PCAST

THE WHITE HOUSE

WASHINGTON

October 27, 1997

TO: Gene Sperling
Katie McGinty
Stephanie Streett
Dan Tarullo
Jack Gibbons
Jim Steinberg

FROM: Phil Caplan

The attached is forwarded for your information.

cc. Todd Stern

THE PRESIDENT HAS SEEN
10-27-97

THE WHITE HOUSE
WASHINGTON

October 27, 1997

MR. PRESIDENT:

We thought you would like to see the attached letter from Dr. John Holdren who, as you know, addressed the WH Conference on Climate Change last week and also chairs PCAST's Energy and R&D Panel.

Holdren makes a number of recommendations about the five-year climate change package and asks to brief you and the VP in person. The package is undergoing OMB/NEC/WH review

We have sent copies of his letter to the climate change team as well as to Stephanie for her consideration.

Phil Caplan
Phil

I need reply
we should see him

BC

PROGRAM IN SCIENCE, TECHNOLOGY, AND PUBLIC POLICY
John F. Kennedy School of Government
Harvard University
Cambridge, Massachusetts 02138

JOHN P. HOLDREN, Director
Teresa and John Heinz Professor of Environmental Policy

24 October 1997

President William Jefferson Clinton
The White House

VIA FAX

Dear President Clinton:

The climate policy position you announced on Wednesday represents a major step forward in dealing with this critical issue. I salute you and the Vice President for your courage and leadership in taking a bolder and more farsighted stance than many were urging upon you, and I thank you for the privilege I have had, as Chair of PCAST's Panel on Energy R&D for the Challenges of the 21st Century and as a participant in the July 24 and October 6 roundtables and many other discussions with members of your team, in making inputs into the deliberations that led to this result.

I write now not only to salute and thank you, however, but also to make a further input to the ongoing deliberations on the detailed content of parts of the position announced Wednesday — specifically, the $5 billion / 5-year package combining energy R&D initiatives and tax incentives for implementation of energy options that would reduce carbon emissions. I take the liberty of addressing you about this now because I know there will be great pressure to define the details of that package quickly and because this matter relates so directly to the recommendations of the PCAST Panel I have been leading for you. I write here as an individual, but I believe the other twenty members of my Panel would support the argument I am going to make.

My argument has two parts. First, while energy R&D and incentives for implementation of improved technologies are both very important, it is particularly critical that the R&D should not be squeezed out or even significantly squeezed down by the incentives part of the budget for this combined package. Second, the cost-effectiveness of incentives varies enormously depending on how they are targeted and structured; to get the most "bang for the buck" from the limited funding that will be available for incentives (no matter how the $5 billion is split) will require very careful attention to targeting the incentives on the biggest opportunities and structuring them appropriately.

The report of the PCAST Panel on Energy R&D, the 33-page Executive Summary of which you received on September 30, offers considerable analysis and advice on both points. The Panel's main report, which provides much more detail (it runs to some 200 pages), is in the process of review by the full PCAST and I hope will be delivered to you by late next week. I very much hope that it will be possible for me to meet with you and the Vice President soon to discuss these findings and their relation to the Administration's climate policy — both in terms of the R&D element and in terms of the incentives element. In the meantime, I'd like to offer a few further lines here on the first of these two points.

If it is assumed that the five years covered by the indicated $5 billion package are 1999 to 2003, and if the baseline against which the increases are measured is the Administration's FY 1998 budget request, then the energy R&D initiatives recommended by the PCAST Panel entail expenditures amounting to $3.7 billion as-spent dollars over the five-year period. (They ramp up from an increase of $369 million above the FY 1998 request in FY 1999 to an increase of $996 million over the FY 1998 request in FY 2003.) Of the proposed billion dollar increase in the FY 2003 applied energy-technology R&D budget compared to the $1.4 billion FY 1998 request in these categories, $73 million would go to fission, $87 million to fossil-fuel technologies, $103 million to fusion, $307 million to renewables, and $426 million to end-use efficiency.

The Panel's proposal for increases in these amounts resulted from taking seriously your charge to make "recommendations...on how to ensure that the United States has a program that addresses its energy and environmental needs for the next century", taking into account the challenges, the opportunities, and the likely magnitude and distribution of future R&D efforts supported by the private sector. As you know, the Panel included representation from the fossil-fuel, nuclear, renewable, and energy-efficiency industries, from the academic community, and from public-interest organizations; and it included a number of individuals of great stature and experience in business and government who are *not* energy specialists or energy enthusiasts and would not be expected to endorse increases in government spending for these purposes without being convinced from scratch that such increases are fully justified. The Panel was fully attentive to the need for frugality with the public's money, and it invested great effort in developing a portfolio that spends neither more than is necessary nor less than is prudent. It recommended that some energy R&D programs in DOE's current portfolio be reduced or terminated, while recommending that others be augmented.

I believe that the recommendations of this Panel, which were unanimous, represent a degree of consensus about energy R&D needs that is remarkable in light of the diversity and stature of this group and in light of the contentiousness of this issue. It is clear to me that the "portfolio" approach taken in these recommendations, in which the package as a whole is crafted to address all of the major dimensions of the energy-related challenges our country faces, across a range of time frames, was crucial to obtaining this consensus and will need to be retained in the Administration's package of R&D initiatives if these are to command the wide support they will need from across the whole energy community. I frankly do not see a way to preserve the essential characteristics of this portfolio of initiatives with significantly less funding for it than the $3.7 billion over five years that the Panel recommended, which is why I am so concerned about the split between R&D and tax incentives in a five-year package that contains only $5 billion altogether.

I also believe that it is especially important, both for the long-term success of your climate policy and for its shorter-term credibility, that the parts of it to be implemented *before* the emissions ceilings and permit-trading go into effect in 2008 should be as robust and concrete as it is possible to make them. It seems to me that an R&D initiative very much along the lines that your PCAST Panel has recommended offers very high leverage for the money in this connection. Such an R&D initiative can and should be augmented by suitably targeted and structured incentives, but it cannot be replaced by them.

Again, I hope to have an opportunity to discuss these matters further with you soon. Thank you in the meantime for your attention to this preview.

Sincerely,

John P. Holdren

cc: The Vice President
Gene Sperling
Katie McGinty
Todd Stern
Franklin Raines
John H. Gibbons

'97 OCT 3 PM 2:00

PCAST

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

THE PRESIDENT HAS SEEN
10-7-97

October 3, 1997

Copied:
entire report
Gibbons/COS
Stern
page 2: VP/CC
Berger
Tarullo
Steinberg

MEMORANDUM FOR THE PRESIDENT

FROM: JOHN H. GIBBONS

CC: ERSKINE BOWLES

SUBJECT: OSTP WEEKLY REPORT

PCAST MAKES RECOMMENDATIONS FOR ENERGY R&D

On September 30 PCAST chairman John Young sent you the Executive Summary of the PCAST report, *Federal Energy Research and Development for the Challenges of the 21st Century*. A PCAST panel chaired by John Holdren prepared the report in response to your January request for a review of the national energy R&D portfolio. The report is a consensus statement by the panel, which represented a cross-section of the energy industry, NGO community, and academia. PCAST fully endorsed the findings and recommendations.

The report recommends increased support for applied energy R&D budgets, beginning with $500 million and reaching $1 billion per year at the end of five years. The biggest increases are called for in efficiency and renewables research, which will help us reach climate protection goals for 2010, including:

This already a part of our climate change position

- Constructing one million "zero-net-energy" buildings
- Reducing industrial energy intensity by 25 percent
- Developing a production prototype of a 100 mpg passenger car
- Producing ethanol from energy crops that is fully cost competitive with gasoline

PCAST urges you to communicate to the public the importance of energy and energy R&D to the nation's future. This message is integral to your outreach on climate change. As PCAST notes, it is also central to all efforts to ensure economic prosperity, environmental quality, and national security.

LAUNCH OF CASSINI MISSION TO SATURN APPROVED

Today I sent Dan Goldin a letter providing safety approval of the Cassini Mission to Saturn. The launch is currently scheduled for October 13.

THE PRESIDENT HAS SEEN
10-7-97

DOD BASIC RESEARCH BUDGET REMAINS STAGNANT

The FY98 defense appropriations conference resulted in an overall increase of $755 million in science and technology over your budget request. While overall this may appear to be good news, Congress cut your request for basic defense research by 7.2 percent, or $83.5 million. Congress' action is particularly ironic given the views Senator Lott expressed in January in a well-reasoned letter to Senator Thurmond expressing his concern over erosion in DOD's basic research program: "Th[e] research investment is also our legacy to our country, children and grandchildren because it ensures this country's continued ability to field technologically superior forces. . . . I believe we do have the capability and must stop the slide in research and commit to a long-term stable and robust program." Unfortunately this trend may be continuing within the Pentagon. The Air Force has proposed cutting back its overall S&T effort by 20 percent in FY99 and 25 percent in FY00 from previously planned levels, while the Navy has proposed respective cuts of 6 and 8 percent. Neither the Army nor the Marines have proposed reductions. I have written Secretary Cohen of my concerns about this disturbing trend of losses in research support and am following it through the budget process.

cc VP
Sandy

OSTP PUBLISHES A PRIMER ON CLIMATE SCIENCE

Attached is a copy of OSTP's recent publication, *Climate Change: State of Knowledge*. This volume was prepared for your October 1 meeting with the meteorologists and for use at the White House Conference on Climate Change October 6.

Copied
VP
COS
Berger

CLIMATE CHANGE

State of Knowledge

PCAST

THE WHITE HOUSE

WASHINGTON

January 14, 1997

Mr. John A. Young
Co-Chair
President's Committee of Advisors
on Science and Technology
3200 Hillview Avenue
Palo Alto, California 94304-1298

Dear John:

Thank you for your letter advising me on key science and technology issues that warrant my Administration's attention over the next four years.

Science and technology contributed significantly to our economic growth in the last half century. Balancing the budget by 2002 and making prudent investments in science and technology will help sustain that growth as we approach the 21st century. My Administration's efforts over the past four years provide a good start on reshaping the Federal science and technology portfolio, particularly in those areas that lacked bipartisan support, such as environmental research, technology partnerships, and human capital research. Your guidance and advice in these areas are extremely important to me.

I want to thank the President's Committee of Advisors on Science and Technology (PCAST) for underscoring the issues PCAST members believe my Administration needs to address in our second term. In response to your recommendations, I have asked Jack Gibbons to work with the new Secretary of Energy, once he is confirmed by the Senate, to review the current national energy R&D portfolio, and make recommendations to me by October 1, 1997 on how to ensure that the United States has a program that addresses its energy and environmental needs for the next century. The analysis should be done in a global context, and the review should address both near- and long-term national needs including renewable and advanced fission and fusion energy supply options, and energy end-use efficiency.

I request that PCAST work with the National Science and Technology Council (NSTC) agencies, industry, and universities, to review and evaluate the Federal technology partnership programs by August 1, 1997, with recommendations on how to increase their effectiveness.

In addition, I have asked Jack Gibbons to work with the NSTC agencies and OMB to address the other three issues highlighted by PCAST: understanding and management of the biological resources, research and technology to improve education and training, and protection, management, and disposition of nuclear materials.

Science and technology research is central to the United States' continued world leadership. Vice President Gore and I commend and thank you for the dedicated service and visionary guidance you and the Committee have provided over the past two years, and we look forward to receiving your help in the future.

Sincerely,

Bill Clinton

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

December 6, 1996

President William J. Clinton
The White House
1600 Pennsylvania Avenue
Washington, D.C. 20500

Dear President Clinton:

Thank you for the opportunity to serve as your Committee of Advisors on Science and Technology (PCAST) during your first term. You and the Vice President understand and support science and technology as critical national investments. A high level of investment, excellence in education, and accelerated innovation through science and technology are key elements that enable growth in the standard of living for every American.

We are writing in response to the Vice President's request for our observations and recommendations regarding science and technology policies and activities over the coming four years. While it may seem far afield from science and technology, we believe that it is extremely important to address the entitlement issues of Medicare and Social Security. Unless these expenditures are realigned, the amounts remaining for all other investment areas after deducting for defense and interest will be under tremendous pressure. For example, in the last Congress, Federal support of science and technology in the nation's leading research universities was projected to decline by 30 percent by 2002 as a result of their misguided tactics to close the budget gap.

Recognizing that there are no short term fixes, we respectfully urge that you present a strengthened science and technology budget for FY 1998 and sustain those levels in the years thereafter. This investment in the future should not be allowed to be diminished by inflation even if modest tax adjustments are required. A firm commitment to support of colleges, universities, and research institutes, where the next generation is trained and the frontiers of research most often are established, is especially important.

Consistent with your leadership in Reinventing Government, getting more for the same Federal science and technology dollars is a key issue. Having a process to clearly prioritize science and technology and to redirect work on the most important areas that address the nation's social, economic and security objectives is an urgent need. With private sector R&D becoming focused on shorter and shorter product life cycles, Federal support for science and advanced technologies is increasingly important and a key contributor to industrial competitiveness. In addition, assuring the nation's sustained technological leadership will require that our national innovation system be strengthened both through Federal support and a fresh look at incentives for private-sector research investment.

In addition to these critical ongoing issues, our own discussions in PCAST of the science and technology challenges facing our nation in the next four years suggest five issues that deserve increased attention:

1) A National Strategy for Energy R&D

Adequate and reliable supplies of affordable energy, obtained and used in environmentally sustainable ways, are essential to economic prosperity, environmental quality, and political stability around the world. Moreover, energy-supply and energy-efficiency technologies represent a multi-hundred-billion-dollar-per-year global market. There is considerable doubt whether the world, which gets three-quarters of all its energy supply from oil, coal, and natural gas, can continue to rely on these fossil fuels to this degree through the expected economic growth of the next few decades without encountering intolerably disruptive climatic change caused by the resulting greenhouse-gas emissions. Yet the United States -- which is the world's largest energy consumer and the largest greenhouse-gas emitter -- is 85-percent dependent on fossil fuels and imports nearly half of its oil at a cost of $50 billion per year. The United States has allowed Federal spending on energy R&D to fall more than three-fold in real terms in the last 15 years, a period in which private funding for energy R&D also was falling. Government spending on energy R&D is more than twice as high in Japan as in the United States, and about four times as high as a fraction of GNP.

- We recommend a substantial and sustained increase in Federal expenditures on energy R&D, coupled with measures to encourage increased energy R&D in the private sector. This effort should include greatly increased work on renewable energy options and energy end-use efficiency, restoration of fusion R&D funding to the levels recommended by PCAST last year, exploration of whether and how the conditions for an expanded contribution to world energy supply from nuclear fission can be achieved, and an expanded effort on clean and more efficient fossil-fuel technologies.

2) Improved Understanding and Management of the Biological Resources

Unfortunately, increased attention in recent years to the issues of global environmental change, biodiversity loss, and environmentally sustainable development has not generated as much new work on the biological underpinnings of these issues as the associated challenges require. The underpinnings to which we refer are the composition, structure, and function of the biota -- the plants, animals, and microorganisms of the planet. This includes their functions in support of human well-being and the ways in which improved management of human interactions with the biota can preserve and enhance those functions to meet the needs of the world's growing population. Individually, plants, animals, and microorganisms are the sustainable sources of our food, most of our medicines, and much of our fuel, fiber, and building materials -- yet we understand only a very small fraction of their diversity or how to use them for our benefit. Yet how all of this actually works remains vastly understudied compared with other areas of science of less immediate and direct importance to the human condition.

- We recommend a major national initiative to increase research and training in the biological and ecological sciences relevant to increasing our understanding of the composition, structure, function, and management of the biota.

3) Research and Technology to Improve Education and Training

Your Administration has promoted national investments in education and training, which are essential to continued economic growth and international competitiveness. The Administration also has recognized that information technology, which is having such a dramatic impact on the performance of the economy, can also have a powerful impact on the way Americans teach and learn. PCAST strongly supports the programs encompassed by the President's Educational Technology Initiative, which aim to provide our nation's schools with modern computer equipment, local network connectivity and Internet access, and to promote development of innovative new forms of educational software and content. The initiative further supports professional development activities designed to ensure that educators are able to use technology effectively within their classrooms. We believe, however, that rigorous new scientific research is urgently needed to determine which approaches to the use of technology in education and training are most likely to be both educationally effective and economical. More generally, new research is needed to assess the efficacy and cost-effectiveness of all aspects of the nation's current educational reform efforts.

- We recommend the initiation of a large-scale, federally funded program for rigorous scientific research on the efficacy and cost-effectiveness of alternative approaches to educational reform, including various applications of information technology to education and training.

4) Industry-Government-University Partnerships

In the rapidly changing global markets of the 21st century, technology innovation will remain the most distinguishing characteristic in economic competitiveness. Breaking sharply from historic growth trends of 5 percent per year, R&D in the corporate community (the funder and performer of more than half of the R&D in the United States) is today undergoing dramatic changes, shifting away from both basic and applied research, and focusing on near-term product development and process improvement. We are being outpaced by Japan and Germany, our chief technology competitors, who invest proportionally more in civilian R&D than the United States. At issue is the appropriate Federal response that has included both fiscal and regulatory initiatives, as well as partnership programs aimed at supporting key enabling technologies identified by industry. The programs that focus on mid- to long-term technology development should now be reviewed carefully and refined for further increasing their effectiveness, restoring their bipartisan Congressional support.

- We recommend that the National Science and Technology Council (NSTC) evaluate, review, and refine the Federal technology partnership programs to assess and further increase their effectiveness.

5) **Improved Protection, Management, and Disposition of Nuclear Materials**

Prevention of nuclear proliferation, protection against nuclear terrorism, and further progress on nuclear arms reductions all depend on improving the systems for minimizing, monitoring, sequestering, and protecting the stocks of nuclear-weapons materials -- separated plutonium and highly enriched uranium -- in both the military and civilian sectors, in the United States and Russia and around the world. (These stocks are associated with nuclear-weapons production complexes, with the nuclear arsenals themselves, and with the residues of nuclear-weapon dismantlement; with civilian nuclear-power facilities of certain kinds; with the fuel-supply chain for naval reactors; and with nuclear-energy research facilities.) The prospects for future contributions of nuclear energy to world energy supply, moreover, depend not only on tight controls on the nuclear-weapon materials in civilian nuclear energy systems, but also on the demonstration of acceptable methods and sites for the disposal of radioactive wastes -- and these two problems are related. Your Administration has devoted substantial efforts to both problems and we were pleased to assist you. The cooperative programs between the United States and the countries of the former Soviet Union to improve management and protection of nuclear materials on the military side, in particular, have made great progress. But much more is required.

- We urge you to continue, strengthen, expand, and better coordinate these national and international efforts in the management, protection, and disposition of nuclear materials.

PCAST hopes that these recommendations will be helpful as you consider how best to carry the Nation into the next century. Bipartisan support and international cooperation will be required to successfully implement this agenda. You can count on our best efforts to help you develop a consensus in the Congress, in the country, and around the globe on these important scientific and technical issues. We have appreciated the opportunity to discuss our concerns with you and the Vice President these past several years, and hope you will continue to look to our members for guidance.

Sincerely,

John A. Young
Co-Chairman
President's Committee of Advisors on Science and Technology

cc: Vice President Al Gore

EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COMMITTEE OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

March 19, 1997

MEMORANDUM FOR MEMBERS OF THE PCAST ENERGY PANEL

FROM: JACK GIBBONS
ASSISTANT TO THE PRESIDENT FOR SCIENCE AND TECHNOLOGY

SUBJECT: Initiation of Energy Panel Activity

On behalf of the President's Committee of Advisors on Science and Technology (PCAST), I want to thank you for agreeing to serve on the PCAST Energy Panel.

As we embark upon the 21st century, increasing attention must be devoted to developing efficient, reliable and affordable energy sources that can supply adequate quantities of energy in an environmentally sustainable manner. In December 1996, PCAST identified for the President several science and technology challenges facing the nation in the next four years that warrant increased attention by the Administration -- A National Strategy for Energy R&D being one of them.

Given the President's direction to PCAST to review the current national energy R&D portfolio and to make recommendations on how to ensure that the United States has a program that addresses its energy and environmental needs for the next century, John Young and I have constituted the PCAST Energy Panel for this purpose. Chaired by Dr. John Holdren, your panel will be guided by a formal terms of reference, to be discussed at your first meeting, and PCAST requests that you specifically address the following issues:

- a synopsis of the energy challenges likely to face the United States and the world in the early part of the 21st century with particular attention to the possible ramifications of these challenges for the country's economic well-being, environmental quality, and national security.

- a description of current and projected U.S. energy R&D activities in relation to the identified challenges and in comparison to the R&D programs of other countries.

- a detailed review of U.S. government R&D programs in renewables, end-use efficiency, fission, advanced fossil-fuel, and fusion technologies -- identifying priority and resource changes that would make the country's Federal energy R&D programs more responsive to the energy-linked economic, environmental, and national security challenges of the next century.

- recommendations on how U.S. investments in publicly supported energy R&D, U.S. incentives for private energy R&D, and U.S. commitments to international cooperation in energy R&D should be modified.

I am confident that your efforts will provide invaluable information for making decisions about the future direction of the nation's energy-related research and development program. We expect that you will report your recommendations to the full PCAST by September 1997, in time to influence development of the Administration's FY 1999 budget request. Dr. Henry Kelly, Acting Associate Director for Technology, Office of Science and Technology Policy (OSTP), will be the OSTP primary point of contact for this effort with supplemental assistance from Dr. Rosina Bierbaum (Environment Division) and Dr. Beverly Hartline (Science Division).

All of the PCAST members look forward to learning your findings and recommendations, and will appreciate meeting you at the September 29 meeting.

I wish you good luck in your efforts, and I thank you again for your contributions.

cc: John A. Young

THE WHITE HOUSE

Office of Media Affairs

FOR IMMEDIATE RELEASE
March 20, 1997

Contact: Rebecca Dittmar
202/456-6020

White House Taps Panel of Experts on Energy Research and Development

Washington -- Dr. John H. Gibbons, Assistant to the President for Science and Technology, today announced formation of a panel of distinguished, independent experts to review the Nation's energy research and development (R&D) program. The panel, created under the auspices of the President's Committee of Advisors on Science and Technology (PCAST), will provide recommendations on how to ensure the United States' energy R&D program addresses the economic, environmental and national security needs of the nation for the next century.

The panel will be chaired by John P. Holdren, the Teresa and John Heinz Professor of Environmental Policy and Director of the Program on Science, Technology and Public Policy at the John F. Kennedy School of Government, Harvard University. Holdren, a member of PCAST, previously chaired 1995 PCAST studies on the U.S. fusion energy program and protection of nuclear-weapon materials.

Working with the White House Office of Science and Technology Policy and the U.S. Department of Energy, the panel will review current and projected U.S. energy R&D programs and will make recommendations on federal support for energy research and development, incentives for private-sector investments in energy research and development and U.S. commitments to international cooperation in energy research and development.

Issues covered by the panel will include R&D on energy and end-use efficiency, renewables, advanced fossil-fuel technologies, nuclear fission and nuclear fusion. The panel will report its findings to the President by October 1997.

A list of panel members is attached.

March 20, 1997

PANEL MEMBERSHIP:

PCAST Study of the Nation's Energy R&D Portfolio

Chair:

John P. Holdren
Harvard University
PCAST Member

Members:

Diana MacArthur
CEO
Dynamac Corporation
PCAST Member

Virginia Weldon
Vice President
Monsanto
PCAST Member

John Young
former CEO, Hewlett-Packard
PCAST Co-Chair

Richard Balzhiser
President Emeritus
Electric Power Research Institute
Research

Joan Bok
Chairman of the Board
New England Electric System

Robert Conn
Dean of Engineering
University of California, San Diego

William L. Fisher
Benow Chair & Professor
Department of Geological Sciences
University of Texas, Austin

Charles Vest
President
MIT
PCAST Member

Lillian Shiao-Yen Wu
Research Scientist
IBM
PCAST Member

John Ahearne
Sigma Xi
Duke University

Robert Frosch
Harvard University
Former head, NASA & GM
Labs

William Fulkerson
Emeritus Associate Director
Oak Ridge National Laboratory

Hal Harvey
President
The Energy Foundation

Thomas L. Fisher
Chairman, President and CEO
Northern Illinois Gas Company

-more-

Larry Papay
Senior VP & Manager of R&D
Bechtel Corporation

Laura D'Andrea Tyson
Professor of Economics
University of California, Berkeley

Robert Williams
Center for Energy & Environmental Studies
Princeton University

Dan Lashof
Senior Scientist
Natural Resources Defense Council

Don Paul
Vice President for Technology and
Environmental Affairs
Chevron Corporation

Maxine Savitz
General Manager
Allied Signal Ceramic Components

TDS
PCAST

Federal Energy Research and Development for the Challenges of the Twenty-First Century

Panel on Federal Energy R&D,
President's Committee of Advisors on Science and Technology

EXECUTIVE SUMMARY

The United States faces major energy-related challenges as it enters the twenty-first century. Our economic well-being depends on reliable, affordable supplies of energy. Our environmental well-being — from improving urban air quality to abating the risk of global warming — requires a mix of energy sources that emits less carbon dioxide and other pollutants than today's mix does. Our national security requires secure supplies of oil or alternatives to it, as well as proliferation-resistant nuclear power. And for reasons of economy, environment, security, and stature as a world power alike, the United States must maintain its leadership in the science and technology of energy supply and use.

All of these energy-related challenges to the well-being of this country and its citizens are made more acute by what is happening elsewhere in the world. The combination of population growth and economic development in the countries of Asia, Africa, and Latin America is driving a rapid expansion of world energy use, which is beginning to augment significantly the worldwide emissions of carbon dioxide from fossil-fuel combustion, increasing the pressures on world oil supplies, and exacerbating nuclear proliferation concerns. Means must be found to meet the economic aspirations and associated energy needs of all the world's people while protecting the environment and preserving peace, stability, and opportunity.

Improvements in energy technologies, attainable through energy research and development, are the key to the capacity of the United States to address its part of these challenges and to help the rest of the world address theirs.

Many of the energy R&D programs of the Federal government (which are primarily conducted by the Department of Energy), have been well focused and effective within the limits of the funding that has been available for them. But these programs, taken as a whole, are not commensurate in scope and scale with the energy challenges and opportunities that the twenty-first century presents. (We take into account, in reaching this judgment, the contributions to energy R&D that can reasonably be expected to be made by the private sector.) The inadequacy of current energy R&D is especially acute in relation to the challenge of responding prudently and cost-effectively to the risk of global climatic change from society's greenhouse gas emissions, of which the most important is carbon dioxide from combustion of fossil fuels. Much of the new R&D needed to respond to this challenge would also be responsive to the others.

SYNOPSIS OF MAIN RECOMMENDATIONS

To close the gap between the energy R&D program we have now and the one that the challenges require, the Panel recommends strengthening the DOE applied energy-technology R&D portfolio by increasing funding for four of its major elements (energy end-use efficiency, nuclear fission, nuclear fusion, and renewable energy technologies) and restructuring part of the fifth (fossil-fuel technologies). We also recommend better coordination between the Department's applied energy-technology programs and the fundamental research carried out in the program on Basic Energy Sciences; increased Department efforts in integrated analysis of its entire energy R&D portfolio and the leverage the portfolio offers against the energy challenges of the next century; targeted efforts to improve the prospects of commercialization of the fruits of publicly funded energy R&D in specific areas; increased attention to certain international aspects of energy R&D; and changes in the prominence given to energy R&D in relation to the Department's other missions, coupled with changes how this R&D is managed.

Applied Energy-Technology R&D Recommendations

The overall budgets we propose for these elements to the year 2003, based on analyses summarized in the body of our report and set out in more detail in its appendices, are summarized in Table ES-1. (The table provides these figures both in as-spent dollars, which are the usual currency of official budget planning, and in constant 1997 dollars, which are more informative about what is really happening to the size of the effort.)

The applied energy-technology R&D programs, which have been the main focus of our study and which are shown in Table ES-1, contain only part of the activities constituting the DOE's Congressional budget lines for "Energy R&D". Table ES-2 shows the relation, under the FY 1997 Congressional appropriation and the FY 1998 DOE request, between the amount budgeted for the activities included in our "applied energy-technology R&D" category and the amounts budgeted for the other activities included under "Energy R&D" in the Congressional budget lines.

The Basic Energy Sciences (BES) budget line, which is part of the DOE's Office of Energy Research, includes research in materials science, chemistry, applied mathematics, biosciences, geosciences, and engineering that is not directed at the development of a particular class of energy sources. Advances produced by research in this category provide an important part of the expanding knowledge base on which progress in applied energy-technology R&D in the public and private sectors alike depends. Constraints of time and resources prevented the Panel from reviewing the BES program in detail, and we do not offer any quantitative proposal about its future budgets.

Our limited inquiry did give us a positive impression about the value of the research that BES supports, however, and we assume that the Department will want to expand its support for such research as the applied energy technology R&D that builds on it expands. We suggest (see below) that greater coordination between BES and the applied energy technology programs could increase the direct benefits that flow from BES into the applied areas. The Panel did not review at all the other "Energy R&D" budget lines shown in Table ES-2, which contain mostly items that are either not very closely linked to advances in civilian energy technology or are not really R&D.

As indicated in Table ES-1, our proposals for the applied energy-technology R&D programs would increase spending in that category from $1.3 billion in 1997 to $2.4 billion in 2003, in as-spent dollars. In constant-dollar terms, the increase from 1997 through 2003 is 61 percent, amounting to an average real growth rate of 8.3 percent per year. The proposed figure for 2003 would return the DOE's real level of effort in applied energy-technology R&D in that year to about where it was in FY 1991 and FY 1992.

Table ES-1. **Recommended DOE Budget Authority for Applied Energy-Technology R&D**

In millions of as-spent dollars.

	1997 actual	1998 request	1999	2000	2001	2002	2003
Efficiency	373	454	615	690	770	820	880
Fission	42	46	66	86	101	116	119
Fossil	365	346	379	406	433	437	433
Fusion	232	225	250	270	290	320	328
Renewables	270	345	475	585	620	636	652
TOTAL AET	1282	1416	1785	2037	2214	2329	2412

In millions of constant 1997 dollars.

	1997 actual	1998 request	1999	2000	2001	2002	2003
Efficiency	373	442	584	638	695	721	755
Fission	42	45	63	80	91	102	102
Fossil	365	337	360	376	391	384	371
Fusion	232	219	237	250	262	281	281
Renewables	270	336	451	541	559	559	559
TOTAL AET	1282	1379	1695	1885	1998	2047	2068

Note: What we call "energy end-use efficiency" in this report and abbreviate as "efficiency" in these tables appears as "conservation" in many budget documents.

Of the Panel's proposed increases in the DOE's applied energy-technology R&D accounts, the largest in dollar magnitude is in the end-use-efficiency programs, in which annual spending in FY 2003 would reach $880 million, about $500 million more than in 1997 (as-spent dollars). This large increase is appropriate because of the high promise of advanced efficiency technologies for relatively quick-starting and rapidly expanding contributions to several important societal goals, including cost-effective reductions in local air pollution and carbon-dioxide emissions, diminished dependence on imported oil, and reductions in energy costs to households and firms.

Improvements in energy efficiency reduced the energy intensity of economic activity in the United States by nearly one third between 1975 and 1995, an improvement that is now saving U.S. consumers about $170 billion per year in energy expenditures and is keeping U.S. emissions of air pollutants and carbon dioxide about a third lower than they would otherwise be. Further major increases in efficiency can be achieved in every energy end-use sector: in transportation, for

Table ES-2. **Relation of Applied Energy Technology R&D to "Total Energy R&D"**

In millions of as-spent dollars.

	1997 actual	1998 request
APPLIED ENERGY TECHNOLOGY R&D	1282	1416
"Energy Research": Basic Energy Sciences	641	661
"Energy Research": Other Non-Fusion	539	585
"Other Nuclear R&D"	216	255
"Other Conservation R&D"	177	234
TOTAL "ENERGY R&D" BUDGET LINES	2855	3151

Notes: The DOE's Office of Energy Research (OER) includes the Department's R&D on fusion energy, as well as Basic Energy Sciences (see main text) and some other science and technology programs including biomedical and environmental research, research in computing, and science education. "Other Conservation R&D" includes the State and Local Partnership Programs and the Federal Energy Management Program (which are not really R&D at all), among other items. "Other Nuclear R&D" includes radioisotope power sources for spacecraft, naval nuclear reactors, electrometallurgical technology, and isotopes for medical applications, among other items. The Panel included fusion in its analysis of applied energy-technology R&D (although, as noted in that analysis, much fusion R&D is in fact basic science).

example, through much more fuel-efficient cars and trucks; in industry through improved electric motors, materials-processing technologies, and manufacturing processes; in residential and commercial buildings through high-technology windows, super-insulation, more efficient lighting, and advanced heating and cooling systems.

The next largest of our proposed increases in the applied energy-technology portfolio is for renewable energy technologies, in which annual spending in FY 2003 would reach $650 million, nearly $400 million more than in 1997 (as-spent dollars). This increase makes sense in light of the rapid rate of cost reduction achieved in recent years for a number of renewable energy technologies, the good prospects for further gains, and the substantial positive contributions these technologies could make to improving environmental quality, reducing the risk of climate change, controlling oil-import growth, and promoting sustainable economic development in developing countries.

There are opportunities for important advances in wind-electric systems, photovoltaics, solar-thermal energy systems, biomass-energy technologies for fuel and electricity, geothermal energy, and a range of hydrogen-producing and hydrogen-using technologies including fuel cells. As in the case of the increases energy-efficiency R&D we propose, the increased support for these renewable-energy technologies would focus on areas where the prospective economic returns to industry R&D investments at this time will not produce an effort as large as is warranted when the prospective public-goods benefits of this R&D are taken into account.

Next in descending order of the dollar amount of the spending increase under our proposals is fusion R&D, in which annual spending in FY 2003 would reach about $100 million more than the 1997 figure in as-spent dollars. In this scenario, fusion funding would reach by 2002 the $320 million figure recommended in the 1995 PCAST study of fusion-energy R&D as a constant level of spending in as-spent dollars to be maintained from FY 1996 onward. (This earlier PCAST recommendation did not prevail, and fusion funding fell instead from $269 million in FY 1995 to $232 million in FY 1997.)

We judge this amount warranted both because about $200 million per year of it would continue a very productive element of the country's basic science portfolio (comparing favorably in cutting-edge contributions and valuable spinoffs with other, better funded fields in that category) and because the rest is easily justified as the sort of investment the government should be making in a high-risk but potentially very-high-yield energy option for society, in which the size and time horizon of the program essentially rule out private funding for it.

The DOE's R&D in nuclear-fission energy systems, which fell 12-fold in real terms between 1986 and 1997, would increase under our proposal from about $40 million per year in FY 1997 to about $120 million per year in 2003 (as-spent dollars), thereby returning in real level of effort to that of 1995. Nuclear fission currently generates about 17 percent of the world's electricity, which if it were generated instead by coal would make world carbon dioxide emissions from fossil-fuel consumption almost 10 percent larger than they currently are.

Fission's future expandability is in doubt in the United States and many other regions of the world because of concerns about high costs, reactor-accident risks, radioactive-waste management, and potential links to the spread of nuclear weapons. We believe that the potential benefits of an expanded contribution from fission in helping address the carbon-dioxide challenge and several others easily warrant the modest research initiative proposed here, in order to find out whether and how improved technology could alleviate the concerns that cloud this energy option's future.

To write off fission now as some have suggested, instead of trying to fix it where it is impaired, would be imprudent in energy terms and would risk losing much U.S. influence over the safety and proliferation resistance of nuclear-energy activities in other countries. Fission belongs in the R&D portfolio.

Energy from fossil fuels currently contributes 85 percent of U.S. annual energy use and 75 percent of the world's. These fuels will continue to provide immense amounts of energy through the middle of the next century and beyond, under any plausible scenario. We judge that the DOE's current fossil-energy R&D program is about the appropriate size in relation to the array of relevant needs, opportunities, and likely continuing private-sector fossil-energy R&D activities. Our proposed budget for DOE's fossil-energy R&D, which increases funding in as-spent dollars by about $70 million per year between 1997 and 2003, actually holds the real level of effort approximately level near its 1997 value of $365 million per year.

We do, however, recommend some changes in emphasis within this program. Specifically, we propose phasing out the DOE's R&D on near-term coal-power technologies and promptly ending the funding for direct coal liquefaction, while increasing the Department's R&D on advanced coal-power programs, carbon capture and sequestration, fuel cells and other hydrogen technology, and advanced oil and gas production and processing. These changes are designed to increase the responsiveness of the DOE's fossil-energy R&D to the carbon-dioxide and oil-import challenges (including technology export opportunities that could favorably affect other countries' carbon emissions and oil imports while improving the U.S. balance of payments), and to improve the program's complementarity with what the private sector does and is likely to do.

Our recommendations for R&D initiatives in the efficiency, renewables, fusion, fission, and fossil-fuel components of the DOE's applied energy-technology portfolio are summarized, together with the budgets we propose for these efforts, in Table ES-3.

Recommendations on Cross-Cutting Issues

We turn now to a synopsis of our further recommendations dealing with issues that cut across the applied energy-technology programs: coordination between those programs and the Department's work in Basic Energy Sciences; portfolio analysis; commercialization considerations; international aspects of energy R&D; and management issues.

The Panel recommends that coordination between the Basic Energy Sciences program and the applied energy-technology programs be improved using mechanisms such as co-management and co-funding with — or budget sign-off by or re-routing budgets through — the applied technology programs.

We recommend that the Department make a much more systematic effort to portray the diverse characteristics of different energy options in a way that facilitates comparisons and the development of appropriate portfolio balance in light of the challenges facing energy R&D and in light of the nature of private-sector and international efforts and the interaction of U.S. government R&D with them.

After consideration of the market circumstances and public benefits associated with the energy-technology options for which we have recommended increased R&D, the Panel recommends that the nation adopt a commercialization strategy in specific areas complementing its public investments in R&D. This strategy should be designed to reduce the prices of the targeted technologies to competitive levels, and it should be limited in cost and duration.

The Panel recommends that the government and government/national-laboratory/industry/university consortia should engage strongly in international energy technology R&D and development and commercialization efforts to regain and/or maintain the scientific, technical, and market leadership of the United States in energy technology.

We recommend, further, that President clearly communicate to the public the importance of energy and energy R&D to the nation's future, and that he clearly designate the Secretary of Energy as the national leader and coordinator for developing and carrying out the national energy strategy.

We recommend that overall responsibility for the DOE energy R&D portfolio should be assigned to a single person reporting directly to the Secretary of Energy, and that, similarly, a single individual should be given the responsibility and authority for coordination of cross-cutting programs between the applied-technology programs, reporting to the single person responsible for the overall R&D portfolio.

RATIONALE FOR THE RECOMMENDATIONS

The rationale for the recommendations summarized above — and for others to be found in the more detailed treatment later in this Executive Summary — is presented in what follows in terms of the importance of energy to our national well-being, the evolution of U.S. and world energy supply and demand, the challenges this evolution poses to energy R&D, recent trends in public and private funding for energy R&D, and the implications of those trends (and the energy R&D status quo) for the prospects of meeting the energy and environmental challenges of the next century.

The Importance of Energy

The characteristics of the technologies available to this nation and others for energy supply and energy end-use are critical to our country's economic well-being, environmental quality, and national security:

- Economically, expenditures on energy account for seven to eight percent of gross economic product in the United States and worldwide and a similar fraction of the value of U.S. and world trade. Sales of new energy-supply technologies globally run in the multi-hundreds of billions of dollars per year. And periods of excessive energy costs, experience has shown, are associated with inflation, recession, and frustrated economic aspirations.

- Environmentally, energy supply accounts for a large share of the most worrisome environmental problems at every geographic scale — from wood-smoke in Third World village huts, to regional smogs and acid precipitation in industrialized and developing countries alike, to the risk of widespread radioactive contamination from accidents at nuclear-energy facilities, to the build-up of carbon dioxide and other heat-trapping gases in the global atmosphere.

- National security is linked to energy through the increasing dependence of this country and many others on imported oil, much of it from the politically troubled Middle East; through the danger that nuclear-weapons-relevant knowledge and materials will be transferred from civilian nuclear-energy programs into national nuclear arsenals or terrorist bombs; and through the potential for large-scale failures of energy strategy with economic or environmental consequences serious enough to generate or aggravate social and political instability.

Scientific and technological progress, achieved through research and development (R&D), is crucial to minimizing current and future difficulties associated with these interactions between energy and well-being, and crucial to maximizing the opportunities. If the pace of such progress is not sufficient, the future will be less prosperous economically, more afflicted environmentally, and more burdened with conflict than most people expect. And if the pace of progress is sufficient elsewhere but not in the United States, this country's position of scientific and technological leadership — and with it much of the basis of our economic competitiveness, our military security, and our leadership in world affairs — will be compromised.

Past, Present, and Projected Patterns of Energy Supply

The challenges and opportunities associated with the economic, environmental, and national-security dimensions of energy have become what they are primarily as a consequence of the tremendous increase in energy use, and especially fossil-fuel use, over the past century and a half. This increase, in which world energy use grew 20-fold between 1850 and 1995 and fossil-fuel use increased more than 100-fold, arose principally from the combination of population growth and rapid economic development in the industrialized countries.

In contrast, by far the largest part of the *future* growth of world energy use is expected to take place in the currently less developed countries of Asia, Africa, and Latin America. Today, with nearly 80 percent of the world's population, these countries still account for only a third of the energy use. But if recent trends continue (the "business as usual" energy future), they will pass the industrialized countries in total energy use (and in carbon dioxide emissions) between 2020 and 2030, and their growth will be the primary driver of a doubling in global energy use between 1995 and 2030 and a quadrupling between 1995 and 2100.

Energy use in industrialized countries would continue to increase in a "business as usual" future, but not as rapidly as in the less developed countries and not as rapidly as in the past. A "business as usual" energy trajectory for the United States would entail increases in energy use, above the 1995 level, of about 40 percent by 2030 and nearly 75 percent by 2100.

The fossil fuels — oil, natural gas, and coal — accounted for 75 percent of energy supply worldwide in 1995. The remainder was nuclear energy (6 percent), hydropower (6 percent), and biomass fuels (13 percent, mostly fuel-wood in developing countries), with wind, solar, and geothermal energy together contributing less than half a percent. The dominance of the fossil fuels would decline only slowly in a "business as usual" future: the world as a whole would still be obtaining perhaps two-thirds of all its energy needs from fossil fuels in 2030 and half or more in 2100. Fossil-fuel resources are adequate to support such an outcome, albeit perhaps with higher dependence on coal than today, relative to oil and gas.

The United States obtained 85 percent of its energy from fossil fuels in 1995, nearly 40 percent from oil alone (of which half was imported). U.S. fossil-fuel dependence, like that of the rest of the world, would decline only slowly in a "business as usual" future. U.S. oil imports, according to the "reference" forecast of the Department of Energy, would grow from 9 million barrels per day in 1995 to 14 million barrels per day in 2015 and continue to increase for some time thereafter.

The Challenge to Energy R&D

Improvements in energy technology can and must play a major role in reducing the costs, increasing the benefits, and alleviating the perils that a "business as usual" energy future without such improvements would be likely to entail.

Energy-technology improvements, achieved in the United States and then deployed here and elsewhere, could

- lower the monetary costs of supplying energy,
- lower its effective costs still further by increasing the efficiency of its end uses,
- increase the productivity of U.S. manufacturing,

- increase U.S. exports of high-technology energy-supply and energy-end-use products and know-how,

- reduce over-dependence on oil imports here and in other countries,

- diversify the domestic fuel-supply and electricity-supply portfolios to build resilience against the shocks and surprises that an uncertain future is likely to deliver,

- reduce the emissions that produce urban smogs and acid precipitation,

- increase the safety and proliferation resistance of nuclear energy operations around the world,

- slow the build-up of heat-trapping gases in the global atmosphere, and

- enhance the prospects for environmentally sustainable and politically stabilizing economic development in the many of the world's potential trouble spots.

The direct and indirect effects of the pursuit of improved energy technologies for these purposes through appropriately sized, tailored, and publicized R&D programs, moreover, will strengthen this country's science and technology base, bolster our research universities, build effective industry-government-university partnerships, help to stem the decline in enrollments of our most talented young people in science and engineering disciplines, and contribute to maintaining the global leadership and influence of the United States in relation to the shape of scientific and technological developments worldwide and their application to the betterment of the human condition.

Among all of these good reasons for adequately funded, suitably focused, effectively managed energy R&D, one is particularly demanding in what it requires of the R&D effort: the need to expand the array of energy technologies available for responding cost-effectively to the risk of global climatic change from heat-trapping ("greenhouse") gases, most importantly carbon dioxide from fossil-fuel combustion.

Many of the characteristics of this risk and of society's potential responses to it are subject to considerable uncertainty and controversy. These aspects include the pace at which climatic change may become more obvious as greenhouse-gas concentrations grow, the magnitude and geographic distribution of the ecological and human consequences of such change, and the impacts on the U.S. and world economies of various measures that might be undertaken to constrain carbon-dioxide emissions.

If greenhouse-gas-induced climate change were to develop along the path deemed most likely in the latest assessment by the Intergovernmental Panel on Climate Change (IPCC), there would be a significant chance that changes in patterns of temperature, humidity, rainfall, soil moisture, and ocean circulation, plus increases in sea-level, would be adversely impacting human well-being over substantial areas of the planet by some time in the twenty-first century. The IPCC assessment also indicates that slowing the build-up of carbon dioxide in the atmosphere will be very difficult to achieve, because of the upward pressure of population growth and economic aspirations on energy demand, the large energy contribution and long turnover time of the fossil-fuel technologies that are the primary source of CO_2 emissions, and the long residence time of this gas in the atmosphere.

Of course, the work of the IPCC to date will not be the last word on the issue of greenhouse-gas-induced climate change. Some members of the research community think the IPCC's projections of future climate change and its consequences are too pessimistic. Others think they are too optimistic. And some contend that adaptation to climate change would be less difficult and less costly than trying to prevent the change, while others argue that a strategy combining prevention and adaptation is likely to be both cheaper and safer than one relying on adaptation alone. Within our own Panel there are significant differences of view on some of these questions.

Notwithstanding these differences, however, we are in complete agreement about the implications of the climate-change issue for energy R&D strategy:

- First, there is a significant possibility that governments will decide, in light of the perceived risks of greenhouse-gas-induced climate change and the perceived benefits of a mixed prevention/adaptation strategy, that emissions of greenhouse gases from energy systems should be reduced substantially and soon. Prudence therefore requires having in place an adequate energy R&D effort designed to expand the array of technological options available for accomplishing this at the lowest possible economic, environmental, and social cost;

- Second, because of the large role of fossil-fuel technologies in the current U.S. and world energy systems, the technical difficulty and cost of modifying them to reduce carbon dioxide emissions, their long turnover times, their economic attractiveness compared to most of the currently available alternatives, and the long times typically required to develop new alternatives to the point of commercialization, the possibility of a mandate to significantly constrain greenhouse-gas emissions is the most demanding of all of the looming energy challenges in what it requires of national and international energy R&D efforts.

- Third (and this finally is the *good* news about the greenhouse-gas issue), many of the energy-technology improvements that would be attractive for this purpose also could contribute importantly to addressing some of the other energy-related challenges that lie ahead, including reducing dependence on imported oil, diversifying the U.S. domestic fuel- and electricity-supply systems, expanding U.S. exports of energy-supply and energy-end-use technologies and know-how, reducing air and water pollution from fossil-fuel technologies, reducing safety and security risks of nuclear energy systems around the world, fostering sustainable and stabilizing economic development, and strengthening U.S. leadership in science and technology.

Energy R&D Spending in Decline

Society's capacity to respond effectively to the challenges just described will be determined in large measure by the *output* of its energy R&D efforts (as well as to the success of measures undertaken to ensure that the output is effectively deployed); and the output of R&D efforts will be substantially affected (with variations depending on the efficiency with which the R&D is managed and conducted) by the *input*, that is, to R&D spending.

Nonetheless, while the challenges looming in the energy futures of the United States and the world have been growing in recent years — or at least growing more apparent — expenditures on R&D have been declining. In the United States, this has been the case in both the public and the private sectors, although the decline in funding from the public sector has been considerably steeper than the decline in funding from industry. Government funding for energy R&D has also been falling in most other industrialized countries, with the conspicuous exception of Japan. (We were not able to compile plausible estimates of trends in private-sector R&D funding in other countries.)

By far the largest part of U.S. Federal funding for energy R&D (about 90 percent) comes from the United States Department of Energy (DOE). Its FY1997 budget for applied energy-technology R&D was $1.28 billion, compared to $2.18 billion five years earlier, in FY1992, and $6.15 billion twenty years earlier, in FY1978 (all figures in constant 1997 dollars).

If one includes the DOE's funding for "Basic Energy Sciences" (BES), the energy R&D decline was from $6.55 billion in FY1978 to $3.04 billion in FY1992 to $1.92 billion in FY1997. Thus the decrease in the past five years was between 37 and 42 percent, depending on whether BES is included in the totals, and the decrease between 1978 and 1997 was between 3.4- and 4.8-fold. As a fraction of real GDP, the DOE's 1997 spending for energy-technology was less than half that of DOE's predecessor agencies 30 years earlier, in 1967, at the height of pre-oil-shock American complacency about energy supply and energy prices.

Although data for energy R&D in the U.S. private sector are less comprehensive than those for government spending, the most recent systematic study of energy-industry R&D trends found that the industry's spending for R&D fell 40 percent in real terms between 1985 and 1994, from $4.4 billion to $2.6 billion. The R&D spending of the 112 largest U.S. operating electric utilities fell 38 percent between 1993 and 1996 alone, and the R&D of the four U.S. oil firms with the largest research efforts approximately halved between 1990 and 1996.

There is evidence that Federal and private investments in R&D in general (that is, not for energy alone) tend to rise and fall together, rather than one's rising in compensation when the other goes down. State-government funding of energy R&D in the United States, which was probably under $200 million in 1995, may follow electric-utility funding downward.

In the G-7 countries other than the United States and Japan, public-sector energy R&D has fallen sharply, decreasing between 1984 and 1994 by more than 4-fold in both Germany and Italy, by about 6-fold in the United Kingdom, and by 2-fold in Canada. Public spending on energy R&D in France, for which 1984 figures were not available, was declining slowly between 1990 and 1995. Japan, however, increased its public-sector energy R&D spending from about $1.5 billion in 1974 to $4.2 billion in 1980; by 1995 the figure was $4.9 billion, about twice as high as the DOE's energy R&D spending (BES included) in that year.

Explanations and Implications of the Declines in Public and Private R&D

Many explanations for the overall downward trends in energy R&D in recent years suggest themselves. One important factor is surely low energy prices. World oil prices fell sharply after 1980, and in the 1990s they have been about where they were in the 1920s and in the 1950s (in inflation-corrected dollars); and natural gas prices in the United States are so low that no other means of electricity generation can compete with gas-fired combined-cycle power plants where gas is available. This situation discourages investment in development of new energy technologies. The very large demonstration projects in fossil, nuclear, and renewable energy that accounted for much of the post-oil-shock increase in U.S. Federal energy R&D spending came to be regarded as costly anachronisms after prices fell again, and their cancellation was, for the most part, appropriate.

In addition, public-sector spending on energy R&D has experienced downward pressure from overall budgetary stringency in government and from public and policy-maker complacency attributable to low prices, no gasoline lines, and high confidence in the capacity of the U.S. and allied military forces to preserve access to Middle East oil. The U.S. DOE has experienced particular budget-inhibiting scrutiny by critics of "big government", and its energy R&D spending has been further constrained from within by pressure from larger parts of the Department's budget (notably environmental clean-up and nuclear-weapons programs).

In the competitive environment of declining government spending on energy R&D, moreover, advocates of each energy option have tended to disparage the prospects of the other options, in hopes of gaining a greater share of the budget for their favorite. Thus the energy community itself has formulated the arguments that budget-cutters have used to downsize energy R&D programs one at a time ("renewables are too costly", "fossil fuels are too dirty", "nuclear fission is too risky", "fusion will never work", "conservation means sacrifice"), with no coherent energy-community voice calling for a responsible portfolio approach to energy R&D that seeks to address and ameliorate the shortcomings of all of the options.

The private sector, meanwhile, has been experiencing a paradigm shift driven by the increasing globalization of the economy, the revolution in information technology, the increasing power of shareholders and financial markets over corporate decisions, and deregulation and restructuring in important parts of the energy business. All this has combined with low energy prices and the inherently low profit margins of commodity-based businesses to cause energy companies to place more emphasis on the short-term bottom line, to decrease risk-taking on broad-based or long-range R&D projects, and to outsource such R&D as they believe they need to specialized R&D contractors (which may represent a part of private-sector energy R&D that is *not* shrinking).

It is also possible, finally, that energy R&D in the private sector or the public sector or both has been becoming more efficient, in which case declining inputs (funding) need not mean correspondingly declining outputs (innovations that can be successfully marketed or that otherwise improve the human condition). We hope that this is so, although it is difficult to verify (partly because there are often significant time lags between the conduct of research and its effects on the actual flow of innovations, so that if outputs remained high while inputs fell this might be a temporary condition).

In any case, that the overall declines in both public-sector and private-sector funding for R&D are largely explainable, and that some of what has disappeared was not needed or effective, does not establish whether what remains is adequate in relation to current and future needs.

In the private sector, energy R&D has been an important engine of progress, enabling firms to improve their products and invent new ones so as to increase their shares of existing markets, establish and penetrate new ones, and maintain or increase performance while reducing costs. Perhaps these benefits will flow in adequate measure from the new paradigm, but it is also possible that important parts of an industrial R&D system that has served our society extremely well for many decades are now being sacrificed for short-term gain. Concerns have been expressed that the trend toward decentralization of industrial R&D, for example, could erode the interconnectedness among people and among different bodies of knowledge that contributes much to technological innovation in the long term.

Public-sector R&D funding has the responsibility for addressing needs and opportunities where the potential benefits to society warrant a greater investment than the incentives to the private sector can bring forth. Such needs and opportunities relate to public goods (such as the national-security benefits of limiting dependence on foreign oil), externalities (such as unpenalized and unregulated environmental impacts), and situations where lack of appropriability of the research results, or the structure of the market, or the size of the risk, or scale of the investment, or length of the time horizon before potential gains can be realized dilute incentives for firms to conduct R&D from which society would greatly benefit.

Needs for public-sector R&D can increase over time if the public-goods and externality challenges grow or if conditions change in ways that shrink the incentives of firms to conduct some kinds of R&D that promise high returns to society. We have said enough already to suggest that both things might recently have been happening. But the real test of whether the current portfolio of public energy R&D is adequate comes from asking whether the R&D programs in the portfolio are addressing, effectively and efficiently, all of the needs and opportunities where the prospects of substantial societal benefits are good and the incentives for the private sector to make the R&D investments are inadequate. Our Panel has analyzed the energy R&D portfolio of the DOE in these terms.

ELABORATION OF FINDINGS AND RECOMMENDATIONS

We turn now to what we found, first in relation to the content of the portfolio's major energy-technology compartments — end-use efficiency, fossil-fuel technologies, nuclear technologies (fission and fusion), and renewable-energy technologies — and then in relation to the cross-cutting issues relating to evaluation and management of the portfolio as a whole, commercialization considerations, and international dimensions.

End-Use-Efficiency Technology

Between 1975 and 1986, the United States increased its energy efficiency by almost a third. This extraordinary achievement helped pull the country out of its two oil shocks and their attendant stagflation. Efficiency improvements now save U.S. consumers some $170 billion per year. And U.S. emissions of air pollution and CO_2 were reduced by a third or more from their expected values.

Challenges and Opportunities

Those achievements are instructive as we look at future energy, economic, and environmental issues. Technological advances and investments in energy efficiency helped rescue the U.S. economy once, and gave the country decades of breathing room to deal with the energy problem. Many of them were made possible by research at the Department of Energy. Can we achieve a similar improvement in the years ahead?

The Panel believes we can. We find that investments in energy efficiency are generally the most cost-effective way to simultaneously reduce the risks of climate change, oil import interruption, local air pollution and improve the productivity of the economy. We have reviewed technologies that can reduce energy use in automobiles by half or more; in motors and drive systems by half; and in buildings by over 70 percent. Many of these technologies are in their infancy, and require a serious R&D effort to make them commercially viable: others are near market readiness, but need standards and incentives to ensure they spread rapidly.

Budget, Goals, and Initiatives

The Panel recommends that the R&D components of the energy efficiency budget at the Department of Energy grow steadily over the next five years, from $373 million to $755 million (constant 1997$). The Panel has identified the following goals for each of the sectors. Some of these were existing goals and some are new ones proposed here.

Buildings. To fund and carry-out research on equipment, materials, electronic and other related technologies and work in partnership with industry, universities, and state and local governments to enable by 2010: (1) the constructing of one million zero-net-energy buildings; and (2) the construction of all new buildings with an average 25-percent increase in energy efficiency as compared to a new building in 1996. Additional longer term research in advanced energy systems and components will enable all new construction to average 70 percent reductions and all renovations to average 50 percent reductions in greenhouse gas emissions by 2030.

Industry. By 2005, develop with industry a more than 40-percent efficient microturbine (40 to 300 kW), and introduce a 50-percent efficient microturbine by 2010. By 2005, develop with industry and commercially introduce advanced combustion systems to reduce emissions of nitrogen oxides by 30 to 50 percent while increasing efficiency 5 to 10 percent. By 2010, achieve a more than one-fourth improvement in energy intensity of the major energy- consuming industries (forest products, steel, aluminum, metal casting, chemicals, petroluem refining, and glass) and by 2020 a 20 percent improvement in energy efficiency and emissions of the next generation of these industries.

Transportation. By 2004, develop with industry an 80-mile-per-gallon production prototype passenger car (existing goal). By 2005, introduce a 10-mpg heavy truck (Classes 7 and 8) with ultra low emissions and the ability to use different fuels (existing goal); and achieve 13 mpg by 2010. By 2010, have a production prototype of a 100-mpg passenger car with zero equivalent emissions (PNGV II Goal). By 2010, achieve at least a tripling in the fuel economy of Class 1-2 trucks (goal analogous to PNGV for light trucks); and double the fuel economy of Class 3-6 trucks.

The R&D areas requiring increased funding to meet these goals have been identified. The Department has a sufficiently rich agenda, management expertise, history of success, and most important, potential for future contribution, to justify these increases.

Further Findings and Recommendations

The buildings program needs high profile leadership from within the Administration, closer links with industry, and better mechanisms to distribute its research results. These elements could be brought together in the "Buildings for the 21st Century Initiative." The codes and standards program needs to be expanded to give greater technical assistance to states and to speed internal progress.

The industries program is effective. It should be expanded to include more industries, and the crosscutting research—which develops technologies for use in many industries—should grow significantly.

Transportation research, most notably the Partnership for a New Generation of Vehicles (PNGV) is extremely valuable. The PNGV program is insufficiently funded, and cannot meet all its goals at current levels. It should be complemented by a "PNGV II" to augment efforts on long-term technologies, such as fuel cells, with extraordinary potential after 2005. PNGV also needs to give greater attention to air-quality issues, to ensure that technologies selected do not undermine national and state clean air programs. The Administration must also develop new transportation policies that, over time, shift the auto fleet toward higher efficiency. And advanced vehicle development programs should be coordinated with alternative fuels programs to ensure they are complementary for transportation systems of the future.

R&D in the Department of Transportation should be reorganized around clear public interest goals, and Transportation's energy and environmental pursuits should be consonant with DOE's goals. DOT should pursue more multi-modal research and system optimization and should increase its focus on transit systems and transit efficiency. The Automated Highway System research needs to be thoroughly evaluated, key technical assumptions must be documented and peer-reviewed, and then the program should be reorganized around the public interest goals mentioned above.

Increasing energy efficiency has an extraordinary payoff. It simultaneously saves billions of dollars; reduces oil imports and trade deficits; cuts local and regional air pollution; and cuts emissions of carbon dioxide. DOE research, complemented by sound policy, can help the country increase energy efficiency by a third or more in the next 15 to 20 years.

Fossil-Energy Technology

Fossil fuels supply 85 percent of U.S. energy and 75 percent globally. They will continue to be essential to the energy economies of the United States and the world well into the 21st century. R&D on fossil-fuel technologies is warranted to minimize the costs, impacts, and risks of this continuing reliance on fossil fuels and to exploit the opportunities it represents for U.S. industry and the U.S. economy.

Challenges and Opportunities

The DOE Fossil Energy R&D programs are directed — appropriately in the Panel's judgment — at two important challenges: (1) reducing the environmental impacts (including CO_2 emissions) that constrain fossil-fuel use; and (2) reducing the vulnerability of the economy to oil price shocks (caused by excessive dependence on imported oil and potential instabilities in the Middle East) by helping ensure the availability of secure and affordable transportation fuels. In the process, the Department aims to maintain U.S. science and technology leadership in fossil-fuel related fields.

Over the past two decades, enormous progress has been made at reducing the environmental impacts of fossil-fuel use — and particularly of coal use in electric power production — in cost-effective ways. This progress has partly been the result of DOE and industry collaborative R&D and the Clean Coal Technology Demonstration Program. DOE seeks to maintain this progress through pursuit of an idea it calls Vision 21, with the objective of economical coal and gas power and fuels technology with zero-to-small CO2 emissions and very low emissions of other air pollutants. This is a most ambitious goal, requiring significant breakthroughs to achieve very high efficiencies of conversion to electricity (and fuels) and cost-effective methods for separating and sequestering CO2.

In the United States, natural gas has become the fuel of choice for new electric generation because of its low cost, small environmental impacts, relatively small scale (yielding versatile siting and quick installation), rapidly advancing turbine technology, and the competitive pressures of coming deregulation. This trend to natural gas is likely to continue for several decades and contributes positively to the DOE's environmental objective, particularly by reducing CO_2 emissions to the extent that gas replaces coal.

As a consequence, the major markets for advanced coal power and fuels technologies will not be in the United States but in coal-intensive developing countries such as China and India where gas is not widely available for these purposes. Providing attractive coal technologies that are much more efficient with greatly reduced CO_2 and other emissions contributes to the DOE environmental objective. For the United States to take advantage of this environmental opportunity, it must maintain technological leadership in coal-power technologies and develop a strong international program including collaborative R&D, development, and commercialization activities. This will require a paradigm shift away from the current U.S.-centric focus and toward coal-intensive developing countries.

Relative to the challenge of ensuring secure and affordable transportation fuels, DOE R&D is developing and demonstrating technologies that can enhance domestic oil and gas production, diversify supply, and reduce the cost of converting natural gas (and coal, biomass and waste) to clean fuels for transportation. Activities to enhance production include technology transfer to independent oil and gas producers to help bolster production from mature resources and high risk R&D investments at the front end of the resource cycle for frontier provinces. The potential return to the government from taxes and royalties alone justifies the investment, not to mention reducing balance of payment imbalance and losses to the economy in event of a future oil price shock. It is good insurance both from the point of view of oil dependence and for the climate change issue because of the importance of natural gas as a transition fuel during the next century.

Budget, Goals, and Initiatives

The Panel's analysis of these challenges and opportunities leads it to recommend that the that the Fossil Energy budget remain at about the current level in constant dollars but with a significant reorientation and new initiatives aimed at Vision 21, gas as a transition fuel, and a comprehensive transportation fuel R&D strategy.

Coal and Gas Power and Fuels. The Panel endorses Vision 21 as the long-term objective and recommends reorientation of the DOE R&D priorities toward it. This should include continued emphasis to improve efficiency of the combined cycle using high temperature fuel cells, development of advanced gasification technologies (for coal, biomass, or waste) for the flexible production of power and clean transportation liquid fuels (ultimately hydrogen and separated CO_2). It should also include initiating a science-based CO_2 sequestration program in cooperation with the US Geological Survey, industry, and universities, with an annual budget rising to $20 million dollars or more in 2003. Hydrogen may prove to be the transportation fuel of the future if fuel cells become the power source of choice for vehicles, and fossil fuels are the likely least expensive route to hydrogen assuming sequestration is practical.

Phase-Outs. As part of this reorientation, the Panel recommends that the Department terminate: (1) direct liquefaction of coal, because it doesn't fit Vision 21; (2) the solid fuels and feedstocks program, directing the funding instead toward a comprehensive, science-based program to reduce hazardous air emissions from existing and future coal power plants; and (3) the Low Emissions Boiler System program. It should phase out near-term clean-coal programs that do not contribute to Vision 21 or to providing much better low-CO_2-emissions technology choices for developing countries.

Oil and Gas Production and Processing. Because of its importance as a transition fuel for the United States in controlling CO_2 emissions, the Panel recommends more intense effort on natural gas production and processing, including a major initiative for DOE to work with USGS, the Naval Research Lab, Mineral Management Services, and the industry to evaluate the production potential of methane hydrates in US coastal waters and world wide. The resource is very large indeed, in the range of 100,000 to 1,000,000 Tcf (trillion cubic feet). This research might well interface with the effort on CO_2 sequestration through the use of CO_2 hydrates as the sequestered state of the gas.

Transportation Fuels Strategy. The Panel recommends that DOE develop a comprehensive transportation fuels strategy, beginning with an analysis of the potential for technologies to increase the price elasticity of oil supply and demand including the impact of substitutes. This effort should include, for example, R&D focused on reducing the cost of producing transportation fuels from natural gas complements and work on indirect liquefaction of coal and biomass. Such an effort is supportive of Vision 21 and may improve its flexibility for combined fuel and power generation, including eventually producing hydrogen for central or distributed use with CO2 sequestering.

Nuclear-Energy Technology

Nuclear energy can be generated by fission (the splitting of a nucleus) or by fusion (the joining of two nuclei). Neither fission nor fusion reactions generate greenhouse gases or the air pollutants that produce urban smogs and regional acid precipitation. Fission power currently provides about 17 percent of the world's electric power, with 442 nuclear power reactors operating in 30 countries and 36 more plants under construction. Fusion power requires much additional work in the quest to make the fusion reaction self-sustaining and to design and build practical fusion power plants; the most optimistic timetable for fusion to reach commercialization is another half century. But the potential benefits of fusion are so large that fusion R&D is an important component of current energy R&D portfolios in the United States and internationally.

Challenges and Opportunities: Fission

Several problems compromise fission's potential as an expandable today and into the future: disposal of spent nuclear fuel; concerns about nuclear weapons proliferation; concerns about the safe operation of plants; and uncompetitive economics. But given the projected growth in global energy demand as developing nations industrialize, and given the desirability of stabilizing and reducing GHG emissions, it is important to establish fission energy as a widely viable and expandable option if this is at all possible. A properly focused R&D effort to address the problems of nuclear-fission power — economics, safety, waste, proliferation — is therefore appropriate. World leadership in nuclear-energy technologies and the underlying science is also vital to the United States from the perspective of national security, international influence, and global stability.

Although the United States has the largest number of operating reactors of any country in the world, the outlook is that no new nuclear plant will be built in the next 10 to 20 years. The decline of nuclear power in the United States has resulted from many factors: a sharp drop in annual electricity consumption growth rates, low gas prices and improved efficiency of gas-fired combined cycle plants, rapid escalation of nuclear plant construction costs, the unsolved problem of waste disposal, and concerns about proliferation and safety. These factors, combined with the upcoming deregulation of the electric utilities, may lead to early shutdown of operating nuclear plants in the United States.

Budget, Goals, and Initiatives: Fission

Based on its analysis of the potential and problems of fission power, the PCAST Energy R&D Panel recommends that nuclear fission R&D be increased from $42 million in FY1997 to $119 million in FY2003 (as-spent dollars). The Panel makes the following further observations and recommendations about the fission R&D effort:

<u>Operating Reactors</u>. Extending the operation of nuclear plants will make it easier to meet GHG emission goals. The panel recommends that DOE work with its laboratories and the utility industry to develop a program to address the problems that may prevent continued operation of current plants. We recommend such a program be funded at $10 million per year, to be matched by industry.

<u>Nuclear Energy Research Initiative</u>. DOE should establish a new program — the Nuclear Energy Research Initiative — funded initially at $50 million per year and increasing by FY 2003 to $100 million per year (as-spent dollars), which would competitively select among proposals by researchers from universities, national laboratories, and industry to

address key issues affecting the future of fission energy including: proliferation-resistant reactors or fuel cycles; new reactor designs with higher efficiency, lower-cost, and improved safety to compete in the global market; lower-output reactors for use in settings where large reactors are not attractive; and new techniques for on-site and surface storage and for permanent disposal of nuclear waste. This approach is in contrast to the traditional style of directed research by the DOE Nuclear Energy program (in which the program office defines the topics, milestones, and scope) and follows instead a model along the lines of the Environmental Management Science Program (EMSP). The panel notes that the EMSP program has attracted many researchers who had not been part of the DOE effort and who have produced new, creative ideas for the clean-up of the weapons sites.

Coordination: DOE should improve coordination and integration among the eight DOE program offices sponsoring R&D applicable to fission energy.

Challenges and Opportunities: Fusion

The objective of the DOE-ER fusion energy sciences program is to develop the scientific and technological basis for fusion as a long-term energy option for the United States and the world. The fusion R&D program is strongly centered in basic research and supports the important field of plasma science. Results and techniques from fusion plasma science have had fundamental and pervasive impact in many other scientific fields, and they have made substantial contributions to industry and manufacturing. Since 1970, fusion power in experiments has increased from less than 0.1 watt to more than 10 megawatts.

The nation's fusion energy research program has received three major reviews since 1990, the most comprehensive being the 1995 study by the PCAST Panel on the U.S. Program of Fusion Energy Research and Development.(PCAST-95). PCAST-95 recommended an annual budget of $320 million. In FY1996, Congress reduced the fusion budget by about one-third and directed DOE to restructure its fusion energy program. The present funding level of $230 million is too low in the view of the PCAST Energy R&D panel; it allows no significant U.S. activity relating to participation in an international program to develop practical low-activation materials; reduces the level of funding for the design of the International Thermonuclear Experimental Reactor (ITER); forced an early shutdown for the largest U.S. fusion experiment; and canceled the next major U.S. plasma science and fusion experiment. It also limited the resources available to explore alternative fusion concepts.

Budgets, Goals, and Initiatives: Fusion

Based on its analysis of the potential of fusion power and the challenges and opportunities in this field, as just described, the PCAST Energy R&D Panel recommends that fusion R&D funding be increased from its annual level of $232 million in the FY 1997 appropriation to reach $320 million per year by FY2002 (as-spent dollars). This would restore fusion R&D funding to the level which the 1995 PCAST study of fusion-energy R&D recommended be maintained from FY 1996 onward.

Our Panel reaffirms support also for the specific elements of the 1995 PCAST recommendation that the program's budget-constrained strategy be around three key principles: (1) a strong domestic core program in plasma science and fusion technology; (2) a collaboratively funded international fusion experiment focused on the key next-step scientific issue of ignition and moderately sustained burn; and (3) participation in an international program to develop practical low-activation materials for fusion energy systems. The Panel makes the following further observations about the fusion R&D effort:

Pre-ITER Collaborations. The U.S. program should establish significant collaborations with both the JET program in Europe and the JT-60 program in Japan. Such collaboration should provide pre-ITER experience in experiments that are prototypes for a burning plasma machine, such as ITER, and that can explore driven burning plasma discharges

ITER. The Panel judges that the proposed 3-year transition between completion of the EDA and an international decision to construct is reasonable and that the ITER effort merits continued U.S. involvement. It would be helpful to all parties in the ITER enterprise if at least one of the parties would express, within the next year or two, its intention to offer a specific site for ITER construction by the end of the 3-year period. Clearly, one major hurdle to ITER construction is its total project cost, most recently estimated to be $11.4 billion, with the host party expected to fund a substantial share. If the parties agree to move forward to construction, the U.S. should be prepared to determine, with stakeholder input, what the level and nature of its involvement should be. The PCAST Energy R&D Panel believes that if no party offers to host ITER in the next three years, it will nonetheless be vital to continue without delay the international pursuit of fusion energy. A more modestly scaled and priced device aimed at a mutually agreed upon set of scientific objectives focused on the key next-step issue of burning plasma physics may make it easier for all parties to come to agreement.

Renewable-Energy Technology

Renewable energy technologies (RETs) can provide electricity, fuels for transport, heat and light for buildings, and power and process heat for industry. These technologies generally have little or no emissions of greenhouse gases (GHGs), air pollutants, or other environmental impacts. RETs can also offset imports of foreign oil and offer important economic benefits; for example growing biomass energy crops on excess agricultural lands would increase farm income while potentially allowing a reduction in Federal farm income support programs.

Challenges and Opportunities

RETs have made remarkable progress over the past two decades. Costs of energy from RETs such as wind turbines and photovoltaics (PVs) have come down by as much as 10 times. Much further progress is expected, to the extent that RETs could become major contributors to U.S. and global energy needs over the next several decades. The Shell International Petroleum Company, for example, projects that by 2025 renewable energy sources could contribute to global energy one-half to two-thirds as much as fossil fuels do at present, with new renewable sources (excluding hydropower and traditional biomass) accounting for one-third to one-half of total renewables.

Much of the global market growth for RETs, as well as for total energy, will take place in developing countries. The small scales and modularity of most RETs are well matched to energy technology needs in developing countries. Also, the inherent cleanliness of most RETS will have a special appeal, making it possible to reduce environmental problems without resorting to complex regulatory controls as is done for conventional energy systems.

Budget, Goals, and Initiatives

In light of the remarkable progress already made in many areas of the DOE Renewable Energy program, the good prospects for further gains, and the substantial potential impacts renewables could have in addressing the multiple challenges posed by energy system in the United States and worldwide, the PCAST Energy R&D Panel believes that the Renewable Energy R&D Program should be substantially expanded, from annual spending of $270 million in FY1997 to a level of about $650 million in 2003 (as-spent dollars), with goals that include the following:

Wind. Reduce by 2005 wind electricity costs to half of today's costs, so that wind power can be widely competitive with fossil-fuel-based electricity in a restructured electric industry, through R&D on a variety of advanced wind turbine concepts and manufacturing technologies.

Photovoltaics (PV): Pursue R&D that would lead to PV systems prices falling from the present price of $6,000/kW to $3,000/kW in 5 years, to $1500/kW by 2010, and to $1,000/kW by 2020. R&D activities should include assisting industry in developing manufacturing technologies, giving greater attention to balance of system issues, and expanding fundamental research on advanced materials.

Solar Thermal Electric Systems. Strengthen ongoing R&D for parabolic dish and heliostat/central receiver technology with high temperature thermal storage, and develop high temperature receivers combined with gas-turbine based power cycles; goals should be to make solar-only power (including baseload solar power) widely competitive with fossil fuel power by 2015.

Biopower. Commercialize in ten years advanced energy-efficient power-generating technologies that employ gas turbines and fuel cells integrated with biomass gasifiers, building on past and ongoing R&D for coal in such configurations, and exploiting the advantages of biomass over coal as a feedstock for gasification. These technologies could be widely competitive in many developing country markets and in U.S. markets that use biomass residues or use energy crops in systems that derive coproducts from biomass.

Geothermal Energy. Continue work on hydrothermal systems, and reactivate R&D on advanced concepts, giving top priority to high-grade hot dry-rock geothermal; this technology offers the long-term potential, with advanced drilling and reservoir exploitation technology, of providing heat and baseload electricity in most areas..

Biofuels. Accelerate core R&D on advanced enzymatic hydrolysis technology for making ethanol from cellulosic feedstocks, with the goal that between 2010 and 2015 ethanol produced from energy crops would be fully competitive with gasoline as a neat fuel, in either internal combustion engine or fuel cell vehicles; coordinate this development with the biopower program so as to co-optimize the production of ethanol from the carbohydrate fractions of the biomass and electricity from the lignin using advanced biopower technology.

Hydrogen. Carry out R&D on hydrogen using and producing technologies; coordinate hydrogen-using technology development with proton-exchange-membrane fuel-cell vehicle development activities in the Department's Energy Efficiency program. Give priority in hydrogen-production R&D to co-optimizing the production of hydrogen from fossil fuels and sequestration of the CO_2 separated out during the production process, in collaboration with the Fossil Energy program.

Crosscutting and other programs. Crosscutting programs that should be strongly supported include Resource Assessment, International Programs, and Analysis. In addition, R&D is needed on hydropower, energy storage, electric sytems, and systems integration.

Further Findings and Recommendations

The Panel believes that there are good prospects that these goals can be realized with the combination of an expanded R&D effort and appropriate demonstration and commercialization initiatives. The DOE program has demonstrated remarkable gains in technology performance and cost reductions and has laid the foundation for large further gains. The R&D effort should be intense over the course of the next decade, with much more emphasis than at present in the DOE program on both core applied research and development and fundamental research directed to serving needs identified in the programs.

For technologies that continue to show promise, R&D budgets should be sustained at the elevated levels for several years (the number varying with the technology) until the technologies become established in the market, the industry has sufficient revenues from these RET markets to shoulder a greater share of needed continuing R&D, and government's role can be reduced to supporting mainly long-term R&D. For both wind power and biopower most of the principal R&D goals could be met in a decade or less; for these technologies Federal R&D budget support could thereafter begin to decline. For other technologies it will take longer, but in nearly all cases principal program goals should be achievable in less than 20 years.

Cross-Cutting Issues

In what follows we elaborate briefly our findings and recommendations relating to four sets of issues that cut-across the applied energy-technology R&D programs discussed above: the relation of the DOE's Basic Energy Sciences program to applied energy-technology R&D, analysis of the portfolio as a whole and the leverage it offers against the energy challenges faced by the nation and the world; considerations related to commercialization of the fruits of R&D; and certain international aspects of R&D.

Links Between Applied Energy Technology R&D and Basic Energy Sciences

The Panel's review of DOE energy R&D activities identified many areas where technological advance could be accelerated if more attention were given to fundamental questions identified in these programs. Examples include better understanding of reactions at the interface of electrodes and electrolytes in fuel cells, the capacity of carbon nanostructures for hydrogen storage, the chemistry and fluid dynamics of CO_2 storage in saline aquifers, the physics of thin-film photovoltaic materials, and many others. The Panel found that linkages between the Basic Energy Sciences (BES) programs (where such issues are investigated) and the applied energy-technology programs (where the findings could be put to use) need to be strengthened in many cases.. While the technology programs do benefit today from the growing body of fundamental knowledge being generated under BES programs, they would benefit much more if BES were to address specific questions identified as important in these programs. The Panel recommends that BES allocate additional resources to support fundamental research activities addressing needs of the technology programs.

Our recommendation that BES direct some of its resources to serving these needs might raise concerns that the creativity of basic science will be lost if it is constrained by premature thought of practical use, and that applied research invariably drives out pure, if the two are mixed. What is being sought here, however, is not to redirect BES resources to applied research. The technology programs support applied research but give little attention to addressing fundamental questions such as the above. The net effect of this recommendation should be to expand, not diminish, the portfolio of fundamental research activities within the limits of overall budget constraints. In light of the growing interest among policy planners in harnessing science for the technological race in the global economy, the allocation of some BES resources to the development of fundamental research programs that would serve the energy technology programs should add to the political appeal of supporting basic research generally.

Portfolio Analysis and Leverage

Developing the appropriate degree of diversity and balance in the Department's overall energy R&D portfolio is difficult. Technologies have many different attributes — cost (of the R&D to develop them and of the technologies themselves, once they are developed), performance, risk, return, potential contributions over time to energy and environmental goals, and others. How can one fairly evaluate the many R&D alternatives and select an R&D portfolio that best meets our national goals and needs? No single quantitative measure can encompass the range of relevant attributes. One technology may have substantial environmental benefits, a second may contribute more to national security, a third may have only modest benefits but have low risks and costs to develop.

The Panel has worked hard at exploiting and refining various ways to portray the diverse characteristics of different energy options in a way that facilitates comparisons and the development of appropriate portfolio balance in light of the challenges facing energy R&D and in light of the nature of private-sector and international efforts and the interaction of U.S. government R&D with them. We have made some progress, but a much larger and continuing effort in this direction by the Department of Energy itself is called for. (In saying this we echo one of the strongest recommendations of the 1995 Secretary of Energy Advisory Board report on Strategic Energy R&D — a recommendation that alas has so far borne little fruit.) Such analyses should be done on a regular basis as national needs and R&D options and opportunities change. We recommend that DOE regularly and systematically conduct — with external peer review — a portfolio analysis across the breadth of R&D options and to use this as an input to overall program planning.

The potential overall impact of the sector-by-sector energy R&D portfolio developed by the Panel can be illustrated by some simple "back-of-the-envelope" analyses. Examples for oil imports and carbon emissions are schematically shown in figures ES-1 and ES-2; details of these highly simplified projections are provided in Chapter 7. For clarity, only a few, highly aggregated sets of technologies are shown.

Consider oil imports. Under "business-as-usual conditions, U.S. oil imports could increase from 8.5 million barrels per day at a cost of $64 billion dollars in 1996 to nearly 16 million barrels per day at a cost of $120 billion (assuming $20 dollars per barrel) in 2030. With continued R&D to increase domestic production from marginal oil supplies, an aggressive ethanol program (based on cellulosic biomass, not corn), and rapid development and penetration of the market by PNGV and light- and heavy-duty truck technologies, we estimate that this import could be reduced to something on the order of 6 million barrels per day oil import demand in 2030, as illustrated in figure ES-1. Estimates of this sort are necessarily highly approximate, since they depend not only on the somewhat unpredictable pace of R&D successes but also future market conditions and measures taken to speed market penetration under whatever those conditions are; nonetheless, such "ballpark" estimates give at least a rough indication of the magnitude of the challenge the nation faces and and size of the opportunity to address it with the stronger R&D program outlined here.

Potential impact on carbon dioxide emissions (customarily measured in tons of carbon contained in the emitted CO_2) is clearly also a crucial element of a portfolio's leverage against the energy-related challenges of the next century. Figure ES-2 illustrates, in a highly stylized and schematic way, how the factors most germane to an analysis of leverage against CO_2 emissions can be portrayed in a single diagram: the length of time until a new technology is ready to begin penetrating the market, the cost of the R&D effort needed to get to that point, and the rate at which the technology could penetrate the market (reflected in the diagram as the rate of increase in avoided CO_2 emissions) after that time. (With some modification such a diagram could also show the effect, on the potential for emissions avoidance, of the different sizes of the various energy-supply or end-use markets being penetrated.)

The Panel has not been able, in the time available for this study, to complete the sorts of analyses that would be necessary to specify the relevant market-entry points, associated research investments, and plausible penetration rates — and the uncertainty ranges associated with all of these — with any confidence. Figure ES-2 is based on very approximate understandings of needed research investments and market-entry points developed in the course of our study, and on crude guesses about penetration rates (which were uniform across the technologies shown, in the absence of the sort of analysis that would be required to do this in a differentiated way). What can be said in favor of this very rough and preliminary depiction of potential leverage is that (a) it illustrates what we believe the DOE should be doing in the way of portfolio analysis, with a much larger analytical effort behind it than they or we have mustered until now, and (b) the timing and magnitudes of the conceivably achievable avoided carbon emissions shown in the diagram are roughly consistent with what other major recent studies of the potential of new technologies for this purpose have found.

Our Figure ES-2 shows only technologies that would not begin penetrating markets until after 2010. They offer large emissions-avoidance potential, but only well into the next century. (Of course, the point of increasing R&D investments in appropriately targeted areas is to move forward the date at which such technologies can begin penetrating their markets.) Options that could have an impact by 2010 are not shown here but have been separately examined by DOE in a recently released report; these earlier-impacting options necessarily depend largely on R&D that has already been done.

Commercialization Considerations

To achieve the sorts of impacts illustrated schematically in Figures ES-1 and ES-2 would require more than R&D in many cases.. New technologies face the chicken-and-egg problem of generally having high costs, and thus being limited to low market volumes, but needing large market volumes to drive costs down. Making this transition is difficult given the low costs of energy today and given that the public benefits of new energy technologies — notably environmental quality and national security — are generally not valued in the market. Industry-led, public-private collaborations in demonstration and commercialization of new energy technologies can be an appropriate way to address this difficulty in ways that ensure that R&D programs are appropriately targeted and market relevant and that the benefits of the public investment in R&D are realized in market penetration rates commensurate with the sum of the private and public benefits of such penetration.

After consideration of the market circumstances and public benefits associated with the energy-technology options for which we have recommended increased R&D, the Panel recommends that the nation adopt a commercialization strategy in specific areas complementing its public investments in R&D. This strategy should be designed to reduce the prices of the targetted technologies to competitive levels, and it should be limited in cost and duration. The Panel does not make a recommendation as to the source of funds for such an initiative. We do believe, however, that such a commercialization effort should be designed to be very efficient in allocating funds to drive prices down, minimally disruptive of energy/financial systems, and temporary.

International Aspects

Markets for many new energy supply technologies will be very limited in the United States for the next decade or two due to slow growth in demand and the availability of low cost natural gas; most of the growth in world energy production and use and in carbon emissions will take place in developing countries. For the United States to maintain scientific, technological, and market leadership in these critical energy technologies, it will be essential for public R&D and development and commercialization programs to broaden their scope to directly address international energy issues, including both collaborative R&D and market competition. This can provide us as well as our partners substantial economic and environmental benefits.

The Panel recommends that the government and government/national-laboratory/industry/university consortia should engage strongly in international energy technology R&D and development and commercialization efforts to regain and/or maintain the scientific, technical, and market leadership of the United States in energy technology. This should include increased R&D — particularly in collaboration with developing countries, temporary support for D&C activities where appropriate — and responses to foreign export promotion activities where necessary.

DOE Management of Its Energy R&D Programs

The necessity of linking fundamental research with applied R&D and with development and commercialization, the increasing complexity of R&D efforts, globalization of R&D and technology markets, heightened global market competition, and other evolving factors in the energy field have several important implications for energy R&D management. The complexity and technical demands of R&D require increased industry/national lab/university peer review and technical oversight and direction of R&D programs. Linkages require improved coordination.

Better communications can enable reduced administrative procedures and management overheads, and can improve coordination by pushing these responsibilities down to the operational level. Efficient use of resources requires careful establishment of R&D targets and timelines, and ongoing measurement of progress. Although DOE has been making some efforts in these areas and some programs are beginning to establish effective models that can be applied more broadly, in general these factors need to be better addressed in DOE energy R&D management.

To address these issues, and above all to increase the efficiency with which public dollars invested in energy R&D yield the results that the national interest requires, the Panel offers the following recommendations:

1. The President should clearly communicate to the public the importance of energy and energy R&D to the nation's future, and should clearly designate the Secretary of Energy as the national leader and coordinator for developing and carrying out the national energy strategy.

2. Overall responsibility for the DOE energy R&D portfolio should be assigned to a single person reporting directly to the Secretary of Energy; similarly, a single individual should be given the responsibility and authority for coordination of cross-cutting programs between the applied-technology programs, reporting to the single person responsible for the overall R&D portfolio.

3. Industry/national-laboratory/university technical oversight committees should work with DOE to provide overall direction to energy R&D programs, with DOE facilitating and administering the process;

4. Coordination between the Energy Research program and the applied energy technology programs should be improved using mechanisms such as co-management and co-funding with — or budget sign-off by or re-routing budgets through — the applied technology programs.

5. All R&D programs should undergo outside technical peer review every 1-2 years, but interim internal process-oriented reviews should be reduced to a minimum.

6. DOE Staff technical skills should be strengthened by training, targeted hiring, and by systematically rotating external technical (and managerial) staff through DOE as senior professionals with significant responsibilities for all aspects of program management.

7. Lead laboratories should be named and laboratories should be treated by DOE as integrated entities, not as collections of projects independently controlled from DOE headquarters.

8. Industry/laboratory/university partnerships should conduct the energy R&D that is funded by the DOE, in most cases.

9. The national laboratories should be encouraged to perform work for clients other than the DOE, inside and outside the government, as appropriate, and processes for doing this should be streamlined.

10. DOE staff procedures for energy technology programs should be reviewed in detail, and staff levels adjusted accordingly.

Conclusion

[Ringing few-paragraph conclusion about the challenges, the opportunities, and the utter reasonableness of what we are recommending will be supplied at the PCAST breakfast if not Sunday evening at the Hay Adams.]

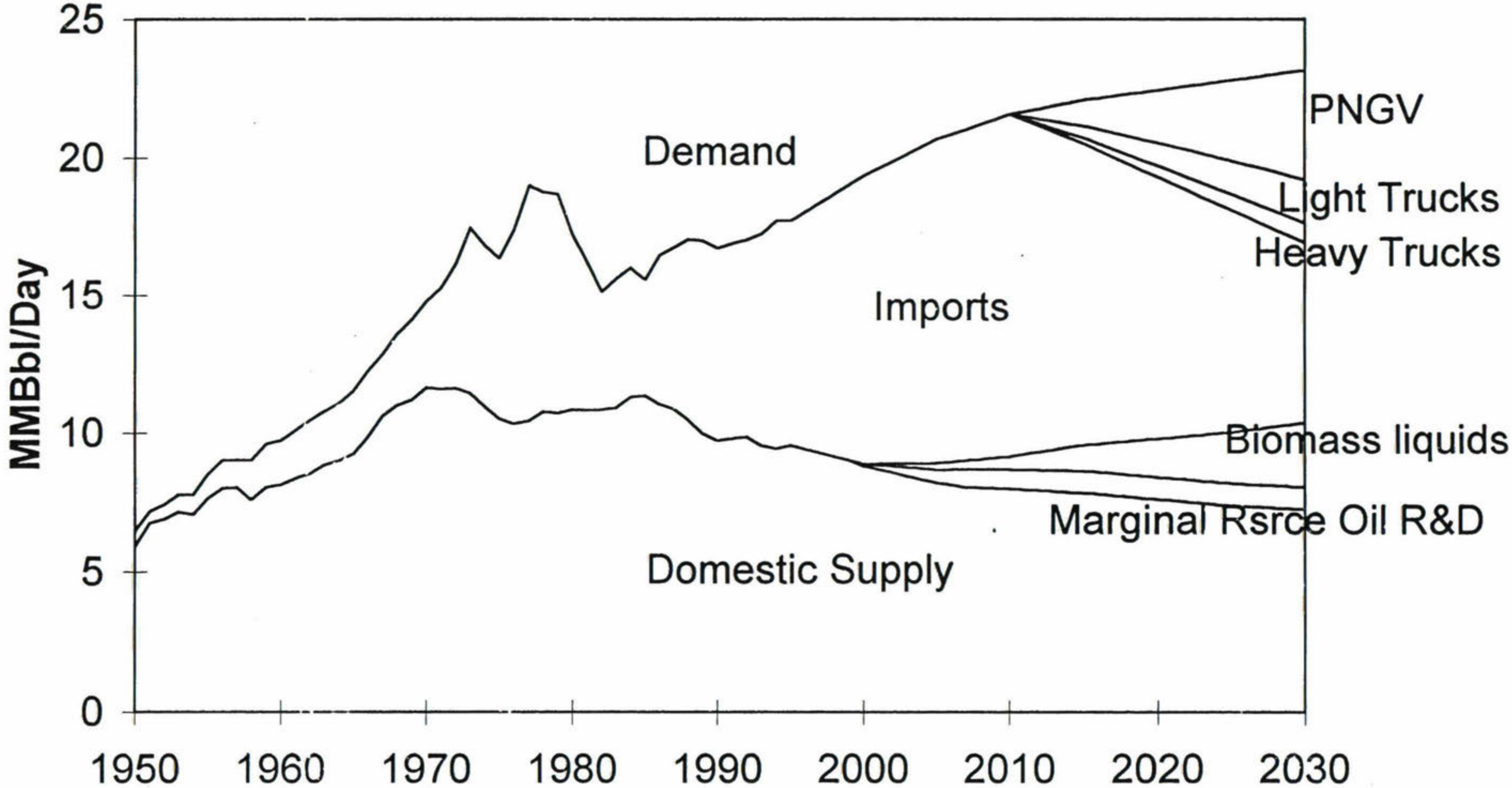
TABLE ES-3. **Recommended DOE Applied Energy-Technology (ET) R&D Initiatives and Budget Authority** (in millions of as spent dollars)

PROGRAM*	R&D Activities, Initiatives, and Budget Changes	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03
Efficiency: Buildings	Building System Design and Operation: advanced sensors; smart controls; automated diagnostics; whole building optimization and design tools;	24	33	38	48	60	72	84
	Building Equipment and Materials: advanced materials; advanced energy-efficient: HVAC, lighting, windows, appliances, office equipment, etc.; insulation initiative	27	37	57	72	85	98	111
	Codes and Standards: for efficient appliances and buildings; technical assistance	12	21	25	25	25	25	25
	Crosscutting Activities: technology roadmapping, and partnership development with industry following the model of the DOE Industries of the Future program.	--	--	20	25	30	35	35
	Other: management and planning, and other activities	19	20	20	20	20	20	20
	Subtotal	81	111	160	190	220	250	275
Efficiency: Industry	Industries of the Future: advanced technologies for energy intensive industries—aluminum, cement, chemicals, forest products, glass, metalcasting, refining, steel, agriculture, and emerging energy-intensive industries following technology roadmaps.	46	56	65	75	85	95	110
	Crosscutting Activities: advanced micro-turbines (40-200 kW), sensors, motor drive systems, materials; work with renewable programs on biomass IGCC	38	38	70	80	90	95	100
	Technology Access: innovation grants; industrial assessments, "Climate Wise", motors	25	37	40	40	45	45	50
	Other: management and planning, and other activities	7	8	10	10	10	10	10
	Subtotal	116	139	185	205	230	245	270
Efficiency: Transport	PNGV: better emissions controls for light diesels; hybrid vehicles; system integration	105	129	100	100	100	100	75
	PNGV II: fuel cells, microturbines, advanced energy storage, system integration	--	--	75	85	100	100	125
	Advanced Heavy Vehicles: efficient diesels, diesel pollution reduction, hybrids	20	18	30	40	50	55	60
	Advanced Materials: high temperature/high strength materials to reduce weight 25%	33	31	35	40	40	40	45
	Technology Deployment: clean cities program, alternative fuel vehicles, and other	11	17	20	20	20	20	20
	Other: management and planning, and other activities	7	9	10	10	10	10	10
	Subtotal	176	204	270	295	320	325	335
Fossil Energy	Coal Power: end LEBS, phase out near-term clean coal activities, accelerate R&D on advanced power systems.	86	84	79	90	87	88	82
	Coal Fuels: end direct liquefaction, and solid fuels and feedstocks R&D; develop science-based hazardous air emissions program	16	16	9	12	15	16	16
	Gas Power: strengthen solid oxide fuel cell R&D and other advanced research.	97	78	92	92	83	74	70
	Oil and Gas Production and Processing: maintain oil programs for marginal resources; strengthen gas production and processing R&D; increase advanced research	70	77	86	94	107	110	113
	Carbon Sequestration: Strengthen science-based carbon sequestration program	1	2	10	11	17	23	22
	Methane Hydrates: develop science-based program with industry, Federal Agencies, and Navy to understand potential of methane hydrates worldwide	0	0	5	5	11	11	12
	Hydrogen Manufacture/Infrastructure: R&D on hydrogen production from fossil fuels	0	0	1	2	6	6	7
	Technology/Oil Price Elasticities: analysis of technology to reduce cost of oil shocks	0	0	1	1	1	1	0
	Developing Country Technologies: collaborative R&D with other countries	0	0	1	2	6	6	6
	Other: management and planning; environmental restoration; cooperative R&D, etc.	95	89	95	97	100	102	105
	Subtotal	365	346	379	406	433	437	433

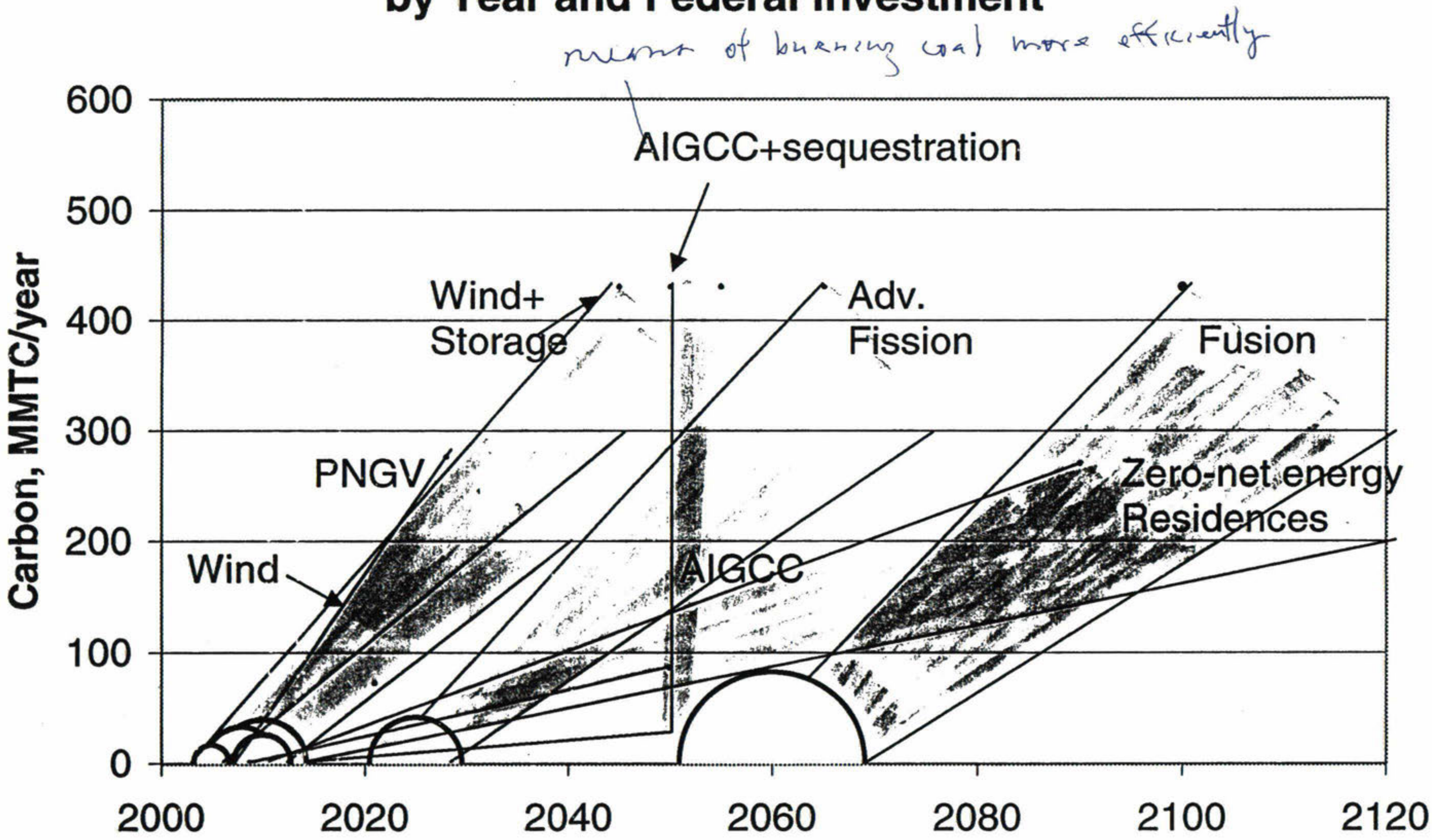
Nuclear Fission	Operating Reactors: R&D to address problems that may prevent continued operation of existing reactors.	4	25	10	10	10	10	10
	Nuclear Energy Research Initiative: to competitively select among proposals by researchers from universities, national laboratories, and industry to address issues including: proliferation-resistant reactors or fuel cycles, new reactor designs with higher efficiency, lower cost, and improved safety; low power reactors; new techniques for on-site and surface storage and for permanent disposal of nuclear waste	0	0	50	70	85	100	103
	Education: university research reactors and other supports	4	6	6	6	6	6	6
	Other: ALWR and Reactor Concepts	34	15	0	0	0	0	0
	Subtotal	42	46	66	86	101	116	119
Nuclear Fusion	Plasma Science: research on fundamental plasma science; develop fusion science and technology, and plasma confinement innovations; and pursue fusion energy science and technology as a partner in international efforts.							
	Subtotal	232	219	237	250	262	281	281
Renewable Energy	Biomass Fuels: strengthen feedstock development; advance enzymatic hydrolysis and other conversion technologies in integrated power and fuel systems	28	38	58	76	94	97	99
	Biomass Power: develop biomass materials handling equipment; integrated gasification combined cycles; biogasification-fuel cell systems; small gasification-engine systems	28	38	63	86	89	91	93
	Geothermal: strengthen hydrothermal research; reactivate R&D on advanced resources; expand advanced drilling R&D; increase R&D on reservoir testing and modeling	30	30	42	49	50	51	52
	Hydrogen: move away from near-term demonstrations and launch initiative with DOE Fossil Energy on innovative hydrogen production from fossil fuels with sequestration	15	15	16	16	17	17	17
	Hydropower: develop "fish-friendly" turbines and low-head run-of-river turbines; analyze coupling of hydropower to intermittent renewables	1	1	4	8	11	11	12
	Photovoltaics: accelerate basic PV science, laboratory scaleup to first time manufacturing, and support engineering science for large-volume, low-cost prodctn,	60	77	105	130	133	137	140
	Solar Thermal: strengthen power tower and dish-stirling, esp. optical materials and solar manufacturing initiative; launch init. advanced high temperature receivers .	22	20	32	43	44	46	47
	Wind: accelerate R&D on lightweight adaptive systems, direct-drive variable speed generators, hybrid systems, system integration—including with storage; wind technology manufacturing initiative; fundamental work on materials,	29	43	53	65	66	68	70
	Systems and Storage: energy storage, esp.. for system integration with intermittents	32	46	51	54	55	57	58
	Solar Buildings: R&D in efficient and passive whole building design and design tools; building integrated PVs and thermal systems; initiative on low cost solar water heaters	3	4	6	9	9	9	9
	International: applications-specific systems integration and development, and field studies; collaborative R&D and training; technical assistance; technical/policy analysis	1	7	11	13	13	14	14
	Resource Assessment: integrated assessments across all resources; further development of geographic information systems; collaborative R&D with developing nations	0	0	5	5	6	6	6
	Analysis: systematic analyses of technologies, system integration, markets, and policies	0	0	4	5	6	6	6
	Other: management and planning; renewable energy production incentive, other.	21	26	25	26	27	26	29
	Subtotal	270	345	475	585	620	636	652
SUBTOTAL		1282	1416	1785	2037	2214	2329	2412

*Activities should be done through various partnerships between industry, national laboratories, universities, and federal/state agencies, as appropriate.

The Oil Gap


25
20
15
10
5
0
MMBbl/Day
1950
1960
1970
1980
1990
2000
2010
2020
2030
Demand
Imports
Domestic Supply
PNGV
Light Trucks
Heavy Trucks
Biomass liquids
Marginal Rsrce Oil R&D

Ultimate Carbon Savings Potential for the U.S. by Year and Federal Investment



9/28/97

J. Holdren

(which doesn't affect demand much (as larger one would) but would yield)

(1) $2 carbon tax $3b which could be used to invest in carbon displacing R&D & get

(2) No one at DOE manages the whole energy portfolio

(3) All rationale actors will rely on & build combined cycle natural gas power plants - 3¢/kwh unless the carbon externality is factored in

R&D alone can't overcome this

(4) payoff in carbon reduc'n based on Fed'l R&D - not down

(5) new R&D won't affect 2010 much - only R&D in pipeline likely to affect that

(6) If no increased price or Regs. add'l R&D spending by 2010 won't get you much in emissions reductions R&D will help a lot longer term such as 2040 or to some degree 2020

JH answer to oil price shock pts out that carbon intensity not just energy intensity is at 133 mi, so we have 2 levers

Thinks $25-50 / carbon tax for 1990 by 2010