DEPARTMENT OF ENERGY'S PLAN FOR CLIMATE CHANGE TECHNOLOGY PROGRAMS

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

ONE HUNDRED NINTH CONGRESS

SECOND SESSION

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DEPARTMENT OF ENERGY'S PLAN FOR CLIMATE CHANGE TECHNOLOGY PROGRAMS

WEDNESDAY, SEPTEMBER 20, 2006

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:00 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Judy Biggert [Chairman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Department of Energy's Plan for Climate Change Technology Programs

September 20, 2006
2:00 PM - 4:00 PM
2318 Rayburn House Office Building

Witness List

Mr. Stephen Eule
Director of the U.S. Climate Change Technology Program at the Department of Energy

Ms. Judi Greenwald
Director of Innovative Solutions of the Pew Center on Global Climate Change

Mr. Chris Mottershead
Distinguished Advisor on Energy and the Environment at BP

Dr. Martin Hoffert
Emeritus Professor of Physics at New York University

HEARING CHARTER

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

Department of Energy's Plan for Climate Change Technology Programs

WEDNESDAY, SEPTEMBER 20, 2006
2:00 P.M.–4:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On September 20, 2006 at 2:00 p.m., the Energy Subcommittee of the House Science Committee will hold a hearing to examine the Administration's Climate Change Technology[1] Program's (CCTP) Strategic Plan.[2] The hearing is designed to review the plan and the CCTP in the light of the Administration's own stated goals for the program and for action on climate change. The final strategic plan (a revision of the draft plan released last September) will be released at the hearing.

2. Witnesses

Mr. Stephen Eule is the Director of the U.S. Climate Change Technology Program at the Department of Energy.

Ms. Judi Greenwald is the Director of Innovative Solutions for the Pew Center on Global Climate Change.

Dr. Martin Hoffert is an Emeritus Professor of Physics at New York University.

Mr. Chris Mottershead is a Distinguished Advisor on Energy and the Environment at BP. He is also a Director of the Carbon Trust in the United Kingdom and the Center for Clean Air Policy in the United States.

3. Overarching Questions

The hearing will address the following overarching questions:

- Does the CCTP draft strategic plan provide a clear blueprint for future federal investments in climate change technologies? What program priorities are specified in the CCTP plan?
- To what extent will the CCTP plan enable the United States to achieve the Administration's stated goal of cutting greenhouse gas intensity by 18 percent over the 2002 to 2012 timeframe? Does the plan set or assume a stabilization level for concentration of atmospheric carbon dioxide?
- How could the CCTP plan be improved? What next steps are needed to implement a clear climate change technology strategy?

4. Brief Overview

- On June 11, 2001, President Bush announced the establishment of CCTP, a multi-agency research and development (R&D) coordination activity led by the Department of Energy (DOE), to focus R&D activities more effectively on the President's near- and long-term climate change goals. At the same time, the President established an interagency Climate Change Science Program (CCSP), led by the Department of Commerce, to coordinate scientific research. According to the Strategic Plan, the Federal Government will spend about $2.8 billion on CCTP in Fiscal Year (FY) 2006 in nine agencies. The FY07 request is close to $3 billion. (See Appendix II.)

[1] Climate change technologies reduce or avoid emissions of greenhouse gases, such as carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated compounds.
[2] U.S. Climate Change Technology Program, *U.S. Climate Change Technology Program Strategic Plan—Draft for Public Comment,* (September 2005). See: http://www.climatetechnology.gov/stratplan/draft/CCTP-SratPlan-Sept-2005.pdf

- On November 21, 2002, the Secretary of Energy established a CCTP office to provide staff and technical support for CCTP coordination and planning activities.
- In 2002, Under Secretary of Energy Robert Card indicated that DOE was developing a draft strategic plan for CCTP that would be released to the public by July, 2002. The plan would define the role for advanced technology in addressing climate change, establish a framework to guide R&D investment decisions for federal agencies involved in climate technology development, and identify steps toward implementation of the Administration's climate change program goals. (CSSP began a similar process and released a draft plan in November, 2002.)
- The CCTP draft plan was not released for public comment until September, 2005. Approximately 30 individuals and organizations (individual scientists, companies, consultants and interest groups) commented on the draft strategic plan, and their comments are posted on the CCTP website.[3] (A list of those commenting is Appendix III.) DOE reviewed the comments as part of its process of completing a final strategic plan. The final plan, which was delivered to the Committee on the afternoon of Sept. 19, will be released at the hearing. At first glance, the final plan does not seem to eliminate the concerns expressed by the commenters, but rather "fine tunes" the draft text.
- In general, commenters were critical of the approximately 200-page draft strategic plan, suggesting that it was a description of currently ongoing activities that provided relatively little guidance on how to direct federal climate technology R&D activities more effectively toward achieving the Administration's stated climate change program goals. Some commenters did say that the plan provided a useful inventory of existing efforts.
- In addition to the public comments, DOE organized a series of workshops at Oak Ridge National Laboratory to review the CCTP R&D portfolio. The workshops produced a May, 2006 report, "Results of a Technical Review of the U.S. Climate Change Technology Program's R&D Portfolio."[4] The Technical Review report included timelines for technology development, identifies R&D priorities and gaps, and analyzed a subset of the R&D portfolio in terms of the potential payoff compared to the probability of technical success—elements that were not included in the draft strategic plan.

5. Issues

Does the CCTP draft strategic plan provide a clear blueprint for future federal investments in climate change technologies?

Commenters on the plan generally believed that it did not provide a clear blueprint or a basis for making or evaluating funding or policy decisions. (Chairmen Boehlert and Biggert reached a similar conclusion. See their letter, Appendix I.)

For each technology research area (e.g., nuclear energy), the plan discusses the potential role of technology, technology strategy, the current R&D portfolio and possible future research directions. The report also cites existing technology roadmaps and technical goals for some specific R&D programs.

DOE officials have generally argued that they see the plan as having a narrower purpose than do the commenters. In the Foreword to the final version of the report, the goal of the strategic plan is described as providing "a long-term planning context, taking into account the many uncertainties, in which the nature of both the challenges and the opportunities for advanced technologies are illuminated and balanced." However, the Foreword goes on to say that, along with other documents, the plan "provides a basis for setting priorities through its technology strategy and investment criteria and it highlights those opportunities that are ripe for advancement."

But, commenters said, the strategy discussion is quite general. The commenters noted that the draft plan does not provide any criteria for evaluating individual technologies. (Possible criteria include technical risk, potential cost, ease of transition to commercialization, likelihood of acceptance by the marketplace, the balance of risk across alternate technical pathways, and the timing of market entry necessary to stabilize emissions profiles.)

The commenters also complained that the draft plan does not provide criteria for allocating funding among CCTP programs and projects. (Possible criteria include the probability of technical success, the cost of adopting that technology, and the poten-

[3] See: http://www.climatetechnology.gov/stratplan/comments/index.htm

[4] See: http://www.ornl.gov/sci/eere/PDFs/CCTP_*Wkshp_Rpt_6-28Final.pdf*

tial for market penetration.) In general, they said, the plan neither sets priorities nor adequately explains how priorities would be set. And while the plan cites existing timelines for some technology programs, it does not integrate them into an overall CCTP timeline.

Commenters also observed that the draft plan is silent on how federal R&D investments will be coordinated with private research efforts. One commenter observed that the draft plan does not discuss the R&D effort in the context of the broad array of statutes that are relevant to the implementation of this plan. Each of these critiques calls into question whether the draft plan fulfills the Administration's intention of having the plan serve as a framework for agencies in formulating their climate change technology R&D portfolio.

How does the CCTP strategic plan relate to the Administration's greenhouse gas emissions goals?

On February 14, 2002, President Bush said, "My Administration is committed to cutting our nation's greenhouse gas intensity—how much we emit per unit of economic activity—by 18 percent over the next 10 years. This will set America on a path to slow the growth of our greenhouse gas emissions and, as science justifies, to stop and then reverse the growth of emissions."[5] The Administration has not set a goal for limiting total U.S. greenhouse gas emissions or for a total greenhouse gas concentrations in the atmosphere. Critics note that it is the absolute concentration of gases in the atmosphere that may affect climate, and a reduction in greenhouse gas intensity will not necessarily result in a drop in total emissions. Moreover, they note that the Energy Information Administration, an independent arm of DOE, has estimated that greenhouse gas intensity would drop by 17 percent by 2012 without any government intervention.

All that aside, the draft strategic plan does not relate any of its goals explicitly to the overall Administration goal of reducing greenhouse gas intensity. Moreover, some critics argue that it is hard to judge among R&D investments without knowing what level of greenhouse gas concentration one is trying to achieve over what time period.

What other gaps have been noted in the draft strategic plan?

Commenters noted that the plan is virtually silent on the question of how to bring new technologies to the marketplace. They view this as a critical question because technology that is being purchased today will likely be in use for decades. In general, the plan is silent on policy questions.

The plan also explicitly states that it does not deal with technologies for adapting to climate change (as opposed to technologies to try to limit climate change by reducing or sequestering emissions).

Commenters have also argued that the plan doesn't adequately distinguish between technology development programs that would produce results in different time frames (short-, medium- and long-term). The commenters and technical reviewers came to diametrically opposed conclusions regarding which direction the draft plan was skewed. Many respondents during the public comment period expressed the view that the plan was too focused on long-term initiatives at the expense of short- to mid-term opportunities that could have a more immediate impact on reducing greenhouse gas emissions. Conversely, experts who participated in the Technical Review, who had greater access to the plan's supporting documentation, budget profiles and technology roadmaps, concluded that CCTP's R&D portfolio was much stronger in the near-term technology development than it was in providing direction for the mid- to long-term.

The technical reviewers, in their May 2006 report, recommended greater emphasis on exploratory research addressing novel concepts to uncover breakthrough technology, enabling R&D, and integrative concepts. For example, R&D on enabling technology, such as nanotechnology, would focus resources on improving the performance of materials and subsystems that find application in a wide variety of energy production and use settings. Integrative R&D would focus resources on combining systems to provide unique advantages. These could include engineered urban planning for low greenhouse gas emissions, integrated waste management, and integration of plug-in hybrid electric vehicles with zero-emissions buildings.

[5] Office of the Press Secretary, *President Announces Clear Skies & Global Climate Change Initiatives* (February 14, 2002). See: *http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html.*

How does CCTP relate to the Administration's existing climate change technology programs?

Since 2001, the Administration has undertaken a number of actions that can begin to reduce greenhouse gas emissions. Many of the Administration's signature R&D initiatives have tended to be longer-term projects—the Hydrogen Fuel Initiative, FutureGen (clean coal power plant), and ITER (large-scale nuclear fusion experiment). Near-term actions include the 2006 fuel economy increases for light trucks and voluntary action such as the Methane-to-Markets program and the Climate VISION Partnership, a voluntary registry for reporting greenhouse gas reductions, and targeted incentives for greenhouse gas sequestration. A June 30, 2005 White House fact sheet that outlined the President's climate change initiatives, as shown in the table below, includes a broad range of activities. (Italicized entries denote international partnerships).[6]

The public comments and the comments from the technical reviewers suggest that the draft strategic plan could better explain how the various activities—both R&D and other policy initiatives—are linked together to achieve stated national goals.

Short Term - Present	**Midterm - 2010-2020**	**Long Term**
Hybrid or Clean Diesel Vehicles	Hybrid/Clean Diesel Vehicles	*Hydrogen*
Clean Coal Efficiency	Clean Coal Gasification	*FutureGen*
Energy Efficiency Standards	*Renewable/Efficiency Partnership*	Zero Energy Homes and Buildings
Renewable Fuel Standard	Cellulosic Biomass	Bio-Energy Systems
Nuclear Plant Re-licensing	Advanced Nuclear	*GenIV Nuclear/Fusion*
Enhanced Oil Recovery	*Geological Sequestration*	
Biological Sequestration		
Methane to Markets		
Federal Facility Management Plan		
Fuel Economy Standards		
Wind, Solar Tax Incentives		
Climate Leaders		
Climate VISION		
SmartWay Transportation		

How is the CCTP portfolio being managed, both within DOE and across agencies?

CCTP is a multi-agency planning and coordination activity with a CCTP Steering Group and six working groups. However, most of the activities in CCTP take place within DOE, which has historically struggled to coordinate efforts within the Department and to overcome "stovepiping," where different parts of an organization pursue different goals, fail to communicate well, or see other parts of the organization merely as competitors. It is not clear that DOE has solved this problem internally. For example, nuclear power has a prominent role in the CCTP plan because nuclear power plants do not emit greenhouse gases. However, the Office of Nuclear Energy and the Office of Civilian Radioactive Waste Management have continued to have trouble coordinating and making decisions about spent nuclear fuel, an issue important to both the current fleet of nuclear power plants and deployment of the next generation of plants.

Beyond describing the basic functions of the various oversight and advisory committees, the draft strategic plan does not describe or address how CCTP will overcome stovepiping and other management challenges at DOE and across agencies, coordinate budgeting activities across agencies, or set priorities to avoid duplication. One commenter observed that non-DOE activities classified as part of the CCTP for funding purposes are not a part of the CCTP functions, nor are they included in the draft plan itself.

[6] The White House, *Fact Sheet: President Bush Is Addressing Climate Change* (June 30, 2005). See: *www.whitehouse.gov/news/releases/2005/06/20050630-16.html*

How does the plan deal with funding?

The CCTP plan is silent on funding beyond listing funds requested for existing programs for FY07. It does not give any sense of whether more funding would be required to pursue the "future research directions" described in the plan.

Has the process for developing the strategic plan been sufficiently open?

DOE officials argue that they have heard from experts outside the government in developing the plan, citing the posting of the draft plan on the web, the posting and review of comments, and the workshop with technical experts.

However, critics point out that this seems to be a less open and broad-based process than the CCSP has followed. The draft plan for CCSP was more broadly announced and the workshop on it was more open, and was attended by more than 1,300 participants. More than 900 pages of comments were received. In addition, the CCSP contracted with the National Academy of Sciences to review the draft plan.

6. Summary of Draft Strategic Plan for Climate Change Technology

The strategic plan describes activities carried out in nine departments and agencies: the Departments of Agriculture, Commerce, Defense, Energy, Interior and Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration and the National Science Foundation. The Department of Health and Human Services, the Department of State and the Agency for International Development also participate in planning and coordination as members of the CCTP effort; however, their activities are not included in efforts funded under CCTP. DOE accounts for 87 percent of the $2.8 billion funding under the CCTP umbrella in fiscal year 2006.[7]

The Administration's draft plan states that:

- the necessary cumulative emissions reductions [worldwide] over the course of the century could be on the order of 200 gigatons of carbon equivalents[8] to 800 gigatons of carbon equivalents (or more);
- emissions reductions of that scale potentially could be achieved through combinations of many different technologies, so a diversified approach to technology R&D is important;
- technologies with zero or near-net-zero greenhouse gas emissions would need to be available and moving into the marketplace many years before the emissions "peaks" occur in [any of] the hypothetical greenhouse gas-constrained cases; and
- some new technologies may need to be commercially ready for widespread implementation between 2020 and 2040, with initial demonstrations between 2010 and 2030.[9]

It is against these concrete insights that the six goals of the strategic plan may be assessed. These goals, articulating what the Administration aims to accomplish with the strategy, are to:

1. reduce greenhouse gas emissions from energy end-use and infrastructure;
2. reduce greenhouse gas emissions from energy supply;
3. capture and sequester CO_2;
4. reduce emissions of non-CO_2 greenhouse gases;
5. improve capabilities to measure and monitor greenhouse gas emissions; and
6. bolster basic science contributions to technology development.

The Administration proposes to implement the strategic plan using a combination of the following seven "core approaches":

1. strengthen climate change technology R&D;
2. strengthen basic research at universities and federal research facilities;

[7] *Federal Climate Change Expenditures Report to Congress* (April 2006). See http://www.whitehouse.gov/omb/legislative/fy07_*climate_change.pdf*

[8] Emissions of non-CO_2 greenhouse gases are usually converted to a common and roughly comparable measure of the "equivalent CO_2 emissions." This conversion weights actual emissions by each gas' global warming potential (GWP). GWP is the ability of a gas, compared to that of CO_2, to trap heat in the atmosphere over a given timeframe. GWP values allow for a comparison of the impacts of emissions and reductions of different gases, although they typically have uncertainties of ±35 percent. All non-CO_2 gases are compared to CO_2, which has a GWP of one. Other greenhouse gases have GWPs, using a 100-year time horizon, ranging from 23 for methane to 22,200 for sulfur hexafluoride (SF_6). (*CCTP Draft Strategic Plan,* p. 7–2).

[9] *CTP Draft Strategic Plan,* p. 3–28.

3. enhance opportunities for partnerships;
4. increase international cooperation;
5. support cutting-edge technology demonstrations;
6. ensure a viable technology workforce of the future through education and training; and
7. explore and provide, as appropriate, supporting technology policy.

7. Witness Questions

Mr. Stephen Eule

1. How is the Administration using the Climate Change Technology Program (CCTP) draft strategic plan in preparing future budgets? Specifically, how will the plan enable the Department of Energy (DOE) and the Administration to choose among competing priorities and set funding requests?
2. Will the CCTP plan enable the Administration to meet its goal of cutting greenhouse gas intensity by 18 percent by 2012? If DOE were able to achieve the programmatic goals for all of the technologies listed in the plan, how would the U.S. emissions profile change in 15 years? In 25 years?
3. How can the Administration have a comprehensive and effective CCTP plan without setting as a goal a specific stabilization level for atmospheric concentration of carbon dioxide and other greenhouse gases?
4. How do you respond to critics who argue that the plan is simply a description of current activities at DOE rather than a roadmap to help the Administration set priorities and make choices among competing technologies?

Ms. Judi Greenwald, Dr. Martin Hoffert, and Mr. Chris Mottershead

1. What do you see as the key strengths and weaknesses of the plan?
2. Will the Climate Change Technology Program (CCTP) enable the Administration to meet its goal of cutting greenhouse gas intensity by 18 percent by 2012? Does CCTP put the United States on a path to stabilizing greenhouse gas emissions?
3. Does the CCTP draft strategic plan provide an integrated framework of sound guidance, clear goals and next steps for agencies and researchers to use when prioritizing and selecting future research efforts? If so, please explain. If not, how should the Administration set research and development investment priorities among various climate change technologies and CCTP agencies?

Appendix I

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON SCIENCE

SUITE 2320 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6301
(202) 225-6371
TTY: (202) 226-4410
http://www.house.gov/science/welcome.htm

December 15, 2005

The Honorable Samuel W. Bodman
Secretary
U.S. Department of Energy
1000 Independence Ave
Washington, DC 20585

Dear Secretary Bodman:

We are writing to express our deep disappointment with the Climate Change Technology Program's (CCTP) draft strategic plan. After excessive and repeated delays in its development, the plan lacks the detail, rigor and clarity necessary to accomplish the President's climate change goals. In short, the plan does not reflect the Administration's repeated emphasis on developing technology as the most important way to address climate change.

The delay in the report is baffling. The Climate Change Science Program's plan (announced at the same time as the CCTP in 2001) was completed in mid-2003, and it underwent two reviews by the National Academy of Sciences. Since the CCTP's announcement, the Committee has expressed an intense interest in the development of its strategic plan. Former Under Secretary Robert Card first told the Committee that a draft plan for the CCTP would be released by July 2002, then later testified that it would be completed by 2003. But the plan, as you know, was only released on September 22 of this year. Inexplicably, the Committee was not immediately notified.

Now that it has been published, we find the plan insufficient. It articulates no clear set of criteria for technology selection and prioritization, no timelines for completing individual programs or projects, no metrics for evaluating progress, no sense of how budget priorities across agencies will be developed, and, compared to the Climate Change Science Program, little open and public process for developing the plan and revising it in the future. (There is apparently no plan to have it reviewed by the National Academy of Science, for example.) Furthermore, the plan does not articulate any plans to evaluate policies that might be necessary to deploy these technologies in the marketplace. Sequestering carbon dioxide, for example, will almost always be more expensive than venting the gas into the atmosphere, but the plan is virtually silent on the best way to encourage the adoption of sequestration technologies.

While the plan does refer to principles for prioritizing investments that the CCTP has set out in a separate document, *Vision and Framework for Strategy and Planning*, it leaves undefined how the principles apply to the technologies described.

In developing the plan, it does not appear that criteria – such as a technology's potential cost, its projected ease in making the transition to the marketplace from the laboratory, the comparative technical risk to successfully developing a technology by a variety of potential approaches, and the time frame in which a technology would be needed to be available in the marketplace if it is to significantly contribute to stabilizing emissions – were evaluated carefully or to have influenced the formulation of the draft strategic plan. Absent such criteria, it is unclear how the CCTP will prioritize investments and avoid becoming no more than a hodge-podge of programs and projects.

The plan also fails to explain how the CCTP's technology programs are linked to the President's stated goals for U.S. climate policy such as achieving "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" and reducing U.S. greenhouse gas intensity by 18 percent by 2012.

It is also unclear how the CCTP relates to other Administration climate initiatives. During the past few years, the Administration has launched the Hydrogen Fuel Initiative, the Methane-to-Markets program, and the Climate VISION Partnership. It has begun participation in an international nuclear fusion energy project (ITER), proposed developing a clean-coal electric power plant (FutureGen), and increased fuel economy for light trucks, to cite just a few examples. But it's not clear from the draft strategic plan how these efforts – all of which directly support or provide incentives for the development of technology with a significant implications for greenhouse gas emissions – relate to the suite of research projects the plan describes.

We urge you to direct the Department to swiftly put together a more credible and complete plan. Shortly after Congress reconvenes, we intend to hold hearings evaluating the CCTP's strategic plan. We hope the Department will have more to show for its efforts by then.

Sincerely,

Sherwood Boehlert
Chairman
Committee on Science

Judy Biggert
Chairman
Subcommittee on Energy

The Secretary of Energy
Washington, DC 20585

March 1, 2006

The Honorable Judy Biggert
Chairman
Subcommittee on Energy
U.S. House of Representatives
Washington, D.C. 20515-6301

Dear Chairman Biggert:

Thank you for your letter regarding the draft strategic plan of the United States Climate Change Technology Program (CCTP). We appreciate your continuing interest in CCTP.

I understand that Mr. David Conover, CCTP Director, briefed several members of your Committee staff about CCTP on January 23, 2006. We plan to continue to communicate with you and your staff on a regular basis.

We believe that the CCTP draft strategic plan for the first time addresses long-term climate change technology challenges broadly and substantively. It is inspired by the President's vision that it is possible to engage America's strengths in innovation and technology to transform energy production and use, and other activities that emit greenhouse gases (GHGs). Over the long-term, such a transformation will enable the United States to achieve major reductions of GHG emissions. If the technologies outlined in this plan emerge successfully from their research and development (R&D) stages, they could enable and greatly facilitate reductions of GHG emissions to the very low levels needed to achieve stabilization of concentrations in the earth's atmosphere.

The plan is unprecedented in its scope and scale. It breaks new ground with its 100-year planning horizon, global perspective, multi-lateral research collaborations, public-private partnerships, and long-term visioning of the roles for new and advanced technology. These are precisely the elements of strategy that are needed to guide and, indeed, embolden Federal R&D activities across all agencies, lead the way for others, and chart meaningful progress toward the President's climate change goals.

The strategic plan is intended to provide long-term strategic direction to the agencies and help guide the formulation of a balanced and diversified portfolio of climate change technology R&D. It identifies high-priority R&D activities, goal-by-goal, technology-by-technology, that respond to the plan's strategies for technology development. The planning process is dynamic and continues to be informed by studies, public comments, technical workshops, assessments of technology potentials, and analyses regarding long-term energy and emissions outlooks and modeling of a range of long-term technology scenarios.

The results of this process are clearly stated in the plan in the context of each strategic goal and at higher levels of aggregation, which are summarized in Chapter 10 and highlighted separately in the *Vision and Framework* (pp. 30-31) as key initiatives and significant elements of the core portfolio. Copies of the *Vision and Framework* were forwarded to you and the Congress with my letter of October 25, 2005.

Regarding your concerns about delays and your comparisons of progress to our sister program, the United States Climate Change Science Program (CCSP), I respectfully refer you to our letter of January 19, 2005. In that letter, we point out differences between these two activities. As you know, the predecessor to CCSP, the United States Global Change Research Program, was authorized by Congress in 1990, now more than 15 years ago. It has since marshaled sufficient resources to maintain a full-time staff that is augmented by contracted technical support. CCTP, by contrast, received a congressional appropriation for the first time in fiscal year 2005 and was just recently authorized by the Energy Policy Act of 2005.

The availability of resources determines CCTP's ability to make progress. When resources became available in the third quarter of fiscal year 2005, CCTP was able to activate staff and technical support. The result was accelerated progress, which was evidenced in part by the publication of the *Vision and Framework* and the public release of the draft strategic plan in September 2005.

Regrettably, in the FY 2006 Energy and the Water Development Appropriation, Congress took action -- we believe without fully appreciating its consequences -- that adversely affected the DOE account intended to support CCTP. This action effectively zeroed-out the President's request for $1 million for CCTP. The loss of funds in FY 2006 will slow CCTP's progress. It also clouds the future for CCTP and affects staff retention. The Department is pursuing other means to find support for CCTP, including possible reprogramming action, but such efforts require time to resolve satisfactorily.

Regarding your concerns about openness of the plan development process, the draft plan has benefited from many external inputs and a formal public comment period, which opened on September 22, 2005. Regarding your comments about the National Academy of Sciences (NAS), we would be delighted to have NAS review the draft strategic plan and provide us the benefit of its findings and recommendations. The CCTP does not currently have the resources, however, to fund a NAS review, which is estimated to cost up to $1 million or more. Seeking external input at lower costs, CCTP recently completed six workshops involving more than 50 non-Federal technical experts. These workshops focused on each of the plan's six strategic goals.

Finally, with regard to the plan's lack of policies necessary to promote technology deployment, you are correct. The CCTP strategic plan primarily addresses R&D matters. It does not articulate policies to aid deployment. However, it does acknowledge their importance and commits the CCTP to explore a range of options.

In closing, the President has articulated a bold vision for the role of innovation and technology in addressing the issue of climate change. The CCTP strategic plan lends substance to this vision and provides a means by which the United States can increase the participation by others, domestically and internationally. With your support, the United States will continue to lead on these fronts and help move the world forward toward the eventual achievement of the President's vision.

If you have any questions, please feel free to contact me or Ms. Jill L. Sigal, Assistant Secretary for Congressional and Intergovernmental Affairs, at (202) 586-5450.

Sincerely,

Sam

Samuel W. Bodman

cc: The Honorable Bart Gordon, Ranking Minority Member
Committee on Science

The Honorable Michael Honda, Ranking Minority Member
Subcommittee on Energy

The Honorable Vernon Ehlers, Chairman
Subcommittee on Environment, Technology and Standards

The Honorable David Wu, Ranking Minority Member
Subcommittee on Energy, Technology and Standards

Chairwoman BIGGERT. The hearing of the Energy Subcommittee of the Science Committee will come to order. I will recognize myself for an opening statement.

I would like to welcome everybody to the hearing examining the Department of Energy's Strategic Plan for a Climate Change Technology Program. Our essential question at this point is was it worth the wait?

Let me start by reviewing a bit of history here. On June 11, 2001, President Bush announced two initiatives to address climate change. Those initiatives are now known as the Climate Change Technology Program, CCTP, and the Climate Change Science Program, CCSP. The Administration has said that these initiatives form the core of its policy to fulfill the U.S. commitment to stabilize greenhouse gas concentrations under the United Nations Framework Convention on Climate Change.

The Administration's admirable work on the science program can serve as a model for how best to shape a research program so it delivers results. Beginning in July 2002, the Department of Commerce undertook the process of preparing a new ten year strategic plan for the CCSP. Science program managers engaged national and international stakeholders in a comprehensive review of research and observational systems needs. CCSP submitted its November 2002 draft plan to the National Academy of Sciences for review and to the public for comment. A December 2002 workshop attended by 1,300 scientists and other participants from 47 states and 36 nations facilitated extensive discussion and debate.

By July 2003, the CCSP strategic plan was complete. This open and orderly progress—process established a research agenda that has been universally supported, and will fill the gaps in our knowledge and understanding of the Earth's climate.

Today, the Commerce Department is executing its CCSP strategic plan. The first of 21 synthesis and assessment reports were released in May of this year, and just this week, the Secretary of Commerce announced a new federal advisory committee to provide advice as the remaining reports are developed.

Why did I go into such great detail for the CCSP when the topic of our hearing today is CCTP? Because the thoughtful deliberation and open process the Administration employed to develop the CCSP gave Congress and others the confidence that the $1.7 billion program is on the right track. Can I say the same thing about the $2.9 billion dollar program, the technological program? Unfortunately, no. Compared to CCSP, the technology program appears stalled near the starting line.

It is now September 2006, four years and two months after the deadline, former Department of Energy Under Secretary Robert Card set for release of the draft technology plan, and the revised plan is being released today. That is unacceptable, that this hearing should be examining progress in year three of that plan. Don't get me wrong. I strongly support the Administration's stated policy of addressing climate change through technology development. Technology investments are like an insurance policy against climate change. Supporting a diverse portfolio of climate change technologies such as energy efficiency, carbon sequestration, and carbon neutral energy technologies, including nuclear energy, will provide us with the most insurance coverage for the best price.

We have a lot riding on this R&D portfolio. Not only are we relying on it to help reduce emissions of greenhouse gases, we need it to secure America's energy independence. As Chair of the Subcommittee with oversight responsible for nearly 90 percent of the programs included in CCTP, I know that research and technology are, by and large, noncontroversial ways we can start addressing climate change now. That is why I am determined to see progress on this front.

Since the July 2002 deadline for the release of the initial plan, the Administration has announced a whole series of energy technology research initiatives: the Hydrogen Fuel Initiative, the Global Nuclear Energy Partnership, the Fusion Experiment, ITER, and the Advanced Energy Initiatives. These are all great energy initiatives that I enthusiastically support.

At the same time, in the absence of a rigorous, well vetted, comprehensive plan, Congress is left to figure out how and to what degree each of these technologies, individually and collectively, will contribute to achieving our climate change goals. This information is critical if Congress is to make informed decisions about how best to allocate technology development resources to address the problems of climate change.

We want DOE to succeed. I think it would be terribly unfair to our children and grandchildren to leave the Earth in worse condition than in the way we received it. That is why the government, the research community, and industry must work together to develop technology solutions that make environmental and economic sense; but for such a collaborative effort to succeed, we need a solid game plan. I think my colleagues share that sentiment.

We want FutureGen, GNEP, sequestration, and all the other climate change technologies to work and to work well. We have high expectations. We believe those expectations can be met with a clear strategic plan. With that, let us get down the business of today's hearing. Fundamentally, we want to know whether the strategic plan can be used to guide R&D investment decisions, and whether it will enable the United States to achieve the Administration's goals.

Most importantly, I cannot stress this enough, we want to know how the CCTP plan and DOE's planning process can be improved, and I look forward to the discussion.

I want to thank the witnesses for sharing their experiences with us today, particularly Professor Hoffert, who graciously agreed to our invitation to serve on this panel at a very late hour. We will make Professor Hoffert's written testimony available within a few days.

Professor Dan Kammen of the University of California at Berkeley, originally scheduled as a witness, is not able to attend today due to a last minute scheduling conflict. I greatly appreciate his willingness to serve as a witness each time we tried to schedule this hearing in the past, and we will have his prepared testimony entered into the hearing record. Without objection.

And with that, I will yield to my colleague, the Ranking Member of the Subcommittee, Mr. Honda from California.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

The hearing will come to order. I want to welcome you to this Energy Subcommittee hearing examining the Department of Energy's strategic plan for the Climate Change Technology Program. Our essential question, at this point, is was it worth the wait?

Let me start by reviewing a bit of the history here. On June 11, 2001, President Bush announced two initiatives to address climate change. Those initiatives are now known as the Climate Change Technology Program—CCTP—and the Climate Change Science Program—CCSP. The Administration has said that these initiatives form the core of its policy to fulfill the U.S. commitment to stabilize greenhouse gas concentrations under the United Nations Framework Convention on Climate Change.

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Mr. HONDA. Thank you, Madam Chairwoman, and I want to thank you for holding this important hearing today. And thank you to the witnesses for taking time to prepare your testimony and to be here personally.

I believe that climate change is one of the most important issues we face as a nation and as a member of the global community. James Hansen, a NASA scientist who is one of the country's leading climate researchers, has said he thinks "we have a very brief window of opportunity to deal with climate change, no longer than a decade, at the most."

Most of my colleagues on this committee, from both sides of the aisle, agree that something must be done, for which I am thankful. Unfortunately, the same cannot be said for the full membership of the House, the Senate, or the current Administration.

In 2002, when the Environmental Protection Agency released a report that concluded global warming "is real and has been particularly strong within the past 20 years, due mostly to human activities," President Bush quickly dismissed the EPA's work as a "report put out by the bureaucracy."

Instead, his Administration has used an argument of "uncertainty" to justify more research and no action. On a positive note, the National Academy of Sciences has declared that the Climate Change Science Program's strategic plan "articulates a guiding vision, is appropriately ambitious, and is broad in scope." However, the review was critical of the program for its failure to state projected budget requirements and lack of milestones and evaluation mechanisms.

Both of these failings seem linked to a broader strategy designed to avoid taking any action on this very real problem. For example, in August, the House Majority Whip stated that he thought the information on climate change is "not adequate yet for us to do anything meaningful."

This effort to foster "uncertainty" has impacted even the setting of goals for greenhouse gas emission reductions. Because of "uncertainty," the Administration has refused to set a goal for the stabilization of greenhouse gas concentrations in the atmosphere. Instead, a goal for greenhouse intensity, how much we emit per unit of economic activity, has been identified.

The problem with this measure is that if our economy grows, emission will increase. But the Earth's systems don't care about our economy. It is the absolute amount of emissions that matter, and more emissions are a problem.

Sadly, even the emissions intensity reductions the Administration has set are week. According to the Energy Information Administration, the goal that has been set is as little as one percent improvement over business as usual.

The main question before us today is whether the Climate Change Technology Program plan actually lays out a path for how to achieve even the moderate targets the Administration has set.

From the many comments about the draft plan, the answer appears to be no. The plan may be an excellent compendium of current technologies, but it seems to be lacking in a number of areas.

To wit, there is no mention of cross-cutting enabling technologies or integrated approaches to greenhouse gas emission reduction. There are no timelines or technology roadmaps. It places a low priority on measurement and monitoring technologies. It makes no mention of adaptation to climate change, and there is no mention of policy framework for making all this happen.

Other problems have been identified with the draft plan, but I won't take the time to list any more. They are in the Committee hearing charter, and I expect that the witnesses will tell us more about them in greater detail.

If we are going to achieve real reductions in greenhouse gas emissions in order to address global climate change, it is critical that we develop the technologies that will allow us to do so.

The Climate Change Technology Program plan is supposed to accelerate the development of those technologies, and so it should be an important part of our response to climate change.

But I am worried that the draft plan that has been developed does not provide the roadmap that is necessary to help the Administration set priorities and make choices among competing technologies. I hope the final plan will do so.

I look forward to hearing from the witnesses today on how we can do just that.

And I again want to thank Madam Chairwoman for this hearing, and I yield back the balance of my time.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

Madam Chairwoman, thank you for holding this important hearing today, and thank you to the witnesses for taking the time to prepare your testimony and to be here.

I believe that Climate Change is one of the most important issues we face as a nation and as a member of the global community. James Hansen, a NASA scientist who is one of the country's leading climate researchers, has said he thinks "we have a very brief window of opportunity to deal with climate change. . .no longer than a decade, at the most."

Most of my colleagues on this committee, from both sides of the aisle, agree that something must be done, for which I am thankful. Unfortunately, the same cannot be said for the full membership of the House, the Senate, or the current Administration.

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Both of these failings seem linked to a broader strategy designed to avoid taking any action on this very real problem. For example, in August, the House Majority Whip stated that he thought the information on climate change is "not adequate yet for us to do anything meaningful."

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- there is no mention of cross-cutting enabling technologies or integrated approaches to greenhouse gas emissions reduction;
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- and there is no mention of a policy framework for making this all happen.

Other problems have been identified with the draft plan but I won't take the time to list any more, they are in the Committee hearing charter and I expect that the witnesses will tell us about them in greater detail.

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But I am worried that the draft plan that has been developed does not provide the roadmap that is necessary to help the Administration set priorities and make choices among competing technologies. I hope the final plan will do so.

I look forward to hearing from the witnesses today on how we can do just that.

Thank you, Madam Chairwoman; I yield back the balance of my time.

Chairwoman BIGGERT. Thank you, Mr. Honda.

With that, any additional opening statements submitted by the Members may be added to the record. Without objection.

[The prepared statement of Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good afternoon. I want to thank the witnesses for appearing before our committee to discuss the Administration's Climate Change Technology Program (CCTP) report being released today.

In 2002, President Bush set a national goal to reduce the greenhouse gas intensity of the U.S. economy by 18 percent by 2012. To this end, the Administration is now implementing numerous programs to implement near-term policies and measures to slow the growth of greenhouse gas emissions, advance climate change science, accelerate technology development and commercialization, and promote international collaboration.

Climate change plays a role in my district because of the combustion of fossil fuels. The coal industry is of great importance to my district in Southern Illinois which is rich in high-sulfur coal. The shifting of production to low-sulfur coal has cost many of my constituents high-paying jobs. The United States and my home state of Illinois have vast reserves of coal, and about half of its electricity is generated from this fuel. Further, coal is projected to continue to supply one-half of U.S. electricity demands through the year 2025. In order to continue to use coal, even under scenarios calling for substantial carbon dioxide emission limitations, I support research and development (R&D) of clean coal technology and I believe clean coal R&D projects must be part of a balanced energy plan for this country. We must burn coal more efficiently and cleanly and I authored provisions in the *Energy Policy Act of 2005* (P.L. 109–58) to accomplish this goal.

In my congressional district, Southern Illinois University Carbondale operates its Coal Research Center, one of the field's most comprehensive programs in the United States, with a combination of facilities and achievements that make it a unique contributor to our nation's energy infrastructure. The Coal Research Center conducts a wide range of studies with direct practical applicability to the commercial development of coal, including carbon sequestration technology. Illinois is a national leader in developing clean and efficient coal technologies, such as carbon sequestration, and I am hopeful we will have the ability to host the President's FutureGen Project to demonstrate how coal can be used cleanly, efficiently, and represents a viable fuel source alternative to natural gas and oil.

As Congress continues to debate climate change, I believe we should continue to further our research and development programs to advance clean coal technology to improve our air quality and reduce greenhouse gas emissions.

I welcome our panel of witnesses and look forward to their testimony.

Chairwoman BIGGERT. At this time, I would like to introduce all of our witnesses, and thank you for being here this afternoon. We have, first of all, Mr. Stephen Eule is the Director of the U.S. Climate Change Technology Program at the Department of Energy.

Next is Ms. Judi Greenwald, the Director of Innovative Solutions for the Pew Center on Climate Change. Thank you for coming. Mr. Chris Mottershead is a Distinguished Advisor on Energy and the Environment at BP. He is also a Director of the Carbon Trust to the United Kingdom, and the Center for Clean Air Policy in the United States. Thank you. Dr. Martin Hoffert is an Emeritus Professor of Physics at the New York University. Thank you for being here.

As the witnesses know, spoken testimony will be limited to five minutes each, after which the members will have five minutes each to ask questions.

And we will begin with Mr. Eule. Thank you.

STATEMENT OF MR. STEPHEN D. EULE, DIRECTOR OF THE U.S. CLIMATE CHANGE TECHNOLOGY PROGRAM, DEPARTMENT OF ENERGY

Mr. EULE. Madam Chairwoman and Ranking Member Honda, and Members of the Subcommittee, thank you for the opportunity to appear before you today. I am particularly pleased to be able to use the occasion of this hearing to announce the release of the Climate Change Technology Program's strategic plan.

The Administration believes the most effective way to meet the challenge of climate change is through an agenda that promotes economic growth, provides energy security, reduces pollution, and mitigates greenhouse gases. To meet these goals, the Administration has established a comprehensive approach, major elements of which include policies and measures to slow the growth of greenhouse gas emissions, advancing climate change science, accelerating technology development, and promoting international collaboration.

Since fiscal year 2001, the Federal Government has devoted nearly $29 billion to climate change programs.

In 2002, President Bush set a goal to reduce the Nation's greenhouse gas intensity, that is, emissions per unit of economic output, by 18 percent by 2012. To this end, the Administration has implemented about 60 federal programs. Recent data suggests that we are well on our way toward meeting the President's goal.

While acting to slow the growth of greenhouse gas emissions in the near-term, the United States is laying a strong scientific and technological foundation. In 2002, two multi-agency programs were established to coordinate federal climate change science and technology R&D activities: the Climate Change Science Program, or CCSP, and CCTP. CCSP is an interagency planning and coordinating entity charged with: investigating natural and human-induced changes in the Earth's global environmental system; monitoring, understanding, and predicting global change; and providing a sound scientific basis for decision-making.

CCTP, which was authorized in the *Energy Policy Act of 2005,* was formed to coordinate and prioritize the Federal Government's investment in climate-related technology, which was nearly $3 billion in fiscal year 2006, and to further the President's National Climate Change Technology Initiative, or NCCTI. Ten R&D agencies participate in CCTP.

CCTP's principal aim is to accelerate the development and lower the cost of advanced technologies that reduce, avoid, or sequester greenhouse gases. It strives for a diversified Federal R&D portfolio that will help to reduce technology risk and improve the prospects that such technologies can be adopted in the marketplace. In August 2005, CCTP issued its *Vision and Framework for Strategy and Planning,* which provided broad guidance for the program, and shortly thereafter released its draft strategic plan for public review. More than 250 comments were received.

This revised strategic plan articulates a vision for the role of advanced technology in addressing climate change, establishes strategic direction and guiding principles, outlines approaches to achieve CTCP's strategic goals, and identifies a series of next steps. The six CTCP goals are: reducing emissions from energy use and infrastructure; reducing emissions from energy supply; capturing and sequestering carbon dioxide; reducing emissions from non-carbon dioxide greenhouse gases; measuring and monitoring emissions; and bolstering the contributions of basic science.

The strategic plan defines clear and promising roles for advanced technologies for the near-, mid-, and long-term, outlines a process and establishes criteria for setting priorities, such as those in NCCTI, and provides details of the current climate change technology portfolio with links to individual technology roadmaps.

CCTP's portfolio includes realigned activities as well as new initiatives, such as the President's Advanced Energy and Hydrogen Fuel Initiatives, carbon sequestration, and FutureGen. CCTP agencies also periodically conduct portfolio reviews to assess the ability of these programs to meet CCTP goals, and to identify gaps and opportunities. In addition, CCTP uses scenario analyses to assess the potential climate change benefits of different technology mixes over the century, on the global scale, and across a range of uncertainties. When comparing the costs of achieving different greenhouse gas constraints, the cost savings for the advanced technologies cases were 60 percent or more.

The Administration believes that well designed multilateral collaborations can leverage resources and quicken technology development. The International Partnership for the Hydrogen Economy, Carbon Sequestration Leadership Forum, Generation IV International Forum, Methane to Markets—all U.S. initiatives—and the ITER fusion project, provide vehicles for international collaboration to advance these technologies.

The New Global Nuclear Energy Partnership seeks to develop a worldwide consensus on approaches to expand safe use of zero emission nuclear power. And of course, through the Asian Pacific Partnership, the U.S. is working with Australia, China, India, and South Korea, and Japan, to accelerate the uptake of clean technologies in this rapidly growing region of the world.

The United States has embarked on an ambitious undertake to develop advanced climate change technologies. CCTP's strategic plan, the first of its kind, sets out an overall strategy to guide these efforts, and provides a long-term planning context in which the nature of both the challenges and the opportunities for advanced technologies are considered and realized.

Thank you for your kind attention, and I will, of course, be delighted to answer any questions you may have.

[The prepared statement of Mr. Eule follows:]

PREPARED STATEMENT OF STEPHEN D. EULE

INTRODUCTION

Madam Chairman and Members of the Subcommittee, thank you for the opportunity to appear before you today and report on the Climate Change Technology Program (CCTP). I am particularly pleased to be able to use the occasion of this hearing to announce the release of CCTP's completed *Strategic Plan.* It represents the culmination of strong interagency effort, shaped by expert technical input and public comment.

I would like to begin my testimony by providing a brief overview of the Administration's approach to climate change, which provides the context in which CCTP operates. I will also discuss the role of CCTP, explain the purpose of the *Strategic Plan,* and discuss how the *Plan* will help the Administration and Congress make decisions about investments in advanced technologies that can have a significant impact on reducing greenhouse gas emissions.

As a party to the United Nations Framework Convention on Climate Change (UNFCCC), the United States shares with many countries its ultimate objective: stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. In February 2002, President Bush reaffirmed the Administration's commitment to this long-term goal of the Framework Convention.

There is a growing recognition that climate change cannot be dealt with effectively in isolation. Rather, it needs to be addressed as part of an integrated agenda that promotes economic growth, provides energy security, reduces pollution, and also mitigates greenhouse gas emissions. In July 2005, the G8 leaders, meeting in Gleneagles, Scotland, agreed to a plan of action that interlinked climate change objectives with these other important considerations.

Meeting these complementary objectives will require a sustained, long-term commitment by all nations over many generations. To this end, the President has established a robust and flexible climate change policy that harnesses the power of markets and technological innovation, maintains economic growth, and encourages global participation.

Major elements of this approach include: (1) implementing near-term policies and measures to slow the growth in greenhouse gas emissions; (2) advancing climate change science; (3) accelerating technology development and commercialization; and (4) promoting international collaboration.

From fiscal years 2001 to the end of 2006, the Federal Government will have devoted nearly $29 billion to science, technology, international assistance, and incentive programs that support climate change objectives, more than any other nation. The President's fiscal year 2007 budget calls for $6.5 billion for climate-related activities.

NEAR-TERM POLICIES AND MEASURES

In 2002, President Bush set an ambitious but achievable national goal to reduce the greenhouse gas intensity—that is, emissions per unit of economic output—of the U.S. economy by 18 percent by 2012. At the time, the Administration estimated that achieving this commitment would avoid an additional 106 million metric tons of carbon-equivalent emissions in 2012 compared to the Energy Information Administration's *Annual Energy Outlook 2002* business as usual base case projection, and would result in cumulative savings of more than 500 million metric tons of carbon-equivalent emissions over the decade.

To this end, the Administration is now implementing numerous programs—including partnerships, consumer information campaigns, incentives, and mandatory regulations—that are directed at developing and deploying cleaner, more efficient energy technologies, conservation, biological sequestration, geological sequestration and adaptation. For example, the Department of Energy's (DOE) Climate VISION program and the Environmental Protection Agency's (EPA) Climate Leaders and SmartWay Transport Partnership programs work in voluntary partnership with specific commitments by industry to verifiably reduce emissions. The Department of Agriculture (USDA) is using its conservation programs to provide substantial incentives to increase carbon sequestration in soils and trees, and to reduce methane and nitrous oxide emissions, two additional and potent greenhouse gases, from crop and animal agricultural systems. The Department of Transportation (DOT) has implemented a new fuel economy standard for light trucks, including sport utility vehicles, that is projected to result in significant reductions in CO_2 emissions over the life of the affected vehicles. DOT has also submitted an Administration proposal to Congress for authority to reform the setting and calculation of fuel economy standards for passenger automobiles.

In terms of financial incentives, new tax rules on expensing and dividends are helping to promote substantial new capital investment, including purchases of cleaner, more efficient equipment and facilities. The *Energy Policy Act of 2005* provides for approximately $1.6 billion in tax credits and incentives in fiscal year 2007 to accelerate the market penetration of clean, efficient technologies. For example, the Act also provides tax credits of up to $3,400 for the most highly fuel efficient vehicles such as hybrids and clean diesel. It also establishes 15 new appliance efficiency mandates and a 7.5 billion gallon renewable fuel requirement by 2012.

We expect these efforts will contribute to meeting the President's 18 percent, 10-year goal, which represents an average annual rate of improvement of about 1.96 percent. Data from the Energy Information Administration (EIA) suggest steady progress. Since 2002, EIA reports annual improvements in greenhouse gas emissions intensity of 1.6 percent and 2.1 percent in 2003 and 2004, respectively. Further, a June 2006 EIA preliminary "flash estimate" estimate of energy-related carbon dioxide emissions—which account for about four fifths of total greenhouse gas emissions—shows an improvement in carbon dioxide emissions intensity of 3.3 percent in 2005. Although we are only a few years into the effort, the Nation appears on track to meet the President's goal.

While acting to slow the growth of greenhouse gas emissions in the near-term, the United States is laying a strong scientific and technological foundation to reduce uncertainties, clarify risks and benefits, and develop realistic mitigation options through better integration and management of its climate change related scientific and technological activities. In February 2002, President Bush announced the creation of a cabinet-level Committee on Climate Change Science and Technology Integration, co-chaired by the Secretaries of Commerce and Energy. Two multi-agency programs were established to coordinate federal activities in climate change scientific research and advance the President's vision under his National Climate Change Technology Initiative (NCCTI). These are the U.S. Climate Change Science Program (CCSP), led by the Department of Commerce, and CCTP, led by DOE.

CLIMATE CHANGE SCIENCE PROGRAM[1]

CCSP is an interagency research planning and coordinating entity charged with investigating natural and human-induced changes in the Earth's global environmental system, monitoring, understanding, and predicting global change, and pro-

[1] See: *http://www.climatescience.gov.*

viding a sound scientific basis for national and international decision-making. CCSP combines the near-term focus of the Administration's Climate Change Research Initiative—including a focus on advancing the understanding of aerosols and carbon sources and sinks and improvements in climate modeling—with the breadth of the long-term research elements of the U.S. Global Change Research Program.

In July 2003, CCSP released its *Strategic Plan* for guiding climate research. The plan is organized around five goals: (1) improving our knowledge of climate history, variability, and change; (2) improving our ability to quantify factors that affect climate; (3) reducing uncertainty in climate projections; (4) improving our understanding of the sensitivity and adaptability of ecosystems and human systems to climate change; and (5) exploring options to manage risks associated with climate variability and change. CCSP is now in the process of implementing its 10-year *Plan.* The President's fiscal year 2007 budget request includes $1.715 billion for the climate change science. The knowledge gained through CCSP will be invaluable in helping CCTP plan for needed technology development.

CLIMATE CHANGE TECHNOLOGY PROGRAM[2]

To address the challenges of energy security, economic development, and climate change, there is need for a visionary, long-term perspective. The International Energy Agency estimates there are about two billion people who lack modern energy services. Many countries are focusing efforts on providing power to their citizens. Although projections vary considerably, a tripling of energy demand by 2100 is certainly not unreasonable. When one considers further that energy-related carbon dioxide emissions account for about four fifths of all greenhouse gas emissions, the scale of the challenge becomes apparent. Most anthropogenic greenhouse gases emitted over the course of the 21st century will come from equipment and infrastructure not yet built, a circumstance that poses significant opportunities to reduce or eliminate these emissions.

As we look to the future, providing the energy necessary to power economic growth and development while at the same time reducing greenhouse gas emissions is going to require cost-effective transformational technologies that can fundamentally alter the way we produce and use energy. Given the huge capital investment in existing energy systems, the desired transformation of the global energy system may take many decades. A robust research effort undertaken today can make new, competitive technologies available sooner rather than later and accelerate modernization of capital stock.

Other greenhouse gases from non-energy related sources—methane, nitrous oxides, sulfur hexafluoride, and fluorocarbons, among others—also pose a concern. They have higher warming potentials than carbon dioxide. In aggregate, these gases present a large opportunity to reduce global radiative forcing and, in many cases, the technical strategies to reduce their emissions are straightforward and tractable. Finding ways to mitigate these other greenhouse gases is an important part of CCTP's technology strategy.

The United States is leading the development of many advanced technology options that have the potential to reduce, avoid, or sequester greenhouse gas emissions. CCTP was created in 2002, and subsequently authorized in Title XVI of the *Energy Policy Act of 2005,* to coordinate and prioritize the Federal Government's investment in climate-related technology and to further the President's National Climate Change Technology Initiative (NCCTI). The fiscal year 2007 Budget includes nearly $3 billion for CCTP-related activities.

CCTP's principal aim is to accelerate the development and reduce the cost of new and advanced technologies with the potential to reduce, avoid, or sequester greenhouse gas emissions. It does this by providing strategic direction for the CCTP-related elements of the overall federal technology portfolio. It also facilitates the coordinated planning, programming, budgeting, and implementation of the technology development and deployment aspects of U.S. climate change strategy. CCTP also is assessing different technology options and their potential contributions to reducing greenhouse gas emissions over the short-, mid-, and long-term to help inform budget decisions and priorities.

STRATEGIC PLANNING FOR TECHNOLOGY DEVELOPMENT: CCTP conducts its planning under conditions of uncertainty and across a wide range of possible futures. The pace and scope of needed change will be driven partially by future trends in greenhouse gas emissions that are subject to great a deal of ambiguity. The complex relationships among population growth, economic development, energy demand, mix, and intensity, resource availability, technology, and other variables

[2] See: *http://www.climatetechnology.gov.*

make it impossible to accurately predict future greenhouse gas emissions on a 100-year time scale.

In August 2005, CCTP issued its *Vision and Framework for Strategy and Planning.* This document provides an overall strategy to guide and strengthen our technical efforts to reduce emissions. Shortly thereafter, CCTP released its draft *Strategic Plan* for public review and comment. More than 250 comments were received and addressed. We appreciate the thoughtful comments we received, which have improved the document.

Today, CCTP issues its completed *Strategic Plan.* Building on the guidance in the *Vision and Framework,* the *Strategic Plan* articulates a vision of the role for advanced technology in addressing climate change, defines a supporting mission for CCTP, establishes strategic direction and guiding principles for Federal R&D agencies to use in formulating research and development portfolio, outlines approaches to attain CCTP's strategic goals, and identifies a series of next steps toward implementation.

CCTP's strategic vision has six complementary goals: (1) reducing emissions from energy use and infrastructure; (2) reducing emissions from energy supply; (3) capturing and sequestering CO_2; (4) reducing emissions of non-CO_2 greenhouse gases; (5) measuring and monitoring emissions; and (6) bolstering the contributions of basic science.

Ten federal agencies support a broad portfolio of activities within this framework. Participating federal agencies in CCTP include the Departments of Energy, Agriculture, Commerce, Defense, Health and Human Services, Interior, State, and Transportation, as well as the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation.

The *Strategic Plan* provides a comprehensive, long-term look at the nature of the climate change challenge and its potential solutions. It defines clear and promising roles for advanced technologies by grouping technologies for near-, mid- and long-term deployment. Together these technologies will facilitate meeting CCTP goals. It also outlines a process and criteria for setting priorities by organizing and aligning federal climate change R&D and discusses in detail the current climate change technology portfolio, with links to individual technology roadmaps and goals. CCTP and the participating agencies periodically conduct and support strategic planning exercises to identify gaps and opportunities in climate change technology and realign the portfolio as appropriate.

The *Strategic Plan* also identifies a number of next steps outlining an ambitious agenda for advancing climate change technology development. These include strengthening the Federal R&D portfolio, intensifying basic research support of the applied technology R&D programs, extending international cooperation, and exploring a number of supporting technology policy mechanisms.

Many CCTP activities build on existing work, but the Administration also has expanded and realigned some activities and launched new initiatives in key technology areas to support the CCTP's goals. The President's NCCTI includes 12 discrete activities that could advance technologies to avoid, reduce, or capture and store greenhouse gas emissions on a large scale. The Administration's budget proposal for fiscal year 2007 included $306 million for these NCCTI priorities.

CCTP anticipates that a progression of advanced technologies will be available and enter the marketplace in the near-, mid-, and long-terms. Figure 1 provides a schematic roadmap for the technologies being pursued under CCTP. Readers wishing a fuller explanation of the technology research described below should consult CCTP's *Research and Current Activities and Technology Options for the Near- and Long-Term* reports, both of which are available on the CCTP web page. Short descriptions of each of the NCCTI priorities are also available on the CCTP web page.

FIGURE 1. CCTP ROADMAP FOR CLIMATE CHANGE TECHNOLOGY DEVELOPMENT

	Near-Term	Mid-Term	Long-Term
Goal #1 Energy End-Use & Infrastructure	• Hybrid & Plug-In Hybrid Electric Vehicles • Engineered Urban Designs • High-Performance Integrated Homes • High Efficiency Appliances • High Efficiency Boilers & Combustion Systems • High-Temperature Superconductivity Demonstrations	• Fuel Cell Vehicles and H_2 Fuels • Low Emission Aircraft • Solid-State Lighting • Ultra-Efficient HVACR • "Smart" Buildings • Transformational Technologies for Energy-Intensive Industries • Energy Storage for Load Leveling	• Widespread Use of Engineered Urban Designs & Regional Planning • Energy Managed Communities • Integration of Industrial Heat, Power, Process, and Techniques • Superconducting Transmission and Equipment
Goal #2 Energy Supply	• IGCC Commercialization • Stationary H_2 Fuel Cells • Cost-Competitive Solar PV • Demonstrations of Cellulosic Ethanol • Distributed Electric Generation • Advanced Fission Reactor and Fuel Cycle Technology	• FutureGen Scale-Up • H_2 Co-Production from Coal/Biomass • Low Wind Speed Turbines • Advanced Biorefineries • Community-Scale Solar • Gen IV Nuclear Plants • Fusion Pilot Plant Demonstration	• Zero-Emission Fossil Energy • H_2 & Electric Economy • Widespread Renewable Energy • Bio-Inspired Energy & Fuels • Widespread Nuclear Power • Fusion Power Plants
Goal #3 Capture, Storage & Sequestration	• CSLF & CSRP • Post Combustion Capture • Oxy-Fuel Combustion • Enhanced Hydrocarbon Recovery • Geologic Reservoir Characterization • Soils Conservation • Dilution of Direct Injected CO_2	• Geologic Storage Proven Safe • CO_2 Transport Infrastructure • Soils Uptake & Land Use • Ocean CO_2 Biological Impacts Addressed	• Track Record of Successful CO_2 Storage Experience • Large-Scale Sequestration • Carbon & CO_2 Based Products & Materials • Safe Long-Term Ocean Storage
Goal #4 Other Gases	• Methane to Markets • Precision Agriculture • Advanced Refrigeration Technologies • PM Control Technologies for Vehicles	• Advanced Landfill Gas Utilization • Soil Microbial Processes • Substitutes for SF_6 • Catalysts That Reduce N_2O to Elemental Nitrogen in Diesel Engines	• Integrated Waste Management System with Automated Sorting, Processing & Recycle • Zero-Emission Agriculture • Solid-State Refrigeration/AC Systems
Goal #5 Measure & Monitor	• Low-Cost Sensors and Communications	• Large Scale, Secure Data Storage System • Direct Measurement to Replace Proxies and Estimators	• Fully Operational Integrated MM Systems Architecture (Sensors, Indicators, Data Visualization and Storage, Models)

ENERGY USE AND INFRASTRUCTURE: Improving energy efficiency and reducing greenhouse gas emissions intensity in transportation, buildings, and industrial processes can contribute greatly to overall greenhouse gas emission reductions. In addition, improving the electricity transmission and distribution "grid" infrastructure can reduce greenhouse gas emissions by making power generation more efficient of by providing greater grid access for wind and solar power.

Key research activities include FreedomCAR (Cooperative Automotive Research)[3] program, a cost-shared government-industry partnership that is pursuing fuel cell and other advanced automotive technologies. Advanced heavy-duty vehicles technologies, zero-energy homes and commercial buildings, solid-state lighting, and superconducting wires that virtually eliminate electricity transmission losses are other areas of research that could yield significant emissions reduction.

ENERGY SUPPLY: Fossil fuels, which emit CO_2 when burned, remain the world's energy supply of choice. A transition to a low-carbon energy future would, therefore, require the availability of cost-competitive low- or zero-carbon energy supply options. When combined with alternative energy carriers—such as electricity and hydrogen—these options could offer the prospect of considerable reductions in greenhouse gas emissions.

Renewable energy includes a range of different technologies that can play an important role in reducing greenhouse gas emissions. The United States invests considerable resources in wind, solar photovoltaics, and biomass technologies. We have made much progress in price competitiveness of many of these technologies, but there still is a need to reduce their manufacturing, operating, and maintenance costs. For example, new biotechnology breakthroughs offer the potential for extensive domestic production of cellulosic ethanol by both improving feedstocks and increasing the efficiency of converting lignocellulosic material to ethanol. DOE's Office of Science has awarded up to $250 million over five years (subject to appropriations) for two new bioenergy research centers to advance the science needed to develop new cellulosic conversion technologies, which could decrease greatly the greenhouse gas emissions from liquid transportation fuels.[4]

There will be a continuing need for portable, storable energy carriers for heat, power, and transportation. Hydrogen is an excellent energy carrier, produces no

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[3] See: *http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.html*

[4] *See: http://genomicsgtl.energy.gov/centers/index.shtml*

emissions when used in a fuel cell, and can be produced from diverse sources, including renewables, nuclear, and fossil fuels (which in the latter case could be combined with carbon capture). President Bush's $1.2 billion Hydrogen Fuel Initiative[5] is exploring these production options as well as the infrastructure needed to store and deliver hydrogen economically and safely. It is expected that the research being performed under the program will make possible a commercialization decision by industry in 2015 and possible market introduction of hydrogen fuel-cell vehicles by 2020.

The United States has vast reserves of coal, and about half of its electricity is generated from this fuel. Advanced fossil-based power and fuels, therefore, is an area of special interest. The FutureGen[6] project is a 10-year, $1 billion government-industry collaboration—which includes India and the Republic of Korea—to build the world's first near-zero atmospheric emissions coal-fired power plant. This project will incorporate the latest technologies in carbon sequestration, oxygen and hydrogen separation membranes, turbines, fuel cells, and coal-to-hydrogen gasification. This research can help coal remain part of a diverse, secure, and environmentally acceptable energy portfolio well into the future.

Concerns over resource availability, energy security, and air quality as well as climate change suggest a larger role for nuclear power as an energy supply choice. The Generation IV Nuclear Energy Systems Initiative[7] is investigating the next-generation reactor and fuel cycle systems that represent a significant leap in economic performance, safety, and proliferation-resistance. While the primary focus for developing a next-generation reactor is on producing electricity in a highly efficient manner, there is also the possibility of coupling a reactor with advanced technology that would allow for the production of hydrogen. These advanced technologies are being developed under the Nuclear Hydrogen Initiative[8] and could possibly enable the production of hydrogen on a scale to meet transportation needs.

Fusion energy[9] is a way to generate power that, if successfully developed, could be used to produce electricity and possibly hydrogen. Fusion has features that make it is an attractive option from both an environmental and safety perspective. However, the technical hurdles of fusion energy are very high, and with a commercialization objective of 2050, its potential impact would be in the second half of the century.

In his 2006 State of the Union Address, President Bush outlined plans for an Advanced Energy Initiative (AEI).[10] AEI aims to accelerate the development of advanced technologies that could change the way American homes, businesses, and automobiles are powered. AEI is designed to take advantage of technologies that with a little push could play a big role in helping to reduce the Nation's use of foreign sources of energy and its pollution and greenhouse gas emissions. AEI includes greater investments in near-zero atmospheric emissions coal-fired plants, solar and wind power, nuclear energy, better battery and fuel cell technologies for pollution-free cars, and cellulosic biorefining technologies for biofuels production.

CARBON SEQUESTRATION: Carbon capture and sequestration is a central element of CCTP's strategy because for the foreseeable future, fossil fuels will continue to be among the world's most reliable and lowest-cost form of energy. A realistic approach, then, is to find ways to "sequester" the CO_2 produced when these fuels—especially coal—are used. The phrase "carbon sequestration" describes a number of technologies and methods to capture, transport, and store CO_2 or remove it from the atmosphere.

Advanced techniques to capture gaseous CO_2 from energy and industrial facilities and store it permanently in geologic formations are under development. The Department of Energy's core Carbon Sequestration Program[11] emphasizes technologies that capture CO_2 from large point sources and store the emissions in geologic formations that potentially could hold vast amounts of CO_2.

Terrestrial sequestration—removing CO_2 from the atmosphere and sequestering it in trees, soils, or other organic materials—has proven to be a low-cost means for long-term carbon storage. The Carbon Sequestration in Terrestrial Ecosystems consortium, supported by DOE's Office of Science, provides research on mechanisms that can enhance terrestrial sequestration.

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[5] See: *http://www.eere.energy.gov/hydrogenandfuelcells/presidents—initiative.html*
[6] See: *http://fossil.energy.gov/programs/powersystems/futuregen/index.html*
[7] See: *http://gen-iv.ne.doe.gov*
[8] See: *http://nuclear.gov/hydrogen/hydrogenOV.html*
[9] See: *http://www.sc.doe.gov/Program—Offices/fes.htm*
[10] See: *http://www.whitehouse.gov/stateoftheunion/2006/energy/index.html*
[11] See: *http://fossil.energy.gov/programs/sequestration/index.html*

In 2003, DOE launched a nationwide network of seven Carbon Sequestration Regional Partnerships[12] that include 40 states, four Canadian Provinces, three Indian Nations, and over 300 organizations. The partnerships' main focus is on determining the best approaches for sequestration in their regions, and they also will examine regulatory and infrastructure needs. Small-scale validation testing of 35 sites involving terrestrial and geologic sequestration technologies began in 2005, and will continue until 2009.

NON-CARBON DIOXIDE GREENHOUSE GASES: A main component of the U.S. strategy is to reduce other greenhouse gases, such as methane, nitrous oxides (N_2O), sulfur hexafluoride (SF_6), and fluorocarbons, among others.

Improvements in methods and technologies to detect and either collect or prevent methane emissions from various sources—such as landfills, coal mines, natural gas pipelines, and oil and gas exploration operations—can prevent this greenhouse gas from escaping to the atmosphere.[13] In agriculture, improved management practices for fertilizer applications and livestock waste can reduce methane and N_2O emissions appreciably.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and SF_6 are all high global warming potential (High GWP) gases. HFCs and PFCs are used as substitutes for ozone-depleting chlorofluorocarbons and are used in or emitted during complex manufacturing processes. Advanced methods to reduce the leakage of, reuse, and recycle these chemicals and lower GWP alternatives are being explored.

Programs aimed at reducing particulate matter have led to significant advances in fuel combustion and emission control technologies to reduce U.S. black carbon aerosol emissions. Reducing emissions of black carbon, soot, and other chemical aerosols can have multiple benefits, including better air quality and public health and reduced radiative forcing.

MEASURING AND MONITORING: To meet future greenhouse gas emissions measurement requirements, a wide array of sensors, measuring platforms, monitoring and inventorying systems, and inference methods are being developed. Many of the baseline measurement, observation, and sensing systems used to advance climate change science are being developed as part of CCSP. CCTP's efforts focus primarily on validating the performance of various climate change technologies, such as in terrestrial and geologic sequestration.

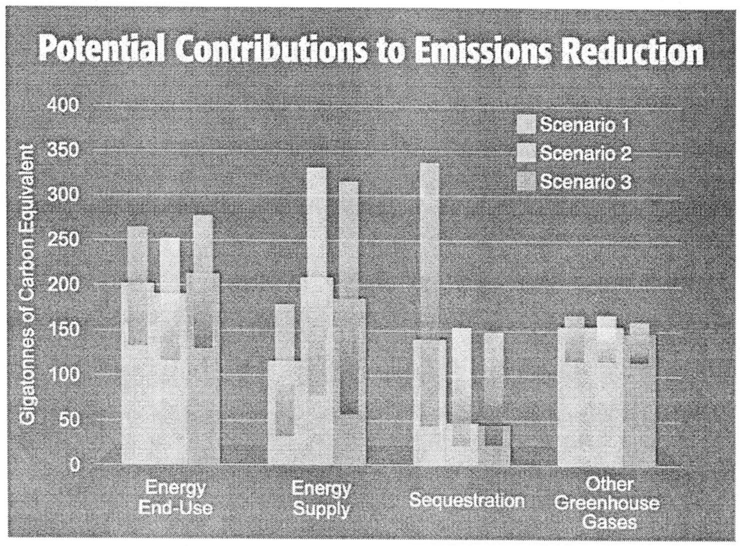
BASIC SCIENCE: Basic scientific research is a fundamental element of CCTP. Meeting the dual challenges of addressing climate change and meeting growing world energy demand is likely to require discoveries and innovations that can shape the future in often unexpected ways. The CCTP framework aims to strengthen the basic research enterprise through strategic research that supports ongoing or projected research activities and exploratory research involving innovative concepts.

SCENARIO ANALYSIS: CCTP uses scenario analyses that incorporate various assumptions about the future to clarify the potential role of climate change technologies and to aid in portfolio planning. Scenarios analyses can provide a relative indication of the potential climate change benefits of a particular technology mix compared to others, and it can help determine which classes of technology would most likely provide larger-scale benefits. Figure 2 offers a glimpse of the range of emissions reductions new technologies in energy end use, energy supply, carbon sequestration, and other non-CO_2 greenhouse gases may make possible on a 100-year scale and across a range of uncertainties and constraints.

[12] See: *http://fossil.energy.gov/programs/sequestration/partnerships/index.html*

[13] Reducing methane emissions may also have a positive benefit in reducing local ozone problems, as methane is an ozone precursor.

FIGURE 2: POTENTIAL CONTRIBUTIONS TO EMISSIONS REDUCTIONS



Potential ranges of greenhouse gas emissions reductions to 2100 by category of activity for three technology scenarios characterized by: viable carbon sequestration (Scenario 1); dramatically expanded nuclear and renewable energy (Scenario 2); and novel and advanced technologies (Scenario 3). Note also the consistently large potential reductions in other greenhouse gas emissions under all three scenarios (CCTP 2006).

INTERNATIONAL COLLABORATIONS

The United States believes that well-designed multilateral collaborations focused on achieving practical results can accelerate development and commercialization of new technologies. The U.S. has initiated or joined a number of multilateral technology collaborations in hydrogen, carbon sequestration, nuclear energy, and fusion that address many energy-related concerns (e.g., energy security, climate change, environmental protection).

Asia-Pacific Partnership on Clean Development and Climate[14] (APP): Launched formally in January 2006, APP is a multi-stakeholder partnership working to generate practical and innovative projects promoting clean development and the mitigation of greenhouse gases. The six APP partnering nations—Australia, China, India, Japan, South Korea, and the United States—account for about half of the world's economy, energy use, and greenhouse gas emissions. APP is pursuing public-private partnerships to build local capacity, improve efficiency and reduce greenhouse gas emissions, create new investment opportunities, and remove barriers to the introduction of clean energy technologies in the Asia Pacific region. At the ministerial launch, the APP partners created eight task forces in the following areas: (1) cleaner fossil energy; (2) renewable energy and distributed generation; (3) power generation and transmission; (4) steel; (5) aluminum; (6) cement; (7) coal mining; and (8) buildings and appliances. Each Task Force is completing an Action Plan that will serve as blueprint for cooperation and provide a strategic framework for identifying and implementing Partnership activities. The President's fiscal year 2007 budget request includes $52 million to support APP.

[14] See: *http://www.asiapacificpartnership.org*

INTERNATIONAL PARTNERSHIP FOR THE HYDROGEN ECONOMY (IPHE)[15]: In November 2003, representatives from 16 governments gathered in Washington, DC to launch IPHE, a vehicle to coordinate and leverage multinational hydrogen research programs. Moreover, IPHE will develop common recommendations for internationally-recognized standards and safety protocols to speed market penetration of hydrogen technologies. An important aspect of IPHE is maintaining communications with the private sector and other stakeholders to foster public-private collaboration and address the technological, financial, and institutional barriers to hydrogen.

CARBON SEQUESTRATION LEADERSHIP FORUM (CSLF)[16]: CSLF is a U.S. initiative that was established at a ministerial meeting held in Washington, DC, in June 2003. CSLF is a multilateral initiative that provides a framework for international collaboration on sequestration technologies. CSLF has as members 22 governments representing both developed and developing countries.

The Forum's main focus is assisting the development of technologies to separate, capture, transport, and store CO_2 safely over the long-term, making carbon sequestration technologies broadly available internationally, and addressing wider issues, such as regulation and policy, relating to carbon capture and storage. To date, 17 international research projects have been endorsed by the Forum, five of which involve the United States.

GENERATION IV INTERNATIONAL FORUM (GIF)[17]: In July 2001, nine other countries and Euratom joined together under U.S. leadership to charter GIF, a multilateral collaboration to fulfill the objective of the Generation IV Nuclear Energy Systems Initiative. GIF's goal is to develop a fourth generation of advanced, economical, and safe nuclear systems that offer enhanced proliferation-resistance and can be adopted commercially by 2030. Six technologies have been selected as the most promising candidates for future designs, some of which could be commercially ready in the 2020 to 2030 timeframe. GIF countries are jointly preparing a collaborative research program to develop and demonstrate the projects.

ITER[18]: In January 2003, President Bush announced that the U.S. was joining the negotiations for the construction and operation of the international fusion experiment called ITER. ITER is a proposed multilateral collaborative project to design and demonstrate a fusion energy production system. If successful, this multi-year, multi-billion dollar project will advance progress toward determining whether fusion technology can produce clean, abundant, commercially available energy by the middle of the century.

GLOBAL NUCLEAR ENERGY PARTNERSHIP (GNEP)[19]: GNEP has two major goals: (1) expand carbon-free nuclear energy to meet growing electricity demand worldwide; and (2) promote non-proliferation objectives through the leasing of nuclear fuel to countries which agree to forgo enrichment and reprocessing. A more fully closed fuel cycle model envisioned by this partnership requires development and deployment of technologies that enable recycling and consumption of long-lived radioactive waste. The GNEP initiative proposes international partnerships and significant cost-sharing to achieve these goals.

Methane to Markets: The Methane to Markets Partnership is another highly practical major element in the series of international technology partnerships advanced by the Administration. Launched in November 2004, the Methane to Markets Partnership focuses on advancing cost effective, near-term methane recovery and use as a clean energy source from coal beds, natural gas facilities, landfills, and agricultural waste management systems. The Partnership will reduce global methane emissions to enhance economic growth, promote energy security, improve the envi-

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[15] See: *http://www.iphe.net.* IPHE members include the United States, Australia, Brazil, Canada, China, European Commission, France, Germany, Iceland, India, Italy, Japan, New Zealand, Norway, Republic of Korea, Russian Federation, and United Kingdom.

[16] See: *http://www.cslforum.org.* CSLF members include the United States, Australia, Brazil, Canada, China, Colombia, Denmark, European Commission, France, Germany, Greece, India, Italy, Japan, Korea, Mexico, Netherlands, Norway, Russian Federation, Saudi Arabia, South Africa, and United Kingdom.

[17] See: *http://gen-iv.ne.doe.gov/GENIVintl-gif.asp.* GIF member countries include the United States, Argentina, Brazil, Canada, France, Japan, Korea, South Africa, Switzerland, and United Kingdom.

[18] See: *http://www.iter.org.* ITER members include the United States, China, EU, India, Japan, Russian Federation, and Republic of Korea.

[19] See: *http://www.gnep.energy.gov*

ronment, and reduce greenhouse gas emissions. Other benefits include improving mine safety, reducing waste, and improving local air quality.

CLOSING OBSERVATIONS

The United States, in partnership with others, has embarked on an ambitious undertaking to develop new and advanced climate change technologies that have the potential to transform the economic activities that give rise to greenhouse gas emissions. CCTP's *Strategic Plan* sets out an overall strategy to guide and strengthen our technical efforts to reduce emissions, articulates a vision of the role for advanced technology in addressing climate change, and provides a long-term planning context in which the nature of both the challenges and the opportunities for advanced technologies are illuminated and balanced.

Innovations can be expected to change the ways in which the world produces and uses energy, performs industrial processes, grows crops and livestock, manages carbon dioxide, and uses land. In keeping with U.S. climate change strategy, which is consistent with the United Nations' Framework Convention, these technologies could both enable and facilitate a gradual shift toward significantly lower global greenhouse gas emissions. They would also continue to provide the energy-related and other services needed to spur and sustain economic growth.

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CCTP 2006—U.S. Climate Change Technology Program, *Strategic Plan,* Chapter 3, "Synthesis Assessment of Long-term Climate Change Technology Scenarios," (Washington, DC: CCTP). Available at: *www.climatetechnology.gov*

Table A-1 CCTP Participating Agency – FY 2005 to FY 2007 Budgets and Requests Categorization of RDD&D Funding To Climate Change Technology (Funding, $ Millions) [5,6]

DEPARTMENT AND ACCOUNT(S)	FY 2005 ENACTED	FY 2006 ENACTED	FY 2007 REQUEST
Department of Agriculture			
Natural Resources Conservation Service (NRCS) – Biomass R&D (Section 9008 Farm Bill)	13.0	12.0	12.0
– NRCS Carbon Cycle	0.5	0.5	0.5
Forest Service R&D – inventories of carbon biomass	0.0	0.5	0.5
Agricultural Research Service – Bioenergy Research	2.4	2.4	2.4
Cooperative State Research, Education and Extension Service (CRSEES) – Biofuels/Biomass Research; formula funds, National Research Initiative	4.7	4.7	3.4
Forest Service – Biofuels/Biomass, Forest and Rangeland Research	2.4	2.4	2.8
Rural Business Service – Renewable Energy Program and Value Added Prducer Grants	24.8	25.3	12.7
Subtotal – USDA	**48.2**	**47.8**	**34.2**
Department of Commerce - ITA			
International Trade Administration (ITA) - Asia Pacific Partnership	0.0	0.0	2.0
Subtotal – DOC/ITA	**0.0**	**0.0**	2.0
Department of Commerce - NIST			
National Institute of Standards and Technology (NIST) Scientific and Technological Research and Services	7.7	7.2	7.2
Industrial Technical Services – Advanced Technology Program	18.1	10.3	0.0
Subtotal – DOC/NIST	**25.8**	**17.4**	**7.2**
Department of Defense			
Army	27.0	36.5	5.5
Navy	18.1	23.4	6.9
Air Force	1.0	0.0	0.0
Defense Advanced Research Projects Agency (DARPA)	11.0	7.1	3.0
R&D, Office of Secretary of Defense	2.0	3.6	0.0
Subtotal – DOD	**59.1**	**70.6**	**15.4**
Department of Energy			
Energy Efficiency and Renewable Energy (EERE)	1,234.3	1,174.0	1,176.3
Fossil Energy	373.8	404.5	419.1
Nuclear Energy	291.4	332.5	463.3
Science	385.5	422.6	551.4
Electricity Delivery and Energy Reliability	57.4	73.0	100.3
Climate Change Technology Program	0.0	0.0	1.0
Subtotal – DOE	**2,342.4**	**2,406.5**	**2,711.4**

5 This table is consistent with the FY 2007 "Federal Climate Change Expenditures Report to Congress" prepared by the Office of Management and Budget, http://www.whitehouse.gov/omb/, and published in April 2006. Minor differences, if any, are due to arithmetic corrections after the OMB report was finalized and due to differences in rounding.

6 All Agency data are current, as of April 2006. Totals may not add due to rounding.

7 In FY 2005, $1.5M was enacted for CCTP Program Direction within DOE's EERE Program Direction account.

DEPARTMENT AND ACCOUNT(S)	FY 2005 ENACTED	FY 2006 ENACTED	FY 2007 REQUEST
Department of Interior			
US Geological Survey – Surveys, Investigations and Research - Geology Discipline, Energy Program	2.4	0.0	0.0
Subtotal – DOI	**2.4**	**0.0**	**0.0**
Department of Transportation			
Office of the Secretary for Technology – Transportation, Policy, R&D	0.8	0.0	0.0
National Highway Traffic Safety Admin	0.0	0.9	0.9
Research and Innovative Technology Admin	0.5	0.5	0.5
Subtotal – DOT	**1.3**	**1.4**	**1.4**
Environmental Protection Agency			
Environmental Programs and Management	90.5	90.0	91.9
Science and Technology	19.0	18.6	12.5
Subtotal – EPA	**109.5**	**108.6**	**104.4**
National Aeronautics and Space Administration[8]			
Exploration, Science & Aeronautics	207.8	104.4	85.8
Subtotal – NASA	**207.8**	**104.4**	**85.8**
National Science Foundation			
Research and Related Activities	10.6	17.7	18.6
Subtotal – NSF	**10.6**	**17.7**	**18.6**
Total for CCTP	**2,807.1**	**2,774.4**	**2,980.4**

ACTIVITIES ASSOCIATED WITH CCTP[9]

USAID Activities Associated with CCTP			
Energy Technology Development	80.1	92.0	57.3
Carbon Capture and Sequestration Measures	87.3	80.3	71.7
Subtotal – USAID	**167.5**	**172.2**	**129.0**
Department of State Activities Associated with CCTP			
Asia Pacific Partnership	0.0	0.0	30.0
Methane to Markets	0.8	6.0	6.0
Subtotal - STATE	**0.8**	**6.0**	**36.0**
Total CCTP and Associated Activities	**2,975.3**	**2,952.6**	**3,145.4**

8 For FY 2006 and FY 2007, NASA is realigning its Aeronautics Research and is no longer pursuing previously reported activities in certain vehicle systems areas.

9 STATE and USAID activities are not included in the totals for CCTP, as they are associated expenditures promoting deployment and adoption of climate change technologies abroad. They are shown here for completeness to the extent that such activities are consistent with the criteria for inclusion in CCTP.

BIOGRAPHY FOR STEPHEN D. EULE

Stephen D. Eule is the Director of the Climate Change Technology Program in the Office of Policy and International Affairs at the U.S. Department of Energy. Mr. Eule also manages DOE's participation in the Climate VISION program and the Asia-Pacific Partnership on Clean Development and Climate, and he represents the Department at various international fora on climate change.

Before joining DOE in June 2003, Mr. Eule spent a decade working in various public policy positions. He spent a number of years in the U.S. House of Representatives, first as a professional staffer and then Subcommittee Staff Director, with the Committee on Science and then as Legislative Director in the personal office of Representative Nick Smith (R–MI). He also served in Christie Todd Whitman's Washington Office as an environmental analyst. Previous to that, he spent about eight years with The Orkand Corporation as an energy consultant to the Energy Information Administration. His experience also includes a stint with the Heritage Foundation, where he was Assistant Editor on the book *Free Market Energy*.

Mr. Eule earned a Master of Arts degree in geography from The George Washington University and a Bachelor of Science degree in biology from Southern Connecticut State College.

Chairwoman BIGGERT. Thank you very much. Ms. Greenwald, you are recognized for five minutes. Push the button on the——

STATEMENT OF MS. JUDITH M. GREENWALD, DIRECTOR OF INNOVATIVE SOLUTIONS, PEW CENTER ON GLOBAL CLIMATE CHANGE

Ms. GREENWALD. Thank you. Madam Chair and Members of the Subcommittee, thank you for the opportunity to testify. My name is Judi Greenwald, and I am the Director of Innovative Solutions for the Pew Center of Global Climate Change.

The Pew Center believes that there are three things we in the United States must do to reduce the real and growing risks posed by global climate change. First, we must enact and implement a comprehensive national program to progressively and significantly reduce U.S. emissions of greenhouse gases in a manner that contributes to sustained economic growth. Given that the U.S. greenhouse gas emissions have risen steadily despite 15 years of voluntary efforts, the national program will need to include mandatory reductions.

Second, the United States must work with other countries to establish an international framework that engages all the major greenhouse gas emitting nations in a fair and effective long-term effort to protect our global climate. Third, we must strengthen our efforts to develop and deploy climate-friendly technologies, and to diffuse those technologies on a global scale.

In your invitation, you asked me to address three specific questions. First, what do you see as the key strengths and weaknesses of the U.S. Climate Technology Program's strategic plan? While the draft strategic plan provides a fine overview of greenhouse gas reducing technologies and the opportunities each could present over the long-term, it does not provide a plan for deploying these technologies, nor does it provide a path to stabilizing concentrations of greenhouse gases.

The technologies considered in the plan are vitally important. However, merely compiling information about them is not sufficient to ensure their widespread penetration into the marketplace. Markets work when individuals can balance out their own costs and benefits. As with many environmental problems, individuals generally don't receive financial benefits from taking action on climate change. There is clearly a value to society of maximizing climate change—of minimizing damaging climate effects, but the market does not capture that benefit for those who bear the costs.

Therefore, simply creating a supply of carbon reduction technologies does not mean that there will be a demand for them. A mandatory constraint on emissions, on the other hand, will make emission reductions financially valuable to the individual producing them, creating a demand for emissions reducing technologies in the marketplace.

Your second question was will the CCTP enable the Administration to meet its goal of cutting greenhouse gas intensity by 18 percent by 2012, and does the CTCP put the United States on a path to stabilizing greenhouse gas emissions? Our response is that the draft plan is likely quite adequate for meeting the current goal of 18 percent reduction in intensity, but that is only because the goal largely reflects business as usual.

But neither the plan nor the 18 percent intensity reduction goal will put the U.S. on a path to stabilizing greenhouse gas emissions. Even if this intensity goal is met, emissions will continue to rise, rather than stabilize. Interestingly, DOE only examined scenarios with emissions constraints to determine the estimates of the technologies' potential contributions to GHG reductions. Thus, DOE's own analysis confirms what those who seriously examine this issue know, that potential reductions are driven by the existence of constraints on emissions.

Further, any effort to reduce emissions should be achieved through a combination of technology push, i.e., R&D, with technology pull, i.e., emission constraints. According to a report from the Congressional Budget Office released just this week, a combination of these two policies would be necessary to reduce carbon emissions at the lowest possible cost. Further, they suggest the largest gains in economic efficiency are likely to come from pricing emissions, for example, through a cap and trade program, rather than from funding R&D. Thus, the Administration's approach is necessary, but not sufficient to achieve stabilization.

Your last question was does the draft strategic plan provide a sound framework? The Pew Center is pleased to see that the plan does not pick winners, but rather, it examines a broad portfolio of technologies that have the potential to reduce emissions on a large scale, making the most cost-effective technologies available for reductions in the future.

The Pew Center supports the portfolio planning and investment criteria that the CCTP uses to evaluate various technologies, maximizing return on investment, supporting public-private partnerships, focusing on technology with large scale potential, and sequencing R&D investments in a logical developmental order are essential in determining what technologies to support.

In addition to the evaluation of known technologies, we believe that efforts to explore new and innovative opportunities should also be promoted. We would also like to see greater assurance that DOE's many programs will be adequately funded on a sustained basis.

I thank and commend the Chair and the Subcommittee for holding this hearing, and for the opportunity to testify. The Pew Center looks forward to working with the Subcommittee in its oversight capacity, and on the development, enactment, and implementation of any future climate change legislation.

Thank you.

[The prepared statement of Ms. Greenwald follows:]

PREPARED STATEMENT OF JUDITH M. GREENWALD

Madam Chair and Members of the Subcommittee, thank you for the opportunity to testify on the U.S. Department of Energy's plan for climate change technology programs. My name is Judi Greenwald, and I am the Director of Innovative Solutions for the Pew Center on Global Climate Change.

The Pew Center on Global Climate Change is a non-profit, non-partisan and independent organization dedicated to providing credible information, straight answers and innovative solutions in the effort to address global climate change.[1] Forty-one major companies participate in the Pew Center's Business Environmental Leadership Council (BELC), making the BELC the largest U.S.-based association of corporations focused on addressing the challenges of climate change. Many different sectors are represented, from high technology to diversified manufacturing; from oil and gas to transportation; from utilities to chemicals. These companies represent $2 trillion in market capitalization, employ over three million people, and work with the Center to educate the public on the risks, challenges and solutions to climate change.

Global climate change is real and likely caused mostly by human activities. While uncertainties remain, they cannot be used as an excuse for inaction. To quote the National Academy of Sciences, in a statement signed by the academies of ten other nations, as well: "The scientific understanding of climate change is now sufficiently clear to justify nations taking prompt action. It is vital that all nations identify cost-effective steps that they can take now, to contribute to substantial and long-term reduction in net global GHG emissions."

The Pew Center believes there are three things we in the United States must do to reduce the real and growing risks posed by global climate change: First, we must enact and implement a comprehensive national program to progressively and significantly reduce U.S. emissions of greenhouse gas (GHG) emissions in a manner that contributes to sustained economic growth. Given that U.S. GHG emissions have risen steadily despite fifteen years of voluntary efforts to reduce them, any such national program must include mandatory reductions. Second, the United States must work with other countries to establish an international framework that engages all the major GHG-emitting nations in a fair and effective long-term effort to protect our global climate. Third, we must strengthen our efforts to develop and deploy climate-friendly technologies and to diffuse those technologies on a global scale.

I would like to address the questions you posed to me directly first:

1. What do you see as the key strengths and weaknesses of the plan?

While the draft Strategic Plan provides a fine overview of GHG-reducing technologies and the opportunities each could present over the long-term, it does not provide a plan for deploying these technologies, nor does it provide a path to stabilizing concentrations of GHGs. The technologies considered in the Plan are vitally important; however, merely compiling information about them is not sufficient to ensure their widespread penetration into the marketplace.

Markets work when individuals can balance out their own costs and benefits. As with many environmental problems, individuals generally do not receive financial benefits from taking action on climate change. There is clearly a value to society in minimizing damaging climate effects, but the market does not capture that benefit for those who bear the costs. Therefore, simply creating a supply of carbon-reduction technologies does not mean there will be a demand for them. A mandatory constraint on emissions, on the other hand, will make emissions reductions financially valuable to the individuals producing them, creating a demand for emissions-reducing technologies in the marketplace.

The estimates of the technologies' potential contributions to emissions reductions in the Strategic Plan are derived from a report prepared by the Pacific Northwest National Laboratory. The report, "Climate Change Technology Scenarios: Energy,

[1] For more on the Pew Center, see *www.pewclimate.org*

Emissions and Economic Implications,"[2] considers a range of energy scenarios accompanied by a range of possible emissions constraints. Three hypothetical scenarios are included, along with a reference (business-as-usual) scenario. The three scenarios are each evaluated for four different emissions-constrained cases of varying levels of stringency. Only the reference scenario is considered under a "no emissions constraint" case. Yet the reference scenario with no emissions constraint—the situation that best matches the current U.S. technology market and policy direction—is not noted in the Strategic Plan. Instead, only the analyses that include emissions constraints—an approach contrary to current U.S. policy—are included in the estimates of the technologies' potential contributions to GHG reductions. This makes it impossible to evaluate the likelihood of the Plan's success under current policies, and also supports what most people who seriously examine this issue know—that potential reductions are driven by the existence of constraints on emissions and the demand for technology to deal with those constraints, rather than purely on the federal effort invested in technology research and development.

A combination of technology "pushing" activities (such as those discussed in DOE's plan) with technology "pulling" legislation that mandates reductions of U.S. GHG emissions would be the most effective and efficient way to deploy climate-friendly technology throughout the economy. Our analysis indicates that combining push and pull will give better results than relying on either alone: studies indicate, for example, that combining R&D incentives with carbon caps will cost the economy an order of magnitude less than relying on either R&D incentives or emissions reduction policies alone.[3]

2. Will the CCTP enable the Administration to meet its goal of cutting GHG intensity by 18 percent by 2012? Does the CCTP put the United States on a path to stabilizing GHG emissions?

The Plan is likely quite adequate for meeting the current goal of 18 percent reduction in intensity, but that is only because the goal largely reflects business as usual. But neither the Plan nor the 18 percent intensity reduction goal will put the U.S. on a path to stabilizing GHG emissions. Even if this goal is met, emissions will continue to rise rather than stabilize.

It should also be noted that the U.S. commitment under the UN Framework Convention on Climate Change, which is noted in the Plan, is not to stabilize emissions, but rather to stabilize atmospheric concentrations of GHGs. The UNFCCC commitment further specifies that concentrations should be stabilized "at a level that would prevent dangerous anthropogenic interference with the climate system."[4] While there is not yet a global consensus on the concentration at which this would occur, it is important to consider the full extent of this commitment in evaluating the Plan's success in achieving it. Impacts generally considered to indicate dangerous interference range from the disintegration of the Greenland ice sheet, eventually raising sea levels by as much as 20 feet,[5] increased hurricane intensity, compounding the danger to millions of citizens in the Southeast and Gulf coasts,[6] depleted water resources in the Western United States due to reductions in winter snow pack,[7] and the threat of extinction of thousands of species,[8] particularly those dependent on highly sensitive habitat (for example, polar bears, threatened by the melting of the arctic ice pack; pika, threatened by the desiccation of alpine meadows, and corals threatened by thermal stress and ocean acidification). Most experts now believe that a doubling of CO_2 concentrations (i.e., around 550 ppm) is too high to avoid dangerous interference with the climate system, such as the impacts just listed. We do not know what a safe level is, though many are proposing 450 ppm as a level that has potential to avoid large-scale effects on the climate. (See Schellnhuber, Cramer, Nakicenovic, Wigley and Yohe, 2006, "Avoiding Dangerous Climate Change," Cambridge University Press.)

While it is understandable that the CCTP has not chosen a specific atmospheric concentration of GHGs to be achieved—this is not its charge—the absence of such

[2] Placet, M., K.K. Humphreys, N.M. Mahasenan. 2004. "Climate Change Technology Scenarios: Energy, Emissions and Economic Implications," Pacific Northwest National Laboratory, August 2004.

[3] See *Induced Technological Change and Climate Policy,* Lawrence H. Goulder, Pew Center on Global Climate Change, Arlington, Virginia, October 2004.

[4] *http://unfccc.int/essentialG5–background/convention/background/items/1349.php*

[5] Alley, R.B., et al., 2005. "Abrupt Climate Change."

[6] Emanuel, K., et al., 2005. "Increasing destructiveness of tropical cyclones over the past 30 years."

[7] Mote, P. et al., 2003. "Preparing for climatic change: The water, salmon, and forecasts of the Pacific Northwest."

[8] Thomas, C.D., et al., 2004. "Climate change and extinction risk."

a target in the Nation's strategy presents another difficulty in assessing the Plan's likelihood of success. While a 450 ppm constraint is considered in the Plan, it is the most stringent of all options considered. The other cases involve concentrations well above this level (up to 750 ppm—almost a tripling of pre-industrial levels) and have a large potential to reflect dangerous anthropogenic interference. Given the Plan's consideration of a range of potential stabilization targets, it would be far more helpful if the Plan described the pace and scale of deployment that would be needed to achieve each of the targets considered. A strategy for CO_2 stabilization at 450 ppm might look very different from a strategy for stabilization at 750 ppm, but those differences would not become evident unless the paths to the targets are outlined. This would aid policy-makers in understanding the technological implications of various targets that might be adopted, as well as aid the CCTP in choosing its technology priorities.

Unfortunately, while the Plan gives a fine overview of GHG-reducing technologies and the role that each could play, the analysis of potential reductions is limited to scenarios that do not match current conditions or stated policy directions. As demonstrated in the estimates made in this Plan, it is mandatory emissions constraints in conjunction with technology investment—rather than technology investment alone—that will spur technology deployment and diffusion. In the absence of these constraints, the potential reductions outlined in this Plan will not be achieved.

3. Does the draft strategic plan provide an integrated framework of sound guidance, clear goals and next steps for agencies and researchers to use when prioritizing and selecting future research efforts? If so, please explain. If not, how should the Administration set R&D investment priorities among various climate change technologies and CCTP agencies?

The Pew Center is pleased to see that the plan does not pick winners, but rather it examines a broad portfolio of technologies that have the potential to reduce emissions on a large scale, making the most cost-effective technologies available for reductions in the future. The Pew Center supports the Portfolio Planning and Investment Criteria that the CCTP uses to evaluate various technologies: maximizing return on investment, supporting public-private partnerships, focusing on technology with large-scale potential, and sequencing R&D investments in a logical, developmental order are essential in determining what technologies to support. In addition to this evaluation of known technologies, efforts to explore new and innovative opportunities should also be promoted. The small portion of section 9 that describes the importance of doing exploratory research aimed at pursuing novel concepts not elsewhere covered should be given more emphasis. The fact remains that, while there are myriad technologies that we currently know can contribute to GHG emissions over the long-term, it may be technologies that have not yet been discovered that will have the most impact. With accommodations for these unknown opportunities, the report acts as a useful summary of the current and future technologies that may have a significant impact on reducing carbon emissions if deployed.

Regarding your overarching questions 1 and 2, please see my response to questions 2 and 3 above. I would like to address your third overarching question specifically.

3. How could the CCTP plan be improved? What next steps are needed to implement a clear climate change technology strategy?

The U.S. Department of Energy is doing a good job in running a rational research and development program for technologies that are likely to contribute to solving the climate change problem in the future. As mentioned, however, what is lacking is an emphasis on deployment. Technologies that sit on the shelf are not useful. Deployment depends on private companies deciding to use these new technologies rather than their old, more carbon-intensive technologies. Without a mandatory GHG constraint, private companies do not have sufficient incentives to do so. The end result is an increase in technology innovation but little demand for those technologies in the market.

Finally, the technology initiatives discussed in the plan can only be effective if they are adequately funded and managed, and implemented with some urgency. DOE and the other federal agencies run a mind-boggling collection of programs that could promote climate-friendly technologies. There are numerous domestic and internationally focused programs, many of these intended to advance the climate-friendly technologies we would want deployed, including the Asia-Pacific Partnership, Climate Leaders, Climate VISION, Climate Challenge, Clean Cities, the Hydrogen Fuel Initiative, the Carbon Sequestration Leadership Forum, the

Methane-to-Markets Partnership, the Industrial Technology Project, the SmartWay Transport Partnership, the Partnership for a Hydrogen Economy, FreedomCAR, Energy STAR, Generation IV Nuclear Initiative, Vision 21, 21st Century Truck, Nuclear Power 2010, ITER22, FutureGen, Future Fuel Cells, Industries of the Future, and Turbines of Tomorrow.

While it is difficult to tell exactly how much has been budgeted for each of these programs, according to the Administration's Federal Climate Change Expenditures Report to Congress (April 2006), the total FY 2006 budget authority for all CCTP initiatives amounts to about $2.8 billion, with a $207 million increase proposed for 2007. This increase is a step in the right direction, but it is not enough. In addition, it is crucial not just that these initiatives be funded, but that they be funded in a long-term, stable way—even forward-funded—to ensure that research managers are able to make the kind of plans that large-scale technology development requires.

Related to this is the challenge of implementing so many initiatives on a timely basis. Because it is far easier to explain to the press and public the launch of an initiative than to explain the boring details of its implementation, the political rewards of launching initiatives greatly outweigh those of implementation. Our sense is that DOE and the other federal agencies are doing a good job implementing these programs, but we are concerned that the Administration may not be placing sufficient priority on them.

It would be a shame if three years from now, in another oversight hearing, we learned that all these programs were under funded and given insufficient priority within the Administration. We simply cannot afford to lose the time.

I thank and commend the Chair and the Subcommittee for holding this hearing and for the opportunity to testify. The Pew Center looks forward to working with the Subcommittee in its oversight capacity and on the development, enactment and implementation of any future climate change legislation.

Biography for Judith M. Greenwald

Judi Greenwald is the Director of Innovative Solutions of the Pew Center on Global Climate Change. She oversees the Solutions program and develops mechanisms for learning about and promoting innovative solutions—including research, publications, web-based information and data bases, and workshops. Ms. Greenwald focuses on business solutions, state and regional solutions, and technological innovation.

Ms. Greenwald has over 20 years of experience working on energy and environmental policy. Prior to coming to the Pew Center, she worked as a consultant, focusing on innovative approaches to solving environmental problems, including climate change. She also served as a senior advisor on the White House Climate Change Task Force. As a member of the professional staff of the U.S. Congress Energy and Commerce Committee, she worked on the 1990 *Clean Air Act Amendments,* the 1992 *Energy Policy Act,* and a number of other energy and environmental statutes. She was also a Congressional Fellow with then-Senate Majority Leader Robert C. Byrd, an environmental scientist with the U.S. Nuclear Regulatory Commission, and an environmental engineer and policy analyst at EPA.

Ms. Greenwald has a Bachelor of Science in Engineering, *cum laude,* from Princeton University, and an M.A. in Science, Technology and Public Policy from George Washington University.

Ms. Greenwald has published papers on the future of water quality monitoring, worker and community adjustment to climate change policy, a multi-media approach to radon, environmental policies affecting the development of newer coal technologies, and the implications for air quality analysis of extended lifetimes for coal-fired boilers.

September 15, 2006

The Honorable Judy Biggert
Chairwoman, Energy Subcommittee
House Committee on Science
Suite 2320, Rayburn House Office Building
Washington DC, 20515-6301

Dear Representative Biggert:

This is to provide a record of financial disclosure according to the Rules of the House of Representatives for testimony at your Subcommittee's Hearing *Department of Energy's Plan for Climate Change Technology Programs* on Wednesday, September 20, 2006.

The Pew Center on Global Climate Change receives no federal funding.

Sincerely,

Judi Greenwald
Pew Center on Global Climate Change
2101 Wilson Blvd.
Suite 550
Arlington, VA 22201
703-516-4146

Chairwoman BIGGERT. Thank you, Ms. Greenwald. Mr. Mottershead, you are recognized for five minutes.

STATEMENT OF MR. CHRIS MOTTERSHEAD, DISTINGUISHED ADVISOR ON ENERGY AND THE ENVIRONMENT, BP

Mr. MOTTERSHEAD. Thank you very much, Madam Chairwoman and Members of the Subcommittee. Thank you for inviting BP to give evidence.

We share the overall objective of finding a way to both stabilize atmospheric concentrations of greenhouse gases, as well as maintaining economic growth, and that we believe that technology is a key component of managing delivery of these two objectives.

Moving to the plan, we believe it is comprehensive, it has the necessary breadth, while actually bringing focus to those things that we believe are most likely to deliver reductions. We believe that the greenhouse gases will be reduced by the investments that we make in the future, and I think that the plan clearly reflects that, and perhaps that challenges some of the short-term questions about its relevance to 2012.

Fourthly, we think that it resonates with the activities of BP, and we recognize the activities as they are laid out, and our participation in many of the projects, from solar, to wind, to biofuels, and to carbon capture and storage.

Fourthly, we do believe that it has weaknesses, but they are probably more to do with the context in which the plan has to operate, rather than in the plan itself. Particularly, we agree with Pew that actually to have an effective plan, you have to be clear about what the overall goal is, and therefore, we would encourage a setting of an overall goal, so that we can see that the necessary reductions are being made for stabilization, and that the optimal cost is being delivered through that plan.

Secondly, we believe that actually, innovation happens largely through learning by doing, and that while research is absolutely necessary and underpins activity, actually, the delivery of the plan will be most effective when it is actually borne out by deployment, and therefore, we would like to see more emphasis placed on deployment and diffusion of the technology, as well as further creation.

And finally, we believe that there is a need to better articulate the relative roles of public and private participation in actually determining the overall outcome. And while there are examples of new forms of partnership, we think that they need to be extended in order to fully embrace the creativity of business in delivering the necessary solutions.

So, Madam Chairwoman, thank you very much, and I would be happy to answer questions later.

[The prepared statement of Mr. Mottershead follows:]

PREPARED STATEMENT OF CHRIS MOTTERSHEAD

Madame Chairman, Members of the Subcommittee—thank you for the opportunity today for BP to participate in this discussion about the Administration's approach to climate change-related technology research, development, demonstration and deployment.

BP is involved in many discussions in the U.S. about climate change. Our objective is to establish how we might most effectively contribute to the task of providing the energy that is necessary to underpin economic growth, while avoiding dangerous interference in the climate system. While the debate continues around the long-term goal and identifying a full set of policy options, we should take action where there does appear to be agreement.

One of these areas is technology. Other policy instruments will be necessary to address climate change, but technological innovation is central. The development of the Strategic Plan clearly recognizes this critical role of technology.

The Climate Change Technology Program's Strategic Plan is comprehensive and well considered. It acknowledges the important role of technology in reducing GHG emissions, providing a framework for identifying, developing and deploying technologies.

I would like to briefly touch on what we view as important components of the Plan, and touch upon what we view as opportunities to improve the Plan.

We share the stated ultimate goal of the Strategic Plan—the stabilization of GHG concentrations in the atmosphere at a level that prevents dangerous interference with the climate system. Of course, there are uncertainties in the science, there always will be, but we believe that based on current science it is only prudent to take action. The Strategic Plan is an acknowledgement of this need to take action.

The Plan acknowledges that the overwhelming majority of GHG emissions will be associated with equipment and infrastructure that has yet to be built, but once built will constrain our future options. So while we recognize the importance of getting started, and the need for short-term emission reductions, we believe the primary focus should be on future investment decisions, ensuring that the best technological options are available and used.

By 2030 the world's consumption of electricity is expected to double, as economies grow. However, the power sector is already the largest single source of GHG's emissions, and as demand grows so will emissions. This growth in demand for electricity is a business opportunity, as over half of the power plants that will be needed have yet to be built. The Plan helps to determine what the technological options are for these investments.

The same is true for the transport sector, where we must develop and invest in both the best available vehicle and fuel technology, as well as looking to improve mobility more generally.

The Plan recognizes that we need research on both renewable and fossil fuels. Solar, wind, biofuels and other alternative energy sources one day will be able to meet a significant part of U.S. and world energy demand. But we also need to develop the technology that allows the U.S. to utilize fossil fuels, and particularly coal. Fossil fuels currently supply about 80 percent of all primary energy and will remain fundamental to global and U.S. competitiveness and energy supply for many decades.

BP is taking action in many areas, including major investments in both the power and transport sectors. BP Alternative Energy provides clean power from wind, solar, gas-fired and hydrogen power. We have already committed to investing $8 billion over the next 10 years in this business. We are pleased to see that these alternatives are comprehensively addressed in the Strategic Plan.

As an example let me briefly talk about Carbon Capture and Storage technology, which sits at the heart of our new hydrogen power business. Over the next 10 years BP, in partnership with GE, aims to develop 10 to 15 hydrogen power projects. BP, together with Edison Mission Energy, has already announced its plans for a hydrogen power plant in Southern California, an investment of over $1 billion dollars. The facility will utilize a low value by-product of the refining process, petroleum coke, to generate much needed supplies of electricity to the Southern California market. The project will accomplish this by gasifying the petroleum coke and using the resulting hydrogen to drive a turbine to generate electricity. The CO_2 produced by the process will be transported by pipeline to a California oil field where it will be injected deep underground, both stimulating domestic oil production and permanently storing the CO_2.

Where we see opportunity to improve the Strategic Plan is in increased clarity about the scale of the task, the emphasis we would place on Learning-By-Doing, and finally a clearer definition of the necessary public and private partnership.

While it is not the role of Plan to determine stabilization goal, without one it is difficult to know whether the plan will deliver sufficient emission reductions at an optimal cost.

Many technologies already exist, and we would like to see greater focus upon deployment and diffusion of these technologies, particularly engineering cost reduction, removal of institutional barriers and the building of material new markets. Many barriers are institutional and behavioral and, as such, the social sciences can make a significant contribution.

Finally, the opportunity exists to better define how government will interact with the private sector. Government and business each play key but distinct roles in developing and deploying technology. We would like to see more thought given to encouraging innovative public-private partnerships.

In conclusion, let me say that it would be difficult, if not impossible, to make a determination as to whether the Strategic Plan, by itself, is capable of meeting the President's goal of reducing GHG intensity. The answer to this question depends largely on the level of success of individual technologies, having the proper regulatory frameworks in place, public acceptance, and an environment in which companies can feel comfortable making long-term investments in these technologies at the necessary scale.

What I can say is that the Plan is a helpful and necessary step. BP looks forward to playing a role in the successful implementation of the Plan.

Thank you and I look forward to answering any questions you may have.

BIOGRAPHY FOR CHRIS MOTTERSHEAD

Chris joined BP Research, at its London-based research laboratories in 1978 as an instrument and control engineer. During the mid-eighties Chris lead a team to create and commercialize large-scale scientific computers as part of BP's then new venture activities. In the late eighties he ran BP's exploration computing activities in London, Glasgow and Houston. During the early nineties he became commercial manager of exploration and production technical activities. Chris then moved to BP's North Sea operations, first to Glasgow and then Aberdeen, becoming the central technical manager. He returned to London, becoming the VP Technology, Engineering and HSE for BP's global gas, power and renewable activities.

He is currently Distinguished Advisor Energy and Environment, and provides leadership to the BP Group on making its products and operations consistent with the principles of sustainable energy and the environment.

He is also a Director of the Carbon Trust in London and the Center for Clean Air Policy in Washington, and on the Advisory Boards of the National Center for Atmospheric Research in Boulder, the Climate Group, the UK Engineering and Physical Sciences Research Council and the G8+5 Legislators and Business Leaders Climate Change Dialogue.

Chairwoman BIGGERT. Thank you very much. Dr. Hoffert, you are recognized. You want to turn—push the button. I don't think it is on.

Dr. HOFFERT. Can you hear me?

Chairwoman BIGGERT. Yes.

STATEMENT OF DR. MARTIN I. HOFFERT, EMERITUS PROFESSOR OF PHYSICS, NEW YORK UNIVERSITY

Dr. HOFFERT. Technology is wonderful, isn't it?

I, too, would like to thank Madam Chairman and the Subcommittee Members for inviting me, albeit on short notice, and I would certainly like to associate myself with some of the comments that have been made thus far regarding the need for goals, and regarding the need for innovation, even more so.

So, I think the best, most effective use of my time might be to specifically discuss those goals, and how they emerge from our scientific understanding of the program, and to make some specific suggestions as to how innovative ideas might be introduced into the program that are not already present in it. In no way does this imply that I don't support the CCTP. It is very much needed.

First, as to the goal, I don't have to belabor any more this issue of 18 percent decrease in specific energy over ten years. At the time GDP goes up by 30 percent, emissions will rise by approximately 1.2 percent, which is the historical rate at which global emissions are rising. So, this is——

Chairwoman BIGGERT. Could you pull the mike just a little bit away from you?

Dr. HOFFERT. Yes, okay. Can you hear me better?

Chairwoman BIGGERT. Yes.

Dr. HOFFERT. With more clarity.

This would certainly not satisfy the objective of the Framework Climate Convention, albeit how it was very poorly defined when the Rio Treaty was originally enacted. It was defined as avoiding dangerous human interference with the climate system without defining that.

Lately, those of us who have worked in climate, I should say parenthetically that I myself have worked both in climate and energy research for the last 30 years, indeed, I was a colleague of Jim Hansen's and Steve Schneider's 30 years ago when this problem was a fascinating intellectual exercise, and before we realized that all of these calculations that we were doing were actually going to happen.

The point I am trying to make is that our understanding of the problem should inform our policy, and let me put it this way. If we were to adopt a goal of not allowing the temperature of the Earth to exceed two degrees Celsius, this is a goal that many have mentioned in the European Union, Tony Blair, and Jim Hansen has articulated the reasons for this having to do with the potential for irreversible melting of the polar icecaps. And if we want to ensure that, and at the same time, grow the GDP of the world between two and three percent, which is a likely minimum for permitting equity between the vast differences of income of developed and developing countries, if that were to be adopted, then it is a mathematical and engineering problem which can be solved, what would be required in the nature of emission reductions.

There is some uncertainty, but we know what the boundaries of that uncertainty is, and the results are staggering and very rarely discussed. In fact, what we would have to do is essentially phase out virtually all carbon dioxide emissions by the middle of this century, and keep them close to constant in the near-term. If, at the same time, we want to reach those GDP goals, and economic growth goals, and require that this be done with our energy consumptive society, one can calculate how much energy capacity we would need that doesn't put CO_2 into the atmosphere. I am emphasizing CO_2, although I know there are other greenhouse gases. And it is truly staggering, it is between 100 and 300 percent of all the energy that the world uses now would have to come, 50 years from now, from some energy source X, as yet undetermined, and that is even with a very large amount of energy efficiency improvements.

I and colleagues have proposed that the focus of the Department of Energy's program on technology should be to roughly look at the three—and this is supply side, I am emphasizing that, but it in no way denigrates the importance of efficiency—roughly one third of that might come from carbonaceous coal with CO_2 sequestered or stored, one third from nuclear reactors, albeit understanding all the problems of nuclear reactors would have to be addressed, in addition to the question of them becoming sustainable energy sources for the long-term, and one third from renewables.

Now, the fact is that the world is building totally wrong infrastructures in all of those three areas: 750 new coal-fired power plants are being built by the U.S., China, and India that will overwhelm Kyoto emission reductions by a factor of five, if those reductions even take place. For the first time, people are contemplating building nuclear reactors in this country, the first time in 30 years, and the ones that are proposed are once-through nuclear reactors using the U–235 isotope.

We need to be having serious discussions about the uranium fuel cycle, because as in the case of the coal plants, once you build these plants, you are sinking the investment for 50 to 75 years. We are, in fact, right now building the energy infrastructure of the second half of the 21st century, certainly the first half, and it is really going by without a whimper, because we are living in these two parallel worlds, the world of potentially what should we do about climate change and energy security, and the real world of what we are doing.

As regards renewables, we are also building the wrong infrastructure. If we want renewable energy, I think the greatest potential, aside from buildings which, as associated with efficiency, is from solar and wind, which are intermittent, dispersed, and low power density sources. We don't have the right kind of electric utility grids to accommodate those energy sources, and when we are talking about rebuilding the national grids to, for example, avoid blackouts, we are not talking about what kind of grids would provide the transmission and the storage capability to allow renewable energy to provide roughly 30 percent.

The problem is also complicated by the fact that we are having this discussion in terms of our own national priorities, when this is actually an international program. And this is the reason why I and several of my colleagues have proposed what some are calling an Apollo program or a Manhattan Project in alternate energy. In fact, we first proposed this program in 1998 in a paper that was published in *Nature.* I was first author with many colleagues, and the week after the paper came out, the *Nature* editorial writer said that well, this was—this isn't such a very good idea, because Jimmy Carter had a program in the 1970s, an energy program, and after all, a lot of money was invested in that, and it didn't bear fruit. I would like to explore that. Time doesn't permit me to, but I absolutely don't believe that. I think that that 30 years ago program, which I am actually old enough to have worked in, had we continued to develop those alternative projects, alternative ways of both producing and conserving and utilizing energy more efficiently, we might actually have something on the shelf right now.

My own view is that the emperor has no clothes, that we really do not have a technologically adequate set of primary power generation to effectively address the CO_2 problem, and things will almost certainly get worse before they get better. But I am a technology optimist, and I would like them to get better, so I would say the absolutely first priority is to clearly define what the energy implications are for stabilizing climate at some level that we would consider acceptable.

The stakes are very high. What is involved is the survival of our high technology society. There is no guarantee that just because things are going along so well that they will continue to do so, and climate change is basically the canary in the mineshaft. It is the first of many problems we are going to have to address. I don't know how much time I have left. I should probably be winding down.

Chairwoman BIGGERT. I think you can wrap up.

Dr. HOFFERT. Yeah. Yeah. So—well, maybe fortunately for you, but unfortunately for me, I didn't really have the time to continue this exposition, which would very likely offend a number of people, but that is what would make it interesting.

Thank you.

[The prepared statement of Dr. Hoffert follows:]

PREPARED STATEMENT OF MARTIN I. HOFFERT

An Energy Revolution for the Greenhouse Century

When there is no vision, the people perish.
—Proverbs 29:18

You see things: and you say, "Why?"
But I dream things that never were; and I say, "Why not?"
—George Bernard Shaw, Back to Methuselah (1921)

We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because the challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win.. . .
—John F. Kennedy, Rice University, 1962

The reality of global warming from the buildup of fossil fuel carbon dioxide in the atmosphere is no longer in doubt. Arctic sea ice, tundra, and alpine glaciers are melting, tropical diseases like West Nile virus and malaria are penetrating higher latitudes, and sea surface temperatures have risen to the point where Katrina-like hurricanes are not only more probable, but actually occur. Also taking place are the extinction of plants and animals adapted to cooler regimes but unable to migrate poleward fast enough to keep pace with a warming climate. Polar bears, already far north, may have nowhere to go. Ominously, the melting of Greenland and Antarctic icecaps is accelerating, threatening worldwide major sea level rise and coastal inundation (Hansen, 2006; Gore, 2006; Kolbert, 2006; Flannery, 2006).

These are well-documented facts, not alarmist predictions by desperate environmentalists in search of funding (Crichton, 2003) or some colossal hoax on the American people (Inhofe, 2003). Atmospheric warming from water vapor, CO_2, and other greenhouse gases is a basic principle of atmospheric science. It is responsible for maintaining Earth as a habitable zone for life, and for making Venus, with its pure CO_2 atmosphere 100 times thicker than Earth's, hot as metaphorical Hell. Cooling can result from suspended aerosol particles also produced by burning fossil fuels, but aerosols remain in the atmosphere a much shorter time than CO_2 and their cooling effect, so far, has mainly served to mask the full impact of warming from CO_2 emissions. (Some propose "geoengineering" climate by intentionally injecting aerosols to cool regions most threatened by global warming, such as the Arctic; see for example Teller, Wood, and Hyde, 2002.) Heat temporarily stored in oceans can also delay or mask committed greenhouse warming, as can variations in the output of the sun and volcanic eruptions. But volcanoes, the sun, and the oceans cause surface temperature to rise and fall in a narrow range. In retrospect, it was inevitable that the explosive growth (on a geological time scale) of human CO_2 emissions, driven by population growth, industrialization and, most of all, by fossil fuel energy use, made it inevitable that human-induced warming would overwhelm climate change from all the other factors at some point. And we are at that point.

That fossil fuel atmospheric carbon dioxide would warm the planet was predicted over a century ago (Arrhenius, 1896). Roughly half the CO_2 input by humans remains in the atmosphere. The rest mostly dissolves in the ocean, creating excess acidity that marine organisms may not be able to tolerate, which is another problem. By the third quarter of the twentieth century, CO_2 buildup in the atmosphere was evident, although greenhouse warming did not emerge from background "noise" until the late 1980s. Hans Suess and Roger Revelle recognized early on that transferring hundreds of billions of tons of carbon in fossil fuels (coal, oil, and natural gas) formed over hundreds of millions of years and locked up in Earth's crust to the atmosphere as CO_2 in a few hundred years was "grand Fig. 1 geophysical experiment" on a scale unseen in human history (Revelle and Suess, 1957). Revelle was to be an influential professor of Al Gore's at Harvard, with ramifications reverberating today (Gore, 2006). By the late 1960s, Syukuro (Suki) Manabe, to my mind, an "Einstein" of atmospheric science, had worked out the detailed physics of how greenhouse gases affect atmospheric temperature from the surface to the stratosphere, including the water vapor feedback that roughly doubles warming from CO_2 alone (Manabe and Weatherald, 1967).

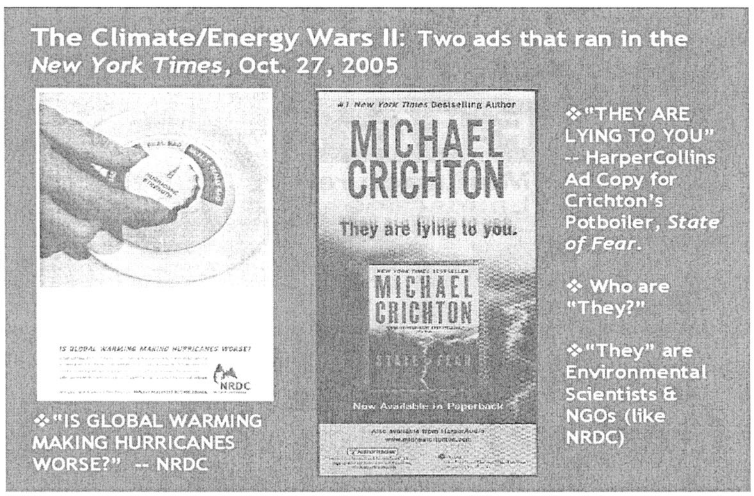


Fig. 1

The discovery of global warming is a fascinating chapter in the history of science (Weart, 2003). Many phenomena that we are now seeing—heat going into the oceans, greater warming at the Arctic, volcanic and aerosol effects—were predicted decades ago. One group, including Steve Schneider, Richard Sommerville, Jim Hansen and this author, worked on this problem in the 1970s, primarily as an intellectual challenge in theoretical climate modeling and computer science at the Goddard Institute of Space Studies (GISS), a NASA-funded research institute near Columbia University started by Robert Jastrow while he was still in his twenties.

Back then, global warming was not yet politicized as it is now (Figure 1). A "back of the envelope" calculation I did at GISS in the '70s suggested fossil fuel greenhouse warming would emerge from background temperature variations by the late '80s. So I thought it might be a good idea to publish some papers predicting this, which I did, as did colleagues at GISS and elsewhere. That limiting CO_2 emissions to avoid adverse global warming might disrupt consumerist civilization and multinational energy companies while putting a damper on industrialization of China and India was implicit, but academic.

Ironically, in light of the conclusive support for it developed at the research institute he founded (Hansen et al., 2005), Jastrow was highly critical of the global warming hypothesis. He never published peer-reviewed climate research, in stunning contrast to the present GISS director, Jim Hansen; but, on taking early retirement from NASA, Jastrow and Fred Seitz of Rockefeller University founded the Marshall Institute in Washington, D.C., a bastion of climate change deniers allied with the American Enterprise Institute, the Cato Institute, and other conservative think tanks in opposition to U.S. participation in the CO_2-emissions-limiting Kyoto Protocol—the first implementation of the UN Framework Climate Change Convention (FCCC).

The United States, China, and India have not ratified Kyoto. Indeed, 850 new coal-fired power plants to be built in these countries by 2012 will overwhelm Kyoto emission reductions by a factor of five (Clayton, 2004). Avoiding "dangerous human interference with the climate system," the goal of the UN FCCC, is a daunting technological challenge because 85 percent of the world's energy comes from fossil fuel; and stabilizing global temperature at acceptable levels will require a revolutionary change in the world's energy systems (Hoffert et al., 1998; 2002; "Energy's Future," 2006). Although global warming is settled science, a public relations battle continues to rage.

Problems exist on both sides of the red-blue divide. In a searing critique of environmental nongovernmental organizations (NGOs) like the National Resources Defense Council and Environmental Defense, Shellenberger and Nordhaus (2005) argue that, despite major campaigns, environmental lobbies have had little success on the global warming front. The authors discount efforts by states in the United States to create renewable energy portfolios with ambitious targets for alternate energy as so much public relations. They claim, with some justification, that "not one of America's environmental leaders is articulating a vision of the future commensurate with the magnitude of the crisis."

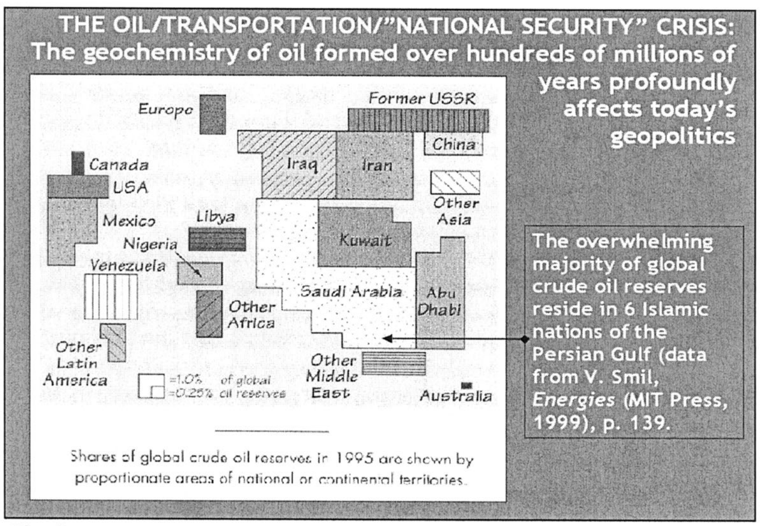


Fig. 2

Why? Global warming is not only different in scale from prior environmental challenges (acid rain, heavy metal contamination, DDT, etc.)—its long-term planet-changing nature requires forethought and imagination to a much greater degree than the threats to which Homo sapiens has evolved adrenaline-pumping instinctive responses. The growth of human population, CO_2 emissions, and global warming in the past millennium are very recent from a human evolutionary perspective. For the first time in its history, Homo sapiens has begun to interact more or less as a unit with the global environmental system (Eldridge, 1996). Because modern technology developed *after* we evolved biologically, we lack appropriate instincts to deal with it—these having been unlikely to confer survivability in our evolutionary past. By default, we have to deal with the climate/energy problem cognitively. So far, we are not doing too well. As Carl Sagan observed, our reptilian brains motivate aggressive and tribal, as opposed to thoughtful, responses in ways we barely perceive and across many spheres of human behavior.

In the climate wars, deniers often get more vociferous as the evidence against their views gets stronger (Hoffert, 2003). The so-called hockey stick curve (developed by paleoclimatologist Mike Mann and colleagues) was recently attacked from the floor on Congress by Representative Joe Barton (R–Texas), based on cherry-picked information suggesting their statistics were flawed reported in the *Wall Street Journal.* Would that Rep. Barton, and legislators in general were better educated in statistical and scientific issues. But my experience briefing legislators and aides is that scientific illiteracy and intellectual laziness are rampant. Educated mainly as lawyers, many do not get it that nature does not care about human politics. (Unfortunately, some academics that should know better likewise argue that science is more a "consensual reality" than an objective description of nature deduced by the scientific method.) Too few bright and imaginative students pursue careers in science and engineering today. We need such students badly.

The hockey stick curve that shows a dramatic recent uptick in global temperature with much more to come is easily perceived as a threat not only to Big Oil and Big Coal, but also to election campaign funds. Easier to blame the messenger than think critically about this. The general trend of the Mann et al. (2003) hockey stick was independently verified by other researchers in a recent report by the National Research Council (NRC, 2006). Overwhelmingly, research-active climate scientists know we are entering climatic territory unseen in human history (Hansen, 2006). Our rapidly melting planet is so dominated by humankind's emissions that the present climatic era is being called the anthropocene (Crutzen and Ramanathan, 2003).

Most knowledgeable researchers are very concerned about global warming. Some, including this author, argue for research and development programs on an Apollo space program—like scale to create low-carbon alternate energy supply and demand—reducing technologies in time to make a difference (Hoffert et al., 1998, 2002; Rees, 2006). This effort should include prompt implementation of energy conservation, efficiency, and existing alternate energy sources (Lovins, 1989; Metz et al., 2001; Pacala and Socolow, 2004; Socolow, 2006).

Whatever the deep evolutionary reasons, the climate/energy issue competes for attention with other problems in the mind of the average citizen. A frequently asked question is: "Why even care about global warming and climate change?" The worst effects occur decades to centuries from now. In cost-benefit accounting, many economists strongly discount the present value of adverse future impacts and "externalize" (that is, neglect) the cost of environmentally degrading the global commons (Daly and Townsend, 1994). Economics is, of course, a legitimate branch of behavioral biology dealing with the allocation of scarce resources by Homo sapiens, one of millions of biological species inhabiting this planet. But, so far, in its predictive mode, it resembles astrology more than a hard science. Economist John Kenneth Galbraith went so far as to say, "The only reason for economists to produce forecasts is to make astrology look respectable" (Jaccard, 2005). Undaunted, Bjorn Lomborg, the "skeptical environmentalist" (Lomborg, 2001), convened a group of economists to prioritize investments in various challenges facing humankind. The group concluded in its "Copenhagen Consensus" that climate change, even if real, is near the bottom (Bohannan, 2004). Reading the group's findings, one is struck by how evolutionarily blind our species can be to existential threats. Among the problems with this indifference—noted by Harvard energy policy analyst John Holdren, and in his film and book, *An Inconvenient Truth,* by Al Gore—is that climate change is more an ethical than an economics problem.

An even more basic flaw to this physical scientist is that the environmental constraint of global warming on energy was entirely missed by the Copenhagen group. The late Nobel laureate Rick Smalley astutely observed that, although civilization has many problems, energy is key to them all. Smalley's list of problems encompasses energy, water, food, environment (including global warming), poverty, terrorism and war, disease, education, democracy, and population (Smalley, 2005). Energy is key because solving all these problems requires sustainable power on a global scale. Without it civilization collapses. Concentrated fossil fuels are a one-shot boon of nature. Coal being still relatively abundant, humankind might have deferred an energy revolution to another primary power source to the twenty-second century, or even later, were it not for global warming. Coal burned for electricity and even shortages caused by peak oil can be handled at higher cost by making synthetic fuels from coal. But potentially catastrophic global warming is the "canary in the mine." It trumps everything else; moving the climate/energy issue to the front of the list.

To generalize the Shellenberger-Nordhaus thesis, there is little evidence that politicians of *any* persuasion appreciate the magnitude of the problem, or can articulate a vision to address it. The most relevant questions are being asked by energy scientists and engineers: Are there technologies likely to lead to a low-carbon world in time and still allow global GDP to continue growing two to three percent per year ("Energy's Future," 2006)? What global energy systems should we be aiming at? Can we get there in time? One leading economist put it this way: "The trouble with the global warming debate is that it has become a moral crusade when it's really an engineering problem. The inconvenient truth is that if we don't solve the engineering problem, we're helpless" (Samuelson, 2006).

The issue of "energy security" makes the need for an energy technology revolution a viable policy option even for "red" states and others indisposed see global warming for the threat it is. Two hundred years of innovation—the famous "Yankee ingenuity"—are behind America's ascent to world power (Evans, 2004). Applied science and entrepreneurship enabled by government research and development since World War II (Bush, 1945) are a historically appropriate response for the United States.

The need is clear. Figure 2, from Smil (1999), shows oil reserves around the world, with the lion's share in the Persian Gulf. But Saudi Arabia, Iran, and Iraq are powderkegs of post-9/11 Islamic fundamentalism. Some Al Qaeda ideologues have drawn up a plan aimed at establishing an Islamic caliphate throughout the Middle East, in which attacks against the petroleum industry are critical to the deterioration of American power through constant expansion of the circle of confrontation (Wright, 2006). And because oil is internationally traded, it is irrelevant whether oil imports by the United States originate under a particular Middle Eastern desert. The more oil money that flows to Saudi Arabia, Iran, etc., the more money that flows to Al Qaeda, Hezbollah, and other terrorist groups that we are ostensibly at war with. As Tom Friedman of the New York Times has repeatedly emphasized, our addiction to oil combined with lack of any serious policy to develop alternatives is why the United States is funding both sides of the "War on Terror."

We know that world hydrocarbon resources are limited. Virtually all major crude oil and natural gas reservoirs have been mapped by seismic probes. Every day, the world consumes about 80 million barrels of oil, a rate that has been increasing with economic growth but is ultimately constrained by geological abundance to peak in coming decades (Deffeyes, 2001). From a global warming perspective, the coming oil peak, accelerated by China and India with booming GDPs, is problematic because it is forcing a transition back to coal for primary energy and thus "recarbonizing" the energy supply since coal emits more CO_2 per unit of energy than oil or natural gas. And, of course, oil prices are rapidly rising, headed for $100 per barrel or more. Figure 3 shows the current range of oil production rate projections. As with the climate change deniers, some "cornucopian" economists say the oil peak is overblown. But consider that oil companies are motivated to inflate, not deflate, their reserve estimates to raise their corporate valuations on Wall Street. Royal Dutch Shell, for example, was recently compelled by the U.S. Security and Exchange Commission to revise its reserve estimate downward 20 percent, suggesting an oil peak sooner rather than later. In any case, most petroleum geologists agree the world will be "out of gas" by the end of the century.

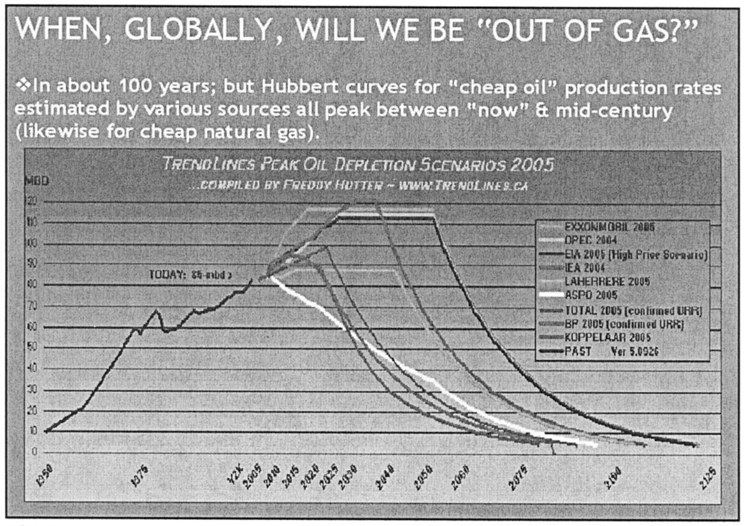
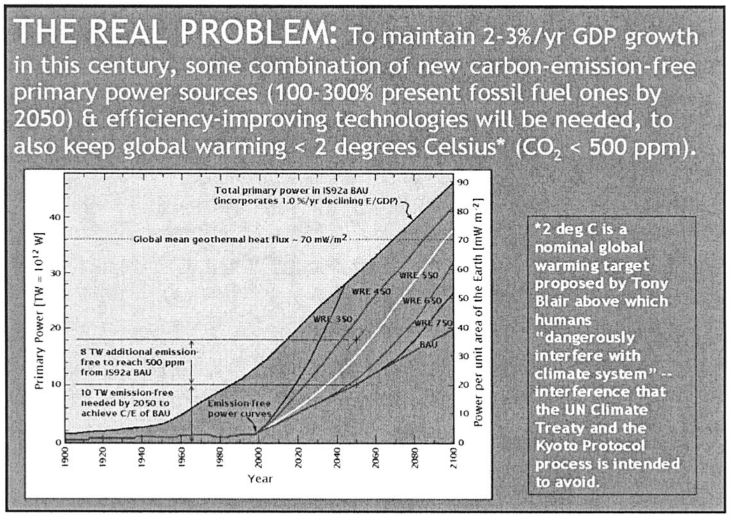


Fig. 3

I want to be clear that I am a technological optimist. I believe we can solve the climate/energy problem. But there is no silver bullet and it will not be easy. It will take the greatest engineering effort in history; bigger than the Manhattan project to build the bomb, bigger than the Apollo program to land a man on the Moon, bigger than the mobilization to fight World War II. Moreover, the effort has to be international in scope with sufficient inducements for developing giants China and India to sign on. This problem will not solve itself through the invisible hand of the market. Relevant costs and values are not being captured. We are moving rapidly in the wrong direction. Particularly serious is that we are investing in the wrong infrastructures for a sustainable energy world. Vision and imagination are critical. Sooner or later the world will realize this. The longer we wait, the harder the job will be.

Exponential growth cannot be sustained indefinitely on a finite planet. We could, and I believe should, try to maintain two to three percent per year world GDP growth to the end of the century (a likely minimum for developing nations to attain income equity) as CO_2 emissions are held constant, decreased, and eventually phased out by mid-century. This would—based on our best current models—keep the atmospheric CO_2 concentration below 500 parts per million (ppm) and global warming below two degrees Celsius. Higher than two degrees could trigger dangerous human interference with the climate system, according to criteria recently adopted by the European Union (Edmonds and Smith, 2006). Two degrees may not sound like much, but more could put us on a planet-changing trajectory with irreversible melting of the Greenland and Antarctic icecaps, which would inundate the world's coastal zones (Hansen, 2006; Gore, 2006). A big job, given that atmospheric CO_2 has already risen to 380 ppm—100 ppm above the preindustrial level from fossil fuel burning and deforestation so far. To do it, some combination of emission-free primary power sources and primary power demand-reduction equivalent to generating 100 to 300 percent of present power from some as yet unidentified set of power systems will be needed by mid-century (Figure 4, based of Hoffert et al., 1998; 2002).

Fig. 4



How hard is that? Consider that 2050 is nearer in the future than when Fermi's first nuclear reactor (then called an "atomic pile") went critical in December 1942 at the University of Chicago is in the past. We now produce about five percent of primary energy worldwide from nuclear power (this is virtually all for electricity; roughly 18 percent of electricity generation is nuclear; the rest is from fossil fuels, mostly coal and hydroelectricity). If we need some new carbon-emission free "energy source X" 50 years hence, the implied growth of these new power sources is 20 to 60 times faster than nuclear power, the last revolutionary power source deployed on a large scale. Not impossible, but we do have to concentrate. Below are some ideas that could work if we get serious.

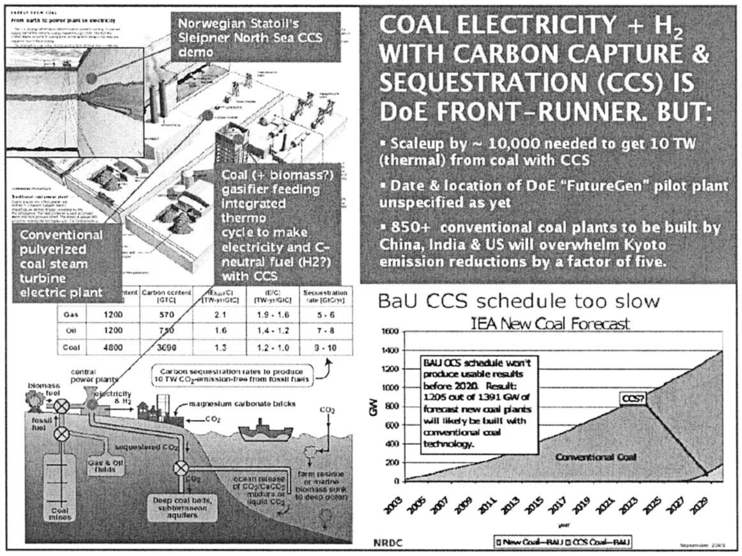
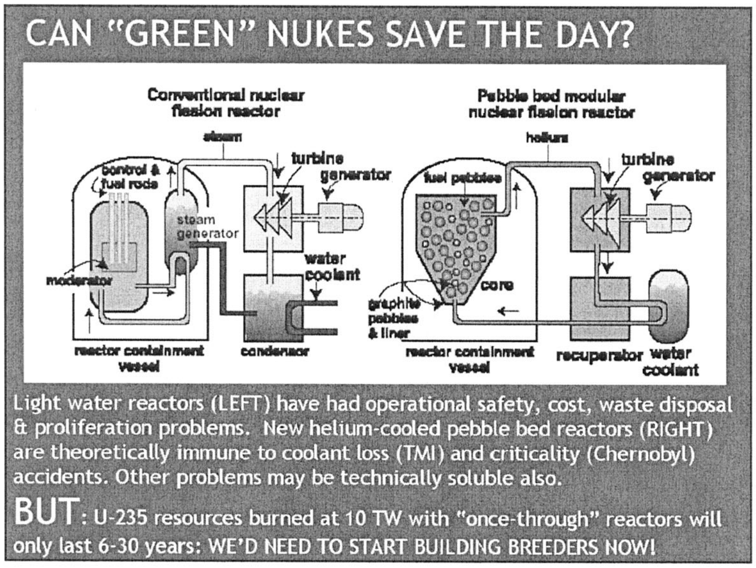


Fig. 5

For starters, we could dramatically accelerate what some engineers believe is the most ready for prime time major emission-free energy source: coal with carbon capture and sequestration (CCS). Figure 5 depicts coal gasification plants making electricity and hydrogen with the CO_2 pumped to reservoirs underground, the rationale being that we have large coal resources that can play a role in a transition to a sustainable energy system if we can get the energy out while putting CO_2 (and other pollutants) away in reservoirs underground. One problem is that coal with CCS deployment is unlikely before pilot plants demonstrate that the combined technology works. Individual components like coal gasification, combined cycle power plants, and even CO_2 sequestration have been shown, but the technology is too costly without a carbon tax or "cap and trade" emissions policy in place. The United States, China, and India have not agreed on emission limits, and these are precisely the countries with massive coal resources where planned buildup of conventional coal electric power stations is most intense. The lower right panel of Figure 5 shows how conventional coal plants in the works will overwhelm proposed CCS plants. A Department of Energy-funded CCS pilot plant called "FutureGen" was cited by this administration at climate negotiations in Montreal as the U.S. premier effort, in partnership with the coal industry, to combat global warming (Revkin, 2005). But this plant is unlikely before 2012 and its location is still unannounced. Experts believe it may be more expensive to retrofit conventional coal plans with CCS than build gasification plants with CCS from scratch. Suppose global warming got bad—really bad. Will conventional coal plants be abandoned, as the $6 billion Shoreham nuclear plant was after Three Mile Island (TMI) and Chernobyl? Once they are generating electricity from cheap coal, with capital costs "sunk" for 50 to 75 years, it might be so expensive to shut down and build new ones that rate payers would balk even to slow a global warming juggernaut. This is not a good scenario.

Fig. 6



Another class of low-carbon primary power now being reconsidered after a disastrous start is "green" nukes (Figure 6). No one has started building a new nuclear reactor in the United States for the past 30 years, though some are planned. Classic problems of nuclear power are operational safety, waste disposal, and weapons proliferation. However, for global warming mitigation, the major constraint may be that planned reactors are "once through" and use the supply-limited uranium 235 (U–235) isotope, which makes up less than one percent of natural uranium. The energy content of U–235 in identified deposits is less than natural gas. We would run out of fuel in 30 years employing such reactors at rates sufficient to supply present primary power demand. As with coal, we do not have the luxury of investing in the wrong nuclear power infrastructure. Longer-term, we will need to breed U–238 (99 percent of natural uranium) into plutonium or more abundant thorium to U–233, a fuel I favor for several technical reasons. Why not start now? Infrastructure and weapons proliferations issues need to be faced now if we are serious about green nukes as alternative energy.

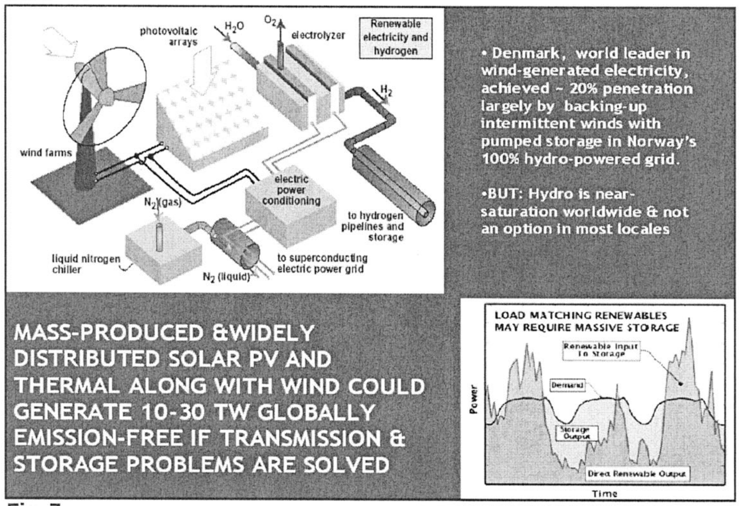


Fig. 7

The third class of primary power, my own preference, is renewable energy, currently less than one percent of primary power (Figure 7). Space limitations prevent an adequate discussion, but I and colleagues at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, and elsewhere believe solar and wind power can be scaled up, with a proper infrastructure of transmission and storage, to provide 30 percent or more of primary emission-free power by mid-century (Pew Center, 2004). President Jimmy Carter, a strong advocate of renewables, created the Solar Energy Research Institute, the precursor of NREL. And Jerry Brown, dubbed California's "governor moonbeam" by critics, in the 1970s initiated tax and other incentives leading to the now cost-effective Altamont wind farms. It is hard to overestimate the damage done by Ronald Reagan who, on becoming president, symbolically ripped the solar panels Carter had put on the roof of the White House, likewise dismantling most of Carter's energy research and development initiative. We have not recovered. Carter's Administration a quarter century ago was the last time the U.S. had a pro-active alternate energy policy. Unfortunately, the institutional memory of this has dimmed. Whatever the problems of Carter plan, and there were some, the United States, and because of our leadership, the world, was headed toward a sustainable energy future. Not now.

What colleagues and I propose as a goal is that by mid-century, renewables should supply roughly a third of the world's power; clean, safe and sustainable nukes another third; and coal gasification with CCS the final third. The total would amount to 100 to 300 percent of present energy demand. There are major roles for business and talented entrepreneurs, but I do not see how we get there without the stimulus of massive Apollo-like government-funded research and development, perhaps starting with ARPA–E (Advanced Research Projects Agency–Energy; after DARDA, the Defense Research Projects Agency, which gave us, among other things, the Internet) proposed by the National Academy of Science (Committee on Science, 2005).

At the same time, we need to implement everything we have in our alternate energy arsenal immediately. I do this myself as best I can. I drive a hybrid and get my home's electricity from green power, mainly wind power purchased by my utility from upstate New York (Hoffert, 2004). At this point, I pay a premium for this "privilege." I do not claim any special virtue as an early adopter. I do think both ethics and "cool" technology can be early drivers of alternate energy. At least until it become cost-effective to the average person, perhaps stimulated by carbon and gas taxes and/or cap-and-trade schemes. We need work on a broad spectrum of possible solutions; picking technology winners is notoriously uncertain, even by experts (Clarke, 1982).

This is not the forum to elaborate on the most innovative high-tech ideas that could allow us to live sustainably on the planet. Interested readers should consult Hoffert et al. (2002) and the special issue of *Scientific American* on "Energy's Future Beyond Carbon" (2006). Climate and sustainable energy is a political as well a science and engineering problem. With the memory of Rick Smalley's brilliant exposition in mind (he gave a most engaging and accessible public lecture at an Aspen Global Change Institute conference that I co-organized a few years ago), I hold that energy and global warming, not terrorism and mind-numbing dogma, are the appropriate organizing principles for this century. There is no guarantee high-tech civilization will survive into an ever richer future. But I find no solace in joining with the peak oilers to hunker down to a long slow decline with a return to agrarian (and eventually hunter-gatherer?) lifestyles as energy runs down and sea levels rise (Urstadt, 2006). Likewise, keep me away from Ted Kaczynski, the "Unabomber," who would destroy even a solar-powered high-tech world (Kaczynski, 2002).

I am optimistic enough about technology to believe policies based on science and engineering can solve the climate/energy problem; that with enough effort, thoughtful energy policies, instead of the usual pork packaged for public relations, can become part of political party platforms by the next U.S. presidential election. The stakes are high. We owe to ourselves and generations to come to fight for our remarkable technological civilization, with all its imperfections, built on the shoulders of earlier generations. It will be hard. We will need every ounce of creative imagination. If we do make it through the twenty-first century without imploding, perhaps someday we might even find a way to cope with those problems our pre-technology evolutionary history has left us quite unprepared for.

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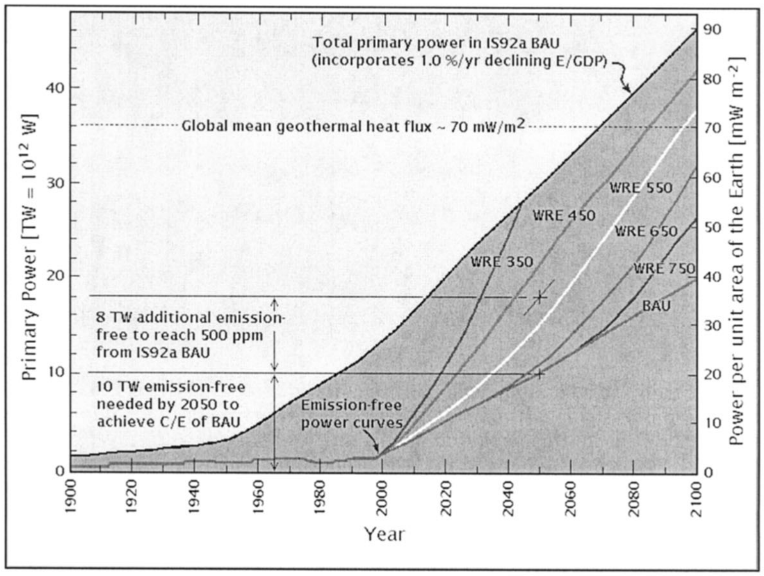
Supplementary Remarks by M. Hoffert on the Original CCTP Plan

This CCTP R&D Plan would be strengthened and would be a far more effective policy tool if the problem to be solved were defined by the quantity and timing of CO_2 emission-free-power and/or efficiency improvements needed to stabilize climate at various levels of atmospheric CO_2, or of global warming, as the global economy grows at projected rates of two to three percent per year.



The future path is unknowable but emission-free primary power levels needed to attain the WRE stabilization scenarios levels for economic growth and fossil energy assumptions of the IPCC IS92a business-as-usual (BAU) scenario.

Primary and emission-free power growth in the previous century is also shown. [Note the emission-free-power growth rate discontinuity in the vicinity of "now," and the subsequently large growth in emission-free energy supply just needed for BAU—with progressively larger ramp-ups for various stabilization levels.] This is the real problem. The Manhattan Project didn't aim to explore nuclear weapons in general; it's goal was building a Bomb before the end of WWII. The Apollo Program didn't aim at exploring manned space flight in general; it's goal was putting a (US) man on the Moon by the end the '60s. So too does the CCTP program need a more concrete goal; specifically, I'm arguing, some combination of terawatts from supply and negaterawatts" from demand sufficient to stabilize global warming at tolerable levels. One doesn't have to advocate what level at this point. That should be publicly debated, perhaps in Congress. In any case this administration has clearly stated its opposition to specific targets. Avoiding "dangerous anthropogenic interference with the climate system," the stated UN FCCC goal, was undefined in that document—though melting Arctic sea ice and tundra and increasing hurricane intensity make it more timely than ever to do so. Tony Blair at the recent Exeter conference in the UK set an upper limit of two degrees Celsius global warming. This might be cited as an example of thinking by a close U.S. ally.

Such a goal implies terawatts of emission-free power in the coming decades (and/or negaterwatts from efficiency improvements)—as is well documented in peer-reviewed literature. Not to be overly alarmist, but if current GDP growth rates continues, the latter half of the 21st century is a climatic disaster waiting to happen. To address this realistically, a conceptual framework similar to that described above needs to be up front of this Strategic R&D Plan; however challenging the goal may be and however much it requires international cooperation. Otherwise what we have is a shopping list, well-motivated and interesting perhaps, but uncoupled from the actual problem.

BIOGRAPHY FOR MARTIN I. HOFFERT

Martin I. Hoffert is Professor Emeritus of Physics and former Chair of the Department of Applied Science at New York University. His academic background includes a B.S. (1960) in Aeronautical Engineering from the University of Michigan, Ann Arbor; M.S. (1964) and Ph.D. (1967) from the Polytechnic Institute of Brooklyn (now the Polytechnic Institute of New York) in Astronautics; and a Master of Arts in Liberal Studies, M.A.L.S. (1969) from the New School for Social Research where he did graduate work in sociology and economics. He has been on the research staff of the Curtiss-Wright Corporation, General Applied Science Laboratories, Advanced Technology Laboratories, Riverside Research Institute and National Academy of Sciences Senior Resident Research Associate at the NASA/Goddard Institute for Space Studies. Prof. Hoffert has published broadly in fluid mechanics, plasma physics, atmospheric science, oceanography, planetary atmospheres, environmental science, solar and winds energy conversion and space solar power. His work in geophysics aimed at development of theoretical models of atmospheres and oceans to address environmental issues, including the ocean/climate model first employed by the UN Intergovernmental Panel on Climate Change (IPCC) to assess global warming from different scenarios of fossil fuel use. His early model of the evolving CO_2 greenhouse in Mars' atmosphere is also of interest today—providing both an explanation of Mars' riverbed-like channels formed in the distant past and a motivation for terraforming its atmosphere for human habitability in the future. His research in alternate energy conversion includes wind tunnel and full-scale experiments on innovative wind turbines, photovoltaic generation of hydrogen and wireless power transmission (WPT) applied to solar power satellites. His present efforts focus on energy technologies that could stabilize climate change from the fossil fuel greenhouse—including (but not limited to) space solar power. He is a Member of the American Geophysical Union (AGU), the American Institute of Aeronautics and Astronautics (AIAA) was elected Fellow of the American Association for the Advancement of Science (AAAS). He is presently a consultant to Lawrence Livermore National Laboratory and Versatility Software, Inc.

DISCUSSION

Chairwoman BIGGERT. Thank you very much, Doctor, and we really do appreciate you coming on such short notice, and really do appreciate your testimony. I think that it really adds something to the discussion, and I would say from a policy, sitting as a policymaker, that it is very important, and I know that we have been working on so much of the alternative fuels, and what I believe is that we have got to do it now, and we have always proceeded along this path since the '70s really, when we had a gas crisis, and all the things that went on, to say we are going to have to solve this problem. We are going to have to reduce our reliance on foreign oil and fossil fuels, and then, the prices would go down, and then people would forget about it, and I think that is why we are now in the situation that we are in right now, because we haven't had the development of those long-term goals, or even the short-term goals that we need to have. And if we don't do it now, you know, we are going to lose the momentum again, and not do that.

In fact—and that really leads me to my question, and I will now recognize myself for five minutes, and we will have questions, then answers, and then, I will alternate.

Mr. Eule, and I would ask you about establishing, you know, a greenhouse gas concentration goal. Don't you have to set the goal before we set up the R&D priorities, and if not, why not?

Mr. EULE. I think there has been some confusion about what the plan is intended to be. The plan is not intended, was never intended to be a mitigation plan. It is a plan to help us coordinate and develop technology so that we can develop mitigation options that are cost-effective. I mean, that is the purpose of the plan.

Now, your question goes to the issue of setting targets. We don't set a target in the plan, but we do take a look at alternate futures. In chapter 3 of the report, we have very detailed scenario analyses. These were done by the folks at Pacific Northwest National Lab, and over at the University of Maryland, and what we essentially did was take a look at different technology futures and assess what type of technologies would be needed, when they would be needed, and how they would have to be deployed in—to achieve certain mitigation levels.

So, the plan does include some scenario analysis, and it does take a look at the timing and the pace and the extent to which these technologies would have to be ready. And I think everybody—do the Members have the plan? I would just point to——

Chairwoman BIGGERT. Sequestered until 2:00, so——

Mr. EULE. Right.

Chairwoman BIGGERT. But we have, you know, addressed the draft plan, the——

Mr. EULE. Right, I think on page 208 and 210, we lay out some goals that we have set for cumulative GHG emissions mitigation under four different constraints, and for the four goals that we have set in reducing emissions in energy end-use, energy supply, carbon capture and sequestration, and non-CO_2 gases, and on 210, we give you an idea of the timing that these advanced technologies would have to be ready to enter the marketplace.

And one thing I want to point out, and this—under the table on page 210, if you look at the four goals we have in reducing emissions from energy, and end-use in infrastructure, on the very high constraint case, we will just use that as an example, technologies ready in the 2010 to 2020 timeframe, those would be largely energy efficiency technologies, the next one in the—would be goal four, reducing emission of non-CO_2 greenhouse gases, those technologies would be ready about 2020 to 2030, and following that, emissions from energy supply, and then carbon capture and sequestration.

So, there is a continuum of technologies that would be available to address these different constraints, and for the four specific goals, so while we haven't settled that, I think we have done a lot of analytical work that would allow us to plan for the future, which is what the strategic plan is all about.

Chairwoman BIGGERT. It is a lot information, certainly, and a lot of different, you know, research and development plans, and that is—we can take this, but my problem is that there doesn't seem to be any connection between the scenario analysis, and then, the actual technology priorities described in the following chapters after that, and I know that we had sent a letter, and I know that you were not, you know, in charge at the time. This was in December, and we had problems with the draft, in that—and I think it—our concerns were that it—there was no clear set of criteria for the technology selection and prioritization, and no timelines for completing individual programs or projects, and no metrics for evaluating the progress, and no sense of how the budget priorities across agencies would be developed.

And I guess, you know, we as policy people have to take this, and you know, make decisions on how to move forward, but we have got research that was done 10 years ago, we don't know how that research is progressing, and how that fits into a plan, and how the new research will then come alone. Have we—you know, have the last 10 years, will they—how will they fit together in how we can progress?

Mr. EULE. Excellent question. I think you are getting to the issue of how we set priorities in the plan, and first of all, I want to say that this is the first plan of its kind in the world. No other country has a similar plan. I have traveled to many countries, and I have briefed them on what we are doing in CCTP. The impression I get is—and when I ask my interlocutors, they really don't have a firm handle on what they are doing in the climate change arena, how much they are spending, and they don't really have an overall strategy.

So, I think this document is visionary in that sense, and—but getting into—getting to your question, we have a number of vehicles for setting priorities. One, we do portfolio assessments. We have an interagency working group, six of them, one for each of the strategic goals in the plan. Three of them are led by the Department of Energy in energy use, energy supply, and in basic research. EPA leads our other greenhouse gas taskforce. NASA does measuring and monitoring, and USDA and DOE jointly lead the one on carbon sequestration. So, we have experts in the agencies who get together in the same room and talk about these things, which has never happened before. So, that is one way.

We also sponsor outside expert reviews. Last year, we sponsored six workshops, again, revolving around each of the strategic goals, and that was very useful in identifying gaps and opportunities in the portfolio. I mentioned the scenario analysis, which is very important, and of course, we take these—take what we have learned from all these activities, and we present it to the management structure that the President has set up. And I am—as a Director of CCTP, I am one of the principals that participates in what we call the Blue Box meetings. These are deputy-level interagency meetings, and so, we present the results of our analyses to them. So, we work through both—at the agency level, and at the interagency level, through management structures, so through those vehicles, we intend to have a big impact on the way the budgets are formed.

Chairwoman BIGGERT. Well, my time has expired, so I will after—come back and ask the other witnesses to respond, to comment on this issue. So, hold that thought, and I will now turn to my colleague, Mr. Honda from California.

Mr. HONDA. Thank you, Madam Chair, and I would like to offer my five minutes to Dr. Hoffert. He ended his comments by saying that he was looking forward to—hoping that we won't be offended, but probably would be, to continue your testimony, and utilize my five minutes to continue your talk, since I am very interested, and I won't take being offended personally to you, so I would like to invite you to——

Dr. HOFFERT. I can't tell you how much I appreciate that.

The part that I was about—would have gotten to, sort of, in this kind of freewheeling exposition, really has to do with innovation. I think innovation is critical. For two hundred years, what has distinguished the United States, what made the 20th century the

American century, is the fact that we are a nation of technological innovators, and we have basically led the world.

And as I said before, that I am a technology optimist. Now, not everyone is, and the times that we are living in are really different than the times that I grew up in in the '50s and the '60s, when there was a general feeling at the end of World War II that the scientists who built the atomic bomb, and the scientists that happened to be German, who built the intermediate range ballistic missile, which could eventually take us to the Moon—and von Braun's Saturn V did take us to the Moon eventually—could do anything, that technology was a positive force, and it was a force for good, and indeed, technology, on balance, in my view, has been an enormous force for good. There are two billion people who are alive today because of the Green Revolution, because we manufacture fertilizers with energy that wouldn't be here, and that could lead to other discussions about whether the planet is overpopulated.

But there is a fundamental issue of whether one believes in the enlightenment in science and in technology, and the ability to move forward with vision, and to maintain this wonderful, in my opinion, civilization, technological civilization that we created. Now, that leads to a longer-term point of view than is associated with the terms of Congressmen, for example, or other legislatures, or even Presidents. And yet, when it exists in a society, you can do amazing things.

I want to get back to the innovation part, though. Innovation is when somebody asks a question that nobody has asked before, and the answer winds up being able to change the world, and there is a practical problem with the way government bureaucratic agencies like the Department of Energy are structured.

I mean, don't get me wrong. Some of my best friends work for these agencies, and I have friends even who are lawyers and economists, and all of those things. But I am coming at this from the perspective of someone who believes that there needs to be fostering of innovation, in the way, for example, there is in the parallel universe of the Defense Department. I did defense research. I worked on the ballistic missile system. I did a lot of bad things when I was young, and I did that kind of R&D, and I admit it, and it was very interesting, technically fascinating, as fascinating as I think working on the Bomb was to the scientists who were working in that era.

But the culture is totally different than the culture at the Department of Energy, or even NASA, to some extent, because many of these projects are away from the scrutiny of the public eye. I mean, one thing I learned, for example, is that the black space program is bigger than the white space program. By black, I mean, you know, the nonpublic one, and every once in a while, something emerges from that military R&D that does transform the world.

Since World War II, if you look at the technologies that have really driven economic growth, and I would include gas turbines, commercial jet aircraft, large scale integrated circuits, computer microchips, satellites, satellite telecommunications, and the Internet, which Wall Street is always taking credit for, was actually supported for twenty years by ARPA, now called DARPA, and then another ten years by the National Science Foundation. And so, these are actually technologies that were sponsored by government research.

There is a perception that government should not be sponsoring technology, and it—I believe it is very hypocritical. This very committee, as you may know, at one time was called the House Committee on Science and Technology. The technology part is gone, as you may know, for when a certain party took control of Congress, they decided, for reasons having to do with their beliefs, or their ideological feelings about the market, that the government shouldn't be developing technology.

And now, we are back to the same issue. The question is would those technologies have come about, and it is a profound question—without government R&D—or would we be living in a totally different world? And when people talk about the market, I would have to say this: it would be financially irresponsible for a large company to support the kind of research that we need to do to deal with the climate change problem, because it is not going to pay off in the three to five year timeframe.

This is a problem that is often called the Valley of Death by researchers. Research that has a timeframe that is intermediate to the really short timeframe that you can get support from industry, and the longer things, timeframes like fusion, where it is so far in the distant future that it doesn't have policy implications that people may fear, in terms of their political persuasion.

We need to be doing a lot more in the Valley of Death, and we also need to be working innovatively and fostering it. There are many areas—now, I am not up here, actually, to be honest——

Chairwoman BIGGERT. Actually, Dr. Hoffert, Mr. Honda's time has expired, so——

Dr. HOFFERT. Oh, I am terribly sorry, but thank you so much, sir, for giving me this opportunity to make those points.

Chairwoman BIGGERT. I feel like you are preaching to the choir up here, because I think this is the one committee that gets it, and we have been trying to spread this to our colleagues, so we appreciated it.

Ms. Woolsey from California——

Ms. WOOLSEY. Thank you, Madam Chairman.

Chairwoman BIGGERT.—recognized for five minutes.

Ms. WOOLSEY. Woman. I, for one, have been preaching an Apollo-sized energy program forever. Actually, I was part of the telecommunications industry when the space program was all put together, and that was the beginning of affordable parts and pieces and integrated circuits, and it was all federal funding that got us to the Moon.

I think our energy Apollo program probably is going to be many, many, many, many, many of these books, these reports and plans and strategic planning and all that, but in the end, it will result in the industry that this United States should be part of, which is the climate change technology industry. I mean, we are giving it away to foreign countries. We are letting them do it using our technologies. I mean, how dumb are we?

So, let us not talk about this. Let us talk about—I mean, let us do something about it. I mean, we have got to talk about it, but let us do something about it. So, what I would like to know from you folks is what do we, as Members of Congress, need to do to push this forward? We can read this strategic plan. We can talk—read the Pew recommendations. We can agree with Dr. Hoffert and Mr. Mottershead. Did I say that right? Yes. But what—agreeing isn't good enough, because we actually should be making action.

So, tell me, sort of this—I love your tie, by the way. It is a statement.

Dr. HOFFERT. Some of you guys would love it.

Ms. WOOLSEY. It is a statement. What are the two things each one of you, the two things that we should be doing right now?

Dr. HOFFERT. Well, I have been saying—let me say one very specific practical thing——

Ms. WOOLSEY. And you have got to go fast, because we don't have——

Dr. HOFFERT.—which wouldn't cost a lot of money, is to support our proposed Exploratory Research and Development program, in other words, to provide funding for an effort that might exist within DOE, or it might be funded by DOE without outside administrators. A proposal has been written on that, and we have submitted it, and it has never been funded, and it its very cheap. Eventually, it will cost more, and I think that Congress should act positively on that.

Ms. WOOLSEY. Thank you, Doctor. Mr. Mottershead.

Mr. MOTTERSHEAD. Two things. Resonates on your point. I think you should focus on building businesses, not for building technology. And that building businesses requires a whole suite of different policy instruments in order to ensure that those businesses are thriving and growing. And it is no different than conventional business development, economic development, whereas climate is seen to be something different from that. And I think that there is a lot of experience about how you nurture and grow economic development through business development.

And my second request is none of this will happen unless you price carbon, so you need to price carbon.

Ms. WOOLSEY. Thank you. Ms. Greenwald.

Ms. GREENWALD. I echo what Mr. Mottershead said. What you really need to do is you need to unleash the power of the private sector to address this problem. I agree with Dr. Hoffert that the federal role is absolutely critical, but it is in the private sector that you are going to get tremendous innovation. What the private sector is going to invest, if they have a price on carbon, if they have a carbon constraint, if we have a national, mandatory policy, and an international policy that is consistent with what works here, and will also work globally, that is how you are going to unleash the power of the private sector to innovate, to respond, and you will get all kinds of inventions that the government won't think of. It is the learning by doing that the private sector can do that the government can't, but we really need to solve this problem.

Ms. WOOLSEY. Thank you. Mr. Eule.

Mr. EULE. I am going to be a little bit parochial here, and urge that Congress fund the budget that we proposed for the Climate Change Technology Program. I will say last year, we didn't receive any funding, and we think that was—we don't think there was any prejudice in that. We think it was oversight. It was the way our budget was arranged, but we missed the money, quite frankly, and I think that one of the reasons the report was delayed is we didn't have the funding that we thought we would have to get the document out the door, but we have asked for $1 million for this fiscal year, and we would certainly appreciate the Members' support in seeing that that gets funded.

Ms. WOOLSEY. So, Mr. Eule, with that $1 million, what would we have besides a report, or $1 billion, or how many——

Mr. EULE. Well——

Ms. WOOLSEY.—million, it is not——

Mr. EULE. It doesn't sound like a lot of money——

Ms. WOOLSEY. No.

Mr. EULE.—but it is a lot of money to us. I think we will get implementation of the report. That is—we have a series of next steps that are listed in Chapter 9, and one thing we would like to do is get busy on implementing on those. I think there are a number of analytical tasks that we would like to undertake, for example, limits analysis.

You know, Dr. Hoffert talked about the potential of some of these technologies, but there could be limits. I mean, when you think about—well, there has been discussion recently about the limits of ethanol production, you know, where it bumps up against food production. So, what we would like to do is take a look at not only ethanol, but other technologies to see what type of limits are out there. That would be an excellent planning tool. That is something that we have in mind for next fiscal year.

We would like to beef up our scenario analyses, which I think are very important for policymakers, and of course, portfolio reviews are sort of the bread and butter of what we do, and help us prioritize the R&D portfolio.

So, I think those three things are, would be at the top of my list for next year.

Ms. WOOLSEY. Thank you all very, very much.

Chairwoman BIGGERT. Thank you. I am—I would recognize the—Mr. Rohrabacher is—I have not recognized him yet, but just recognize that he is here, and has joined our committee, and would ask unanimous consent that he be—join our committee. He is a part of the Science Committee, but not on this subcommittee, and with that, I would call on Mr. Green from Texas. Recognized for five minutes.

Mr. GREEN. Thank you, Madam Chair, and thank also the ranking member, and I am tempted very much to give Mr. Hoffert another five minutes, but I think I can fight the temptation.

The report addresses a number of things, and perhaps this is contained therein. How do we deal with Mr. Hoffert's notion that we need a global program to address the CO_2 problem? How do we inculcate the rest of the world into this grand scheme? Yes, sir.

Mr. EULE. The Administration has actually done quite a bit of outreach with our partners overseas. Just let me give you a few examples. Earlier, I believe it was in July 2001, we launched the Generation IV International Forum, which has ten countries that are partners, plus EURATOM, and they are looking at six advanced Generation IV design for nuclear power plants.

In 2003, we launched the Carbon Sequestration Leadership Forum. It has, I believe, over 20 members at this point, and it is looking at technologies, primarily geological sequestration. We all recognize that, for the foreseeable future, fossil fuels are going to be one of the most available sources of energy. The question is what do you do with the emissions that you get when you use them. So, we have engaged internationally with the Carbon Sequestration Leadership Forum on technologies that could solve that.

The International Partnership for the Hydrogen Economy is another U.S. initiative. It has 17 members, and it is working on fuel cell, distribution, and production technologies to make the hydrogen economy a reality. And I want to point out here, too, that in these international initiatives, we have developed countries, we have developing countries, we have countries that are parties to the Kyoto Protocol, and countries that are—so it is a big mix, but each of them, each country brings to the table some technology capability, and we think that these are great collaborative efforts that we can leverage our own resources, and so our budgets go further.

And I would mention Methane to Markets as another partnership that we have, that is led by the Environmental Protection Agency, and it is focusing on using methane from landfills, oil and gas systems, agriculture, and coal mines, and using that as a clean fuel. Methane emissions are 20 times—over 20 times more potent than carbon dioxide, so these are great short-term opportunities to have an impact.

So, I would just offer those as some examples of how we are engaging internationally on the technology front.

Mr. GREEN. Yes, ma'am.

Ms. GREENWALD. I think the most important thing that we can do as a country is to engage with other countries in designing an international regime for dealing with greenhouse gas emissions. We are a quarter of the world's greenhouse gas emissions. The Kyoto Protocol may not have been the right agreement for the United States, but we have to figure out what the right agreement is. We have to participate actively in developing an international response to this issue that develops a market for greenhouse gas emissions that our companies can participate in, that develops markets for technologies that we can develop and that we can implement. We need a global response to this problem, and as an important player, a critical player in this globally, we have a tremendous responsibility and opportunity to help design how the world is going to respond to this over the long-term.

Mr. GREEN. You mentioned Kyoto. Before you go on, are we still encouraging others to become a part of Kyoto?

Ms. GREENWALD. It depends who the we is.

Mr. GREEN. The United States.

Ms. GREENWALD. The Europeans are moving ahead, and the United States has decided not to participate. I think it is probably moot at this point for our country, because it starts in about a year or two, so I think it would be very difficult for us to sign onto the Kyoto Protocol and participate at this moment, but there are lots of discussions going on about what happens beyond Kyoto? How do you develop a regime that can work for us, that can work for developing countries, to sort of involve all the major emitters in the world in dealing with this problem, because it is global. We have to have a national policy that works for us, and we have to work toward an international program that works for us and for the rest of the world.

Mr. GREEN. Was that decision that Kyoto doesn't work for us more scientific than political?

Ms. GREENWALD. I think it was more political than scientific.

Mr. GREEN. Did you have an additional comment, sir?

Mr. MOTTERSHEAD. I think that business competes, and this is an issue of international competitiveness, and while cooperation has its place, you can see that they—in the development of solar photovoltaics, there actually—that international competition has caused the technology to develop more quickly than probably if we just had an international cooperation.

So, the Japanese, building an internal industry by creating a market inside Japan clearly led and continue to lead the industry. Then Germany, clearly starting to build, followed by Spain, and now, California following. And those industries are getting built on the back of markets that were created by policy. At the moment, actually, the most, probably the most favorable place to come if you want to develop a wind business is into the U.S., and that is very good and supportive. As will next generation biofuels. But the Germans are clearly developing a view about biodiesel, because of the importance of diesel in their infrastructure.

Then you come to carbon capture and storage, and it seems too, well, as everybody was interested in cooperation on research, and we took that, and said well, actually, we are more interested in building hydrogen power stations. So, we have committed to building between 10 and 15 hydrogen power stations in the next 10 years. Each one of those, therefore—an example of one is in Carson City in California—is a $1 billion investment, will generate 500 megawatts of power, will be operational in 2011, and that is what is required. If you want to actually build a business, you have to build customers who want to buy the product. Businesses will respond. But we have—that is an investment of something like $8 billion over the next decade. I mean, you know, once you get into that, then that is the degree of competition that will pull——

Mr. GREEN. Before my time expires, I have a question for you, one additional question. Give a practical example, if you would, please, of pricing carbon, a practical example of how we can price it?

Mr. MOTTERSHEAD. In Europe, the European Emission Trading Scheme provides a cap on all large emitters, both in the utility sector and in industry, which creates a price on carbon that has fluctuated over the last two years between 15 to 30 a ton of carbon dioxide, and that clearly changes businesses' attitude to their own emissions, and to their future investments.

Mr. GREEN. Yes, sir.

Mr. EULE. I just want to follow up with the—you asked about the Kyoto Protocol earlier. One of the concerns about the Kyoto Protocol from the U.S. perspective was that it did not include participation from developing countries in any obligations, and I think one of the things we have to consider as we think about policy over the long-term is that developing countries for the most part haven't shown any interest in committing to reducing greenhouse emissions. They are much more interested in providing power to their citizens and economic development.

The International Energy Agency estimates that there are about two billion people worldwide that do not have access to modern energy services, and governments across the globe are working furiously to provide that energy to their citizens, which propels economic growth. So, the question is, if carbon can't be the driver, then what is? And what we have done through the Asia Pacific Partnership, which includes the U.S., Japan, Australia, South Korea, China and India, we have placed climate change within a much broader context, the context that will include energy security, reducing air pollution, and mitigating greenhouse gas emissions. So it is not focused exclusively on climate change, and we think that—well, the partnership with those six countries accounts for about half the greenhouse gas emissions of the world, half the population, half the economic activity of the globe, so it is a small group, but it is a very big group in those terms.

And so, through the partnership, we are looking at ways to deploy cleaner technologies in those countries, and we think that will have a big impact.

Chairwoman BIGGERT. The gentleman's time has expired. Mr. Rohrabacher, you are recognized for five minutes.

Mr. ROHRABACHER. Thank you very much. I have looked at this issue, and I can—you know, with a lot of skepticism in the past, and I do today. I mean, having noted the countless, perhaps a dozen times that there has been global cooling and global warming over the long history of this planet. I mean, we have had ice ages come and go before human beings ever were on this planet. I have to assume they weren't caused by manmade greenhouse gases as the glaciers went back and forth before mankind even emerged.

So, pardon my skepticism. Also, being a surfer, I go out on the ocean, and I know the number one rule is you don't fight Mother Nature, you know. Surfers don't fight the waves, they understand how the waves go, and you work with the waves. And so, it is frustrating to hear about, you know, people assigning, for example, political motives to—saying is this science or this politics? Well, how about economics? You know, maybe economics is the decision-making factor. That the—because you can prove anything with science eventually, if you are willing to spend all the money that is necessary for health care, education, and everything else in our country and the world. You dilute the Third World of all their resources, in order to prevent certain greenhouse gases from emerging in their electric plant.

But the question I have for you, and this is a question, well, first, one other observation, I had a British Member of Parliament out with me in California last weekend, and he told me about how in Roman times, they have uncovered the fact that England was covered with vineyards, where they grew wine grapes, and by the year 1000, the Vikings were colonizing Greenland and Iceland, but by the year 1400, it was so cold that the colonies in Iceland and Greenland were actually almost starved to death, because they couldn't—no longer depend on agriculture, and the Thames River was freezing over. I don't think that was caused by any manmade greenhouse gases, because I think that they didn't have a lot of industry at that time.

With that said, let me say I have three babies at home, and I want them to breathe clean air, and while I am not sympathetic at all with this—which I consider to be total baloney of that manmade climate change, you know, you are going through this cycle because of what man has done, especially considering that all the other cycles man wasn't present, but I do want my babies to breathe clean air. I do want them to live in an environment where what is being—producing our energy does not hurt their health.

Is there—is this a consistent—this is a question for the panel—if I have a target of global pollution, trying to stop global pollution, and trying to help and clean the air that way, is this in some way contradictory, in terms of what I would do, then what you are proposing that we do to prevent global warming, which of course, I reject? So, are we at odds, or is it reality that if we really believe in it, we want to try to do everything we can to check pollution for health reasons, that we are actually on the same track?

Dr. HOFFERT. Who are you asking?

Mr. ROHRABACHER. The whole panel, just give a thumbs up, thumbs down, you're crazy, go back to California, go surfing. Whatever you want to do.

Ms. GREENWALD. I will start. If I have to say just one thing about the science, that the National Academy of Sciences, which is not a, sort of, one wing or the other, has made it very clear——

Mr. ROHRABACHER. Yeah. And——

Ms. GREENWALD.—that this is a very serious problem, and we have to take——

Mr. ROHRABACHER. And you noted that they—that the guy who was in charge of the report, that they—has now indicated that that was not his conclusion, and that his name was basically forced on that report?

Ms. GREENWALD. No.

Mr. ROHRABACHER. Okay. Well, you should note that.

Ms. GREENWALD. It is—well, our understanding is that that is not correct, but our view is——

Mr. ROHRABACHER. We have heard about it.

Ms. GREENWALD.—and I think that is really important to keep in mind that just over the past few years, the science has gotten much, much stronger, and we have been closely tracking the peer reviewed literature, and there is sort of two sets of studies that have been coming out that are very important.

One is very careful assessments that indicate we are actually already seeing impacts of climate change, and also, a number of very careful assessments of pattern analysis, taking on the specific question about is this natural variability, or is this something new? And in all of the impact categories, we are seeing very clear evidence that what is happening now is unprecedented.

Mr. ROHRABACHER. How is it different from the other warmings and coolings, then? Do we have—I mean, why is that we have had all of these different ice ages and warming ages? How is this one different from that?

Ms. GREENWALD. Well, this one is caused by greenhouse gases in the atmosphere, and if you look at sort of a 400,000 year temperature chart, we are going into temperature zones that we have never been before.

Mr. ROHRABACHER. And were there greenhouse gases in all the other ones as well?

Ms. GREENWALD. In part of the—we do have some natural CO_2, but the—what is taking us——

Mr. ROHRABACHER. Some.

Ms. GREENWALD.—into new—a new zones, is——

Mr. ROHRABACHER. Yeah, 95 percent of all greenhouse gases, and we have been through these hearings before, come from natural sources. But was it greenhouse gases in the past that came from natural sources that caused the global cooling and warming, or was it sunspots, which some other scientists tell me that it was caused from?

Ms. GREENWALD. Okay. Well, we will defer this for another time, but let me just answer your other question, which is on——

Mr. ROHRABACHER. Okay.

Ms. GREENWALD.—on the overlap between what you do about conventional air pollution and climate change.

Mr. ROHRABACHER. Right.

Ms. GREENWALD. There actually is substantial overlap. Many of the technological solutions that are good on climate change are also good on air pollution. For example, renewables, very limited air pollution. Nuclear power, which has——

Mr. ROHRABACHER. Right.

Ms. GREENWALD.—no greenhouse gas emissions, or very small on a lifecycle basis, is also low on air emissions, sort of NOx, SOx, the more traditional air pollution. Biofuels also has—there is a little bit of a mixed bag, but there are—there is some evidence that we can have good performance, better performance on air pollution from biofuels as well, and I think hydrogen also has some great characteristics, in terms of air pollution.

So, there are, if you are looking at it sort of from the overlap between——

Mr. ROHRABACHER. Right.

Ms. GREENWALD.—someone who cares about air pollution and climate change, I think there is significant overlap.

Mr. ROHRABACHER. So, there is ways we can work together even if we disagree with the analysis.

Ms. GREENWALD. I think so.

Mr. ROHRABACHER. Okay.

Dr. HOFFERT. I have a comment. First, I want to say how delighted I am to have the opportunity to meet you, Congressman Rohrabacher, as there is one area in which we may very well find an area of agreement.

The global—the need for a global scale source of base-load electricity is very acute. Right now, as you know, the world is spending $12 billion for the International Thermonuclear Experimental Reactor experiment, which the U.S. DOE is involved in, in part. There is another potential source of long-term base-load electricity which would involve capturing sunlight in orbit, geostationary orbit. That program is, at this point, completely unfunded, and the Department of Energy does not have a program in space solar power——

Mr. ROHRABACHER. And you know I have been pushing for just that, you know.

Dr. HOFFERT. Pardon me?

Mr. ROHRABACHER. You know, I have been pushing for just that.

Dr. HOFFERT. Well, that is why I would like to——

Mr. ROHRABACHER. Exactly.

Dr. HOFFERT.—start with, at least, with something I think that we might agree upon. People have different views on different matters. I think if we can agree that it would be desirable for a sustainable world to have a source of renewable energy that is very long-lasting, I think one could make technical arguments, and I know that you are aware of them, because you have written about it yourself.

Where space solar power could become competitive, depending on breakthroughs in technology having to do with launch vehicles, thin film photovoltaic cells, and all the rest, and I have heard many of your talks about this.

Mr. ROHRABACHER. Thank you.

Dr. HOFFERT. Having said that——

Mr. ROHRABACHER. Uh-oh.

Dr. HOFFERT.—and I am a fan of yours on that topic. Having said that, sir, one of the major reasons for developing that technology in this century, rather than the Twenty Second Century, is climate change. If not for climate change, there is plenty of coal, and everyone knows that we could basically make synthetic fuels at a higher price, but we could make synthetic fuels with coal, and we could run our electric power plants, and if it weren't for the fact that coal produces more CO_2 per unit of energy, and the fact that virtually all of us who have done relevant, climate-relevant research, believe that that is going to cause global warming, we wouldn't really have to worry about this problem of a global scale energy source.

I think it is very paradoxical that the very technology that you yourself would endorse is probably best motivated by this problem facing us. Now, none of this has to do with whether nature is actually causing global warming, which are remarks that you have made, and others have made from—at various times. Various people with expertise ranging from Michael Crichton to Congressman Barton to Senator Inhofe, I must tell you that it isn't just a matter of consensus of research active scientists. Scientists are not supposed to believe arguments from authority. You really have to take the long march through the data. Every one of your objections are things that we ourselves thought about. I have been working on this for 30 years, this problem. And you basically need to protect yourself from fooling yourself, if you are a scientist, because you get attached to your own theories, you start to love them, and there is nothing more disappointing than having a beautiful theory destroyed by an ugly fact, and we have to deal with that all the time, and some of our colleagues in the social sciences don't deal with it as much.

But I think I am coming to the end of my time.

Chairwoman BIGGERT. I think you are. And we are very happy that the illustrious Chairman of the Science Committee has joined us, Mr. Boehlert from New York, and you are recognized.

Mr. BOEHLERT. Thank you very much, Madam Chair.

I don't want anyone to think this is a point counterpoint, but Dr. Hoffert, like you, I have great admiration for my colleague, Mr. Rohrabacher. He is a very valued Member of this committee and this Congress. Unfortunately, on this issue, he happens to be more wrong than he is right.

There are a lot of people in this town who think that global climate change is a figment of the imagination of someone like me, or scientists like you, when in fact, it is a hard, sober reality that we have to face. And not only is it serious and documented, overwhelming scientific consensus, but man has contributed significantly to global climate change, and we know that, too, and that is documented.

And incidentally, I would point out that is the current thinking at the White House. They acknowledge it is for real. They acknowledge that man has contributed to it.

The question is now what do we do about it? Now, times have changed, and hope springs eternal, and I am very optimistic as we go forward, because of a lot of things. If you had told me a few years ago that one of the most respected journalists in America, Tom Brokaw, would have a highly acclaimed special on television on the Discovery Channel about this very subject, I would have said nobody will watch it—people were watching. If you would have told me a while back that people would be paying money to go to their local cinema to see a movie like "An Inconvenient Truth," starring, of all people, Al Gore, I would have said what do you mean? That is not going to happen. Well, that has happened, and they have. And I think he has added immensely to the national dialogue.

We have got to stop thinking the old way, Republicans versus Democrats, or scientists versus the rest of us. And there are some people on this Hill, as you know too well, who, instead of trying to be informed by science, try to intimidate the scientists, and I happen to work in a town where everyone likes to say, particularly in this institution, they are for science-based decision-making, until the overwhelming scientific consensus leads to a politically inconvenient conclusion. Then, they want to go to plan B. And I am not talking about the morning after pill. The fact of the matter is that this is very serious, and we have got to deal with it in a very serious, non-confrontational, nonpartisan way.

I would ask Mr. Eule, DOE has been doing research on clean energy technologies for decades, a long time, done some good work. Yet, the CCTP plan is silent on deployment strategies for those technologies already near or at the end of the R&D pipeline. What is the Department doing to help deploy technologies that will start making a difference next year, rather than 15 or 20 years from now?

In other words, I think what we have before us is a pretty—a reframing of the issue, so that we are all starting from the same point, but we have got to establish some priorities, and we have got to have some policy steps that are recommended, and we have got to have forward movement. We just can't stay static, and everybody bemoan about it. I am tired of picking up magazines like Newsweek, where I see a cover story about the greening of America, people are now very concerned about this issue, and when I channel surf, as I did one day recently, or a couple months ago, there was Miles O'Brien on CNN having an outstanding piece on global climate change. Everybody is talking about it. What the American people want is for somebody to start doing something about it, and Mr. Eule, the ball is in your court, and I think you have an opportunity.

So, enlighten me, please.

Mr. EULE. Thank you, Chairman Boehlert. You ask an excellent question. I think the Department—what the Secretary of Energy likes to say now is the biggest source of energy we have is the energy that we don't use wisely. So, the Department is making a concerted effort, I think, to get energy efficiency technologies out into the marketplace.

Let me give you a few examples. Our Industrial Technologies Program is undergoing two hundred energy assessments at some of the most energy-intensive facilities in the country. We have the Advanced Energy Initiative, which is looking at putting money into some specific technologies, that with just a little bit of push, we can get, make some real gains, and get them out into the marketplace.

And I would also draw your attention to the Energy Policy Act. I mean, the Administration has been arguing for the need for an Energy Policy Act for a number of years, and I think we have what I think are a number of provisions in there that are going to be very, very useful in getting technologies in the marketplace. In Fiscal Year 2007 alone, there is about $1.6 billion in tax credits and incentives. And I think some of the other provisions of the bill that don't get a lot of coverage, but are vitally important, are going to have a big impact, Title VI, for example, provides—authorizes, I believe, $1.5 billion in standby support coverage for the next six new nuclear plants that are built, in case of a regulatory delay. There are also nuclear tax credits in there, but quite frankly, builders of nuclear power plants aren't going to take the risk to take advantage of the tax credit if they can't get their plants commissioned and running. So, this provision in Title VI of the bill goes to a specific risk that was really holding back nuclear power plant constructions. I believe this is going to be a huge, huge impetus to building new nuclear power plants. And of course, if you couple that with our NP2010 program, which looks at the regulatory system, I mean, I think we have in place a good strategy to deploy nuclear power in the near-term.

And I also say that the Department is looking at exercising its authority to issue loan guarantees. We are talking about a figure of about $2 billion for technologies to—that avoid, reduce, or sequester greenhouse gas emissions or reduce air pollutants, and the office is in the process of setting up a program to do that. And I think that will also have a tremendous impact on getting these technologies to market.

Mr. BOEHLERT. Pardon me if I may, you know. Those are longer range. What are we doing, you know, I want to talk months, not years. What are we doing that offers some promise that at least, there is some movement in the direction of deploying technologies in months rather than years? You know, most people look at Washington, and say, you know, everybody agrees—well, everybody, even Mr. Rohrabacher, I think, is reluctantly coming around to the conclusion that global climate change is for real. I wish we could harness his energy. Maybe we could solve some of the problems. But they say do something about it in Washington, and Washington is not doing something that is more immediate in nature.

And let me quickly, parenthetically add that I have the greatest respect for Secretary Bodman. I think he is unquestionably one of the best Cabinet choices this President has made. I mean, I view him as first among equals in the Cabinet, but we have some differences. For example, I think our energy policy is flawed. I think we have ignored CAFE standards and things like that. That offers some immediate hope, some relief, but what do we—talk about months, not years.

Mr. EULE. Chairman, I can't resist putting in a plug that we have asked Congress for authority to reform the CAFE program.

Mr. BOEHLERT. Well, there is some disagreement, Mr. Eule.

Mr. EULE. Yes, I understand.

Mr. BOEHLERT. There is some disagreement on whether or not the President has that authority. So, given the authority——

Mr. EULE. Okay.

Mr. BOEHLERT. What good is the authority if you are not willing to use it?

Mr. EULE. I understand. No, you have asked some very good questions. As I have said, we are doing these assessments. Our buildings program, for example, is working with builders today on the new home designs that are much more energy-efficient than current homes. They have a longer-term plan, it goes out to 2020, but they are also doing, working with the builders now, and I believe at last count, there were close to 34,000 homes that were built through this program in the United States today.

So, I can certainly get you—I am not prepared to get——

Mr. BOEHLERT. Sure, I understand, and it is not——

Mr. EULE.—but I will certainly get something for the record.

[The information follows:]

DOE-Sponsored Climate Change Technology Deployment Activities and Best Practices

COMMITTEE:	COMMITTEE ON SCIENCE SUBCOMMITTEE ON ENERGY
DATE:	September 20, 2006
WITNESS:	Stephen Eule
INSERT FOR THE RECORD	Page: 67, Line: 1561

Department of Energy Technology and Best Practice Deployment Programs and Activities

The Department of Energy supports a number of programs and activities designed to accelerate the commercial use of new, clean technologies and best practices. These activities include technology demonstration, labeling and information dissemination, consumer information campaigns, education, training, and workforce development, codes and standards, incentives, market conditioning and government procurement, and international partnerships. The following provides a representative list of programs and activities undertaken by DOE to promote technologies and practices leading to greater energy efficiency and greenhouse gas emission reductions in the relatively near term. Detailed information for these programs may be found at the web address provided for each.

Program/Activity	Web Address
Clean Cities Program	http://www.eere.energy.gov/cleancities/
Clean Cities International	http://www.eere.energy.gov/cleancities/international.html
E85: The Campaign for an American Fuel	http://www.eere.energy.gov/afdc/e85campaign/
FreedomCAR and Vehicle Technologies Program	http://www1.eere.energy.gov/vehiclesandfuels/
Hybrid and Electric Propulsion Subprogram	http://www1.eere.energy.gov/vehiclesandfuels/technologies/systems/index.html
21st Century Truck Partnership	http://www1.eere.energy.gov/vehiclesandfuels/about/partnerships/21centurytruck/index.html
Graduate Automotive Technology Education	http://www1.eere.energy.gov/vehiclesandfuels/deployment/education/fcvt_gate.html
Advanced Vehicle Testing Activity	http://www1.eere.energy.gov/vehiclesandfuels/avta/
Challenge X: Crossover to Sustainable Mobility	http://www1.eere.energy.gov/vehiclesandfuels/deployment/education/fcvt_challengex.html
Hydrogen, Fuel Cells & Infrastructure Technologies Program	http://www1.eere.energy.gov/hydrogenandfuelcells/
National Hydrogen Learning Demonstration	http://www.eere.energy.gov/hydrogenandfuelcells/tech_validation/fleet_demonstration.html
Hydrogen and Fuel Cells Technology Validation	http://www.eere.energy.gov/hydrogenandfuelcells/tech_validation/

DOE-Sponsored Climate Change Technology Deployment Activities and Best Practices

Solid State Energy Conversion Alliance	http://www.netl.doe.gov/technologies/coalpower/fuelcells/seca/
Building Technologies Program	http://www.eere.energy.gov/buildings/
Building America	http://www.eere.energy.gov/buildings/building_america/
Rebuild America	http://www.eere.energy.gov/buildings/program_areas/rebuild.html
Building Energy Codes Program	http://www.energycodes.gov/
Appliances and Commercial Equipment Standards	http://www.eere.energy.gov/buildings/appliance_standards/
Geothermal Technologies Program	http://www1.eere.energy.gov/geothermal/
GeoPowering the West	http://www.eere.energy.gov/geothermal/gpw/
Solar Energy Technologies Program	http://www1.eere.energy.gov/solar/
Utility Solar Water Heating Initiative	http://www1.eere.energy.gov/solar/ush2o/
Solar America Initiative	http://www1.eere.energy.gov/solar/solar_america/index.html
Solar Decathlon	http://www.eere.energy.gov/solar_decathlon/about.html
Wind Powering America	http://www.eere.energy.gov/windandhydro/windpoweringamerica/
Weatherization Assistance Program	http://www.eere.energy.gov/weatherization/
International Renewable Energy Program	http://www.eere.energy.gov/wip/international.html
State Energy Program	http://www.eere.energy.gov/state_energy_program/
Tribal Energy Program	http://www.eere.energy.gov/tribalenergy/
Federal Energy Management Program	http://www1.eere.energy.gov/femp/
Super Energy Savings Performance Contracts (ESPC)	http://www1.eere.energy.gov/femp/financing/superespcs.html
Industrial Technologies Program	http://www1.eere.energy.gov/industry/
Easy Ways to Save Energy	http://www.eere.energy.gov/consumer/save_energy/
Energy Savers campaign	http://www.energysavers.gov/
Biofuels Initiative	http://www1.eere.energy.gov/biomass/
Loan Guarantee Program	http://www.lgprogram.energy.gov/
Voluntary Greenhouse Gas Emissions Registry	http://www.eia.doe.gov/oiaf/1605/vrrpt/
Asia-Pacific Partnership on Clean Development and Climate (multinational)	http://www.asiapacificpartnership.org/
Climate VISION—Voluntary Innovative Sector Initiatives: Opportunities Now	http://www.climatevision.gov/
ENERGY STAR Program (with EPA)	http://www.energystar.gov/
AgSTAR Program (with USDA and EPA)	http://www.epa.gov/agstar/

DOE-Sponsored Climate Change Technology Deployment Activities and Best Practices

Carbon Sequestration Regional Partnerships	http://www.fossil.energy.gov/programs/sequestration/partnerships/index.html
Methane to Markets Partnership (multi-agency and multi-national)	http://www.methanetomarkets.org/
Nuclear Power 2010	http://www.ne.doe.gov/np2010/neNP2010a.html

Mr. BOEHLERT. All right. Thank you very much, Madam Chair.

Chairwoman BIGGERT. I—this is the first time I have gaveled down the Chairman.

Mr. BOEHLERT. Well, I feel very passionately about this subject.

Chairwoman BIGGERT. And you have done it to me, I know.

Mr. BOEHLERT. I think it is kind of obvious that I am interested. Thank you, Madam Chair.

Chairwoman BIGGERT. And thank you so much for being here, and I would like to thank everyone who has participated in this hearing today, and we really appreciate your input, and your efforts.

And let me express my appreciation to the Department for releasing the revised CCTP strategy plan, but let me also put you on notice that this issue is not closed. I take oversight responsibilities seriously, and I would like to see continued progress, and first, we need to be able to better compare the relative value of R&D investments across the full CCTP portfolio. And I think next, that the DOE needs to make a—needs a better process for evaluating its plans and priorities, and I would expect the DOE to solicit input and advice from the technical community, industry associations, and environmental groups on the full suite of climate change technology activities.

And finally, I think we need to be better able to assess the relative impact on climate change of the different technologies in the CCTP portfolio. So, with that, I look forward to learning of the Department's progress in these areas in the future. I really thank all of the experts for being here, and your excellent testimony.

If there is no further objection, the record will remain open for additional statements from the Members, and for answers to any followup questions the Subcommittee may ask the panelists. Without objection, so ordered.

This hearing is now adjourned.

[Whereupon, at 3:33 p.m., the Subcommittee was adjourned.]

Appendix 1:

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Stephen Eule, Director of U.S. Climate Change Technology Program, Department of Energy

Questions submitted by Chairman Judy Biggert

Q1. The technical reviewers, in their May 2006 report, recommended greater emphasis on exploratory research addressing novel concepts to uncover breakthrough technology, enabling research and development (R&D), and integrative concepts. How does the revised plan address cross-cutting R&D opportunities that do not neatly fit into any one of your technology categories? Please provide examples.

A1. The Climate Change Technology Program's (CCTP) *Strategic Plan* highlights the importance of identifying and pursuing cross-cutting R&D opportunities that do not neatly fit into any one of the applied technology categories in Chapters 4 through 8. Specifically, Chapter 9 states that there is a need "to augment existing applied R&D and strategic research programs with exploratory research. Such research would pursue novel, advanced or emergent, enabling and integrative concepts that do not fit well within the defined parameters of existing programs, and are not elsewhere covered."

Chapter 9 provides some specific examples of novel concepts. We note that many of these concepts are already being funded within ongoing programs. In fact, in 2002, we posted a Request for Information (RFI) for novel concepts to support our budget request for a National Climate Change Technology Initiative competitive solicitation program. Less than 10 of the 180 RFI responses were simultaneously assessed as high in technical merit, responsive to the RFI criteria, and unique or novel, that is, not easily fitting into the scope of any existing R&D funding program, if broadly considered.

Q2. The President's budget requests $3 billion in Fiscal Year 2007 for climate change technology development. What is the annual estimated cost of the activities outlined in your plan?

A2. A breakdown by agency of the annual estimated federal cost of the current CCTP portfolio, about $2.8 billion, may be found in the budget table of Appendix A. However, this should be interpreted as a partial figure in the overall global effort to develop new technologies. For example, the federal cost is often augmented in the applied R&D areas by non-federal partnering and cost-sharing, which can be as much as, or greater than, the federal share. Further, the U.S.-sponsored activities may be augmented independently by RDD&D activities in the private sector, and by State, local, and regional governments. Finally, many of the R&D activities in the *Plan* are being pursued, as well, by national governments of other countries, which is why the *Plan* emphasizes the importance of U.S.-sponsored initiatives for international cooperation. The annual global investment is not known, but the figure in this regard is likely to be significantly higher than the annual estimated federal cost.

Q3. The Secretary of Commerce just announced that an advisory committee will be established to provide advice on the further development of the Climate Change Science Program. Please describe your process for soliciting input from existing Department of Energy (DOE) advisory committees. If no such advisory committee structure exists to provide advice on the priorities and direction of the Climate Change Technology Program (CCTP) R&D portfolio, would CCTP benefit from a similar committee to provide advice on the priorities within the CCTP R&D portfolio?

A3. The organizational structure of CCTP is one that relies on the technical competencies of its six Working Groups (WGs)—one for each of six strategic goals. These WGs are led and populated by senior technical professionals among the agencies, who direct R&D programs that are advised by external experts. The WGs, additionally, are advised by experts in the DOE national and other federal laboratories and academia. In this way, CCTP builds on the foundations of the technology programs and incorporates the input of both ongoing programmatic advisory activities and external inputs. CCTP also sponsors its own independent technical reviews.

Q4. Mr. Mottershead indicated that BP would like to see more thought given to encouraging innovative public-private partnerships. Several other commenters to the draft plan made the same suggestion. Can you discuss the types of public-private partnerships already underway at DOE and how those partnerships and others will be used to advance CCTP?

A4. The Administration believes that private sector participation is critical to accelerating the development and commercialization of new energy and climate technologies. This recognizes not only the private sector's technical expertise, but also the fact that commercialization of advanced technologies will be largely a private sector function. It is only by government and industry working together that we can advance a new, cleaner energy future. Partnerships are therefore a key aspect of CCTP's approach.

Under the provisions of the *Energy Policy Act of 1992* (Section 3002), significant cost sharing of all DOE energy-related applied R&D (20 percent minimum) and demonstration projects (50 percent minimum) is required. This requirement necessitates public-private partnering on virtually all projects in a substantive, financial way. Since much of CCTP's R&D portfolio is energy-related, much of its portfolio is cost-shared. Notable examples include innovative partnering in the carbon sequestration program, in both the area of regional partnerships and demonstration projects. Public-private partnerships extend beyond cost-sharing; they include sharing a common long-term goals and strategies to achieve them. Some examples include: FutureGen, Methane to Markets, Nuclear Power 201 0, and FreedomCAR.

Questions submitted by Representative Michael M. Honda

Q1. Why has the Administration chosen to use greenhouse gas intensity (a ratio of emissions to economic output) as a metric for measuring reductions in greenhouse gases and not an absolute reduction in emissions or in atmospheric levels of greenhouse gases? Please explain how this metric does not effectively mask actual increases in the absolute level of emissions.

A1. The most useful and informative measure for policy management purposes is relative improvement in greenhouse gas emissions intensity. The intensity measure appropriately recognizes reductions that are achieved through increased investment in efficiency, productivity, and economically valuable activities that require less energy or lead to fewer emissions. The intensity measure sharply discounts reductions produced by economic decline, job loss, or policies that shift greenhouse gas emitting activity from the U.S. to another country.

For example, an absolute emissions reduction caused by an economic recession may say more about reduced energy use owing to reduced economic activity and say less about structural changes in the economy towards more energy efficiency. However, with an intensity metric, any slowdown in economic growth is taken into account in the results so that no credit, from an emissions perspective, is given for a slowing economy. Actual emissions reduction will occur when the rate of emissions intensity decline exceeds the rate of economic growth.

Details on total U.S. emissions are provided in annual reports both by the Energy Information Administration (EIA), which also provides a measure of greenhouse gas intensity, and by the Environmental Protection Agency. The most recent EIA greenhouse gas inventory report indicates that total U.S. emissions grew just 0.6 percent in 2005, despite economic growth of 3.2 percent.

Q2. The Energy Information Administration estimates that under a business-as-usual scenario the U.S. would achieve a 17 percent reduction in greenhouse gas intensity by 2012. The President's goal is to reduce greenhouse gas intensity by 18 percent.

- *How much would actual emissions grow under business-as-usual?*
- *How much will the Administration's current plan, with the 18 percent goal, affect U.S. emissions by 2012 and beyond?*

A2. In 2002, President Bush set an ambitious but achievable national goal to reduce the greenhouse gas intensity of the U.S. economy by 18 percent by 2012. At the time, this goal represented a nearly 30 percent improvement in the expected rate of improvement in intensity over the period. The Administration estimated that achieving this commitment would avoid additionally over 100 million metric tons of carbon-equivalent (MMTCe) of greenhouse gas emissions in 2012 compared to a business-as-usual baseline[1] and would result in cumulative savings of more than 500 MMTCe in greenhouse gas emissions over the decade. Under the business-as-usual scenario used in this 2002 analysis, total emissions were projected to climb

[1] The baseline used in the 2002 analysis was based on forecasts of energy-related carbon dioxide emissions and economic growth derived from the Energy Information Administration's *Annual Energy Outlook 2002* and forecasts of other carbon dioxide and greenhouse gas emissions derived from Environmental Protection Agency reports.

from 1,917 MMTCe in 2002 to 2,279 MMTCe in 2012. Achieving the President's goal was estimated to reduce the 2012 figure to 2,173 MMTCe.

The *Annual Energy Outlook (AEO) 2006* contains a projection suggesting that total U.S. greenhouse gas emissions will climb from 1,885 MMTCe in 2002 to 2,154 MMTCe in 2012. Concerning the EIA *AEO2006* intensity baseline of 16.8 percent, it is important to note that we would expect EIA's *AEO* baseline to show improvement over time as policies are implemented in support of the President's intensity goal, which was set in 2002. The effect of higher energy prices is clearly evident in the *AEO2006* baseline projection, but it also is influenced by new policies being implemented. For example, the CAFE standards for light trucks finalized in 2003 and the tax credits, incentives, and standards in the *Energy Policy Act of 2005* are incorporated in the *AEO2006* baseline.

Data from EIA suggest steady progress. Since 2002, EIA reports annual improvements in greenhouse gas emissions intensity of 1.6 percent in 2003, 1.6 percent in 2004, and 2.5 percent in 2005. Although we are only a few years into the effort, the Nation appears on track to meet the President's goal.

The impact of the Administration's program beyond 2012 will be included as part of the Climate Action Report, now in preparation, that the U.S. will submit to the United Nations Framework Convention on Climate Change.

Q3. The Congressional Budget Office just released a report that states that technology development combined with carbon constraints provides the most cost-effective approach to climate change mitigation. The CCTP's own draft plan only included technology emissions scenarios with carbon constraints.

- *Has the President's position on climate change uncertainty and carbon constraints policy changed?*
- *The CCTP lays out technology options, but what are the policy drivers to get those technologies deployed into the marketplace? If it is not your job to identify and push for these policy drivers, who is charged with that task in the Administration?*

A3. In 2002, President Bush reaffirmed the U.S. Government's commitment to the United Nations Framework Convention on Climate Change and its long-term goal of stabilizing greenhouse gas emissions in the atmosphere at a level that avoids dangerous human interference with the climate system—a level that at present is unknown. The President set a national goal to reduce the greenhouse gas intensity of the U.S. economy by 18 percent by 2012. This goal sets America on a path to slow the growth in greenhouse gas emissions and—as the science justifies and the technology allows—to stop and reverse that growth.

The Administration places great emphasis on the development and commercial use of advanced technologies, without which it is difficult to see how climate mitigation can be reconciled with other pressing needs, such as economic growth, energy security, and pollution reduction. Given the nature of the challenge and the many unknowns, it is appropriate that CCTP adopt a long-term planning context for the role of technology in addressing climate change. While CCTP does not set policy, it supports policy development, and by significantly reducing the costs of advanced technologies, its R&D programs can open up a wider range of politically and economically acceptable options for policy-makers.

Overall climate policy is directed by the Executive Office of the President with input from federal agencies.

Q4. Critics of the program claim that CCTP is merely a "repackaging" of existing programs. Five and one-half years after its establishment, CCTP should be in the position of directing climate technology research throughout the federal agencies involved in the program. Of the R&D programs listed as part of the CCTP, which initiatives originated in CCTP, or as a direct result of CCTP recommendations to an agency? Please explain in detail the role CCTP staff have played in developing budgets and priorities for all the programs listed as components of CCTP in the Offices of Fossil Energy, Energy Efficiency, Nuclear Energy or Science?

A4. CCTP's *Strategic Plan* does include current activities. To assess the overall portfolio and set priorities, a good understanding of current programs relevant to CCTP's mission is needed. However, the *Plan* goes considerably further. It provides an overarching technology roadmap organized by five CCTP strategic goals over the short-, mid-, and long-term. In each of the goals chapters there are discussions of future research directions. The *Plan* sets out a process and criteria for prioritizing the federal technology R&D portfolio. These criteria include: (1) maximizing return on investment; (2) supporting public-private partnerships; (3) focusing on technology with large-scale potential; and (4) sequencing R&D investments in a logical order. CCTP's analysis and strategy inspires the pursuit of innovative technology concepts designed, not just to address short-term GHG emissions reductions, but the fundamental transformations required over the long-term to meet the challenge of stabilizing GHG concentrations.

Since its inception in 2002, this multi-agency planning and coordination activity has encouraged a number of important technology initiatives aimed at reducing greenhouse gas emissions. There are many rationales besides climate change mitigation—energy security, for example—for many of the major initiatives the Administration has undertaken, such as the Hydrogen Fuel and FreedomCAR Initiatives, FutureGen, Advanced Energy Initiative, etc. CCTP helped provide long-term programmatic rationale. Moreover, CCTP in the *Plan* has established 12 priorities that respond to the President's National Climate Change Technology Initiative (NCCTI). These NCCTI priorities, which are described in Appendix B of the *Plan,* represent R&D and other activities that with a little push could result in significant technological advances to reduce, avoid, or sequester greenhouse gases.

Appendix A

CCTP Participating Agency – FY 2004 to FY 2006 Budgets and Requests Categorization of RDD&D Funding To Climate Change Technology (Funding, $ Millions) (3)

Department and Account(s)	FY 2004 Actual	FY 2005 Enacted	FY 2006 Proposed (Preliminary)
Department of Agriculture			
Natural Resources Conservation Service – Biomass R&D (Section 9008 Farm Bill)	13.9	14.4	12.4
Natural Resources Conservation Service – Carbon Cycle	0.5	0.5	0.5
Forest Service R&D--inventories of carbon biomass	0.0	0.5	0.5
Agricultural Research Service--Bioenergy Research	2.4	2.4	2.4
Cooperative State Research, Education and Extension Service--Biofuels/Biomass research; formula funds, National Research Initiative	5.4	5.4	6.9
Forest Service--Biofuels/Biomass, Forest and Rangeland Research	0.4	2.4	2.5
Rural Business Service – Renewable Energy Program	22.8	22.8	10.0
Subtotal – USDA	**45.4**	**48.4**	**35.2**
Department of Commerce - NIST			
National Institute of Standards and Technology (NIST) Scientific and Technological Research and Services	9.8	9.5	7.4
Industrial Technical Services - Advanced Technology Program	18.1	20.2	0.0
Subtotal – DOC - NIST	**27.9**	**29.7**	**7.4**
Department of Defense			
Research, Development, Test and Evaluation, Army	15.3	50.5	43.0
Research, Development, Test and Evaluation, Navy	16.5	11.0	7.1
Research, Development, Test and Evaluation, Air Force	0.8	0.8	0.0
Research, Development, Test and Evaluation, Defense-wide	16.8	12.7	9.5
Research, Development, OSD	2.0	0.0	0.0
Subtotal – DOD	**51.5**	**75.0**	**59.6**
Department of Energy			
Energy Conservation	868.0	868.2	846.8
Energy Supply/Electricity Transmission & Distribution	73.0	103.0	84.0
Energy Supply/Nuclear	308.7	394.4	416.1
Energy Supply/Renewables	352.3	380.3	353.6
Fossil Energy R&D (Efficiency and Sequestration)	455.0	388.2	405.3
Science (Fusion, Sequestration, and Hydrogen)	332.7	370.6	398.7
Climate Change Technology Program Direction	0.0	0.0	1.0
Subtotal – DOE	**2389.6**	**2504.7**	**2505.5**

Department and Account(s)	FY 2004 Actual	FY 2005 Enacted	FY 2006 Proposed (Preliminary)
Department of the Interior			
US Geological Survey - Surveys, Investigations and Research - Geology Discipline, Energy Program	0.5	2.0	2.0
Subtotal – DOI	**0.5**	**2.0**	**2.0**
Department of Transportation			
Office of the Secretary for Technology - Transportation, Policy, R&D	4.0	0.8	0.0
National Highway Traffic Safety Admin	0.0	0.0	1.4
Research and Innovative Technology Admin	0.5	0.5	1.0
Subtotal – DOT	**4.5**	**1.3**	**2.4**
Environmental Protection Agency (1)			
Environmental Programs and Management	89.8	91.5	95.7
Science and Technology	20.5	17.5	17.7
Subtotal – EPA	**110.3**	**109.0**	**113.4**
National Aeronautics and Space Administration (2)			
Exploration, Science & Aeronautics	226.6	207.8	127.6
Subtotal – NASA	**226.6**	**207.8**	**127.6**
National Science Foundation			
Research and Related Activities	11.2	10.6	11.3
Subtotal – NSF	**11.2**	**10.6**	**11.3**
CCTP Total (3)	**2867.5**	**2988.5**	**2864.5**

USAID Activities Associated with CCTP (4)			
Development and Assistance	173.0	173.0	147.0
Subtotal – USAID	**173.0**	**173.0**	**147.0**
Total CCTP and Associated USAID Activities	**3040.5**	**3161.5**	**3011.5**

Notes:

(1) For EPA, FY 2005 Enacted numbers are for those of the President's FY05 request, not enacted, and that once EPA operating plans are complete, the FY05 numbers will change.

(2) For FY 2006, NASA went through a realignment within its Aeronautics Research. NASA no longer plans to pursue previously reported activities in certain vehicle systems areas.

(3) Totals may not add due to rounding. All agency data are as of March 2005.

(4) USAID activities are not included in the totals for CCTP, but are shown here for completeness, to the extent that such activities are consistent with the criteria for inclusion in CCTP, as shown below.

Appendix B

List of Commenters to CCTP Draft Plan

Name	Organization
Bernstein, Leonard	American Petroleum Institute
Caldeira, Ken	Department of Global Ecology, Carnegie Institution
Cunningham, Bill, President	Unions for Jobs and the Environment (UJAE)
Fang, William L., Eric Holdsworth	Edison Electric Institute (EEI)
Fulkerson, Bill	Joint Institute for Energy and Environment
Hoffert, Marty	New York University
Holliday, G.H.	Holliday Environmental Services, Inc.
Hoyte, Patricia A.; James D. Johnson	Caiteur Group, Inc.
Janke, Joel	Datapex Services, LLX
Kammen, Daniel M.; Gregory F. Nemet	University of California, Berkeley
Kelly, Carter Lee	Waste Management, Inc.
Kiser, Thomas	PSI, Inc.
Kraemer, Thomas A.	CH2M HILL
Kueter, Jeffrey	George Marshall Institute
Lane, Lee	Climate Policy Center
Lashof, Daniel A., Science Director, Climate Center	NRDC (Natural Resources Defense Council)
Lê, Khanh	Air Products and Chemicals, Inc.
MacAdam, Scott	Clean Energy Systems, Inc.
Mazer, Marshall	The Babcock & Wilcox Company
Miller, Lance	Jersey Board of Public Utilities
Rau, Greg	Institute of Marine Sciences, LLNL
Romeri, Mario Valentino	Independent Expert
Satterfield, May Barclay	Princeton University, Chem. Eng.
Schoenfield, Mark ; Thomas Weber; Brian Patrick	Jupiter Oxygen Corporation
Schoenfield, Mark K.	Jupiter Oxygen Corporation
Schowalter, David G.	Fluent, Inc.
Shipiro, Sol	US Citizen
Steinberg, Meyer	HCE, LLC
Tolman, Chad A.	Coalition for Climate Change Study and Action, Citizens Alarmed About Global Warming
White, Dustin	City of San Francisco
Zebroski Edwin L. Ph.D.	Retired

ANSWERS TO POST-HEARING QUESTIONS

Responses by Judith M. Greenwald, Director of Innovative Solutions, Pew Center on Global Climate Change

Questions submitted by Chairman Judy Biggert

Q1. Your testimony suggests that development of carbon reduction technologies is not very useful in the absence of mandatory constraints on greenhouse gas emissions. But, doesn't it make sense to move aggressively on technology development first and then tackle the regulatory framework? Won't that sequence allow society to move toward reducing greenhouse gas concentrations in the least economically disruptive manner?

A1. Aggressive technology development is critical, but R&D alone will not result in widespread deployment of low-carbon technologies. Installation of new technologies comes at a cost, and in the absence of mandatory constraints on emissions, most emitters have no incentive to take on this cost. Technology development produces a supply of carbon-reduction technologies without the corresponding demand provided by emissions constraints. In addition, research has shown that carbon reduction can be achieved at a lower cost through a combination of mandatory emissions constraints and technology R&D than through either approach alone. This conclusion was reached in a 2004 Pew Center report by Larry Goulder, "Induced technological change and climate policy," and echoed in a September 2006 study by the Congressional Budget Office, "Evaluating the Role of Prices and R&D in Reducing Carbon Dioxide Emissions." The CBO study stated that "a combination of the two approaches—pricing emissions in the near-term and funding R&D—would be necessary to reduce carbon emissions at the lowest possible cost."

Q2. How much do you feel the Federal Government should reasonably be spending per year on climate change technology at the Department of Energy and how did you arrive at that figure?

A2. The Pew Center has not calculated the specific level of funding needed. Most importantly, it is critical that funding levels be stable enough to ensure that key programs can plan long-term research. We would point to the testimonies submitted by Martin Hoffert and Daniel Kammen for specific suggestions in this area.

Questions submitted by Representative Michael M. Honda

Q1. Why has the Administration chosen to use greenhouse gas intensity (a ratio of emissions to economic output) as the metric for measuring reductions in greenhouse gases, and not an absolute reduction in emissions or in atmospheric concentrations of greenhouse gases?

- *Does the use of this metric not mask actual increases in emissions or atmospheric levels of carbon?*
- *What metrics are used in guiding climate policies elsewhere?*
- *In general, do the major companies in the Business Environmental Leadership Council find greenhouse gas intensity to be an acceptable and useful metric?*

A1. While we cannot speak for the Administration, President Bush has repeatedly stated that he believes emissions intensity is the most useful metric to consider. The Pew Center disagrees, but the metric is much less important to us than the environmental result it achieves. Intensity metrics do not indicate the overall growth or decline of greenhouse gas emissions and an intensity-based target may allow emissions to rise. GHG intensity can decrease while absolute emissions increase, so an intensity target typically is not as environmentally sound as an absolute cap. That being said, if a sufficiently strict intensity target is chosen, one could see absolute GHG reductions. Unfortunately, the Administration's goal of an 18 percent reduction in GHG intensity is not noticeably different from business as usual, and does in fact correspond to a continuing increase in GHG emissions.

The Kyoto Protocol uses an absolute GHG metric, as do the northeastern states' Regional Greenhouse Gas Initiative and California's new law, AB 32.

In the absence of federal policy, businesses have taken to creating GHG reduction goals themselves to anticipate policy and get ahead of the curve. Many of these goals are absolute (DuPont—reduce GHG emissions by 65 percent from 1990 levels by 2010; Weyerhaeuser—reduce GHG emissions by 40 percent by 2020; Bank of America—Reduce GHG emissions nine percent by 2009, relative to their 2004 levels; BP—Reduce GHG emissions by 10 percent from 1990 levels by 2010), but several companies use indexed metrics. For example, Baxter International has a GHG target to reduce energy use and associated GHG emissions by 30 percent per unit of product value from 1996 levels by 2005. Using indexed metrics increases the efficiency of operations without guaranteeing an absolute reduction is made.

Q2. You say in your testimony that the roughly $3 billion the Department claims to be spending on climate change is not enough.

- *What, do you believe, is required to adequately address climate change?*
- *Are the priorities for the various programs in line with where they should be?*

A2. Again, the Pew Center has not calculated the specific level of funding needed. We would point to the testimonies submitted by Martin Hoffert and Daniel Kammen for suggestions in this area, as well as on the priorities for funding.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Martin I. Hoffert, Emeritus Professor of Physics, New York University

General Response: It's important to distinguish between (1) CCTP-type research on alternate energy technologies that in some sense already "exist" at laboratory scales, or at industrial scales for certain components, but are too costly to permit penetration to significant energy market share; and (2) exploratory energy R&D of the ARPA–E type, exploiting recent scientific discoveries like high temperature superconductivity, nanotech or bioengineering, or embodying highly innovative systems for tapping energy flows and stores in nature, aimed at radically transforming the global energy system to permit continued economic growth even as fossil fuel $CO_2$2 emissions are phased out—this being the objective problem to be solved.

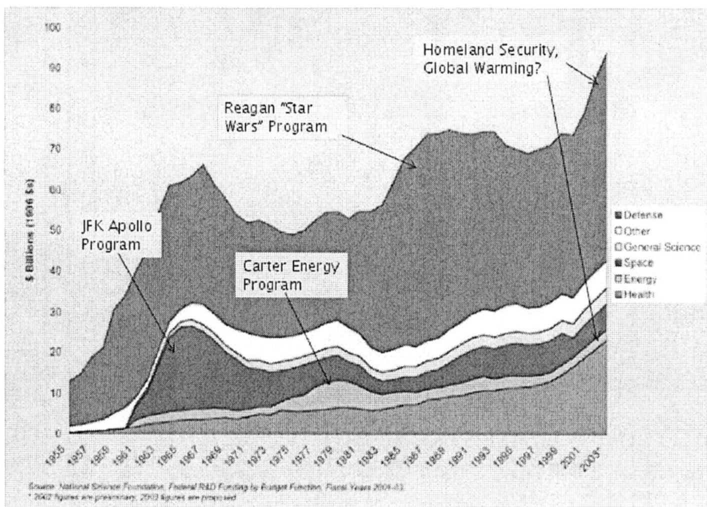
Climate and energy are the technology challenges of the century. The 9/11 Commission concluded that the most dangerous mistake one can make when challenged by an existential threat is "failure of imagination." Likewise does the climate/energy issue call for technological imagination, followed by rigorous testing and development to the point of commercial viability. These are unique strengths in which the U.S. has led the world for 200 years, particularly as stimulated by targeted government-funded initiatives over the past 50 years. The proposed energy R&D should build on prior successful U.S. efforts to address the technical issues and global scale of the climate/energy problem (Hoffert, 2006). I will discuss CCTP-type funding in my response to Representative Biggert, ARPA–E funding in my response to Representative Honda.

Question submitted by Chairman Judy Biggert

Q1. How much do you feel the Federal Government should be reasonably spending per year on climate change technology at the Department of Energy and how did you arrive at that figure?

A1. The short answer is that the CCTP program, which at this point essentially repackages government funded energy R&D of about $3 billion/year, needs to grow to $20–30 billion per year, or more. This level of funding is similar to prior U.S. technology initiatives like FDR's Manhattan Project of the '40s, JFK's Apollo program of the '60s, Carter's Energy program of the '70s (unfortunately aborted) and Reagan's Strategic Defense Initiative of the '80s, as illustrated in the figure showing U.S. R&D expenses in 1996 dollars by sector from data in Meeks (2002). The U.S. Government today spends more than $120 billion (2002 dollars) a year on research and development (Nemet and Kammen, 2006), of which declining fraction, only a few percent, is expended on energy, the driver technology of civilization. We've been lulled into passivity by historically cheap fossil fuels. Not for much longer, as hydrocarbon production peaks and global warming become all too evident in coming decades.

HISTORY OF US FEDERAL GOVERNMENT R & D



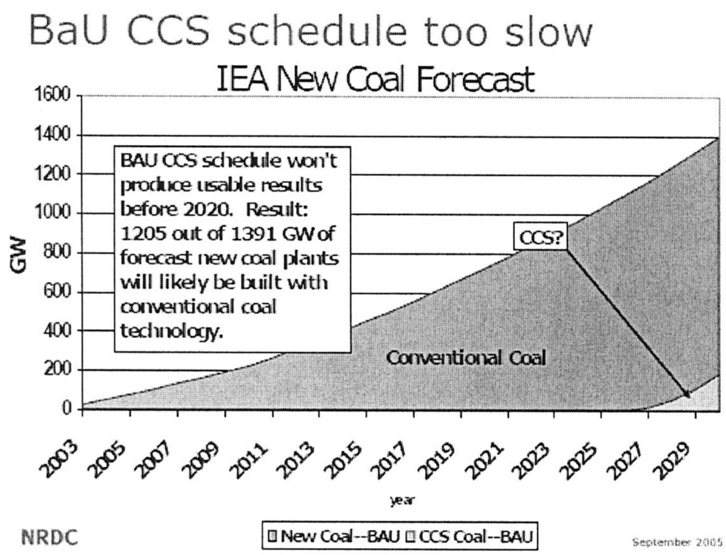
However much some may say the technology already exists to solve the climate/energy problem many colleagues and I disagree. Such technologies could exist, but they won't spring into existence spontaneously, any more than gas turbines, radar, lasers, commercial aviation, nuclear power, nuclear medicine, satellite telecommunications, computers, and the Internet sprang into existence without billions invested by Federal R&D since World War Two. World War II, which President Truman in the wake of Hiroshima and von Braun's V–2 rockets characterized as a "battle of laboratories" as much as a battle of armies. Vanever Bush, FDR's science advisor, is credited with beginning large-scale public support for R&D. Frankly much of this was motivated by defense and space during the Cold War. To emphasize this the Mansfield amendment added "D" for Defense at the beginning of ARPA (Advanced Research projects agency) to create DARPA.

But the results drove economic growth of the civil economy. Given that we already spend $120 billion present dollars on government R&D, the question is not whether there's enough money. When the U.S. was attacked at Pearl Harbor our nation was in a deep depression. After a half decade of war the "greatest generation" went from virtually no air force to building fifty thousand planes a year, aircraft which evolved technologically from biplanes to jets in an astoundingly short time, it built the atomic bomb, created radar, and accomplished many other technologically Herculean things, with the result that the U.S. emerged as the leading world power in what has been called the American Century. We're richer now than we've ever been, though this will not last if we fail to address the major problem of the present century, the climate/energy challenge. The problem is not lack of money. The problem is whether we can put in the required level of engineering creativity, effort and skill to fight a threat that doesn't involve blowing each other's brains out.

President Carter tried to make alternate energy a "moral equivalent of war." At its peak in the late '70s, Carter's R&D program was running at $10 billion a year and showing real progress. Too bad the institutional memory of Carter's initiative has dimmed and been distorted over the years. It was, of course, Carter's energy program under which DOE built the coal-to-natural gas demonstration plant that later became the Dakota Gasification Company. The plant was later sold by DOE, i.e., "privatized," at ~6 cents on the dollar of the of the government's investment. Ironically, this plant became a poster child for this administration's FutureGen coal-to-hydrogen plus electricity with carbon capture and storage (CCS) project, as the

CO_2 separated out is piped to (and sold for secondary oil recovery to) Saskatchewan's Weyburn oilfields. The project is touted—along with Norwegian Statoil's North Sea CCS project, also state subsidized, as showing the viability of CCS. But who in this administration credits Carter with demonstrating technology leading to FutureGen, or even knows the story? The DOE demo isn't slated for operation until 2012.

The fact is that the most ready for prime time project to mitigate carbon emissions from coal power plants now being built is too little, too late. By the time FutureGen is up and running at least 850 conventional coal fired power plants in the works by non-Kyoto signatories—the U.S., China and India—will overwhelm Kyoto emission cuts, if they even happen, by a factor of five. The figure (submitted by Dan Lashof of the NRDC as a critique of CCTP Strategic Plan) shows the cumulative capacity of conventional coal plants in the works now and carbon captures, a mere blip. Not signing Kyoto is one thing. But offering FutureGen as a significant U.S. technology initiative to cut carbon emissions (as was done at last winter's Kyoto meetings in Montreal by U.S. negotiator Harlan Watson) is simply refusing to face reality.



As Economist Robert Samuelson put it, "The trouble with the global warming debate is that it has become a moral crusade when it's really an engineering problem." Solving an engineering problem requires defining the goal quantitatively, facing the technical challenges, and creating systems to address these as cost-effectively as possible. Right now, we have little on the shelf for primary energy but burning coal for electricity and gasoline from crude oil for cars, both of which emitting CO_2 up the stack and out the tailpipe. Nuclear is roughly five percent and renewables collectively roughly one percent of primary energy (neglecting hydro, which is saturated, and firewood in preindustrial societies).

Getting serious enough about R&D to solve the climate/energy problem to avoid, for example, more than two degrees Celsius global warming relative to pre-industrial conditions above which polar icecap melting may become irreversible (Hansen, 2006) will cost $20–$30 billion per year, at least. The specific way this funding would ramp up needs careful consideration. But we have an applicable experience base from the Manhattan, Apollo, Energy Independence & SDI programs. Also needed is a major science education initiative, as was done in the post-Sputnik era. The U.S. should take the lead. But we don't have to go it alone. This is a global problem, and scientists and engineers worldwide have a tradition of working together on a common goal like the International Space Station, the International Thermonuclear Experimental Reactor, high-energy particle accelerators and other projects. Particularly important is to involve China and India in projects that can implement on the short-term.

In summary, and without at this point preparing a detailed budget, there is good reason to shoot for $20 to $30 billion a year for an Apollo-type program in alternate energy. The rapid convergence of urgent energy security issues and growing evidence of global warming may make money the least of our problems. We need real options to do this job and we don't have them. Out of the box ideas, like coal gasification demonstration plants in China and India funded by the U.S., might be an alternative to Kyoto, which the Senate has clearly indicated its indisposition to sign. These might stem the tide while we work on the fundamental energy system transformation; as might geoengineering experiments to "save the arctic." Other important issues are incentivizing research by private industry and entrepreneurial innovators, about which I have more to say below. All this will require an integrated climate/energy policy, including diplomacy, to implement effectively.

Question submitted by Representative Michael M. Honda

Q1. This committee has considered in various forms legislation regarding the creation of an Advanced Research Projects Agency for Energy, and you have advocated for the creation of a new innovation-focused research organization.

- *If Congress were to move forward with a plan to develop ARPA–E, what do you believe would be the essential elements of such a program?*

A1. Recent proposals for an independent exploratory R&D program (Caldeira et al., 2005) or an ARPA–E (Committee on Science, Engineering, and Public Policy, 2005) in alternate energy technology are motivated by the perception that breakthrough research isn't being pursued with sufficient urgency, in some cases not at all, by DOE or elsewhere because it falls outside bureaucratic program funding lines, or lacks champions. Not surprisingly these proposals have been resisted on grounds that DOE is already doing what needs doing, for example, in the CCTP and Basic Energy Science initiatives.

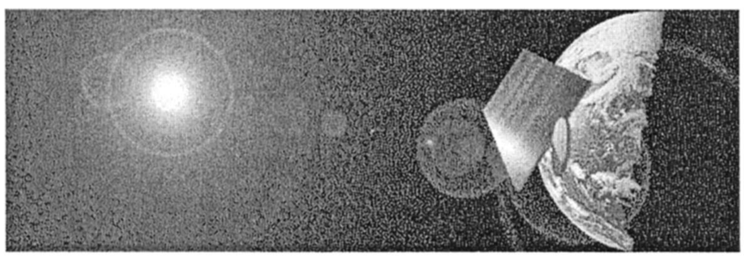
I indicated previously that I strongly support expanding existing DOE R&D programs. That said, existing bureaucratic structures are not, for reasons I won't expound upon here, the best way to incubate innovative, potentially disruptive technology shifts. Revolutionary technologies have changed the world many times over in the past century, often as spin-offs of military projects. The course of future technologies is difficult to impossible to predict, particularly by experts. But like biological evolution, technological evolution needs mutations.

I argue that the most robust R&D strategy is to support a broad spectrum of potentially revolutionary technologies that are physically plausible and address objectively real problems. For example, the transmission and storage of intermittent widely distributed renewable energy (solar and wind) is necessary if renewables are supply load curves for 20 percent or more electric power generation market share. Many states have Renewable Energy Portfolios mandating such targets by a set date. This won't happen unless grids in the region become "user friendly" to renewables. Existing grids designed for central power generation by fossil fuel or nuclear plants are totally inadequate, and deregulation of electric utilities has removed financial incentives for anyone to even think about this problem. It's telling that the country with the highest penetration of wind generated electricity, Denmark (near 20 percent), has only accomplished his because it is integrated into a Scandinavian grid with Norway which is 100 percent hydropower. Power emerging from Danish wind turbines is stored by pumping water to the reservoirs backing up Norwegian dams, and flows down them to supply electricity as needed. But the U.S. (and most other nations) lack such a convenient resource, so some technology for storage, perhaps compressed air, or flywheels, or something entirely different, is needed. This is just one example of needed research that isn't being done, perhaps because the question hasn't been asked.

It must be realized at the outset that many ARPA–E projects will hit an obstacles bad enough to terminate it. Beware on the other hand of giving up too early. Hands-on engineers are familiar with Murphy's Law: "If something can go wrong, it will." And progress often means a number of cycles of "build, break, fix, and build again." Notice that I'm emphasizing the nuts and bolts of research, as opposed to forecasting its economics, which I confess to have little faith in. Politicians want a sure thing. But however much we try, there will be uncertainty and random elements at play. And still, we must stay the course.

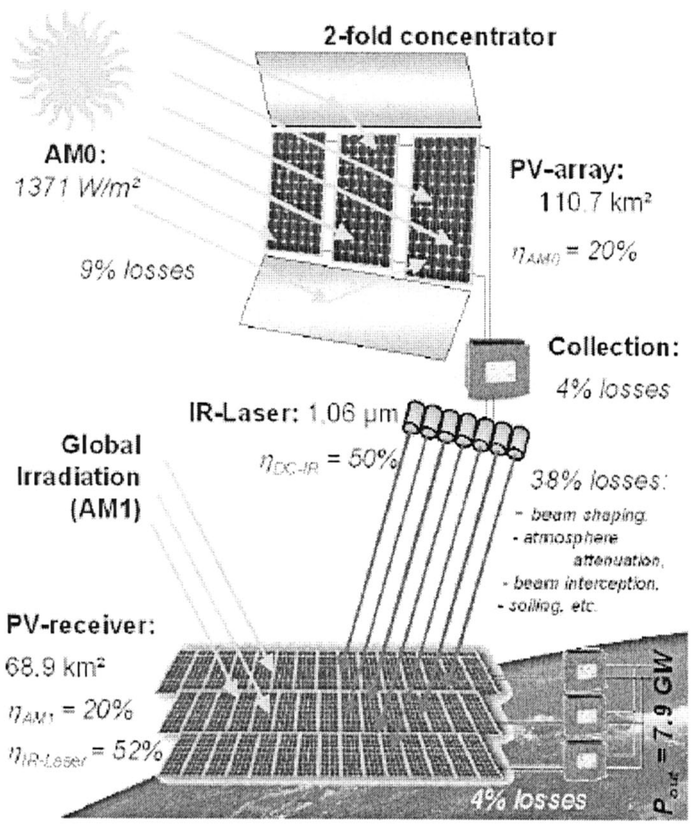
Technology evolution resembles biological evolution in the sense that most mutations are unfavorable. But without mutations evolution grinds to a halt. It only takes one transistor to justify all of Bell Labs. Sadly, that private sector temple of applied science is a shadow of its former glory. Today, industrial R&D is expected by large companies and venture capitalists to yield profits on a three-year time scale, whereas DOE basic energy sciences is often most comfortable with "blue sky" projects 20 or more years from fruition to avoid conflict with industry. The result is the well-known (by researchers) "Valley of Death" in the three- to 20-year payoff range for which it may be virtually impossible to get support for a new idea from either the private or public sector. This is the time frame ARPA–E should be targeting. I bring this up to illustrate that the program manager is crucial. She or he must be technically astute and possessed of excellent judgment based on experience (and compensated accordingly).

Can we build these elements into an exploratory energy R&D program? It was to insure that U.S. stayed on top militarily that ARPA was born (now DARPA) with a unique program management style aimed at creating new capabilities from scratch, funding the most able investigators without prejudice wherever they might be—universities, national labs, industry, entrepreneurs & inventive guys working out of garage. So too should it be with ARPA–E. In many cases DARPA has created technologies providing a hitherto undreamt of capability (like the Internet). As someone who's done it I can attest that military R&D supports far more imaginary ideas than civilian. Of course there's more money (and less oversight) there. The "black" space program is bigger than the "white" (NASA) one. Even with less revolutionary ideas, a performance improvement in some metric of many orders of magnitude improvement often a precondition for DARPA to be interested. The climate/energy problem is important enough to do likewise.



Do such ideas exist in alternate energy? This September's *Scientific American* in their article "Plan B for Energy," identifies several that are high risk & high payoff. In no particular priority they are (Gibbs, 2006): nuclear fusion breeding of fissionable fuel from thorium, a potentially early payoff from a longer-term investment in pure fusion; high-attitude wind turbines; space-based solar power, a technology in which I and Representative Rohrabacher (R–CA) of the House Science Committee share an interest (Rohrabacher and Weldon, 1998); nanotech solar cells; a global supergrid, originally proposed by Buckminster Fuller; innovative wave and tidal energy; designer microbes, for such applications as enzymes to convert abundant cellulose to sugar, for fermentation to ethanol fuel. At this point R&D in many of these areas—all of which could contribute in a major way to carbon-free power if successful—are either unsupported by DOE or any U.S. agency, or supported at too low a level to break out in the next few years as worth pursuing with real money.

Some thoughts on funding levels and whether DOE as now constituted can do it: A typical DARPA program is $300–$500 thousand in the first year and can go up substantially as projects progress. Of course, many ideas will be cut early on as they fail to make their targets and milestones or encounter problems the program manager considers showstoppers. It may be prudent to start with 100 projects at this level by budgeting $30 to $50 million. It needs further discussion to decide whether it would be better to continue support as projects grow in scale within ARPA–E, or whether they should be transferred to DOE under its growing budget, which I hope would include targeted Apollo-like programs for the most promising systems. One such system shown in the inset proposed by aerospace researchers in Europe would collect solar energy in geostationary orbit with solar cells and beam it by laser to surface photovoltaic modules in north Africa, and thence northward by high voltage Dc transmission line. The authors find, for plausible assumptions and available technology, that the entire electric load curve of Europe could be powered cost-effectively by such a system (Geuder et al., 2004). To some, but not I suspect Congressman Rohrabacher, this vision might seem too "far out." Space launch costs may seem presently too high, and so on. But the science is sound, and I, for one, can only admire that Europeans and Japanese and others dream of a sustainably powered planet while we in the good old USA, the most technologically advanced nation on Earth, seem intent on marching backward to the Coal Age.



I hope that we as a nation will regain our bearings, as we were on the right track 30 years ago. Just as Carter's effort was gaining steam, Ronald Reagan became President. Reagan ripped off the solar panels that Carter had put on the White House roof while simultaneously dismantling Carter's energy program based on the disastrous ideology that the government has no role in technology and that only private sector should create energy technology by the market mechanism. Newt Gingrich and colleagues made a similar move when the GOP took control of Congress in '84 when they changed the name of the "House Committee on Science and Technology" to the "House Committee of Science."

What does our government have to do with future technology development? Almost everything. One thing I agree with in the recent Stern report on the economics of global warming mitigation is that the market is broken. Too many costs and values aren't being captured and consumers are anything but enlightened about their energy self-interest. It may be the global warming is too complex for our puny hominid minds. As a technological optimist I believe we can solve the climate/energy problem in time with the right leadership. But leadership is key. To cite *Proverbs* 28:18, "When the vision fails, the people perish."

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Appendix 2:

ADDITIONAL MATERIAL FOR THE RECORD

STATEMENT OF UNITED TECHNOLOGIES CORPORATION

United Technologies (UTC), based in Hartford, Connecticut, is a diversified company that provides high technology products and services to the aerospace and commercial building industries worldwide. UTC's products include Otis elevators, escalators and people movers; Carrier heating, air conditioning and refrigeration systems; UTC Fire & Security fire safety and security products and services; UTC Power fuel cells and on-site combined cooling, heating and power applications; Pratt & Whitney aircraft engines; Hamilton Sundstrand aerospace systems; and Sikorsky helicopters.

The U.S. Department of Energy (DOE) Climate Change Technology Program Strategic Plan (*hereinafter,* Strategic Plan) proposes a coordinated federal approach to accelerate the development of advanced technologies in order to reduce greenhouse gas emissions. To help combat climate change, UTC is working to reduce greenhouse gases by reducing energy use in its operations and incorporating energy-efficient innovations in its products and services. Since 1992, UTC has set corporate-wide performance goals to reduce its environmental footprint worldwide in its factories, with its suppliers and throughout its product line. UTC supports a sustained investment in federal public-private partnerships for research, development, demonstration and deployment (RDD&D) of greenhouse gas-reduction technologies. UTC agrees with the DOE that it is essential to make wise RDD&D investments in order to expedite innovative and cost-effective approaches to reducing greenhouse gas emissions.

UTC has a diverse portfolio of advanced technology solutions that enhance the energy efficiency of transportation applications as well as residential, commercial and industrial buildings. We have chosen to focus this testimony on how we are working to reduce emissions in the building environment. We look forward to expanding our partnerships with the Department of Energy and other federal agencies to deploy these technologies commercially in a timely and efficient manner.

The Building Environment—Opportunities and Needs

According to the Pew Center for Global Climate Change, the building sector is the single largest consumer of energy in the United States, with residential, commercial and industrial buildings producing approximately 43 percent of U.S. carbon dioxide emissions. The generation and transmission of electricity for buildings account for most of these emissions, but energy consumption by equipment and appliances is also growing rapidly. In the long-term, buildings will continue to be a significant contributor to energy demand. Increasing population, economic expansion and urban development will create corresponding demand for more building appliances and services. Therefore, it is essential that the DOE commit considerable resources to fulfill its Strategic Plan Goal #1: to "reduce emissions from energy end-use and infrastructure," including the buildings sector.

Energy conservation presents the most near-term opportunity to reduce both consumption and emissions and should be a high priority for our nation. Currently available technologies can save considerable energy use in new buildings in a cost-effective manner when evaluated on a life-cycle basis. New technologies are emerging that can lead to further cost-effective savings. The DOE's current portfolio appropriately targets research on residential and commercial building equipment, including improved efficiency of heating, cooling, ventilating, thermal distribution, microturbine and heat recovery systems. However, the RDD&D funding for these existing technologies must be boosted in the near-term to advance more quickly the transition to buildings that are net-zero greenhouse gas emitters and net-zero energy users.

The DOE's portfolio also includes a strategy for advanced research on distributed energy systems, including highly efficient combined cooling, heating and power systems that use waste heat from small-scale, on-site electricity generation to provide heating and cooling for the buildings and export excess electricity to the grid. Stationary fuel cells for assured power also represent a significant opportunity for near-term commercialization. Funding for these programs should be increased to accelerate the transition to a hydrogen economy. For example, implementation of the 2005 Energy Policy Act's (EPAct) market transition provisions that authorize the purchase of fuel cells for use in government buildings and fleets will help build volume and public awareness and signal the government's endorsement of the technology. Similarly, extension of the existing two-year fuel cell investment tax credit will provide greater certainty and market acceptance.

UTC agrees with the DOE that significant research opportunities exist in new building design, retrofitting of existing buildings and integration of whole building systems. We'd like to discuss three areas we believe to be worthy of a continued and expanded RDD&D focus, given their applications to new and existing buildings and their potential for delivering cost-effective greenhouse gas emission reductions and increased energy efficiency: integrated heating, ventilation and air conditioning; advanced combined heat and power systems, and; stationary fuel cells.

Integrated Heating, Ventilation and Air Conditioning

The DOE has significant opportunities to expand work with industrial partners to reduce energy consumption in commercial and residential buildings. The Energy Information Administration (EIA) has attributed 33 percent of the primary energy consumption in the United States to building space heating and cooling. There are opportunities to reduce the energy consumed by buildings by increasing equipment efficiency, exploiting integrated system designs, improving installation quality and ensuring efficient operation throughout the product life cycle. A modest aggregate increase in heating, ventilation and air conditioning (HVAC) efficiency of only one percent would provide direct economic benefits to taxpayers, enable reduction and better management of electric utility grid demand and reduce dependence on fossil fuels.

To realize these benefits, many new technology options must be evaluated to ensure their affordability and to demonstrate reliability. The speed of technology development and market insertion in HVAC is limited by the size of the investment. At current funding levels and without increased funds to enable industrial partnerships, the DOE will miss significant opportunities to accelerate the impact of HVAC technologies on energy consumption. The federal investment in HVAC RDD&D should be increased in the near-term.

The DOE has established aggressive peak power and energy savings goals for buildings, and the DOE's Office of Building Technologies has defined roadmaps and strategic plans for zero-energy buildings that produce as much energy as they consume. Consistent with those roadmaps, the HVAC industry, their suppliers, and the DOE's Buildings Technologies Program officers have engaged in cooperative discussions to implement a multi-year program plan that has already improved HVAC equipment seasonal energy efficiency ratings (SEER) by 30% in January 2006. Additional annual investments in HVAC research could produce a return on investment (energy saved per R&D dollar invested) on a par with, or in excess of, that of other ongoing government-supported energy savings programs by 2020.

UTC is committed to overcoming technology and market barriers to enable reduced energy consumption. The net energy consumption of homes, offices, restaurants and retail stores can be reduced through a combination of technologies to reach a 50 percent gain in air conditioning efficiency relative to the required 2006 standard. Additional work is needed to develop and demonstrate affordable high efficiency HVAC systems that are more than twice as efficient as the systems most prevalent in the marketplace today. Some of the high-risk enabling technologies we think will have high impact are:

- system control technologies that recognize user demand, comfort and habit profiles along with the current "health/capability" of the HVAC equipment while continuously optimizing system energy performance;
- wireless technologies to accelerate the market penetration of the needed controls and diagnostics technologies and wireless sensor technologies to simply and more cheaply detect leaks;
- variable speed systems with intelligent controls to operate at peak efficiency independent of load and ambient conditions;
- fault detection and diagnostics technologies to reduce or eliminate the loss of system efficiency due to improper installation, poor maintenance and faulty operation;
- high efficiency heat exchangers to improve HVAC efficiencies by reducing losses in evaporators and condensers;
- technologies to advance air purification devices required for indoor air quality control;
- integrated building system components to take advantage of otherwise wasted resources and increase net building efficiency;
- heat pumps using carbon dioxide in residential systems that can be used for hot-water on-demand and integrated to take advantage of waste heat from HVAC;
- thermoelectric devices that use electrical energy to create thermal gradients and/or electricity from waste heat;
- enhanced energy recovery ventilation technologies which allow increased natural ventilation rates at reduced energy consumption; and

- increased use of geothermal for heating and cooling systems.

Advances in HVAC materials and device technology research will be needed if these products are to be affordable and gain market acceptance. New HVAC devices should be designed and deployed through an integrated building system to maximize returns.

Advanced CHP Systems

The *Energy Policy Act of 2005* recognized distributed energy (DE) as an important contributor to the enhancement of grid reliability and disaster recovery. Combined heat and power (CHP) DE systems are the means to also obtain high efficiency. Increased investment is necessary to ensure that the DOE supports continuation of vital RDD&D efforts to achieve CHP reliability, security and efficiency benefits.

CHP systems combine engines that generate electricity with thermal devices that capture wasted engine heat (e.g., hot exhaust) and recycle it into an energy stream useful to the owner. Engine choices include microturbines, small gas turbines and reciprocating engines, while thermal components include heat exchangers to produce hot air or water and absorption chillers to produce air conditioning. The desired CHP is fully integrated to include these major components and the controls to ensure that the system operates predictably, reliably and safely.

Among the benefits of CHP systems are:

- CHP systems can operate in parallel with the grid to provide enhanced power reliability and quality without new transmission or distribution infrastructure.
- CHP systems can operate independently of the grid to sustain critical services (e.g., health care, communications, shelter, public safety) after natural or man-made disasters.
- CHP systems recycle waste energy and put it to productive use for heating and cooling, doubling fuel utilization efficiency as compared to central power and increasing customer benefit from each cubic foot of natural gas consumed. CHP systems can also use renewable fuel.
- Efficient CHP technologies decrease emission of toxic pollutants and greenhouse gases.
- CHP relieves grid congestion directly and provides power not only to remote sites, but also to any constrained area, avoiding investment for new grid wires in cities and beyond the "end of the line."
- A public-private partnership has successfully developed technology for a first-generation packaged system from which trial grocery, hotel and educational sites are benefiting. Additional RDD&D is required for advanced technology CHP systems and their enabling technologies to achieve greater system efficiency and reliability, multiple and simultaneous thermal streams and robust operation for isolated communities and disaster relief.

Stationary Fuel Cells

In 2003, President Bush expanded federally supported fuel cell technology development to help meet our growing demand for energy. The *Energy Policy Act of 2005* expanded fuel cells' potential to address energy dependence, improve energy efficiency and reduce greenhouse gas emissions. UTC Power, a UTC company, is the only company in the world that develops and produces fuel cells for applications in each major market: on-site power, transportation and space flight applications. UTC Power is also the world leader in the development of innovative combined cooling, heating and power applications in the distributed energy market. We believe the need for a continued role by the Federal Government in the commercialization of fuel cell technology is vital and cannot be overstated.

Fuel cells provide an opportunity to address a variety of U.S. energy needs including reducing dependence on foreign oil; delivering assured, high quality reliable power; decreasing toxic air and greenhouse gas emissions; and improving energy efficiency. We do not see any "show stopper" technical barriers to the advancement of fuel cells, but continued U.S. commitment to research, development, demonstration and market transition initiatives are essential to reduce cost, improve durability and enhance performance. Hydrogen storage and infrastructure requirements represent challenging obstacles for transportation applications, but near-term opportunities exist with stationary fuel cells for assured power and fleet vehicles such as transit buses.

We believe government plays an absolutely central role in establishing the rules, creating the incentives and adopting the requirements necessary to build a new market that encourages customers and electric distribution companies to invest in efficient, clean energy options that will increase our nation's energy independence and security through environmentally-benign means. Government is also an important customer because its vast purchasing power can help increase volume and reduce costs to levels more competitive with traditional energy sources.

Fuel cells are available today for the stationary and fleet markets. Near-term successes are required to create public awareness and acceptance, establish a viable supplier base and stimulate continued investment. The EPAct provides the basic framework for a comprehensive strategic focus, but a sustained national commitment to robust funding will be critical to our success. Hurricane Katrina reconstruction efforts represent an opportunity to deploy fuel cells in schools to serve as emergency shelters, hospitals and other critical infrastructure facilities to demonstrate their ability to provide sustainable energy for assured power requirements.

Our dependence on imported oil is well-documented and personal automobiles consume the lion's share of it. Deployment of fuel cell vehicles powered by renewable sources of hydrogen can break our dependence on imported oil and, at the same time, take transportation out of the environmental debate. The auto market also represents the highest-volume market, which is another reason this sector has received so much attention. But fuel cell vehicles for private use in meaningful quantities are a decade away since they represent the most demanding application in terms of cost, packaging and infrastructure. Existing electrical infrastructure and state and federal regulations create hurdles for any form of base load distributed generation to overcome.

Stationary fuel cells have less demanding requirements and can compete at costs higher than those required by autos. Concentrating on these applications would enhance our ability to establish a profitable industry today and create stepping stones to the most demanding longer-term auto application. Few companies can survive the next ten years waiting for the high volumes offered by the car market. Instead, they must find applications where profits can be realized today that will support the development of a strong industrial base in preparation for the future auto market. Success in these early applications can build the necessary public awareness and public confidence.

Since fuel cells can be deployed at the point of use and are not reliant on the vulnerable transmission and distribution assets of the grid, customers can benefit from the ability to capture waste heat and put it to constructive use for space heating, domestic hot water heating and industrial processes. Our units operating in the combined heat and power mode can operate at 85–90 percent efficiency, generating energy savings that can reduce the cost of electricity by four to five cents per kilowatt hour. The cost of UTC Power's fuel cell power plants is currently around $4,500 per kilowatt, but at volumes of 500 units per year and with the aggressive cost reduction efforts we have underway, we expect our next generation technology to be competitive at less than $2,000 per kW.

In short, technology development barriers for technology fuel cells are being addressed at a rapid pace. On a small scale, we can meet the identified requirements and we don't envision any formidable show stoppers. This doesn't mean, however, that we don't need to continue our public-private partnership research, development or demonstration efforts. We strongly endorse the continuation of these activities and increased financial commitment to accelerate the progress we have made in the last few years.

The basic concepts of fuel cell technology have been proven. Our task now is to enhance key performance characteristics (such as durability); reduce costs; validate the technology in real world operating conditions; identify hidden failure modes through extended operation; and then identify and incorporate cost-effective solutions.

Three strategies are necessary for cost reduction:

- Internal programs to reduce cost through material substitution, longer life parts, and fewer parts. Examples include less expensive membranes, better seals, reduced use of platinum, enhanced performance materials for bipolar plates and reduced system complexity.
- Improved manufacturing processes to eliminate labor-intensive processes and identify high-volume manufacturing solutions; and
- Incentives to help increase volume, and thereby spread costs over a larger product base.

A comprehensive national strategy is needed to achieve fuel cell commercialization. Last year's enactment of the EPAct establishes such a framework, but more work needs to be done. Budget requests and appropriation figures for this year fall far short of levels authorized by Congress. We recognize there are tight budget constraints, but given the benefits of fuel cell technology and the price we pay today for imported oil, health costs associated with poor air quality and lost productivity due to lack of reliable power, substantial increases in fuel cell technology investment represent a fiscally sound strategy.

Energy Efficiency Buildings Project

The World Business Council for Sustainable Development has formed the Energy Efficient Buildings project, an alliance of leading global companies to determine how buildings can be designed and constructed so they are energy- and carbon-neutral and can be built and operated at fair market values. The industry effort is led by UTC, one of the world's largest suppliers of capital goods including elevators, cooling/heating and on-site power systems to the commercial building industry, and Lafarge Group, the world leader in building materials including cement, concrete, aggregates, gypsum and roofing.

The effort to transform the way buildings are conceived, constructed, operated and dismantled has ambitious targets: by 2050 new buildings will consume zero net energy from external power supplies and produce zero net carbon dioxide emissions while being economically viable to construct and operate. Constructing buildings that use no net energy from power grids will require a combination of on-site power generation and ultra-efficient building materials and equipment.

To spur industry-wide investment in climate change technologies, governments must commit to a sustained, robust investment in public-private partnerships for RDD&D, financial incentives and market transition initiatives. Some of these technologies are already under development by UTC, including collaborative information tools that facilitate energy-efficient and economically viable buildings; technologies that increase heating/cooling system performance and efficiency; information infrastructures that better manage fire and security systems; elevator-regenerable power drives; and advanced, clean energy technologies for on-site power co-generation. With stronger federal support for such RDD&D activities, the technologies needed for a self-sufficient, energy-efficient building are right around the corner.

Conclusion

Shareholder value comes in part from research and development. UTC spends approximately $2.9 billion annually, 90 percent of that in the United States, to develop tomorrow's technologies. Each UTC business makes certain that their products and services are the most innovative and technologically advanced in the world. The United Technologies Research Center (UTRC) is an incubator for UTC products, researching energy and environmental innovations to assist UTC in developing, and then building, new products for the next generation. Whether it's conducting research on hydrogen production and storage technologies, inventing ways to heat and cool more efficiently or improving jet engine design and efficiency, UTRC provides valuable technical experience to further UTC's pursuit of better environmental quality in its products. Genuine corporate responsibility requires that we make environmental considerations priorities in new product development and investment decisions. By creating products that use less energy and help lower greenhouse gases that contribute to climate change, we can differentiate our products in an increasingly environmentally conscious global marketplace.

We are pleased to see that the DOE Strategic Plan seeks to expand partnerships with the business community in research and development planning, program execution and technology demonstrations, leading to more efficient and timely commercial deployment of greenhouse gas-reducing and energy-efficient technologies. UTC regularly forms partnerships with the Federal Government to encourage greenhouse gas emission reductions and meet energy efficiency goals. As an EPA Climate Leaders partner, UTC pledged to reduce its global greenhouse gas emissions by 16 percent per dollar of revenue from 2001 to 2007. As an EPA Energy Star member, we are helping Americans save energy and avoid greenhouse gas emissions by providing energy-efficient products in residential and commercial settings. UTC Power is a member of the EPA CHP Partnership, a public-private endeavor committed to providing clean, efficient power and thermal energy and reducing pollutants and greenhouse gases.

We thank the House Science Committee for giving us the opportunity to share our thoughts on the DOE Strategic Plan and some steps that need to be taken to "stimulate and strengthen the scientific and technological enterprise of the United States, through improved coordination and prioritization of multi-agency federal climate change technology R&D programs and investment. . .."

STATEMENT OF DANIEL M. KAMMEN

Professor in the Energy and Resources Group (ERG); Professor of Public Policy in the Goldman School of Public Policy; Co-Director, Berkeley Center for the Environment; Director, Renewable and Appropriate Energy Laboratory (RAEL), University of California, Berkeley

Introduction

Chairwoman Biggert and Members of the House Committee on Science, I am grateful for the opportunity today to speak with you on the critical issue of the United States' approach to the great challenges that climate change presents our nation and the planet. At the heart of my comments is the finding that leadership in protecting the environment and improving our economic and political security can be achieved not at a cost, but through political and economic gain to the Nation in the form of reasserted leadership both technologically and financially, through increased geopolitical stability and flexibility, and through job growth in the 'clean energy' sector.

I hold the Class of 1935 Distinguished Chair in Energy at the University of California, Berkeley, where I am a Professor in the Energy and Resources Group, the Goldman School of Public Policy, and the Department of Nuclear Engineering. I am the founding director of the Renewable and Appropriate Energy Laboratory, an interdisciplinary research unit that explores a diverse set of energy technologies through scientific, engineering, economic and policy issues. I am also the Co-Director of the University of California, Berkeley Institute of the Environment. I have served on the Intergovernmental Panel on Climate Change (IPCC), and have testified before both U.S. House and Senate Committees on the science of regional and global climate change, and on the technical and economic status and the potential of a wide range of energy systems, notably renewable and energy efficiency technologies for use in both developed and developing nations. I am the author of over 160 research papers, and five books, most of which can be found online at *http://socrates.berkeley.edu/~rael*.

In July of last year the Honorable R. John Efford, the then Minister of Natural Resources Canada, announced my appointment, as the only U.S. citizen, to serve on the Canadian National Advisory Panel on the Sustainable Energy Science and Technology (S&T) Strategy. The Panel provides advice on energy science and technology priorities to help Canada develop sustainable energy solutions, and is tasked to produce a document similar in objectives to the Climate Change Technology Program Strategic Plan, which we are here today to discuss.

Overview of Climate Change and Innovation in the Energy Sector

As described in the CCTP Strategic Plan climate change presents our nation with a serious, long-term challenge. Central to the difficulty of this challenge is that reducing the risks posed by climate change will require us to transform the largest industry on the planet, the energy industry. Energy is important, not only for its direct contribution to ten percent of economic output by our nation's private sector, but also as the fundamental enabling infrastructure for an array of economic activities, from manufacturing to agriculture to health care. The availability of reliable and affordable energy should not be taken for granted. The challenges of renewing the U.S. energy infrastructure to enhance economic and geopolitical security and prevent global climate change are particularly acute, and depend on the improvement of existing technologies as well as the invention, development, and commercial adoption of emerging ones. Recent trends in the energy sector—which show declining levels of technology investment and innovation—heighten the need for an aggressive response (Appendix A). The CCTP provides a tremendous opportunity to reverse this trend, open up new technological options, and stimulate economic growth through the development of a new clean energy-based sector of the economy. Key strengths of the CCTP Strategic Plan are its leadership by the President, the acknowledgement of the long-term nature of the problem, and the breadth of its technology portfolio. Yet the CCTP Strategic Plan, in its current draft, is seriously flawed. The goal that it seeks to reach, and the basis on which we are here to evaluate it today, is far too modest; it is not commensurate with the magnitude of the challenges we face and not reflective of our nation's capacity for innovation. This testimony will outline the magnitude of effort that will be required, an overview of the innovation environment in the energy sector, and recommendations for improvement.

The Nation's climate technology program should be based on a goal that reduces emissions

The most significant shortcoming of the CCTP strategic plan is that the goal it seeks to reach is not commensurate with the magnitude of the challenges posed by climate change and other energy-related problems. In evaluating the CCTP strategic plan one must first seriously consider what goal it is trying to achieve. To avoid the adverse impacts of climate change we will need to stabilize concentrations of greenhouse gases in the atmosphere. This will require real reductions in the amount of carbon dioxide and other greenhouse gases that we emit. As the strategic plan itself asserts:

> Stabilizing GHG concentrations, at any atmospheric concentration level, implies that global *additions* of GHGs to the atmosphere and global *withdrawals* of GHGs from the atmosphere must come into a net balance. This means that growth of *net* emissions of GHGs would need to slow, eventually stop, and then reverse, so that, ultimately, *net* emissions would approach levels that are low or near zero." (p 2–2)

However, today we are here to evaluate the program based on its ability to meet the Administration's emissions intensity target of an 18 percent reduction in GHG intensity by 2012. Throughout this testimony, I will argue that a major flaw in the CCTP plan is that it is designed to meet a goal that is wholly inadequate to the challenge we face. Only when we take this challenge seriously will we be able to meaningfully mobilize our nation's scientific, technological, and economic resources to meet it, as well as to reap the benefits of international leadership in the clean and sustainable energy sector.

The need to reduce uncertainties in current climate science around climate sensitivity and expected impacts is often cited as a reason for delaying commitments to emissions reductions. Yet, the plan is correct in pointing out that scientific uncertainty is neither a valid justification nor a wise strategy for choosing to delay. In fact, there is not much uncertainty about the basic problem and its magnitude. Estimates done at Lawrence Livermore National Lab of carbon emissions which assume we find a way to reduce emissions to zero by 2050 while meeting energy service demands—i.e., very conservative estimates—will still almost certainly result in CO_2 levels exceeding 550 ppm in the atmosphere, if not more. Given that the CO_2 level is now 380 ppm—30 percent higher than it has been at any point in the last 650,000 years—we are essentially conducting an unprecedented experiment with the Earth. Despite the long time horizons of the climate change problem, the availability of carbon-free energy technologies is a relatively urgent matter because the 100-year residence time of CO_2 in the atmosphere, the 30- to 50-year lifetime of capital stock in the energy industry, and the typical decades-long diffusion curve for infrastructure-related technologies are to varying extents outside of our control. The response to this combination of uncertainty and urgency should be a commitment to the creation of a multitude of new technological options, not a timid approach that narrows the range of possibilities at our disposal in the future.

In contrast, meeting the Administration's current target will require only a slight change from the business as usual case (Figure 1) (EPA 2005). More relevant to the climate problem, reaching this target would actually allow emissions to grow by 12 to 16 percent. This target would thus represent a larger increase than the 10 percent increase that occurred in the previous decade. If we are to be serious about meeting the climate challenge we need to set a goal consistent with the CCTP's objective of moving toward zero net emissions. While the Kyoto Protocol has its flaws, its targets do represent a substantial shift toward reducing emissions. Similarly, the Governor of California's GHG emissions targets announced last summer include both near-term and longer-term goals that delineate a path of emissions reductions toward climate stabilization. The administration should set a series of targets that show a clear path to emissions reductions.

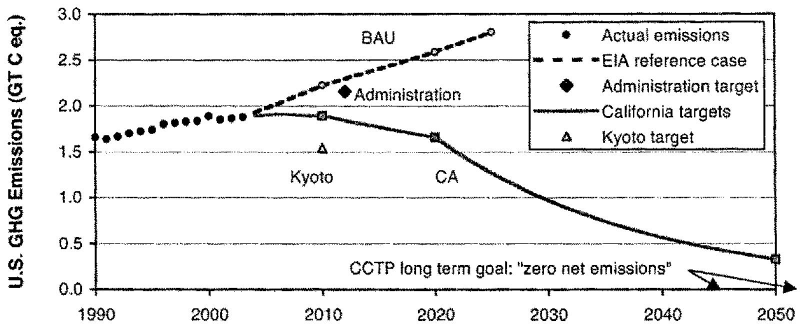

Figure 1 Historical U.S. GHG emissions and targets

Figure 1 shows actual U.S. GHG emissions from 1990 through 2003 (EPA 2005) in giga-tons of carbon equivalent. Four future paths for future U.S. emissions are shown; circles show the business-as-usual (BAU), or "reference case," as calculated by the Energy Information Agency (EIA). The diamond shows the Administration's GHG intensity target for 2012 of 18 percent below 2002 level in tons of carbon per unit of GDP, or a 3.6 percent reduction in emissions from BAU. The squares show U.S. emissions if the Nation were to meet the percentage reductions that have been announced in California for 2010, 2020, and 2050 (California Executive Order 3–05, and California AB32, the "Pavley-Nuñez Bill). The triangle shows the U.S.'s target for 2010 under the Kyoto Protocol. Arrows indicate the levels required to meet the CCTP's long-term goal of "levels that are low or near zero" (p. 2–2).

What is needed is a serious and sustained commitment to emissions reductions and a time scale that conveys to the country the urgency of the need to open future options. Much as President Nixon's announcement of a program in the early-1970s to reduce reliance on foreign oil stimulated efforts by the private sector to invest in alternative energy sources, the articulation of a bold and clear target for emissions reductions would send a signal to the private sector that would leverage the Federal Government's direct investments in new technologies.

Raising climate technology investment to adequate levels

In recent work, we calculated the investment in R&D required to reach a climate stabilization level of 550 ppm, a level that would double the amount of GHG in the atmosphere relative to that at the beginning of industrialization in the eighteenth century. Using emissions scenarios from the Intergovernmental Panel on Climate Change and a previous framework for estimating the climate-related savings from energy R&D programs (Schock et al., 1999), we calculate that U.S. energy R&D spending of $15–$30 billion/year would be sufficient to stabilize CO_2 at double pre-industrial levels (see Appendix for calculations). A strategy that employs a diversified portfolio approach to manage technological uncertainty is diluted quickly when funding levels are five to ten times below their socially optimal levels.

The plan itself states, *"successful development of advanced technologies could result in potentially large economic benefits"*(p. 3–28). As an example of the effect of policy on abatement costs, we can observe how a combination of R&D and demand-side policy has stimulated cost reductions in energy technologies (Duke and Kammen, 1999, Margolis and Kammen, 1999). For example, solar cells, known as photovoltaics, have declined in cost by more than a factor of 20 and wind turbines by a factor of 10. Accelerating future cost reductions in these and other technologies will require further investments in technology development and market creation.

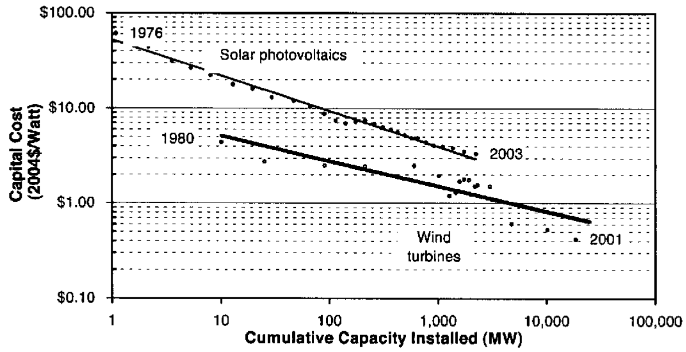

Figure 2 Cost reductions in carbon-free energy technologies

Figure 2 shows the capital costs of photovoltaics and wind turbines in constant 2004 $ per Watt. The horizontal axis shows cumulative worldwide installations of each technology (Duke and Kammen, 1999).

Climate change programs would address other problems as well

An important finding in ours and previous work on energy R&D is that many of the same programs that would help abate the climate problem would address other societal problems too. Adoption of improved zero emissions energy production and end-use technologies would offset the adverse health effects associated with emissions of mercury, sulfur dioxide, and oxides of nitrogen. Increased use of renewables-based power and fuels would reduce our sensitivity to energy production in politically unstable regions. A more distributed power system based on smaller scale production would enhance the robustness of the electricity system and reduce dangerous and costly power outages. And a more diverse mix of technologies and fuels would lessen the macro-economic effects of rapid changes in energy prices.

Comparing a major R&D initiative on climate to past programs

In our recent work we have asked how feasible it would be to raise investment to levels commensurate with the energy-related challenges we face. One way to consider the viability of such a project is to set the magnitude of such a program in the context of previous programs that this committee has participated in launching and monitoring. Scaling up R&D by five or ten times from current levels is not a 'pie in the sky' proposal, in fact it is consistent with the scale of several previous federal programs (Table 1), each of which took place in response to a clearly articulated national need. While expanding energy R&D to five or ten times today's level would be a significant initiative, the fiscal magnitude of such a program is well within the range of previous programs, each of which have produced demonstrable economic benefits beyond the direct program objectives.

Table 1 Comparison of energy R&D scenarios and major federal government R&D initiatives

Program	Sector	Years	Additional spending over program duration (2002$ Billions)
Manhattan Project	Defense	1942-45	$25.0
Apollo Program	Space	1963-72	$127.4
Project Independence	Energy	1975-82	$25.6
Reagan defense	Defense	1981-89	$100.3
Doubling NIH	Health	1999-04	$32.6
War on Terror	Defense	2002-04	$29.6
5x energy scenario	***Energy***	***2005-15***	***$47.9***
10x energy scenario	***Energy***	***2005-15***	***$105.4***

"Major R&D initiatives" in this study are federal programs in which annual spending either doubled or increased by more than $10 billion during the program lifetime. For each of these eight programs we calculate a "baseline" level of spending based on the 50-year historical growth rate of U.S. R&D, 4.3% per year. The difference between the actual spending and the baseline during the program we call additional program spending. Kammen, D. M. and G. F. Nemet (2005). "Reversing the Incredible Shrinking U.S. Energy R&D Budget." Issues in Science and Technology 22: 84-88.

Declining investment in energy R&D

My students and I have documented a disturbing trend away from investment in energy technology—both by the Federal Government and the private sector (Figure 3). The U.S. invests about $1 billion less in energy R&D today than it did a decade ago. This trend is remarkable, first because the levels in the mid-1990s had already been identified as dangerously low, and second because, as our analysis indicates, the decline is pervasive—across almost every energy technology category, in both the public and private sectors, and at multiple stages in the innovation process. In each of these areas investment has been either been stagnant or declining. Moreover, the decline in investment in energy has occurred while overall U.S. R&D has grown by six percent per year, and federal R&D investments in health and defense have grown by 10 to 15 percent per year, respectively.

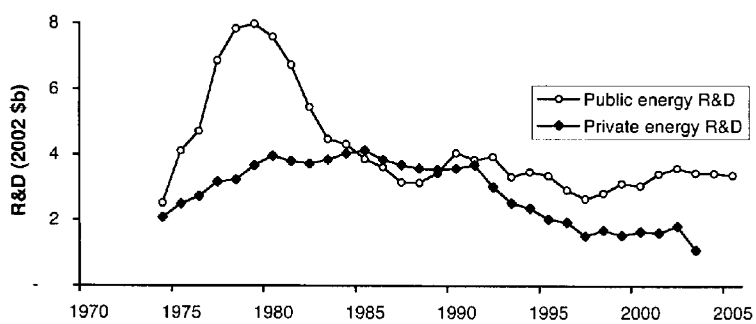

Figure 3 Declining energy R&D investment by both public and private sectors

By looking at individual energy technologies, we have found that in case after case, R&D investment spurs invention. For example, in the case of wind power patenting follows the wild swings in R&D budgets (Figure 4).

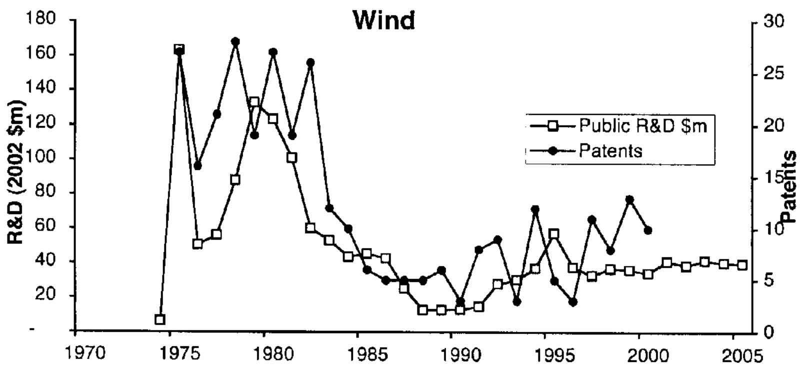

Figure 4 Federal R&D and U.S. wind power patents

A further concern regards U.S. competitiveness in these increasingly important technologies. For example, a glance at other nations' investments in new renewable energy technology shows the U.S. playing a secondary role (see Appendix C). Both Europe and Japan are investing more in R&D for renewable energy. Moreover, they have established leading companies in the fast growing wind and solar industries. Our economic competitiveness in these increasingly important sectors hinges on our commitment to investing in new technologies.

Finally, the drug and biotechnology industry provides a revealing contrast to the trends seen in energy. Although energy R&D exceeded that of the biotechnology industry 20 years ago, today R&D investment by biotechnology firms is an order of magnitude larger than that of energy firms (Figure 5). Today, total private sector energy R&D is less than the R&D budgets of individual biotech companies such as Amgen and Genentech.

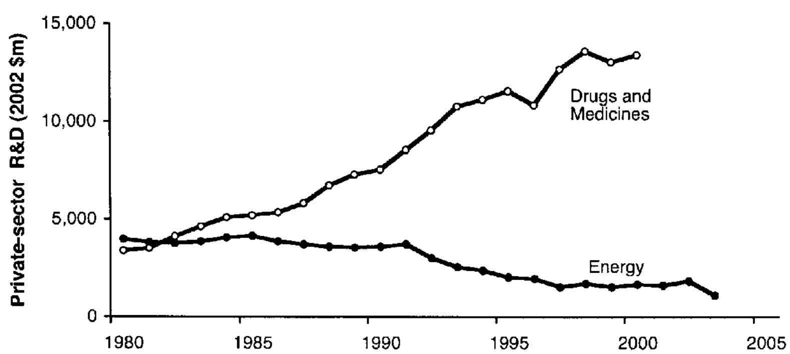

Figure 5 Private-sector R&D investment: energy vs. drugs and medicines

Addressing the Committee's questions

I now address specific questions posed by the Committee.

To what extent will the draft strategic plan meet the Administration's goal of reducing U.S. greenhouse gas emission intensity (the amount of emissions per unit of production) by 18 percent by the year 2012?

In responding to this question, it is important to make clear how *small* a change is necessary for the Nation to meet the Administration's GHG intensity goal for

2012. In Figure 6 we compare the President's climate change goal to the business-as-usual reference case established by the EIA. In order to achieve the President's goal, a reduction of 3.6 percent, or 66 million tons of carbon equivalent, would be required below the BAU projection. To put this amount in perspective, this change could be accomplished by switching about 100 of our nation's 1500 coal burning power plants to natural gas. New technology would make such a switch easier. But we could accomplish such a change with no research program at all with a relatively modest change in only one sector. If an array of changes were implemented throughout the energy sector, to include end-use and transportation, meeting the carbon intensity goal would be even easier. Meeting other goals such as the Kyoto Protocol or stabilization at levels of 450 or 550 ppm would require much larger changes, including widespread deployment of technologies described in the Strategic Plan.

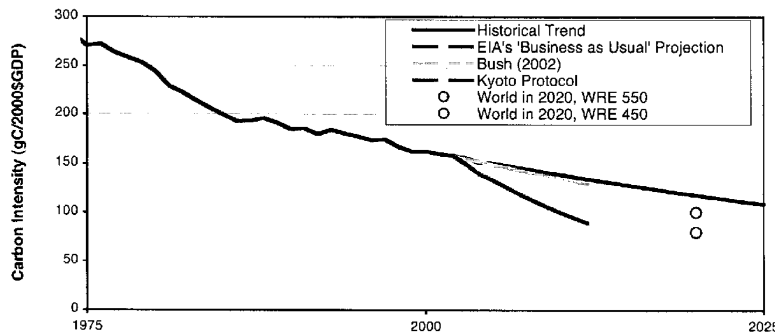

Figure 6 Carbon Intensity of the US Economy: Historical trend since 1975 and projection to 2025, with selected scenarios

Figure shows the carbon intensity of the U.S. economy (in gC-equivalent/2000$GDP). The historical trend is shown from 1975 to 2002, with the EIA's "business as usual' (BAU) projection to 2025. Also shown are is the President's 2002 goal of an 18 percent reduction in carbon intensity below the 2002 level by 2012 and the Kyoto Protocol's goal of a seven percent reduction in carbon emissions below 1990 levels by 2012. Additionally, the world "WRE stabilization pathways," named for the authors of a paper in Nature that has become a frequently used basis for carbon stabilization concentrations (see references), are used to calculate projected world average carbon intensity in 2020 for the 450 ppmv and 550 ppmv stabilization levels. In order to achieve Bush's goal, a reduction of 3.6 percent, or 66 million tons of carbon equivalent, would be required below the BAU projection. By contrast, in order to achieve the Kyoto Protocol's goal, a reduction of 33 percent, or 613 million tons of carbon equivalent, would be required. Note also that the WRE projections are world averages, which means that if enough other countries had carbon intensities higher than these values, it is possible that the U.S. would have to reduce carbon intensity to below these values.

Does the Administration's strategic plan provide clear, unambiguous resource allocation guidance for the government's climate change technology R&D portfolio?

The plan's description of each technology program, including each program's overall strategy, current status, and future directions, does provide insight into the where resources will need to be allocated in order to bring programs toward commercially viable products. The broad array of technological options is an impressive feature of the plan. However, it is difficult to reconcile this rich and diverse technology portfolio with the budget summary in Appendix A.3. First, the plan does not clearly and unambiguously describe how each of the dozens of technology programs are to be funded. The budgets are listed at the level of the funding agency which gives little direction, for example, as to how much should be invested in biofuels versus carbon capture and sequestration. Second, it is difficult to imagine how a budget of slightly over three billion dollars per year can be used to fund the array of activities described in the plan at more than a trivial level. Real progress in programs such as fusion facilities and demonstrations of geological storage will require construction of facilities that will range in the tens to hundreds of millions of dollars. Funding a wide array of programs at relatively equal levels will ensure that these levels are low. A real danger exists that this funding will remain below critical thresholds for mobilizing needed technological improvements. If there is a prioritization of the programs that will allocate significant funds to a few key areas, it is not evident in the current public draft of the plan. Finally, a troubling omission is that the plan contains no budgets beyond 2006. This extremely short timeline for the budgets contained in the plan lies in stark contrast to the well-specified descriptions at the beginning of the document about the long-term nature of the problem and the time it will take to develop the technological solutions to address it. The lack of clarity here is especially damaging because the absence of a longer-term commitment sends an unnecessarily ambiguous signal to the private sector dampening the effect of the virtuous cycle that can emerge from government investment in R&D and subsequent investment by the private sector.

Does the draft strategic plan appropriately balance the research needs that will enable the country to take short-, medium- and long-term actions to limit our greenhouse gas emissions and to adapt to any anticipated effects of climate change?

The strategic plan makes good use of emissions scenarios in its treatment of technology timing. On page 3–28, the plan makes the crucial point that the slow turnover of capital stock in the energy sector implies that technologies that need to achieve widespread deployment by mid-century will need to reach commercial readiness well before that, maybe even decades earlier. This infrastructural inertia combined with natural lags in the flows of GHG in the ocean, atmosphere, and biosphere creates an urgency that belies the long-time scales involved in the climate problem.

The "roadmap" in Figure 10-1 is a helpful visualization of the staged deployment of technology programs within the plan. Perhaps the most important text in Chapter 10 is the phrase "significant deployment." Offsetting GHG emissions with new technologies requires widespread deployment of low and zero-carbon technologies. This need for broad adoption of the technologies at issue really brings into question the adequacy of our near-term response to the problem. For example, achieving widespread deployment of hydrogen fuel cell automobiles in the 2025 to 2045 period, as the plan recommends, means that a significant number of those vehicles would need to begin entering the market ten years from today when a viable hydrogen fueling infrastructure would need to be in place. Significant deployment by 2035 means almost all new vehicles would need to be fuel cell vehicles by 2025, which implies that a large number of commercially available models would be available by 2015. Yet the plan's goal for 2015 is merely to achieve reliability and cost targets in demonstration projects.

The roadmap is a succinct outline of the sequencing of the technology programs. What is missing is a clearer path for how these technologies emerge from modestly funded research programs, to demonstration, to early commercial applications, to rapid adoption, to the end goal, which is widespread deployment. As an example of what such a path might look lie, my students and I have produced a detailed analysis that shows how we can "decarbonize" the vehicles and electricity sectors through a small set of specific policies. We provide these illustrative scenarios in Appendix D, and note that work underway place in the Energy and Environment Division at Lawrence Livermore National Laboratory under the leadership of Dr. Jane Long is coming to similar conclusions.

Two important considerations: incentives for high-payoff research and commercialization

I would like to emphasize two additional important aspects of a substantially enhanced climate technology program. First, special emphasis may be needed to create incentives for high risk, high payoff research. We refer to a section within a recent National Academies report on this topic. And second, development efforts to hasten commercialization need to be included as well so that research programs acknowledge the need for demand-side incentives too.

This past fall, the National Academy of Science released an important report that raised the issue of American technological competitiveness and provided recommendations for improving the country's capacity for innovation (Augustine, 2005). That report focused on the two fundamental issues that, in the opinion of its panel of experts, challenge our country's technical competence:

- Creating high quality jobs for Americans, and

- The need for clean, affordable, and reliable energy.

Setting energy-related challenges at the top of our country's science and technology agenda is an important step and fits well with the situation outlined in the rest of this testimony. The recommendations in this study are admirable for their breadth including suggestions for K–12 education, basic research, university training, and incentives for innovation. Of particular interest to this committee is the panel's vision of a Defense Advanced Research Projects Agency (DARPA) for energy, "ARPA–E." Such a program would fund "high-risk research to meet the Nation's long-term energy challenges" including universities, existing firms, and start-up ventures. The flexibility and independence of the DARPA model are key attributes that such a program seeks to emulate. Establishing an adequately funded organization like this would be a powerful commitment to securing our nation's energy future much as the way DARPA has done for our military power.

Important details to consider in setting up such an agency include ensuring that the demand-side of the problem is addressed as well. The military is unique in that the technologies being developed are created for a single customer under public sector control. Decision-making and technology adoption in the energy sector are much more dispersed and are deeply impacted by market forces as well as regulation. As a result, an ARPA–E program would need to be more cognizant of the demand-side of the innovation process in order to bring high-risk, high-payoff energy technologies to widespread adoption. This may include more emphasis on collaboration and technology transfer activity between the government and the private sector. Prior work on federal energy R&D, such as the PCAST studies (PCAST, 1997, 1999), has emphasized the importance of designing programs and policies that provide pathways for technologies that emerge from R&D programs to find full-scale commercial applications. The notion of the "valley of death" is based on the observation that technologies that succeed in proceeding from research to development to demonstration face important new obstacles in becoming viable commercial products. Technologies at this stage are often one-of-a-kind demonstrations and have not been built at full scale, large volume manufacturing problems need to be solved, and reliability must be demonstrated to skeptical customers. Past experience shows that technological success is not sufficient to bring new energy technologies to market. The challenges of scaling up, investing in manufacturing and distribution, building institutional capacity, and customer education need to be addressed as well. Past energy R&D programs may have put too little emphasis on this critical stage and a large new initiative needs to address these issues as well if the United States is to take full advantage of the benefits that emerge from the research programs. For example, public funding may need to be allocated for demonstration projects that stimulate learning effects, prove the viability of unfamiliar technologies, and mediate the risks to early adopters.

Common misconceptions about an aggressive energy R&D program

Some have expressed skepticism about the need for a national program for high-payoff energy R&D. Here I'd like to point out important misconceptions behind five criticisms of such a program:

1. *"Energy research is already well funded by private firms."* Our figures shown above show that this is clearly *not* the case, as R&D investment by private firms has fallen by 50 percent in the past decade and R&D intensity by energy firms is a factor of 10 below the U.S. average.
2. *"Public sector R&D will crowd-out private sector R&D."* For the economy as a whole, the evidence for this assertion is mixed at best (David et al., 2000). In the energy sector, there is so little private energy R&D that could be crowded out that this problem is small if it exists at all.
3. *"Venture capital will identify promising opportunities in the energy sector."* The emergence of VC investment in the energy sector has been encouraging. However, this is overwhelmingly for late-stage technologies with the potential for widespread adoption within three to five years.
4. *"Government programs would pick winners rather than let markets decide."* In early stage technologies, when uncertainty is high and risks are large, the best strategy is making a diverse set of uncorrelated investments. This strategy is best seen as placing multiple bets, not picking winners.
5. *"Emulating the success of DARPA for an ARPA–E program does not make sense because Department of Energy research programs are more productive than DARPA's."* It is extremely difficult to measure the productivity of the early stage research that DARPA funds. R&D productivity measures that focus on the direct and easy-to-measure benefits of new technologies, tend to

underestimate the benefits of public R&D. For example, how would we assess the worthiness of DARPA's funding of research on semiconductors in the 1940s and 1950s and the Internet in the 1970s?

Recommendations

- **Make Energy and the Environment a Core Area of Education in the United States.** Public interest and action on energy and environmental themes requires attention to make us 'eco-literate and economically savvy.' We must develop in both K–12 and college education a core of instruction in the linkages between energy and both our social and natural environment. The Upward Bound Math-Science Program and the Summer Science Program each serve as highly successful models that could be adapted to the theme of energy for a sustainable society at all educational levels. The launch of Sputnik in 1957 mobilized U.S. science and technology to an unprecedented extent, and should serve as a lesson in how powerful a use-inspired drive to educate and innovate can become. The Spring 2005 Yale Environment Survey found overwhelming interest in energy and environmental sustainability. Contrast that interest with the results of the Third International Mathematics and Science Study (TIMSS) where American secondary school students ranked 19th out of 21 countries surveyed in both math and science general knowledge. The United States can and should reverse this trend, and sustaining our natural heritage and greening the global energy system is the right place to begin.
- **Establish a Set of Energy Challenges Worthy of Federal Action.** Establish *Sustainable Energy USA* awards—modeled after the successful efforts of the Ashoka Innovators awards for social entrepreneurs and the Ansari X Prize initially given for space vehicle launch—that inspire and mobilize our remarkable resources of academia, industry, civil society, and government. These initiatives would support and encourage groups to take action on pressing challenges. An initial set of challenges include:
    - Buildings that cleanly generate significant portions of their own energy needs ('zero energy buildings');
    - Commercial production of 100 mile per gallon vehicles, as can be achieved today with prototype plug-in hybrids using a low-carbon generation technologies accessed over the power grid, or direct charging by renewably generated electricity, and efficient biofuel vehicles operating on ethanol derived from cellulosic feedstocks.
    - Zero Energy Appliances (Appliances that generate their own power).
    - 'Distributed Utilities'; challenges and milestones for utilities to act as markets for clean power generated at residences, businesses, and industries.
- **Make the Nation the Driver of Clean Vehicle Deployment.** As the Zero Emission Vehicle Mandate and the Pavley Bill (AB 1493) have shown in California, dramatic improvements in vehicle energy efficiency and reductions in carbon emissions are eminently achievable, given political leadership. A clear message, as well as dramatic carbon and financial savings, would come from a decision to only purchase for state transportation needs vehicles meeting a *high* energy efficiency target, such as 40 miles per gallon for sedans and 30 miles per gallon for utility vehicles. These standards are now possible thanks to improvements in vehicle efficiencies and the wider range of hybrids (including SUV models) now available. A key aspect of such a policy is to announce from the outset that the standards will rise over time, and to issue a challenge to industry that a partnership to meet these targets will benefit their bottom line and our nation.
- **Expand International Collaborations that Benefit Developing Nations at a Carbon Benefit.** The needs of many developing nations are focused on the challenges meet fundamental economic and environment goals for their people. At the same time, these are our goals as well, both as a nation that must lead the charge to a sustainable and equitable world, and as citizens of a world where we share the rights and responsibilities to protect the atmosphere. Greenhouse gases emitted anywhere impact us all, not only today but for decades to come. In many cases, tremendous opportunities exist to offset future greenhouse gas emissions and to protect local ecosystems both at *very* low cost, but also to directly address critical development needs such as

sustainable fuel sources, the provision of affordable electricity, health, and clean water. My laboratory has recently detailed the local development, health, *and* the global carbon benefits of research programs and partnerships on improved stoves and forestry practices (Bailis, Ezzati, and Kammen, 2005) across Africa. Far from an isolated example, such opportunities exist everywhere, with the recent wave of interest in 'sustainability science' (Jacobson and Kammen, 2005) a resource, aid, and business opportunity that the U. S. should embrace.

- **Recognize and Reflect Economically the Value of Energy Investment to the Economy.** Clean energy production—through investments in energy efficiency and renewable energy generation—has been shown to be a winner in terms of spurring innovation and job creation. This should be reflected in federal economic assessments of energy and infrastructure investment. Grants to states, particularly those taking the lead on clean energy systems, should be at heart of the federal role in fostering a new wave of 'cleantech' innovation in the energy sector.
- **Begin a Serious Federal Discussion of Market-Based Schemes to Make the Price of Carbon Emissions Reflect Their Social Cost.** A carbon tax and a tradable permit program both provide simple, logical, and transparent methods to permit industries and households to reward clean energy systems and tax that which harms our economy and the environment. Cap and trade schemes have been used with great success in the U.S. to reduce other pollutants and several northeastern states are experimenting with greenhouse gas emissions trading. Taxing carbon emissions to compensate for negative social and environmental impacts would offer the opportunity to simplify the national tax code while remaining, if so desired, essentially revenue neutral. A portion of the revenues from a carbon tax could also be used to offset any regressive aspects of the tax, for example by helping to compensate low-income individuals and communities reliant on jobs in fossil fuel extraction and production.

Acknowledgments

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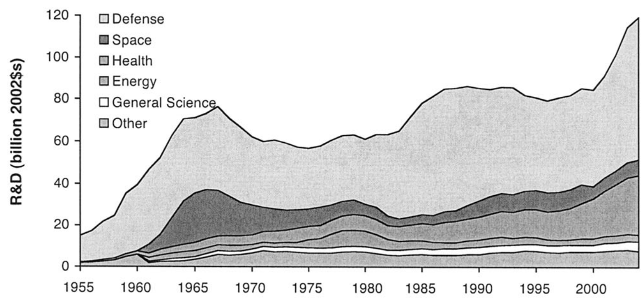
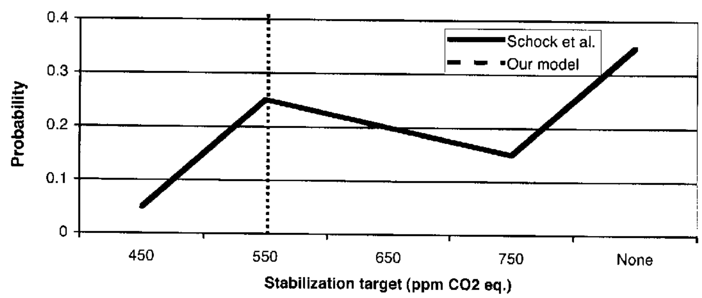
Appendix A: Previous federal R&D programs

This chart shows all U.S. federal R&D programs since 1955. Notice the thin strip showing how small the energy R&D program is relative to the others. The current budgets for energy R&D would continue this situation, or even reduce R&D investment (Kammen and Nemet, 2005).



Appendix B: Estimating energy R&D investments required for climate stabilization

This note describes the methodology used to arrive at the estimates for future energy R&D in Kammen and Nemet (2005). Schock et al. (1999) valued energy R&D by providing estimates of the insurance needed against oil price shocks, electricity supply disruptions, local air pollution, and climate change. By estimating the magnitude of the risks in each area and the probabilities of energy R&D programs to reduce them, they found that increasing energy R&D by a factor of four would be a 'conservative' estimate of its insurance value. We note that this estimate assumes a mean climate stabilization target of between 650 and 750 ppm CO_2 equivalent and incorporates a 35% probability that no stabilization at all will be needed. This possibility of no stabilization at all is especially concerning as it would potentially involve levels exceeding 1000 ppm CO_2 by the end of the century, with higher levels thereafter.



Probability density function for climate stabilization used by Schock *et al.* compared with the 550 ppm target used in Kammen and Nemet (2005).

A recalculation of their model to target the 550-ppm atmospheric level, scenario A1T ('rapid technological change') of the Intergovernmental Panel on Climate Change (Nakicenovic, Alcamo et al. 2000), increases the optimal R&D investment in energy R&D to $11 to $32 billion, 3 to 10 times the current level of investment.

Model Description

The model devised by Schock et al. establishes an "insurance value" of federal energy R&D. It is based on assessing risk mitigation due to R&D for four types of energy-related risks. The non-climate risks are discussed at the end of this appendix. The value of R&D for mitigating climate change is calculated according to the following:

The value of R&D for the U.S. (V_{US}) is the product of the climate mitigation savings derived from R&D programs (S), the assumed probability of R&D success (P), and the probability of needing to achieve each stabilization level (L). These values are summed for each stabilization level (i) and multiplied by the contribution to worldwide climate R&D by the U.S. (A).

$$V_{US} = A \sum_i (S_i P_i L_i)$$

Like Schock *et al.*, we assume that the contribution to worldwide R&D by the U.S. (A) is in proportion to its current share of worldwide greenhouse gas emissions, approximately 25%.

The subscript i represents 5 greenhouse-gas stabilization levels: 450 ppm, 550 ppm, 650 ppm, 750 ppm, and the case of no stabilization.

The probabilities (L) of needing to stabilize at each level i, are used as shown in the figure above. For the Schock et al. model these are: 0.05 at 450 ppm, 0.25 at 550 ppm, 0.2 at 650 ppm, 0.15 at 750 ppm, and 0.35 for the case of no stabilization. In contrast to the probability density function used by Schock et al., we select the doubling of pre-industrial levels as our target and thus assign the level i = 550ppm a "probability" of 1.

We use the values developed by Schock et al. for the assumed probability of R&D success (P). These probabilities decrease with stabilization levels, under the assumption that lower stabilization will require larger contributions from early-stage technologies whose ultimate viability is less likely than near-term options. The range for 550 ppm is 0.5 to 0.8. We use both ends of this range to bound our estimate.

For each stabilization level i, the climate mitigation savings derived from R&D programs (S) is the difference between the costs to stabilize using the outcomes of a successful R&D program (CRD) and the costs to stabilize without the R&D program (C).

$$S_i = C_i - CRD_i$$

We use the costs to stabilize (C) calculated by Schock et al., who used the MiniCAM 2.0 model applied to two sets of mitigation scenarios, those by Wigley et al. (1996) and the IPCC. The cost to stabilize at 550 ppm is in the range of $0.9 to $2.4 trillion. It is important to note that these scenarios already include technology improvement, although they do not specify how much R&D is implied to achieve this "autonomous" improvement. As Schock *et al.* point out, if any of this assumed improvement depends on higher levels of R&D, the estimates calculated in this model will then underestimate the R&D required.

The costs to stabilize using the outcomes of a successful R&D program (CRD) are lower because the energy technologies developed in the R&D program can be used to offset greenhouse gas emissions at lower costs than using existing technologies. We use the assumption by Schock et al. that a successful R&D program will enable us to deploy technologies that produce energy at costs similar to business-as-usual costs while reducing emissions sufficient to stabilize at the 550 ppm level.

Data comparison

The table below shows the values used in the model. In our version of the model we use the same values as Schock et al. for the 550 ppm level. The one exception is the probabilities assumed for the needing to achieve each stabilization level (L). Our model is conditional on a stabilization target of 550 ppm, because we are deriving the amount of R&D required to achieve a specific target. In contrast, Schock et al. treat the stabilization level as an uncertain parameter with a known probability density function.

Parameter values used in the model

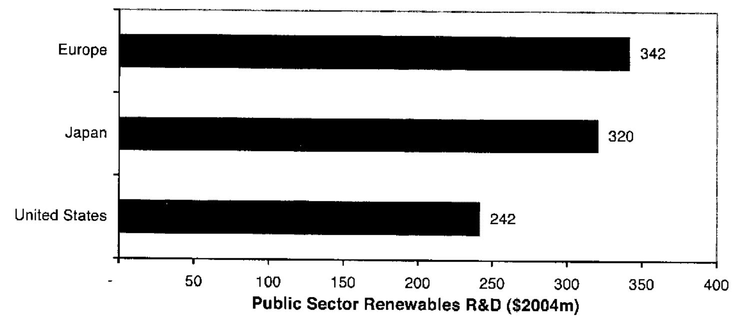
Study	Kammen and Nemet (2005)	Schock *et al.* (1999)				
Stabilization level CO_2 (ppmv)	550	550	450	650	750	*None*
Cost to stabilize without R&D (C) $trillions	0.9 to 2.4	0.9 - 2.4	3.7 - 4.5	0.3- 1.3	0.2 - 0.5	0
Cost to stabilize with R&D (CRD) $trillions	0	0	0.4	0	0	0
Savings from R&D (S) $trillions	0.9 to 2.4	0.9 - 2.4	3.3 - 4.1	0.3 - 1.3	0.2 - 0.5	0
Probability of R&D success (P)	0.5 to 0.8	0.5 - 0.8	0.1	1.0	1.0	--
Probability of needing to achieve stabilization level (L)	1.0	0.25	0.05	0.2	0.15	0.35
U.S. share of worldwide R&D (A)	0.25	0.25				
Discount rate	0.05	0.05				

Outcomes

In our model, the total required spending was discounted and annualized to arrive at estimates for the required amount of annual federal energy R&D to stabilize atmospheric concentrations of CO_2 at 550 ppm. We arrive at a range of $6 to $27 billion in 2005 dollars.

Finally, we note that in their model, Schock et al. show energy R&D can be used as insurance against other risks as well, such as oil price shocks, electricity outages, and air pollution. Using energy R&D to mitigate these risks has an annual value estimated to be $9 to $10 billion. The figures above are if anything, overly conservative in that they assume that the R&D programs launched to address climate stabilization perfectly overlap with the programs used to address these other risks. A less conservative estimate would be to assume that perhaps half of the other risks would be addressed by the climate R&D program and half would not. For example, investments to improve the reliability of the electricity grid would reduce damages due to power outages but would not necessarily be included in a large climate R&D program. In that case, optimal energy R&D would rise to $11 to $32 billion per year, or roughly 3 to 10 times current levels. In our paper, we use scenarios of increases of factors of 5 and 10 to compare this range to the large R&D programs of the past.

Appendix C: Investments in renewables R&D across countries.



Investments in Renewable Energy Research and Development by OECD countries in 2004 (Data: Kammen and Nemet, 2005; International Energy Agency, 2005).

Appendix D: Achieving a low-carbon economy

By committing to a program of feasible carbon reductions in electricity and transportation sectors, we find that emissions can be reduced by up to 75% from today's levels.

At the current rate of demand increase, the electricity market has and will likely continue to grow at an annualized rate of 1.5%. With current electricity use estimated at 4000 terawatt-hours (TWh) per year, it is poised to increase to 5500 TWh/yr by 2025 and 7500 TWh/yr by 2050. Today, the net carbon emissions from different fossil fuel sources is about 2400 million metric ton carbon equivalents (MMTCE) per year and is projected to go up to 3700 MMTCE by 2025 and 5100 MMTCE by 2050.

We examine alternative scenarios of supply and demand in the electricity market between now and the year 2050 (Figure 1). Deployment of efficiency along with the growth of renewables are examined for their impact on electricity consumption and greenhouse gas emissions (Table 1).

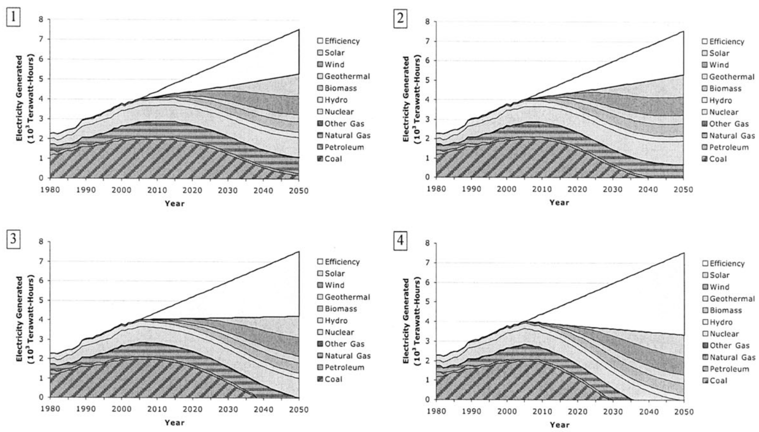


Figure 2. Alternative scenarios in the electricity market.

	Business-As-Usual	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Strategy	1.5% annual increase	1.0% Efficiency, Moderate	1.0% Efficiency, Aggressive	1.5% Efficiency, Moderate	2.0% Efficiency, Aggressive

		Renewables, Moderate Nuclear	Renewables, Aggressive Nuclear	Renewables, Moderate Nuclear	Renewables, No Nuclear
Electricity Consumed	7500 TWh	5300 TWh	5300 TWh	4200 TWh	3400 TWh
Carbon Emissions	5100 MMTCE	747 MMTCE	411 MMTCE	9 MMTCE	0 MMTCE
RPS [a]	5%	60%	64%	76%	100%

[a] Renewable Portfolio Standard (hydro, wind, solar, geothermal, and biomass)

Table 1. Description of scenario strategies and key findings for 2050 in the US electricity market.

The US currently uses 17 quads of primary energy for light duty fleet transportation. This figure is expected to grow to 24 quads in 2025 and 39 quads in 2050 under the current projected growth rate of 1.9% per year. Present emissions from light duty fleet transportation are 1,560 MMTCE and are projected to grow to 2,229 MMTCE by 2025 and 3,604 MMTCE by 2050. We examined potential reductions in CO_2 emissions from a business-as-usual approach by improving CAFÉ standards, increasing the market share of hybrid vehicles and meeting a larger portion of fuel demands with ethanol. We analyzed four scenarios based on moderate or aggressive paths of CAFÉ increases, hybrid market share increases and ethanol market share increases (Table 2).

Scenario	Description
BAU	BAU
Scenario 1	Moderate CAFE Moderate Hybrids Moderate Ethanol
Scenario 2	Moderate CAFE Aggressive Hybrids Aggressive Ethanol
Scenario 3	Aggressive CAFE Aggressive Hybrids Moderate Ethanol
Scenario 4	Aggressive CAFE Aggressive Hybrids Aggressive Ethanol

Table 2. Scenarios examined.

By 2025, light duty fleet carbon emissions can be reduced by approximately 29-45% from BAU and by 2050, carbon emissions can be reduced by approximately 58-72%.

	2025		2050	
	CO_2 Emissions	% Reduction from BAU	CO_2 Emissions	% Reduction from BAU
Strategy	MMTCE	%	MMTCE	%
BAU	2,229	-	3,604	-
Scenario 1	1,571	29.51	1,514	58.00
Scenario 2	1,508	32.34	1,242	65.54
Scenario 3	1,238	44.44	1,116	69.04
Scenario 4	1,218	45.36	1,010	71.98

Table 3. Potential reductions in light duty fleet CO_2 emissions.

Substantial savings from both the electricity and light vehicle sectors, which combined account for 65% of US emissions today, can be realized through a set of scenarios in both of these sectors (Figure 2). Nearly 75% from today's 4000 MMTCE can be saved under the most aggressive scenario.

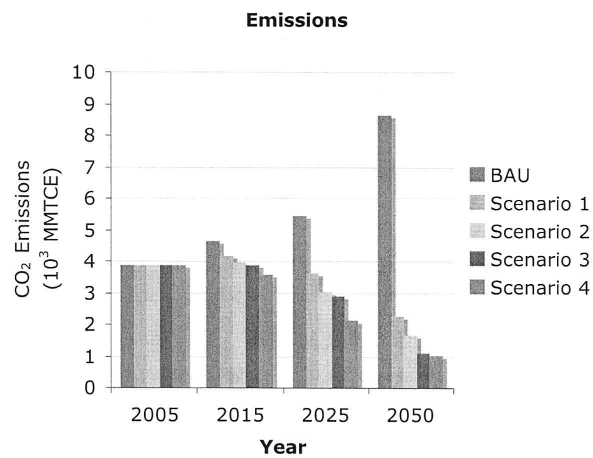


Figure 2. Carbon emissions from combined electricity and transportation sectors.

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CLEAN POWER

The Rise of Renewable Energy

Solar cells, wind turbines and biofuels are poised to become major energy sources. New policies could dramatically accelerate that evolution **BY DANIEL M. KAMMEN**

OVERVIEW

- Thanks to advances in technology, renewable sources could soon become large contributors to global energy.
- To hasten the transition, the U.S. must significantly boost its R&D spending on energy.
- The U.S. should also levy a fee on carbon to reward clean energy sources over those that harm the environment.

KENN BROWN

No plan to substantially reduce greenhouse gas emissions can succeed through increases in energy efficiency alone. Because economic growth continues to boost the demand for energy—more coal for powering new factories, more oil for fueling new cars, more natural gas for heating new homes—carbon emissions will keep climbing despite the introduction of more energy-efficient vehicles, buildings and appliances. To counter the alarming trend of global warming, the U.S. and other countries must make a major commitment to developing renewable energy sources that generate little or no carbon.

Renewable energy technologies were suddenly and briefly fashionable three decades ago in response to the oil embargoes of the 1970s, but the interest and support were not sustained. In recent years, however, dramatic improvements in the performance and affordability of solar cells, wind turbines and biofuels—ethanol and other fuels derived from plants—have paved the way for mass commercialization. In addition to their environmental benefits, renewable sources promise to enhance America's energy security by reducing the country's reliance on fossil fuels from other nations. What is more, high and wildly fluctuating prices for oil and natural gas have made renewable alternatives more appealing.

We are now in an era where the op-

▼ A world of clean energy could rely on wind turbines and solar cells to generate its electricity and biofuels derived from switchgrass and other plants to power its vehicles.

portunities for renewable energy are unprecedented, making this the ideal time to advance clean power for decades to come. But the endeavor will require a long-term investment of scientific, economic and political resources. Policymakers and ordinary citizens must demand action and challenge one another to hasten the transition.

Let the Sun Shine

SOLAR CELLS, also known as photovoltaics, use semiconductor materials to convert sunlight into electric current. They now provide just a tiny slice of the world's electricity: their global generating capacity of 5,000 megawatts (MW) is only 0.15 percent of the total generating capacity from all sources. Yet sunlight could potentially supply 5,000 times as much energy as the world currently consumes. And thanks to technology improvements, cost declines and favorable policies in many states and nations, the annual production of photovoltaics has increased by more than 25 percent a year for the past decade and by a remarkable 45 percent in 2005. The cells manufactured last year added 1,727 MW to worldwide generating capacity, with 833 MW made in Japan, 353 MW in Germany and 153 MW in the U.S.

Solar cells can now be made from a range of materials, from the traditional multicrystalline silicon wafers that still dominate the market to thin-film silicon cells and devices composed of plastic or organic semiconductors. Thin-film photovoltaics are cheaper to produce than crystalline silicon cells but are also less efficient at turning light into power. In laboratory tests, crystalline cells have achieved efficiencies of 30 percent or more; current commercial cells of this type range from 15 to 20 percent. Both laboratory and commercial efficiencies for all kinds of solar cells have risen steadily in recent years, indicating that an expansion of research efforts would further enhance the performance of solar cells on the market.

Solar photovoltaics are particularly easy to use because they can be installed in so many places—on the roofs or walls of homes and office buildings, in vast arrays in the desert, even sewn into clothing to power portable electronic devices. The state of California has joined Japan and Germany in leading a global push for solar installations; the "Million Solar Roof" commitment is intended to create 3,000 MW of new generating capacity in the state by 2018. Studies done by my research group, the Renewable and Appropriate Energy Laboratory at the University of California, Berkeley, show that annual production of solar photovoltaics in the U.S. alone could grow to 10,000 MW in just 20 years if current trends continue.

The biggest challenge will be lowering the price of the photovoltaics, which are now relatively expensive to manufacture. Electricity produced by crystalline cells has a total cost of 20 to 25 cents per kilowatt-hour, compared with four to six cents for coal-fired electricity, five to seven cents for power produced by burning natural gas, and six to nine cents for biomass power plants. (The cost of nuclear power is harder to pin down because experts disagree on which expenses to include in the analysis; the estimated range is two to 12 cents per kilowatt-hour.) Fortunately, the prices of solar cells have fallen consistently over the past decade, largely because of improvements in manufacturing processes. In Japan, where 290 MW of solar generating capacity were added in 2005 and an even larger amount was exported, the cost of photovoltaics has declined 8 percent a year; in California, where 50 MW of solar power were installed in 2005, costs have dropped 5 percent annually.

Surprisingly, Kenya is the global leader in the number of solar power systems installed per capita (but not the number of watts added). More than 30,000 very small solar panels, each producing only 12 to 30 watts, are sold in that country annually. For an investment of as little as $100 for the panel and wiring, the system can be used to charge a car battery, which can then provide enough power to run a fluorescent lamp or a small black-and-white television for a few hours a day. More Kenyans adopt solar power every year than make connections to the country's electric grid. The panels typically use solar cells made of amorphous silicon; although these photovoltaics are only half as efficient as crystalline cells, their cost is so much lower (by a factor of at least four) that they are more affordable and useful for the two billion people worldwide who currently have no access to electricity. Sales of small solar power systems are booming in other African nations as well, and advances in low-cost photovoltaic manufacturing could accelerate this trend.

Furthermore, photovoltaics are not the only fast-growing form of solar power. Solar-thermal systems, which collect sunlight to generate heat, are also undergoing a resurgence. These systems have long been used to provide hot water for homes or factories, but they can also produce electricity without the need for expensive solar cells. In one design, for example, mirrors focus light on a Stirling engine, a high-efficiency device containing a working fluid that circulates between hot and cold chambers. The fluid expands as the sunlight heats it, pushing a piston that, in turn, drives a turbine.

In the fall of 2005 a Phoenix company called Stirling Energy Systems

5,000 megawatts
Global generating capacity of solar power

37 percent
Top efficiency of experimental solar cells

20 to 25 cents
Cost per kilowatt-hour of solar power

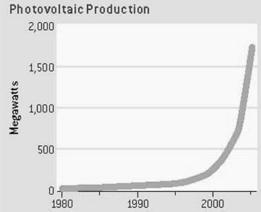
GROWING FAST, BUT STILL A SLIVER

Solar cells, wind power and biofuels are rapidly gaining traction in the energy markets, but they remain marginal providers compared with fossil-fuel sources such as coal, natural gas and oil.

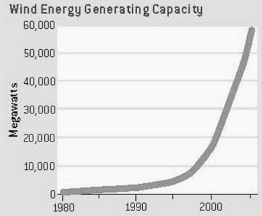
THE RENEWABLE BOOM

Since 2000 the commercialization of renewable energy sources has accelerated dramatically. The annual global production of solar cells, also known as photovoltaics, jumped 45 percent in 2005. The construction of new wind farms, particularly in Europe, has boosted the worldwide generating capacity of wind power 10-fold over the past decade. And the production of ethanol, the most common biofuel, soared to 36.5 billion liters last year, with the lion's share distilled from American-grown corn.

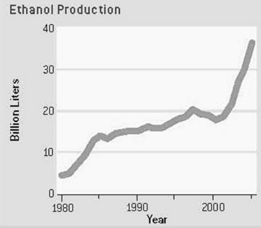
Photovoltaic Production



Wind Energy Generating Capacity

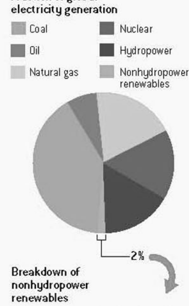


Ethanol Production

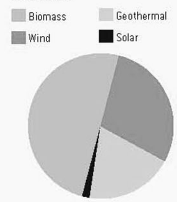


COMPETING ENERGY SOURCES

Fraction of global electricity generation



Breakdown of nonhydropower renewables



THE CHALLENGE AHEAD

Suppliers of renewable energy must overcome several technological, economic and political hurdles to rival the market share of the fossil-fuel providers. To compete with coal-fired power plants, for example, the prices of solar cells must continue to fall. The developers of wind farms must tackle environmental concerns and local opposition. Other promising renewable sources include generators driven by steam from geothermal vents and biomass power plants fueled by wood and agricultural wastes.

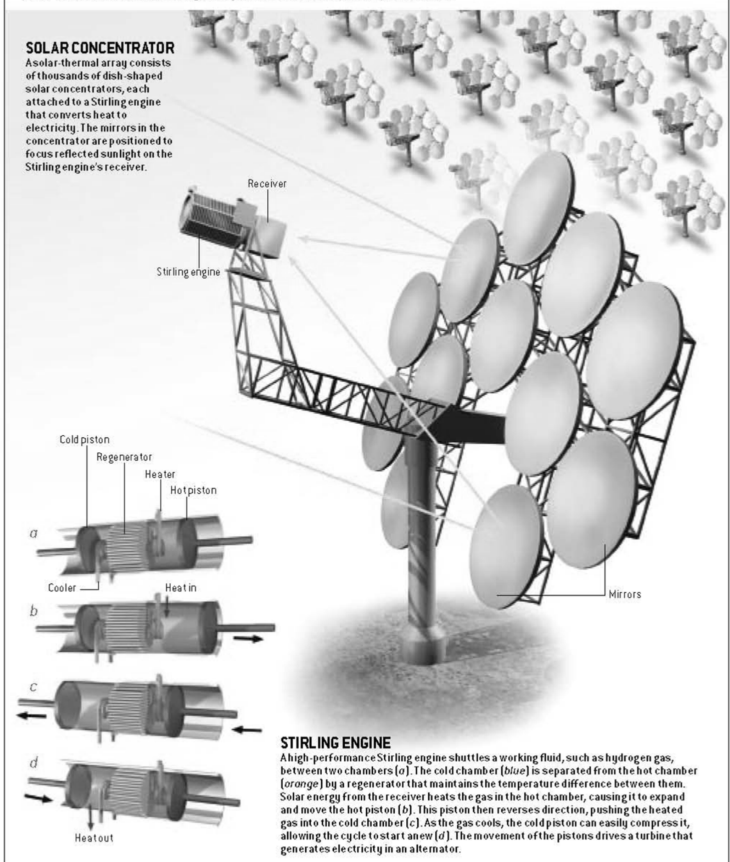
JEN CHRISTIANSEN; SOURCES: PV NEWS, BTM CONSULT, AWEA, EWEA, F.O. LICHT AND *BP STATISTICAL REVIEW OF WORLD ENERGY 2006*; SHARP ELECTRONICS CORPORATION (*solar arrays*); DON RYAN *AP Photo* (*wind turbines*); DOUG WILSON *Corbis* (*corn*)

HOT POWER FROM MIRRORS

Solar-thermal systems, long used to provide hot water for homes or factories, can also generate electricity. Because these systems produce power from solar heat rather than light, they avoid the need for expensive photovoltaics.

SOLAR CONCENTRATOR

A solar-thermal array consists of thousands of dish-shaped solar concentrators, each attached to a Stirling engine that converts heat to electricity. The mirrors in the concentrator are positioned to focus reflected sunlight on the Stirling engine's receiver.



STIRLING ENGINE

A high-performance Stirling engine shuttles a working fluid, such as hydrogen gas, between two chambers (*a*). The cold chamber (*blue*) is separated from the hot chamber (*orange*) by a regenerator that maintains the temperature difference between them. Solar energy from the receiver heats the gas in the hot chamber, causing it to expand and move the hot piston (*b*). This piston then reverses direction, pushing the heated gas into the cold chamber (*c*). As the gas cools, the cold piston can easily compress it, allowing the cycle to start anew (*d*). The movement of the pistons drives a turbine that generates electricity in an alternator.

DON FOLEY; SOURCE: U.S. DEPARTMENT OF ENERGY announced that it was planning to build two large solar-thermal power plants in southern California. The company signed a 20-year power purchase agreement with Southern California Edison, which will buy the electricity from a 500-MW solar plant to be constructed in the Mojave Desert. Stretching across 4,500 acres, the facility will include 20,000 curved dish mirrors, each concentrating light on a Stirling engine about the size of an oil barrel. The plant is expected to begin operating in 2009 and could later be expanded to 850 MW. Stirling Energy Systems also signed a 20-year contract with San Diego Gas & Electric to build a 300-MW, 12,000-dish plant in the Imperial Valley. This facility could eventually be upgraded to 900 MW.

The financial details of the two California projects have not been made public, but electricity produced by present solar-thermal technologies costs between five and 13 cents per kilowatt-hour, with dish-mirror systems at the upper end of that range. Because the projects involve highly reliable technologies and mass production, however, the generation expenses are expected to ultimately drop closer to four to six cents per kilowatt-hour—that is, competitive with the current price of coal-fired power.

60,000 megawatts
Global generating capacity of wind power

0.5 percent
Fraction of U.S. electricity produced by wind turbines

1.9 cents
Tax credit for wind power, per kilowatt-hour of electricity

Blowing in the Wind

WIND POWER has been growing at a pace rivaling that of the solar industry. The worldwide generating capacity of wind turbines has increased more than 25 percent a year, on average, for the past decade, reaching nearly 60,000 MW in 2005. The growth has been nothing short of explosive in Europe—between 1994 and 2005, the installed wind power capacity in European Union nations jumped from 1,700 to 40,000 MW. Germany alone has more than 18,000 MW of capacity thanks to an aggressive construction program. The northern German state of Schleswig-Holstein currently meets one quarter of its annual electricity demand with more than 2,400 wind turbines, and in certain months wind power provides more than half the state's electricity. In addition, Spain has 10,000 MW of wind capacity, Denmark has 3,000 MW, and Great Britain, the Netherlands, Italy and Portugal each have more than 1,000 MW.

In the U.S. the wind power industry has accelerated dramatically in the past five years, with total generating capacity leaping 36 percent to 9,100 MW in 2005. Although wind turbines now produce only 0.5 percent of the nation's electricity, the potential for expansion is enormous, especially in the windy Great Plains states. (North Dakota, for example, has greater wind energy resources than Germany, but only 98 MW of generating capacity is installed there.) If the U.S. constructed enough wind farms to fully tap these resources, the turbines could generate as much as 11 trillion kilowatt-hours of electricity, or nearly three times the total amount produced from all energy sources in the nation last year. The wind industry has developed increasingly large and efficient turbines, each capable of yielding 4 to 6 MW. And in many locations, wind power is the cheapest form of new electricity, with costs ranging from four to seven cents per kilowatt-hour.

The growth of new wind farms in the U.S. has been spurred by a production tax credit that provides a modest subsidy equivalent to 1.9 cents per kilowatt-hour, enabling wind turbines to compete with coal-fired plants. Unfortunately, Congress has repeatedly threatened to eliminate the tax credit. Instead of instituting a long-term subsidy for wind power, the lawmakers have extended the tax credit on a year-to-year basis, and the continual uncertainty has slowed investment in wind farms. Congress is also threatening to derail a proposed 130-turbine farm off the coast of Massachusetts that would provide 468 MW of generating capacity, enough to power most of Cape Cod, Martha's Vineyard and Nantucket.

The reservations about wind power come partly from utility companies that are reluctant to embrace the new technology and partly from so-called NIMBY-ism. ("NIMBY" is an acronym for Not in My Backyard.) Although local concerns over how wind turbines will affect landscape views may have some merit, they must be balanced against the social costs of the alternatives. Because society's energy needs are growing relentlessly, rejecting wind farms often means requiring the construction or expansion of fossil fuel–burning power plants that will have far more devastating environmental effects.

Green Fuels

RESEARCHERS ARE ALSO pressing ahead with the development of biofuels that could replace at least a portion of the oil currently consumed by motor vehicles. The most common biofuel by far in the U.S. is ethanol, which is typically made from corn and blended with gasoline. The manufacturers of

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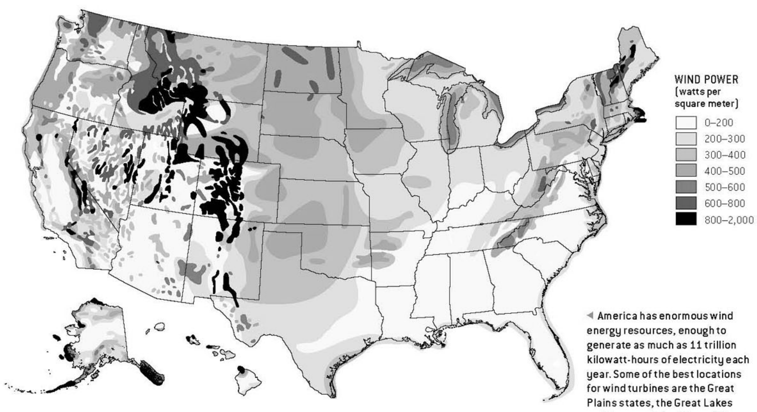


◀ America has enormous wind energy resources, enough to generate as much as 11 trillion kilowatt-hours of electricity each year. Some of the best locations for wind turbines are the Great Plains states, the Great Lakes and the mountain ridges of the Rockies and the Appalachians.

ethanol benefit from a substantial tax credit: with the help of the $2-billion annual subsidy, they sold more than 16 billion liters of ethanol in 2005 (almost 3 percent of all automobile fuel by volume), and production is expected to rise 50 percent by 2007. Some policymakers have questioned the wisdom of the subsidy, pointing to studies showing that it takes more energy to harvest the corn and refine the ethanol than the fuel can deliver to combustion engines. In a recent analysis, though, my colleagues and I discovered that some of these studies did not properly account for the energy content of the by-products manufactured along with the ethanol. When all the inputs and outputs were correctly factored in, we found that ethanol has a positive net energy of almost five megajoules per liter.

We also found, however, that ethanol's impact on greenhouse gas emissions is more ambiguous. Our best estimates indicate that substituting corn-based ethanol for gasoline reduces greenhouse gas emissions by 18 percent, but the analysis is hampered by large uncertainties regarding certain agricultural practices, particularly the environmental costs of fertilizers. If we use different assumptions about these practices, the results of switching to ethanol range from a 36 percent drop in emissions to a 29 percent increase. Although corn-based ethanol may help the U.S. reduce its reliance on foreign oil, it will probably not do much to slow global warming unless the production of the biofuel becomes cleaner.

But the calculations change substantially when the ethanol is made from cellulosic sources: woody plants such as switchgrass or poplar. Whereas most makers of corn-based ethanol burn fossil fuels to provide the heat for fermentation, the producers of cellulosic ethanol burn lignin—an unfermentable part of the organic material—to heat the plant sugars. Burning lignin does not add any greenhouse gases to the atmosphere, because the emissions are offset by the carbon dioxide absorbed during the growth of the plants used to make the ethanol. As a result, substituting cellulosic ethanol for gasoline can slash greenhouse gas emissions by 90 percent or more.

Another promising biofuel is so-called green diesel. Researchers have produced this fuel by first gasifying biomass—heating organic materials enough that they release hydrogen and carbon monoxide—and then converting these compounds into long-chain hydrocarbons using the Fischer-Tropsch process. (During World War II, German engineers employed these chemical reactions to make synthetic motor fuels out of coal.) The result would be an economically competitive liquid fuel for motor vehicles that would add virtually

16.2 billion
Liters of ethanol produced in the U.S. in 2005

2.8 percent
Ethanol's share of all automobile fuel by volume

$2 billion
Annual subsidy for corn-based ethanol

JEN CHRISTIANSEN; SOURCE: NATIONAL RENEWABLE ENERGY LABORATORY

PLUGGING HYBRIDS

The environmental benefits of renewable biofuels would be even greater if they were used to fuel plug-in hybrid electric vehicles (PHEVs). Like more conventional gasoline-electric hybrids, these cars and trucks combine internal-combustion engines with electric motors to maximize fuel efficiency, but PHEVs have larger batteries that can be recharged by plugging them into an electrical outlet. These vehicles can run on electricity alone for relatively short trips; on longer trips, the combustion engine kicks in when the batteries no longer have sufficient juice. The combination can drastically reduce gasoline consumption: whereas conventional sedans today have a fuel economy of about 30 miles per gallon (mpg) and nonplug-in hybrids such as the Toyota Prius average about 50 mpg, PHEVs could get an equivalent of 80 to 160 mpg. Oil use drops still further if the combustion engines in PHEVs run on biofuel blends such as E85, which is a mixture of 15 percent gasoline and 85 percent ethanol.

If the entire U.S. vehicle fleet were replaced overnight with PHEVs, the nation's oil consumption would decrease by 70 percent or more, completely eliminating the need for petroleum imports. The switch would have equally profound implications for protecting the earth's fragile climate, not to mention the elimination of smog. Because most of the energy for cars would come from the electric grid instead of from fuel tanks, the environmental impacts would be concentrated in a few thousand power plants instead of in hundreds of millions of vehicles. This shift would focus the challenge of climate protection squarely on the task of reducing the greenhouse gas emissions from electricity generation.

PHEVs could also be the salvation of the ailing American auto industry. Instead of continuing to lose market share to foreign companies, U.S. automakers could become competitive again by retooling their factories to produce PHEVs that are significantly more fuel-efficient than the nonplug-in hybrids now sold by Japanese companies. Utilities would also benefit from the transition because most owners of PHEVs would recharge their cars at night, when power is cheapest, thus helping to smooth the sharp peaks and valleys in demand for electricity. In California, for example, the replacement of 20 million conventional cars with PHEVs would increase nighttime electricity demand to nearly the same level as daytime demand, making far better use of the grid and the many power plants that remain idle at night. In addition, electric vehicles not in use during the day could supply electricity to local distribution networks at times when the grid was under strain. The potential benefits to the electricity industry are so compelling that utilities may wish to encourage PHEV sales by offering lower electricity rates for recharging vehicle batteries.

Most important, PHEVs are not exotic vehicles of the distant future. DaimlerChrysler has already introduced a PHEV prototype, a plug-in hybrid version of the Mercedes-Benz Sprinter Van that has 40 percent lower gasoline consumption than the conventionally powered model. And PHEVs promise to become even more efficient as new technologies improve the energy density of batteries, allowing the vehicles to travel farther on electricity alone.

—D.M.K.

HYMOTION

no greenhouse gases to the atmosphere. Oil giant Royal Dutch/Shell is currently investigating the technology.

The Need for R&D

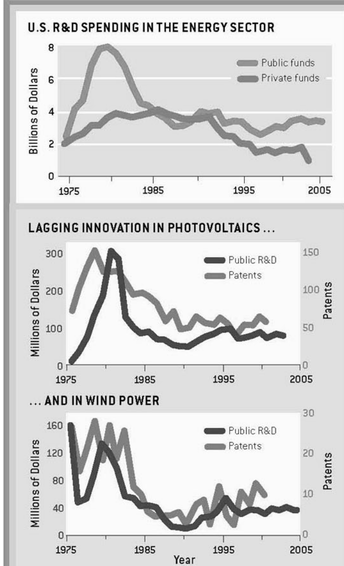
EACH OF THESE renewable sources is now at or near a tipping point, the crucial stage when investment and innovation, as well as market access, could enable these attractive but generally marginal providers to become major contributors to regional and global energy supplies. At the same time, aggressive policies designed to open markets for renewables are taking hold at city, state and federal levels around the world. Governments have adopted these policies for a wide variety of reasons: to promote market diversity or energy security, to bolster industries and jobs, and to protect the environment on both the local and global scales. In the U.S. more than 20 states have adopted standards setting a minimum for the fraction of electricity that must be supplied with renewable sources. Germany plans to generate 20 percent of its electricity from renewables by 2020, and Sweden intends to give up fossil fuels entirely.

Even President George W. Bush said, in his now famous State of the Union address this past January, that the U.S. is "addicted to oil." And although Bush did not make the link to global warming, nearly all scientists agree that humanity's addiction to fossil fuels is disrupting the earth's climate. The time for action is now, and at last the tools exist to alter energy production and consumption in ways that simultaneously benefit the economy and the environment. Over the past 25 years, however, the public and private funding of research and development in the energy sector has withered. Between 1980 and 2005 the fraction of all U.S. R&D spending devoted to energy declined from 10 to 2 percent. Annual public R&D funding for energy sank from $8 billion to $3 billion (in 2002 dollars); private R&D plummeted from $4 billion to $1 billion [*see box on next page*].

To put these declines in perspective, consider that in the early 1980s energy companies were investing more in R&D than were drug companies, whereas today investment by energy firms is an order of magnitude lower. Total private R&D funding for the entire energy sector is less than that of a single large biotech company. (Amgen, for example, had R&D expenses of $2.3 billion in 2005.) And as R&D spending dwindles, so does innovation. For instance, as R&D funding for photovoltaics and wind power has slipped over the past quarter of a century, the number of successful patent applications in these fields has fallen accordingly. The lack of attention to long-term research and planning has significantly weakened our nation's ability to respond to the challenges of climate change and disruptions in energy supplies.

R&D IS KEY

Spending on research and development in the U.S. energy sector has fallen steadily since its peak in 1980. Studies of patent activity suggest that the drop in funding has slowed the development of renewable energy technologies. For example, the number of successful patent applications in photovoltaics and wind power has plummeted as R&D spending in these fields has declined.



Spending amounts are expressed in 2002 dollars to adjust for inflation.

Calls for major new commitments to energy R&D have become common. A 1997 study by the President's Committee of Advisors on Science and Technology and a 2004 report by the bipartisan National Commission on Energy Policy both recommended that the federal government double its R&D spending on energy. But would such an expansion be enough? Probably not. Based on assessments of the cost to stabilize the amount of carbon dioxide in the atmosphere and other studies that estimate the success of energy R&D programs and the resulting savings from the technologies that would emerge, my research group has calculated that public funding of $15 billion to $30 billion a year would be required—a fivefold to 10-fold increase over current levels.

Greg F. Nemet, a doctoral student in my laboratory, and I found that an increase of this magnitude would be roughly comparable to those that occurred during previous federal R&D initiatives such as the Manhattan Project and the Apollo program, each of which produced demonstrable economic benefits in addition to meeting its objectives. American energy companies could also boost their R&D spending by a factor of 10, and it would still be below the average for U.S. industry overall. Although government funding is essential to supporting early-stage technologies, private-sector R&D is the key to winnowing the best ideas and reducing the barriers to commercialization.

Raising R&D spending, though, is not the only way to make clean energy a national priority. Educators at all grade levels, from kindergarten to college, can stimulate public interest and activism by teaching how energy use and production affect the social and natural environment. Nonprofit organizations can establish a series of contests that would reward the first company or private group to achieve a challenging and worthwhile energy goal, such as constructing a building or appliance that can generate its own power or developing a commercial vehicle that can go 200 miles on a single gallon of fuel. The contests could be modeled after the Ashoka awards for pioneers in public policy and the Ansari X Prize for the developers of space vehicles. Scientists and entrepreneurs should also focus on finding clean, affordable ways to meet the energy needs of people in the developing world. My colleagues and I, for instance, recently detailed the environmental benefits of improving cooking stoves in Africa.

But perhaps the most important step toward creating a sustainable energy economy is to institute market-based schemes to make the prices of carbon fuels reflect their social cost. The use of coal, oil and natural gas imposes a huge collective toll on society, in the form of health care expenditures for ailments caused by air pollution, military spending to secure oil supplies, environmental damage from mining operations, and the potentially devastating economic impacts of global warming. A fee on carbon emissions would provide a simple, logical and transparent method to reward renewable, clean energy sources over those that harm the economy and the environment. The tax revenues could pay for some of the social costs of carbon emissions, and a portion could be des-

JEN CHRISTIANSEN; SOURCE: *REVERSING THE INCREDIBLE SHRINKING ENERGY R&D BUDGET*, D. M. KAMMEN AND G. NEMET IN *ISSUES IN SCIENCE AND TECHNOLOGY*, FALL 2005

THE LEAST BAD FOSSIL FUEL

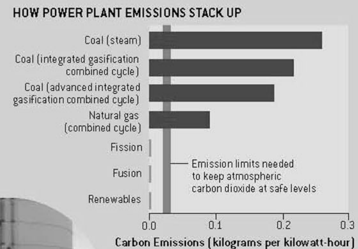
Although renewable energy sources offer the best way to radically cut greenhouse gas emissions, generating electricity from natural gas instead of coal can significantly reduce the amount of carbon added to the atmosphere. Conventional coal-fired power plants emit 0.25 kilogram of carbon for every kilowatt-hour generated. (More advanced coal-fired plants produce about 20 percent less carbon.) But natural gas (CH_4) has a higher proportion of hydrogen and a lower proportion of carbon than coal does. A combined-cycle power plant that burns natural gas emits only about 0.1 kilogram of carbon per kilowatt-hour (*graph at right*).

Unfortunately, dramatic increases in natural gas use in the U.S. and other countries have driven up the cost of the fuel. For the past decade, natural gas has been the fastest-growing source of fossil-fuel energy, and it now supplies almost 20 percent of America's electricity. At the same time, the price of natural gas has risen from an average of $2.50 to $3 per million Btu in 1997 to more than $7 per million Btu today.

The price increases have been so alarming that in 2003, then Federal Reserve Board Chair Alan Greenspan warned that the U.S. faced a natural gas crisis. The primary solution proposed by the White House and some in Congress was to increase gas production. The 2005 Energy Policy Act included large subsidies to support gas producers, increase exploration and expand imports of liquefied natural gas (LNG). These measures, however, may not enhance energy security, because most of the imported LNG would come from some of the same OPEC countries that supply petroleum to the U.S. Furthermore, generating electricity from even the cleanest natural gas power plants would still emit too much carbon to achieve the goal of keeping carbon dioxide in the atmosphere below 450 to 550 parts per million by volume. (Higher levels could have disastrous consequences for the global climate.)

Improving energy efficiency and developing renewable sources can be faster, cheaper and cleaner and provide more security than developing new gas supplies. Electricity from a wind farm costs less than that produced by a natural gas power plant if the comparison factors in the full cost of plant construction and forecasted gas prices. Also, wind farms and solar arrays can be built more rapidly than large-scale natural gas plants. Most critically, diversity of supply is America's greatest ally in maintaining a competitive and innovative energy sector. Promoting renewable sources makes sense strictly on economic grounds, even before the environmental benefits are considered. *—D.M.K.*

HOW POWER PLANT EMISSIONS STACK UP



ignated to compensate low-income families who spend a larger share of their income on energy. Furthermore, the carbon fee could be combined with a cap-and-trade program that would set limits on carbon emissions but also allow the cleanest energy suppliers to sell permits to their dirtier competitors. The federal government has used such programs with great success to curb other pollutants, and several northeastern states are already experimenting with greenhouse gas emissions trading.

Best of all, these steps would give energy companies an enormous financial incentive to advance the development and commercialization of renewable energy sources. In essence, the U.S. has the opportunity to foster an entirely new industry. The threat of climate change can be a rallying cry for a clean-technology revolution that would strengthen the country's manufacturing base, create thousands of jobs and alleviate our international trade deficits—instead of importing foreign oil, we can export high-efficiency vehicles, appliances, wind turbines and photovoltaics. This transformation can turn the nation's energy sector into something that was once deemed impossible: a vibrant, environmentally sustainable engine of growth.

MORE TO EXPLORE

Reversing the Incredible Shrinking Energy R&D Budget. D. M. Kammen and G. F. Nemet in *Issues in Science and Technology*, pages 84–88; Fall 2005.

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Ethanol Can Contribute to Energy and Environmental Goals. A. E. Farrell, R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare and D. M. Kammen in *Science*, Vol. 311, pages 506–508; January 27, 2006.

All these papers are available online at **http://rael.berkeley.edu/papers.html**

JEN CHRISTIANSEN; SOURCE: PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY; STEVEN SENNE *AP Photo* (*natural gas plant*)