: http://www.oe.energy.gov/DocumentsandMedia/EISA_Title_XIII_Smart_Grid.pdf.

[33] National Science and Technology Council. 2008. "Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings."

[34] National Science and Technology Council. 2008. "Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings.

highly efficient appliances; lighting; heating, ventilating, and air conditioning (HVAC) systems; and advanced building materials. Zero-energy buildings also incorporate options such as daylighting (i.e., strategic placement of windows in order to maximize the use of natural sunlight as lighting), and evaporative cooling and passive ventilation. In addition, they minimize energy losses by generating electricity on-site using renewable technologies such as solar photovoltaic, solar hot water, and wind energy.

Many of the technologies needed to implement zero-energy buildings are currently available. However, because of the long average lifespan of a commercial building, major renovations are often needed to implement energy saving changes. Currently, the National Science Foundation, the National Institute for Standards and Technology, the United States Department of Agriculture, and the Smithsonian Institution are all funding RD3E activities related to zero-energy buildings. One critical focus area is developing measurement science to enable the development of zero-energy buildings. In addition, there is a range of Federal deployment programs executed by the Environmental Protection Agency, the Department of Energy, and other Federal agencies. The private sector, consumers, and Federal and state governments can all implement zero-energy building technologies to increase energy efficiency and reduce greenhouse gas emissions.

II. Current State of U.S. Energy Supply and Consumption

In 2007, the United States consumed energy through four end-use sectors: residential, commercial, industrial and transportation.[35] The Energy Information Agency (EIA) records data for primary energy consumption in those four sectors, but separates energy consumed as electricity in a fifth sector. Total energy consumption, sources of energy consumption, and carbon dioxide emissions for all five sectors are described in this section.

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 is consumed by three industries (bulk chemicals, petroleum refining, and paper products).[36] 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 (Figure 1).[37] Figure 2 depicts primary consumption of energy by end-use sector and separately categorizes energy used in electricity production, transmission, and distribution. Electricity provides the greatest proportion of energy consumed in the United States , and the transportation sector accounts for the next largest share of U.S. energy consumption. Figure 3 depicts energy-related carbon dioxide emissions by end-use sector. Transportation is the largest contributor to total U.S. carbon dioxide emissions followed by the industrial, residential, and commercial sectors, respectively.

Across all sectors, petroleum is the highest 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), according to 2007 data.[38] The transportation sector has historically consumed the most petroleum,

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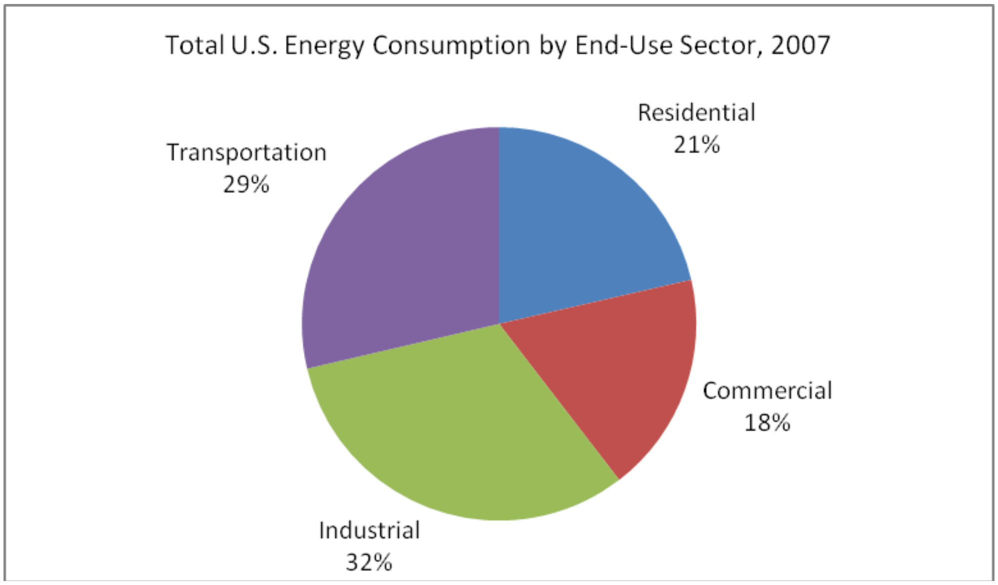
[35] Energy Information Administration. Annual Energy Review 2009. Table 2.1a Energy Consumption by Sector, 1949-2007.
[36] Energy Information Administration. Annual Energy Review 2009.
[37] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007). Released for printing: June 23, 2008.
[38] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007).

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.[39]

Released for printing: June 23, 2008.

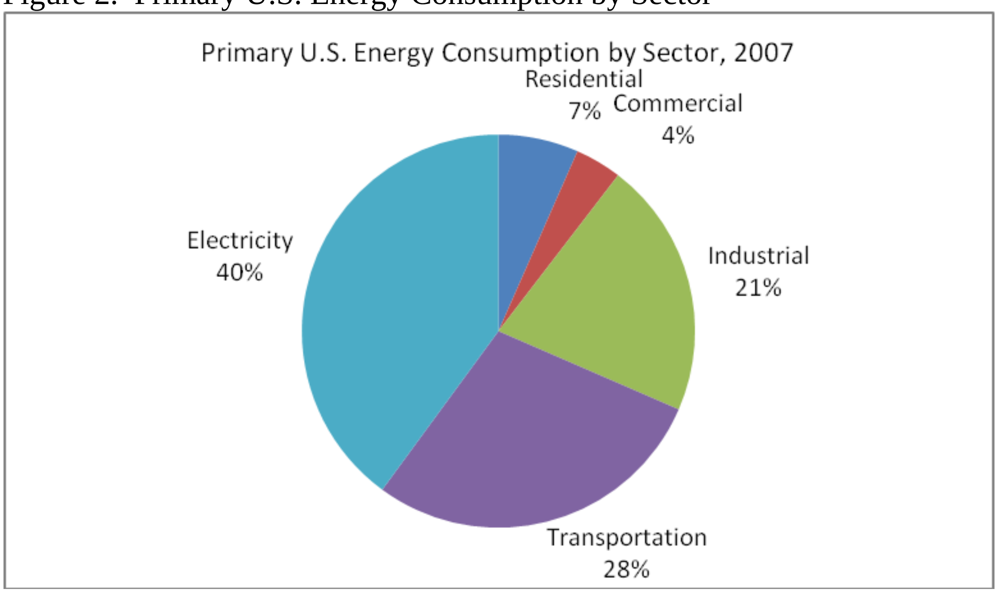
[39] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007). Released for printing: June 23, 2008.

Figure 1. Total U.S. Energy Consumption by End-Use Sector



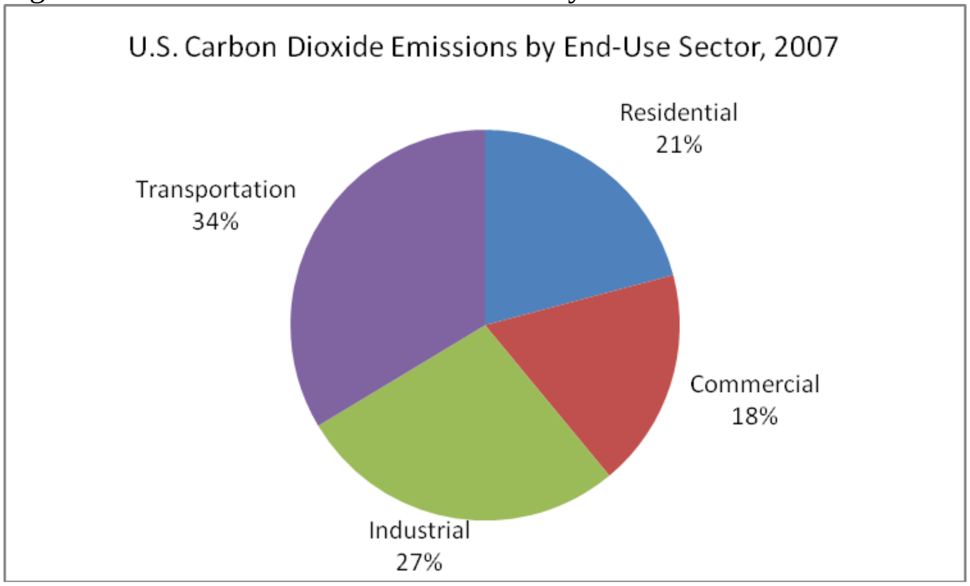
Source: EIA. Annual Energy Review 2009. Table 2.1a Energy Consumption by Sector, 1949-2007.

Figure 2. Primary U.S. Energy Consumption by Sector



Source: EIA. Annual Energy Review 2009. Table 2.1a Energy Consumption by Sector, 1949-2007.

Figure 3. U.S. Carbon Dioxide Emissions by End-Use Sector



Source: EIA. Emissions of Greenhouse Gases Report. Table 6. U.S. Energy-Related Carbon Dioxide Emissions by End-Use Sector, 1990-2007

U.S. Industrial Sector

The U.S. industrial sector includes manufacturing enterprises, such as producers of bulk chemicals, refineries, paper products, primary metals, food, glass, and cement. Collectively, these energy-intensive manufacturing industries produce about one-fifth of the dollar value of industrial shipments, while accounting for more than two-thirds of delivered energy consumption.[40] The industrial sector also includes three non-manufacturing categories - agriculture, mining, and construction. Energy is mainly consumed through industrial processes, assembly lines, and building operations. The industrial sector generates most of its own power produced through methods that utilize boilers, steam, cogeneration, and purchased electricity.[41] Most energy sources in the industrial sector come from fossil fuels (e.g., petroleum, natural gas, and coal). Fossil fuels are responsible for nearly all of carbon dioxide emissions from this sector. Biomass feedstocks, such as corn, sugarcane, and soybeans produce 6 percent of the energy in the transportation sector.[42] Biomass is mainly a domestic energy source.

Because of the high energy intensity of many industrial subsectors, inexpensive fuels are a priority for this sector. Non-intermittent renewable sources, such as biomass, geothermal, and hydro, could be introduced in greater shares if prices were competitive with fossil fuels and in cases in which those resources are located in close geographic proximity to industrial sites. Increasing consumption of non-intermittent renewable sources would directly displace fossil fuel consumption.

U.S. Transportation Sector

The U.S. transportation sector includes all modes of transportation (i.e., automotive vehicles, rail, marine vessels, aircraft, and mass transit). Transportation is an important component in military and

[40] Energy Information Administration. Annual Energy Review 2009.
[41] Energy Information Administration. Industrial Sector Demand Module. Available at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m064(2001).pdf.
[42] Energy Information Administration. Annual Energy Review 2009.

freight operations, as well as personal and commercial travel.[43] Petroleum is the primary source of energy and carbon dioxide emissions in the transportation sector—it supplies 96 percent of energy consumed and accounts for 98 percent of carbon dioxide emissions produced by the sector. The remaining 4 percent of energy consumed in the transportation sector is supplied by natural gas and biomass.

Current transportation vehicles and associated infrastructure in the United States are designed for a petroleum-based transportation sector. The United States imported 65 percent of the crude oil and petroleum products it used in 2007, mainly from Canada (18 percent of imports), Saudi Arabia (11 percent), Mexico (11 percent), Venezuela (10 percent), and Nigeria (8 percent).[44] The United States could significantly reduce its dependence on imported oil by increasing its use of domestically produced electricity to fuel the transportation sector. Shifting to electricity as the main transportation fuel would affect carbon dioxide emissions, but more research is needed to determine its specific effects. Biofuels, specifically corn and cellulosic ethanol, are expected to achieve increased market penetration as the Federal Renewable Fuel Standard[45] is implemented. Corporate Average Fuel Economy[46] standards will reduce the carbon intensity of the transportation sector by increasing the efficiency of cars and light-duty trucks.

U.S. Residential Sector

The U.S. residential sector includes single- and multi-family homes and mobile homes. Energy is consumed in this sector for heating, cooling, refrigeration, lighting, and powering electric appliances.[47] Fossil fuels supply the majority of energy in the residential sector, with domestic coal sources converted into electricity accounting for 36 percent.[48] For every unit of energy delivered to the residential sector in the form of electricity, over two units of energy are lost as waste heat in electric power generation and transmission.[49] Natural gas provides over 20 percent of the primary energy used in this sector, while less than five percent of residential primary energy comes from sustainable sources, (largely biomass, followed by solar and geothermal). Carbon dioxide emissions from the residential sector correlate closely with its energy consumption percentages: 72 percent of residential carbon dioxide emissions result from electrical power generation, transmission, and end-use. Natural gas and petroleum used in home heating and cooking contribute 21 percent and 7 percent, respectively, to residential carbon dioxide emissions.

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[43] Energy Information Administration. Transportation Sector Demand Module. Available at: http://www.eia.doe.gov/bookshelf/models2002/tran.html.

[44] Energy Information Administration and STPI calculation. "Petroleum Navigator." Available at: http://tonto.eia.doe.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm and http://tonto.eia.doe.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_a.htm.

[45] As legislated by the Energy Independence and Security Act of 2007, the EPA will increase the volume of renewable fuels in the nation's motor fuel supply from 9 billion gallons in 2008 to 36 billion gallons in 2022. More information available at: http://www.epa.gov/OMS/renewablefuels/.

[46] Corporate Average Fuel Economy Standards: These standards, first implemented in 1975 and updated in 2007 with the Energy Independence and Security Act, will eventually raise the average fuel economy of vehicle fleets to 35 mpg (miles per gallon) by 2020. More information available at: http://www.unece.org/trans/doc/2008/wp29/WP29-145-13e.pdf.

[47] Energy Information Administration. Residential Sector Demand Module. Available at: http://www.eia.doe.gov/bookshelf/models2002/rsdm.html.

[48] Energy Information Administration. Annual Energy Review 2009.

[49] Power generation involves the combustion of fossil fuels to generate heat, which is then used to boil water and create steam. The steam powers a turbine connected to a generator, which produces electricity. At each stage of this process, some heat is lost to the environment, therefore reducing the efficiency of the operation. Similarly, heat losses occur as a result of resistance in power transmission lines. If these electrical system losses are included, about 70 percent of total energy consumption for the residential sector is attributable to electricity generation, transmission, and end-use.

The residential sector can increase its on-site consumption of renewable energy by using solar heating, solar photovoltaic, and geothermal ground source heat pumps. Solar photovoltaic roof panels produce electricity that can be utilized on-site and, in some cases, sold back to the electricity grid if production exceeds demand. Ground source heat pumps are heat exchangers that pump a working fluid through pipes a few meters underground, and then deliver that fluid at a relatively constant temperature to homes and offices for air conditioning and heating, displacing some of the need for electricity and to a lesser extent, the need for natural gas.

U.S. Commercial Sector

The U.S. commercial sector consists of retail and service buildings (e.g., for food, healthcare, lodging, and business services), warehouses, assembly buildings, and educational facilities. Energy is consumed by these buildings and facilities for heating, cooling, ventilation, lighting, and powering office equipment.[50] The commercial sector consumes nearly 80 percent of its energy in the form of electricity and associated electrical system losses. Natural gas provides about 17 percent of energy to this sector.[51] Biomass, hydropower, and geothermal sources provide a small amount of sustainable energy for the commercial sector. Most carbon dioxide emissions in the commercial sector are due to using fossil fuel sources to generate electricity and its extensive associated losses. In 2007, the commercial sector accounted for 18 percent of total U.S. carbon dioxide emissions. Approximately 21 percent of carbon dioxide emissions in the commercial sector are attributable to electric power generation, transmission, and end-use consumption.

The commercial sector is similar to the residential sector in that consumption of renewable energy can be increased by using on-site technologies such as roof-based solar water heating, solar photovoltaic panels on roofs, and geothermal ground source heat pumps.

U.S. Electric Power Sector

The U.S. electric power sector is made up of electric utilities and independent power producers.[52] The electric power sector generates and delivers electricity and useful heat (in the case of combined heat and power plants) to all other economic sectors. Three energy sources account for almost 90 percent of energy consumption in the U.S. electric power sector: coal accounts for 51 percent of energy consumed in the electric power sector, nuclear power accounts for 21 percent (of which 91 percent of uranium used comes from foreign sources[53]), and natural gas accounts for 17 percent.[54] Coal accounts for 81 percent of carbon dioxide emissions in the electric power sector, and natural gas accounts for 16 percent of carbon dioxide emissions.

Electric power contributes to every end-use sector of the economy. Higher capacity and improved

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[50] Energy Information Administration. Commercial Sector Demand Module. Available at: http://www.eia.doe.gov/bookshelf/models2002/csdm.html.

[51] Energy Information Administration. Natural Gas Consumption by End Use. Available at: http://tonto.eia.doe.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm.

[52] Energy Information Administration. Total Electric Power Summary Statistics. Available at: http://www.eia.doe.gov/cneaf/electricity/epm/tablees1a.html.

[53] Energy Information Administration. Uranium Purchased by Owners and Operators of U.S. Civilian Nuclear Power Reactors. Available at: http://www.eia.doe.gov/cneaf/nuclear/umar/summarytable1.html.

[54] U.S. Department of Energy, Energy Information Agency. *Annual Energy Review 2007*. DOE/EIA-0384(2007). Released for printing: June 23, 2008.

transmission lines, electricity storage capacity, and Smart Grid[55] implementation could help to integrate more sustainable energy into the electric power sector. Undertaking action only to increase sustainable energy in the electricity sector may not reduce total carbon emissions or dependence on foreign energy suppliers, due to expected increases in demand and the high proportion of domestically produced energy sources already powering this sector.

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[55] "Smart Grid" encompasses a system of technologies designed to make the electricity grid more efficient, reliable, and capable. Smart Grid technologies reduce utilities' operating costs by easing congestion and increasing capacity utilization through transmission corridors to accommodate the growing demand for electricity. In addition, Smart Grid technologies reduce the environmental impact of electricity production by reducing load during peak demand as well as making it easier to integrate clean sources of energy into the grid. Aspects of a Smart Grid include:

- Integration of digital, controls, and cyber-security technologies that allow the grid to perform more reliably and securely;
- Utilization of advanced storage technologies, including plug-in hybrid electric vehicles, to mitigate peak load and integrate intermittent energy sources, such as wind and solar; and
- Deployment of intelligent appliances in homes and offices, as well as smart meters that can communicate signals from the power provider to consumers and appliances about price signals and demand response.

Achieving these goals will require new communication standards for appliances and grid-connected equipment and removal of barriers to adopting Smart Grid technologies and protocols.
For more information, see: http://www.oe.energy.gov/DocumentsandMedia/EISA_Title_XIII_Smart_Grid.pdf.

III. U.S. Legislative Timeline: Key Policy Actions Related to Sustainable Energy[56]

Year	U.S. Policy Actions Related to Sustainable Energy
1946	President Truman signs the Atomic Energy Act (McMahon Act), transferring control of atomic energy activities from the military to the Atomic Energy Commission (AEC), a civilian agency. The transfer took effect in 1947.
1950	President Truman signs the National Science Foundation (NSF) Act of 1950, authorizing the creation of the new Federal agency and the National Science Board (NSB).
1951	The Experimental Breeder Reactor - 1 (near Arco, Idaho) produces the first electric power from a nuclear reactor.
1954	President Eisenhower signs the Atomic Energy Act of 1954, providing a foundation for the development of a civilian nuclear power program.
1956	The AEC authorizes the construction of world's first two privately owned nuclear power plants.
1957	The Shippingport Atomic Power Station (located in Beaver County, Pennsylvania), the world's first full-scale nuclear power plant, becomes operational.
1958	GE produces the first commercially successful fuel cell, and it is used by NASA in the Gemini program.
1960	First large-scale geothermal power plant in United States begins operation at The Geysers (located in the Mayacamas Mountains, north of San Francisco, California).
1968	President Johnson signs the Wild and Scenic Rivers Act, which restricts dam building and hydropower along designated segments of some U.S. rivers.
1969	President Johnson signs the National Environmental Policy Act, requiring Federal agencies to integrate environmental values into their decision-making processes
1970	President Nixon signs the Clean Air Act, defining EPA's responsibilities for protecting and improving the nation's air quality and the stratospheric ozone layer.
1970	President Nixon signs the Geothermal Steam Act, which governs lease of geothermal steam resources on public lands.
1972	The Atomic Energy Commission announces a cooperative agreement with industry to build a Liquid Metal Fast Breeder Reactor on the Clinch River in Tennessee. (The Clinch River Breeder Reactor project is later discontinued in 1983.)
1973	The Yom Kippur War spurs the Organization of Petroleum Exporting Countries (OPEC) to raise oil prices by 70 percent and impose an embargo on the United States. The embargo was lifted later that year.

[56] Information in this table is drawn from various sources including historical timelines generated by the National Science Foundation (NSF) and the Department of Energy (DOE), available online at: http://www.nsf.gov/about/history/overview-50.jsp and http://www.energy.gov/about/timeline.htm.

1973	President Nixon establishes the Energy Policy Office (renamed the Federal Energy Office in 1973). The office is assigned the tasks of allocating reduced petroleum supplies to refiners and consumers and of controlling the price of oil and gasoline.
1974	President Nixon signs the Federal Administration Act of 1974, creating the Federal Energy Administration to replace the Federal Energy Office.
1974	President Ford signs the Energy Reorganization Act, which splits the AEC into the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA). The NRC is charged with regulating the nuclear power industry, and the ERDA is given responsibility for management of nuclear weapons and energy development programs.
1974	President Ford initiates the Energy Resources Council, which is charged with insuring "communication and coordination among the agencies of the Federal Government which have responsibilities for the development and implementation of energy policy or for the management of energy resources."
1974	President Ford signs the Solar Energy Research, Development, and Demonstration Act, which establishes the Solar Energy Research Institute in Golden, Colorado.
1974	The Hydrogen Economy Miami Energy (THEME) Conference, the first international conference on hydrogen-based energy, is held in Miami Beach, Florida.
1975	President Ford signs the Energy Policy and Conservation Act, which establishes Corporate Average Fuel Economy (CAFE) standards.
1975	The United States Geological Survey (USGS) releases the first national estimate and inventory of geothermal resources.
1976	Congress enacts the Electric and Hybrid Vehicle Research, Development, and Demonstration Act, despite veto by President Ford. The Act enables ERDA to address research and development (R&D) issues in energy storage, vehicle control systems, vehicle design, etc.
1977	President Carter signs the Department of Energy (DOE) Organization Act, replacing ERDA with the DOE. This Act also establishes the Federal Energy Regulatory Commission (FERC).
1977	President Carter issues Executive Order 12003, which orders energy audits and new standards for energy conservation in Federal facilities and fleets.
1977	President Carter signs the Food and Agricultural Act, which authorizes the United States Department of Agriculture (USDA) to guarantee loans for biomass-fired power plants and provides funding for renewable energy.
1977	President Carter installs solar panels on the White House. The panels are later removed by President Reagan.
1977	Congress abolishes the Joint Committee on Atomic Energy, which was established to oversee activities of the AEC.
1977	The first hot dry rock reservoir is developed in Fenton Hill, New Mexico to mine geothermal energy.
1977	The Solar Energy Research Institute in Golden, Colorado becomes operational.

1978	President Carter signs the National Energy Act, which includes the National Energy Conservation Policy Act, the Power Plant and Industrial Fuel Use Act, the Public Utilities Regulatory Policy Act, the Energy Tax Act, and the Natural Gas Policy Act.
1978	President Carter issues Executive Order 12038 to supplement the DOE Organization Act by transferring functions to the newly created position of Secretary of Energy.
1978	President Carter signs the United States Public Utility Regulatory Policies Act (PURPA), which creates a market for independent power producers.
1978	President Carter signs the Energy Tax Act, which creates Federal ethanol tax incentives.
1979	NASA completes the world’s first village photovoltaic (PV) system in Schuchuli, Arizona.
1979	President Carter signs the Interior and Related Agencies Appropriation Act, which provides funding for alternative fuels and alternative fuel power plants.
1980	A solar cell power plant demonstration is dedicated at Natural Bridges National Monument in Utah. The project is a result of a Massachusetts Institute of Technology (MIT), DOE, and National Park Service (NPS) collaboration.
1980	President Carter signs the Supplemental Appropriation and Rescission Act, which provides funding for ethanol feasibility studies.
1980	President Carter signs the Crude Oil Windfall Tax Act, which intends to recover revenues earned by oil producers after the sharp rise in oil prices resulting from the OPEC oil embargo.
1980	President Carter signs the Energy Security Act, including the U.S. Synthetic Fuels Corporation Act, Biomass Energy and Alcohol Fuels Act, Renewable Energy Resources Act, Solar Energy and Energy Conservation Act and Solar Energy and Energy Conservation Bank Act, Geothermal Energy Act, and Ocean Thermal Energy Conversion Act.
1981	President Reagan signs Executive Order 12287, which provides for the decontrol of crude oil and refined petroleum products.
1981	President Reagan signs the Nuclear Waste Policy Act of 1982, the Nation’s first comprehensive nuclear waste legislation. The act provides for the development of repositories for disposing high-level radioactive waste and spent nuclear fuel, and establishes a program of research, development, and demonstration with respect to waste disposal.
1983	President Reagan signs the Surface Transportation Assistance Act, which raises the gasoline excise tax to 9 cents per gallon and increases the tax exemption for gasohol to 5 cents per gallon.
1983	DOE establishes an Office of Civilian Radioactive Waste Management, which is charged with safely managing and disposing of the Nation’s spent nuclear fuel and high-level radioactive waste.
1984	The Federal Advisory Act establishes the National Coal Council (NCC) as a private, nonprofit advisory body chartered by the U.S. Secretary of Energy. The NCC’s mission is to advise both government and industry on ways to improve cooperation in areas of coal

	research, production, transportation, marketing, and use.
1984	President Reagan signs the Tax Reform Act as part of the Deficit Reduction Act of 1984; the Act raises the level of the gasohol tax exemption.
1987	The United Nations (UN) World Commission on Environment and Development publishes the Brundtland Report (Our Common Future), defining the concept of sustainable development.
1987	President Reagan signs the National Appliance Energy Conservation Act of 1987, which establishes Federal minimum efficiency standards for many household appliances.
1987	Congress amends the Nuclear Waste Policy Act, designating Yucca Mountain, Nevada, as the only site to be considered as a high-level nuclear waste repository.
1990	President George H.W. Bush signs into law the Omnibus Budget Reconciliation Act, which decreases the gasohol tax exemption.
1990	President George H.W. Bush signs into law the Clean Air Act Amendments, which contain regulatory provisions to address acid rain, urban air emissions, and toxic air pollutants.
1990	President George H.W. Bush signs into law the U.S. Global Change Research Act, creating a U.S. Global Change Research Program that is "aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions toward international protocols in global change research, and for other purposes."
1991	President George H.W. Bush issues Executive Order 12759, which mandates energy conservation at Federal Facilities with.
1991	The Solar Energy Research Institute is renamed the National Renewable Energy Laboratory.
1992	The UN Conference on Environment and Development (also known as The Earth Summit) is held in Rio de Janeiro, Brazil. The conference results in the establishment of The United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty.
1992	President George H.W. Bush signs the Energy Policy Act of 1992, which addresses a variety of issues including energy efficiency, alternative fuels, and storage of radioactive waste material.
1993	President Clinton releases a Climate Change Action Plan, which states the U.S. will stabilize greenhouse gas emissions at 1990 levels by the year 2000.
1993	President Clinton issues Executive Order 12844, which authorizes Federal acquisition and use of alternative fueled vehicles.
1993	President Clinton issues Executive Order 12845, which requires agencies to purchase energy-efficient computer equipment.
1994	President Clinton issues Executive Order 12902, which requires all Federal agencies to develop and implement 30 percent energy use reduction plans and to increase use of solar and alternative sources.
1994	A favorable Internal Revenue Service ruling extends the excise tax exemption and income

	tax credits to ethanol blenders producing the fuel oxygenate ethyl tert-butyl ether (ETBE).
1994	EPA enacts a Renewable Oxygen Standard (ROS) that requires that 30 percent of the oxygenates contained in fuels be produced from renewable sources. A year later, a U.S. court rules that the EPA's ROS was an unconstitutional constraint on commerce
1996	DOE announces the creation of the National Center for Photovoltaics, combining research efforts at the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories.
1998	DOE announces the award of a contract that will result in the world's first high temperature superconductor power cable to deliver electricity in a utility network owned by Detroit Edison.
1998	DOE and the Occidental Petroleum Corporation sign final papers for the sale of the U.S. interest in the Elk Hills Naval Petroleum Reserve.
1999	DOE and the U.S. Department of Interior (DOI) launch the Green Energy Parks Program, designed to increase the use of sustainable energy technology in the nation's parks.
1999	President Clinton issues Executive Order 13123, which sets new goals for Federal energy management.
1999	President Clinton issues Executive Order 13134, which establishes an Interagency Council on Biobased Products and Bioenergy.
1999	The United States withdraws from the International Thermonuclear Experimental Reactor after Congress eliminates funding for participation in the project.
2000	President Clinton signs the Biomass Research and Development Act, which establishes a Biomass R&D Board to coordinate Federal activities related to biobased fuels and biobased products. The Board is co-chaired by DOE and USDA.
2000	President Clinton introduces the Climate Change Technology Initiative to develop renewable energy resources and efficient technologies.
2000	DOE and the American Institute Of Architects announce a national design competition for the largest solar energy system on a U.S. Government building.
2000	The global theme for Earth Day 2000 is "Clean Energy Now." Power for the event on the National Mall in Washington, DC is provided entirely by renewable energy sources.
2001	The United States and the European Union (EU) sign agreements to conduct joint research in the areas of fusion energy and non-nuclear energy.
2001	President George W. Bush announces the Climate Change Research Initiative (CRRI) and the National Climate Change Technology Initiative.
2001	The United States withdraws from the Kyoto Protocol.
2001	The United States and France sign an agreement to jointly fund research in advanced reactors and fuel cycle development.
2001	Governments of leading nuclear nations sign formal charter that established the Generation IV International Forum dedicated to the development by 2030 of the next generation of nuclear reactor and fuel cycle technologies.
2002	DOE, in partnership with the automobile industry, announces the FreedomCar Initiative to

	develop hydrogen cars.
2002	President George W. Bush signs an economic stimulus bill that includes tax credits for power generators using renewable sources and consumer purchasing of electric vehicles.
2002	The Generation IV International Forum agrees on six nuclear energy systems to be pursued for joint development.
2003	President George W. Bush announces the Climate VISION program to reduce greenhouse gas emissions.
2003	President George W. Bush announces FutureGen, a $1 billion initiative to build a near-zero atmospheric emissions coal fired power plant using carbon capture and sequestration and other advanced technologies. The FutureGen mission is restructured in 2008.
2005	The Asia-Pacific Energy Initiative is announced as a response to the Kyoto Protocol.
2005	President George W. Bush signs the Energy Policy Act of 2005, which includes tax incentives for energy production and procurement guidelines for energy-efficient products by Federal agencies.
2006	President George W. Bush announces the Advanced Energy Initiative, which includes research in alternative energy, nuclear energy, hybrid and electric cars.
2006	Secretary of Energy Bodman announces the Global Nuclear Energy Partnership, designed to promote safe use of nuclear power worldwide and to close the nuclear fuel cycle.
2007	President George W. Bush issues Executive Order 13423, which orders the reduction of Federal energy facility use by 3 percent per year through 2015.
2007	The G8+5 countries agree on the Washington Declaration, the outline of a successor to the Kyoto Protocol.
2007	President George W. Bush signs the Energy Independence and Security Act of 2007, which orders reductions in Federal energy use.
2008	DOE restructures the FutureGen mission due to escalating costs, and changes its approach to fund multiple commercial clean coal projects.
2008	President George W. Bush and Prime Minister Singh grant final approval to a U.S.-India civilian nuclear deal. The agreement creates a strategic partnership between the United States and India with respect to nuclear cooperation and prohibits India from reprocessing nuclear fuel.
2008	President George W. Bush signs the Emergency Economic Stabilization Act, which contains tax incentives for energy efficient homes and commercial buildings, as well as an extension of wind and solar investment and production tax credits.
2008	Secretary of Energy Bodman and Secretary of Agriculture Schafer release the National Biofuels Action Plan developed by the Biomass Research and Development Board.
2009	President Obama signs the American Recovery and Reinvestment Act, which includes billions of dollars for energy efficiency and renewable energy programs and research throughout the Federal government.

Appendix B: Charge to the Task Force on Sustainable Energy

NSB-07-121
October 3, 2007

Statutory Basis
"The Board shall render to the President and to the Congress reports on specific, individual policy matters related to science and engineering and education in science engineering, as the Board, the President, or the Congress determines the need for such reports." *(42 U.S.C. Section 1863) SEC. 4. (j) (2)*

Action Recommended
The National Science Board (Board) will examine the role of the U.S. Government in addressing the science and engineering (S&E) challenges related to development of sustainable energy, and provide recommendations to the President and Congress regarding a nationally coordinated S&E research and education initiative on sustainable energy with specific guidance on the role of the National Science Foundation (NSF) in such an initiative.

Background
The interest of the National Science Board in sustainable energy was encouraged by President George W. Bush's national call to action on energy with the announcement of the Advanced Energy Initiative in his January 31, 2006 State of the Union Address. The rapidly expanding literature warns of a number of threats from our Nation's and the World's reliance on fossil energy sources. These include:

- the economic and societal impacts of a rapidly growing global demand for energy and the increasing costs, both economic and environmental, of fossil fuel as the more easily accessible sources are depleted,
- the threat to national security and balance of trade as the U.S. and other countries, especially emerging economies, become increasingly dependent on a relatively few, often politically unstable, oil exporting nations, and
- the often cited threat of anthropogenic carbon loading in the atmosphere and its effects on the global climate and on human life.

These threats have given rise to a global call to move rapidly to a sustainable energy economy. However, most projections of trends for the next quarter to half century suggest little change in the future global energy mix without more concerted action. It is of concern that the scale and speed of the adoption of sustainable and clean energy technologies will be far short of that necessary to address the threats that will only become more acute with the passage of time. Of particular concern is the heavy dependence on fossil fuels for the transport sector and the carbon footprint that current and projected energy use represents.

Given the Board's responsibility to advise the President and Congress on national policy matters relating to science and engineering, the Board arranged for three expert presentations on the scientific challenges related to the development of sustainable energy:

- *Energy from Biomass*, Chris Somerville, Professor of Biological Sciences, Stanford University, September, 2006;
- *Scientific Challenges in the Development of Sustainable Energy*, Nathan S. Lewis, Professor of Chemistry at Caltech, November, 2006; and
- *Transformational Science for Energy and the Environment*, Raymond L. Orbach, Under Secretary for Science, U.S. Department of Energy, March, 2007.

The Board is also mindful of President Bush's challenge to the nation in his 2007 State of the Union Address: *"America is on the verge of technological breakthroughs that will enable us to live our lives less dependent on* *oil. And, these technologies will help us be better stewards of the environment, and they will help us to confront the serious challenge of global climate change."*

These presentations and the President's challenge energized the Board regarding the immediacy of the need to develop sustainable energy sources that would lessen the dependence on increasingly difficult to access fossil fuels and decrease the rate of atmospheric carbon loading Given the vital strategic importance of energy use in carrying out the missions of most government agencies, the Board believes it to be an imperative for the long-term prosperity of this Nation for the government to develop a long-term, coordinated, inter-agency strategy to achieve a stable sustainable U.S. energy future. Such an approach will require that the attributes of a sustainable energy economy be defined and that all technology options be weighed and evaluated against their ability to meet these attributes. Further, this would need to be done in a global context. The Board is uniquely suited to make recommendations regarding the S&E research and education challenges in developing such a nationally coordinated strategy, with specific guidance to NSF on its role in this effort. The Board's Committee on Programs and Plans (CPP) should establish a formal Task Force on Sustainable Energy to lead this Board effort.

Policy Objectives

The following issues will be analyzed and discussed by the Task Force before constructive policy recommendations and a proposed strategy is recommended to CPP and the full Board consistent with the Board's statutory charge.

- Examine existing S&E sustainable energy research and educations policies and efforts at the NSF, the Federal Government and U.S. corporations, and around the world in scope, scale, time frame, and in the context of national and global challenges.
- Develop recommendations for the Board to consider with respect to a nationally coordinated S&E research and education initiative on sustainable energy.
- Provide explicit guidance on NSF's role with respect to basic research and education in the overall national effort.

Based upon the work of this Task Force, the Board will then provide policy guidance to NSF, and broader recommendations to the Administration and Congress relative to a long-term coordinated inter-agency strategy for the development of sustainable U.S. energy production in light of President Bush's challenge to be better stewards of the environment.

Logistics

Once the Task Force has completed its initial analysis of existing policies and efforts, the Task Force will bring together representatives of NSF, academe, private sector industry and investors, NGOs, and other pertinent U.S. Federal agencies involved in energy, as well as members of the broader scientific community, through a series of workshops to examine, discuss and address the issues identified above. The Task Force will have the ability to convene such working groups as it deems necessary to obtain additional relevant information as well as to frame recommended strategies. It is anticipated that the Task Force will produce a final report that summarizes its findings and presents recommendations regarding the role of the U.S. Government in addressing S&E challenges related to development of sustainable energy, with specific recommendations for the NSF role in a national S&E research and education initiative on sustainable energy. Printed copies of a final Board report will be widely distributed and available on the Board Web site for the general public, universities, Congress, various special interest groups, and the broad scientific community. In addition, a regular and pro-active outreach effort to communicate task force activities will be implemented throughout the duration of the Task Force life. The Task Force expects to present a draft report to the Board in 12 months, and conclude its activities within 18 months, from the date that formation of the Task Force is approved. The Board Office will serve as the focal point for coordination and implementation of all Task Force activities.

Appendix C: Roundtable 1—Agenda and Participant List

NATIONAL SCIENCE BOARD
TASK FORCE ON SUSTAINABLE ENERGY

Roundtable Discussion #1
Science, Engineering, and Education Challenges
Related to the Development of Sustainable Energy

National Science Foundation
4201 Wilson Blvd., Room 1235
Arlington, VA 22230
February 8, 2008

AGENDA

8:00 a.m. **Welcoming Remarks**
- Dr. Steven Beering, Chairman, National Science Board

8:05 a.m. **Overview, Purpose, and Goals of the Roundtable Discussion**
- Dr. Dan Arvizu and Dr. Jon Strauss, Co-Chairmen, Task Force on Sustainable Energy, National Science Board

8:15 a.m. **Process and Logistics for Board Roundtable Discussions**
- Dr. Craig Robinson, Acting Executive Officer, National Science Board

8:20 a.m. **Introduction of Participants**

8:30 a.m. **Presentation: *Facing the Hard Truths About Energy: A Comprehensive View To 2030 of Global Oil and Natural Gas***
Speaker: Mr. Rod Nelson, Vice President, Schlumberger

8:50 a.m. **Discussion Session 1: Sustainable Energy Research and Development**
Discussion Co-Moderators: Dr. Arvizu and Dr. Strauss

10:15 a.m. **Break**

10:30 a.m. **Presentation: *IPCC IV Assessment Report: Synthesis Report on Climate Change 2007***
Speaker: Dr. Robert Corell, Program Director, Heinz Center

10:50 a.m. **Presentation: *NSF and Energy Research and Education***
Speaker: Dr. Richard Buckius, Assistant Director, Directorate for Engineering, National Science Foundation

11:10 a.m. **Working Lunch**
Discussion Session 2: NSF's Role in a National Sustainable Energy Initiative
Discussion Co-Moderators: Dr. Arvizu and Dr. Strauss

12:45 p.m. **Break**

1:00 p.m. **Presentation: *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?***
Speaker: Mr. Kenneth Ostrowski, Director of the Americas Electric Power and Natural Gas Practice, McKinsey & Company

1:30 p.m. **Discussion Session 3: Recommendations for a National Research and Education Initiative in Sustainable Energy**
Discussion Co-Moderators: Dr. Arvizu and Dr. Strauss

2:45 p.m. **Summary and Next Steps for the Task Force**

- Dr. Arvizu and Dr. Strauss

List of Participants: Roundtable Discussion #1

Name	**Affiliation**
National Science Board Participants	
Dr. Dan E. Arvizu	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Jon C. Strauss	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Mark R. Abbott	Task Force on Sustainable Energy Member, National Science Board
Dr. Steven C. Beering	Chairman, National Science Board
Dr. Camilla P. Benbow	Task Force on Sustainable Energy Member, National Science Board
Dr. John T. Bruer	Task Force on Sustainable Energy Member, National Science Board
Dr. Patricia D. Galloway	Task Force on Sustainable Energy Member, National Science Board
Dr. José-Marie Griffiths	Task Force on Sustainable Energy Member, National Science Board
Dr. Daniel E. Hastings	Task Force on Sustainable Energy Member, National Science Board
Dr. Douglas D. Randall	Task Force on Sustainable Energy Member, National Science Board
Mr. Arthur K. Reilly	Task Force on Sustainable Energy Member, National Science Board
Dr. Arden Bement, Jr., *ex officio*	Director, National Science Foundation
Participants	
Dr. Ghassem Asrar	Deputy Administrator, U.S. Department of Agriculture
Dr. Sam Baldwin	Chief Technology Officer and Member, Board of Directors; Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy
Dr. Jan Brecht-Clark	Associate Administrator, RD&T Research and Innovative Technology Administration, United States Department of Transportation
Dr. Richard Buckius	Assistant Director, Directorate for Engineering, National Science Foundation
Dr. Robert (Bob) Corell	Program Director, Heinz Center
Dr. Jon Creyts	Principal, McKinsey & Company
Dr. Patricia Dehmer	Deputy Director of Science Programs, Office of Science, U.S. Department of Energy

Mr. Chris DiPetto	Developmental Test and Evaluation Deputy Director, Defense Systems and Software Engineering, Deputy Under Secretary for Acquisition and Technology, United States Department of Defense
Dr. James (Jim) Dooley	Senior Staff Scientist, Joint Global Change Research Institute
Dr. Luis Echegoyen	Division Director, Division of Chemistry, National Science Foundation
Dr. Carolyn Fischer	Fellow, Resources for the Future
Dr. Alan Hecht	Director for Sustainable Development, Office of Research and Development, U.S. Environmental Protection Agency
Mr. Joe Loper	Vice President of Policy and Research, Alliance to Save Energy
Mr. Richard Mertens	Deputy Associate Director for Energy, Science, and Water, White House/Office of Management and Budget
Dr. Nebojsa Nakicenovic	Professor of Energy Economics, Vienna University of Technology
Mr. Rod Nelson	Vice President, Schlumberger
Dr. Robert O'Connor	Program Director, Decision, Risk and Management Sciences, Division of Social and Economic Sciences, National Science Foundation
Mr. Ken Ostrowski	Director of the Americas Electric Power and Natural Gas Practice, McKinsey & Company
Ambassador Richard Russell	Associate Director and Deputy Director for Technology, Office of Science and Technology Policy, Executive Office of the President
Mr. Jim Presswood	Energy Advocate, Natural Resources Defense Council
Dr. Harvey Sachs	Director, Buildings Programs, American Council for an Energy Efficient Economy
Mr. Jonathan Spector	Chief Executive Officer, The Conference Board, Inc.
In Attendance & Supporting a Confirmed Participant	
Dr. Linda Blevins	Technical Advisor, Office of Basic Energy Sciences, U.S. Department of Energy
Mr. Brad Hancock	Associate Director for Energy and Utilities, U.S. Department of Defense
Dr. Kevin Hurst	Senior Policy Analyst, Technology Division, Office of Science and Technology Policy, Executive Office of the President
Dr. Tom Zimmerman	Fellow, Schlumberger

Appendix D: Roundtable 2—Agenda and Participant List

NATIONAL SCIENCE BOARD
TASK FORCE ON SUSTAINABLE ENERGY
Roundtable Discussion #2
Science, Engineering, and Education Challenges
Related to the Development of Sustainable Energy

National Renewable Energy Laboratory Visitors Center
15013 Denver West Parkway
Golden, CO 80401
June 19, 2008

AGENDA

8:00 a.m. **Welcoming Remarks**
- Dr. Steven Beering, Chairman, National Science Board

8:05 a.m. **Summary of the First Task Force Roundtable Discussion on February 8, 2008; Overview, Purpose, and Goals of Today's Roundtable Discussion**
- Dr. Dan Arvizu and Dr. Jon Strauss, Co-Chairmen, Task Force on Sustainable Energy, National Science Board

8:20 a.m. **Process and Logistics for Board Roundtable Discussions**
- Dr. Craig Robinson, Acting Executive Officer, National Science Board

8:25 a.m. **Introduction of Participants**

8:35 a.m. **Presentation: *Sustainable Energy Supplies to Power Higher Education: Challenges and Opportunities***
Speaker: Mr. Dave Newport, Director, Environmental Center, University of Colorado-Boulder

9:00 a.m. **Discussion Session 1: Linking Regional and Higher Education Activities to a National Research and Education Initiative in Sustainable Energy**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

10:00 a.m. **Break**

10:15 a.m. **Presentation: *Renewable Energy Technologies***
Speaker: Dr. Douglas Arent, Director, Strategic Energy Analysis and Applications Center, National Renewable Energy Laboratory

10:45 a.m. **Discussion Session 2: New Generation Sustainable Energy Technologies**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

12:15 p.m. **Lunch**
Luncheon Presentation: *The U.S. Department of Energy Solar Decathlon*
Speaker: Mr. Mike Wassmer, Senior Engineer, National Center for Photovoltaics, National Renewable Energy Laboratory

1:30 p.m. **Break**

1:45 p.m. **Presentation: *Nuclear Science and Technology***
Speaker: Dr. David Hill, Deputy Director, Idaho National Laboratory

2:00 p.m. **Discussion Session 3: Sustainable Nuclear Technology Status and Potential**

Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

2:25 p.m. **Presentation: *Moving Forward With Clean Coal Technology***
Speaker: Mr. Carl Bauer, Director, National Energy Technology Laboratory

2:40 p.m. **Discussion Session 4: Advanced Clean Coal Technologies**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

3:00 p.m. **Break**

3:15 p.m. **Presentation: *Colorado's Clean Energy Initiatives***
Speaker: Ms. Heidi VanGenderen, Senior Adviser on Climate Change and Energy, Office of the Governor, State of Colorado

3:40 p.m. **Discussion Session 5: Role of Federal, State, and Local Education Initiatives to Respond to Workforce Needs in the Sustainable Energy Sector**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

4:45 p.m. **Summary and Next Steps for the Task Force**
- Dr. Dan Arvizu and Dr. Jon Strauss

List of Participants: Roundtable Discussion#2

Name	**Affiliation**
National Science Board Participants	
Dr. Dan E. Arvizu	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Jon C. Strauss	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Mark R. Abbott	Task Force on Sustainable Energy Member, National Science Board
Dr. Steven C. Beering	Chairman, National Science Board
Dr. Camilla P. Benbow	Task Force on Sustainable Energy Member, National Science Board
Dr. John T. Bruer	Task Force on Sustainable Energy Member, National Science Board
Dr. Patricia D. Galloway	Task Force on Sustainable Energy Member, National Science Board
Dr. José-Marie Griffiths	Task Force on Sustainable Energy Member, National Science Board
Dr. Douglas D. Randall	Task Force on Sustainable Energy Member, National Science Board
Mr. Arthur K. Reilly	Task Force on Sustainable Energy Member, National Science Board
Dr. Craig Robinson	Acting Executive Officer, National Science Board
Participants	
Dr. Douglas Arent	Director, Strategic Energy Analysis and Applications Center, National Renewable Energy Laboratory

Mr. Carl Bauer	Director, National Energy Technology Laboratory (NETL)
Dr. Richard Buckius	Assistant Director, Directorate for Engineering, National Science Foundation
Dr. David Hill	Deputy Laboratory Director for Science & Technology, Idaho National Laboratory
Dr. Douglas Hittle	Professor, Department of Mechanical Engineering, Colorado State University
Dr. Zakya Kafafi	Division Director, Division of Materials Research, National Science Foundation
Dr. Carl Koval	Faculty Director, Dept. of Chemistry and Biochemistry, University of Colorado at Boulder
Dr. Mark Lusk	Professor of Physics, Director, Golden Energy Computing Organization, Colorado School of Mines
Dr. Nigel Middleton	Provost and Senior Vice-President for Strategic Enterprises, Colorado School of Mines
Ms. Joan Miller	Senior Vice President, Energy and Chemicals Group, CH2M HILL
Mr. Chris Namovicz	Operations Research Analyst, EIA's Office of Integrated Analysis and Forecasting
Mr. Dave Newport	Director, University of Colorado at Boulder Environmental Center
Dr. Trung Van Nguyen	Director of the Energy for Sustainability Program, National Science Foundation
Dr. Anu Ramaswami	Professor of Environmental Engineering, and Director of the Sustainable Urban Infrastructure program, University of Colorado Denver
Dr. Dmitri Routkevitch	Product Manager, Synkera Technologies, Inc.
Dr. Ann Russell	Program Director, Division of Environmental Biology, National Science Foundation
Mr. James Spaeth	Director, Office of Commercialization & Project Management, U.S. Department of Energy
Dr. Rita Teutonico	Advisor for Integrative Activities, Directorate for Social, Behavioral, and Economic Sciences, National Science Foundation
Ms. Heidi VanGenderen	Senior Adviser on Climate Change and Energy, Office of the Governor, State of Colorado
Mr. Michael Wassmer	Senior Engineer, National Renewable Energy Laboratory; Competition Manager, DOE Solar Decathlon
Dr. Bryan Willson	Director, Clean Energy Supercluster, Colorado State University (CSU); Chief Scientific Officer, Cenergy; Professor, Department of Mechanical Engineering, CSU

Appendix E: Roundtable 3—Agenda and Participant List

NATIONAL SCIENCE BOARD
TASK FORCE ON SUSTAINABLE ENERGY

Roundtable Discussion #3
Science, Engineering, and Education Challenges
Related to the Development of Sustainable Energy

University of California, Berkeley
Clark Kerr Campus Conference Center
2601 Warring St.
Berkeley, CA 94720
September 4, 2008

AGENDA

8:00 a.m. **Welcoming Remarks**
- Dr. Steven Beering, Chairman, National Science Board

8:05 a.m. **Summary of Previous Task Force Roundtable Discussions: February 8, 2008 in Arlington, VA and June 19, 2008 in Golden, Colorado**
- Dr. Dan Arvizu and Dr. Jon Strauss, Co-Chairmen, Task Force on Sustainable Energy, National Science Board

8:15 a.m. **Overview, Purpose, and Goals of Today's Roundtable Discussion**
- Dr. Dan Arvizu and Dr. Jon Strauss

8:25 a.m. **Introduction of Participants**

8:30 a.m. **Presentation:** ***What Roles Can Federal and State Governments Play in Promoting Sustainable Energy?***
Speaker: Dr. Mark Levine, Staff Senior Scientist and leader of China Energy Group, Lawrence Berkeley National Laboratory

8:45 a.m. **Discussion Session 1: Regulatory Environment for Sustainable Energy Research**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

9:15 a.m. **Break**

9:30 a.m. **Presentation:** ***Sustainable Energy Policy: Integrating Energy, Ecology, and Economics***
Speaker: Dr. Mark Brown, Professor, Department of Environmental Engineering Sciences; Program Director, Center for Environmental Policy, University of Florida

9:55 a.m. **Discussion Session 2: Sustainable Energy Policy: Integrating Energy, Ecology, and Economics**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

10:55 a.m. **Presentation:** ***A Renewable Energy Perspective: Financing, Forecasting, Modeling, and Trajectory***
Speaker: Mr. Vinod Khosla, Founder and Partner, Khosla Ventures

11:20 a.m. **Presentation:** ***Federal Support for Sustainable Energy Research***
Speaker: Dr. Daniel M. Kammen, Class of 1935 Distinguished Professor of Energy, University of California, Berkeley; Founding Director, Renewable and Appropriate Energy Laboratory

11:45 p.m. **Discussion Session 3: Public-Private Investment in Sustainable Energy Research**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

12:30 p.m. **Lunch**
Luncheon Welcoming Remarks: Chancellor Robert Birgeneau, University of California at Berkeley

12:40 p.m. **Luncheon Presentation:** ***Net Zero Energy, High-Performance Green Buildings: Rationale and Vision for the Federal R&D Agenda***
Speaker: Dr. S. Shyam Sunder, Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, United States Department of Commerce

1:40 p.m. **Break**

1:55 p.m. **Presentation:** ***Advancing Public Awareness of Topics in Sustainable Energy***
Speaker: Dr. Eric R.A.N. Smith, Professor, Department of Political Science and Environmental Studies Program, University of California, Santa Barbara

2:20 p.m. **Presentation:** ***Education in Sustainable Energy and Global Sustainability: NSF Context***
Speaker: Dr. Al DeSena, Program Director, Division of Research on Learning in Formal and Informal Settings (DRL), National Science Foundation; Coordinator, Lifelong Learning Cluster, DRL, NSF

2:45 p.m. **Discussion Session 4: Public Awareness and Education of Sustainable Energy**
Co-Moderators: Dr. Dan Arvizu and Dr. Jon Strauss

4:00 p.m. **Presentation with Q&A:** ***Current Sustainable Energy Initiatives in NSF's Directorate for Mathematical & Physical Sciences***
Speaker: Dr. Tony Chan, Assistant Director, Directorate for Mathematical & Physical Sciences, National Science Foundation

4:30 p.m. **Summary and Next Steps for the Task Force**
- Dr. Dan Arvizu and Dr. Jon Strauss

List of Participants: Roundtable Discussion #3

Name	**Affiliation**
National Science Board Participants	
Dr. Dan E. Arvizu	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Jon C. Strauss	Co-Chairman, Task Force on Sustainable Energy, National Science Board
Dr. Mark R. Abbott	Task Force on Sustainable Energy Member, National Science Board
Dr. Steven C. Beering	Chairman, National Science Board
Dr. Camilla P. Benbow	Task Force on Sustainable Energy Member, National Science Board
Dr. Patricia D. Galloway	Task Force on Sustainable Energy Member, National Science Board
Dr. José-Marie Griffiths	Task Force on Sustainable Energy Member, National Science Board
Dr. Douglas D. Randall	Task Force on Sustainable Energy Member, National Science Board
Mr. Arthur K. Reilly	Task Force on Sustainable Energy Member, National Science Board

Dr. Craig R. Robinson	Acting Executive Officer, National Science Board
Participants	
Dr. Robert Birgeneau	Chancellor and Professor of Physics, University of California, Berkeley
Dr. Harvey Blanch	Chief Science and Technology Officer, joint BioEnergy Institute; Professor of Chemical Engineering, University of California, Berkeley; Senior Faculty Scientist, Lawrence Berkeley National Laboratory
Dr. Carl Blumstein	Director, California Institute for Energy and the Environment
Dr. Severin Borenstein	Director, University of California Energy Institute; E. T. Grether Professor of Business Economics and Public Policy, Haas School of Business, University of California, Berkeley
Dr. Mark Brown	Professor, Department of Environmental Engineering Sciences; Program Director, Center for Environmental Policy, University of Florida
Dr. Tony Chan	Assistant Director, Directorate for Mathematical & Physical Sciences, National Science Foundation
Mr. John Denniston	Partner, Kleiner Perkins Caufield & Byers
Dr. Al DeSena	Program Director, Division of Research on Learning in Formal and Informal Settings (DRL) ; Coordinator, Lifelong Learning Cluster, DRL, National Science Foundation
Dr. Sossina Haile	Professor of Materials Science and of Chemical Engineering, California Institute of Technology
Mr. Rich Halvey	Energy Program Director, Western Governors' Association
Dr. Zakya Kafafi	Division Director, Division of Materials Research, National Science Foundation
Dr. Daniel Kammen	Class of 1935 Distinguished Professor of Energy, University of California, Berkeley; Founding Director, Renewable and Appropriate Energy Laboratory
Mr. Vinod Khosla	Founder and Partner, Khosla Ventures
Mr. Hal LaFlash	Director, Emerging Clean Technology Policy, Pacific Gas and Electric Company
Dr. Mark Levine	Staff Senior Scientist and Leader of China Energy Group, Lawrence Berkeley National Lab
Dr. Jane Long	Principal Associate Director at Large, Lawrence Livermore National Laboratory
Dr. Arun Majumdar	Director, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory; Almy & Agnes Maynard Chair Professor, College of Engineering, University of California, Berkeley
Dr. Trung Van Nguyen	Director, Energy for Sustainability Program, National Science Foundation
Dr. Ann Russell	Program Director, Division of Environmental Biology, National Science Foundation
Dr. Nancy Ryan	Chief of Staff, Office of President Michael Peevey, California Public Utilities

	Commission
Dr. Eric Smith	Professor, Department of Political Science and Environmental Studies Program, University of California, Santa Barbara
Dr. S. Shyam Sunder	Director, Building and Fire Research Laboratory, National Institute of Standards and Technology, United States Department of Commerce
Dr. Duane Wegener	Professor of Psychological Sciences; Initiative Leader for Social, Economic, and Political Aspects of Energy Use and Policy, Energy Center at Discovery Park, Purdue University
Dr. Catherine Wolfram	Executive Director, Center for Energy & Environmental Innovation; Associate Professor of Business Administration, Haas School of Business, University of California, Berkeley

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