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PROPOSALS ON ENERGY RESEARCH AND DEVELOPMENT

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

TO

RECEIVE TESTIMONY REGARDING DRAFT LEGISLATIVE PROPOSALS ON ENERGY RESEARCH AND DEVELOPMENT

MARCH 5, 2009

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PROPOSALS ON ENERGY RESEARCH AND DEVELOPMENT

THURSDAY, MARCH 5, 2009

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 9:38 a.m. in room SH–216, Hart Senate Office Building, Hon. Jeff Bingaman, chairman, presiding.

OPENING STATEMENT OF HON. JEFF BINGAMAN, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Why don't we go ahead and get started. I know Senator Murkowski is on her way. There she is right there.

Let me thank everyone for coming. This is an oversight hearing to review future directions of energy research and development to identify key scientific and technological hurdles that need to be overcome in order to pursue some of these new directions. We particularly thank Secretary Chu for being here to testify at this hearing on research and development within the Department of Energy. Of course the second panel as well.

The purpose of the hearing, as I stated is to find out what is happening with regard to research and development. Also to get comments to the extent that witnesses have comments on the draft legislation that the Committee has posted on its website. This is legislation that the staff has developed to address some of these issues.

Last year I was fortunate to travel to both Japan and Korea to understand some of the initiatives being pursued there to advance energy research and development programs. In Japan we were given a copy of this cool Earth 50 program that we've given copies of to, at least the front page of the brochure that was provided to us, where they are trying to coordinate their energy industries to produce technologies that will enable Japan to reduce its greenhouse emissions by at least 50 percent by the year 2050. Obviously an additional benefit of this program as they see it would be the payback of being a leader in world markets in energy technologies that have minimal carbon emissions associated with them.

I hope we can benefit from learning from what others, including Japan are doing in this regard. Let me again thank the witnesses, and call on Senator Murkowski for any statement she has before hearing from Secretary Chu.

[The prepared statement of Senator Udall follows:]

PREPARED STATEMENT OF HON. MARK UDALL, U.S. SENATOR FROM COLORADO

Mr. Chairman, thank you for holding today's hearing on energy research and development (R&D).

Energy R&D is the future of our energy industry, but is also critical to our national security, our environment, and our economy. This work will help us address climate change, lessen our dependence on foreign oil, and help make energy m ore affordable and efficient.

These R&D issues are important for our nation, but also for Colorado. Colorado is home to some of the nation's top universities and several federal laboratories. This includes the National Renewable Energy Laboratory (NREL), our nation's premiere renewable energy R&D facility.

NREL has lead the way on research into making wind power safer and more efficient, lowering the cost of solar energy production, and advancing hydrogen energy production from renewable sources, as well as storage of hydrogen energy.

This is not a mew subject to me. During my ten years in the House, I was a member of the Science and Technology Committee, which oversaw several of DOE's science offices, including the Office of Science and Office of Energy Efficiency and Renewable Energy. I helped fight for funding for these offices and encouraged them to succeed.

for example, the 2007 energy bill included a provision that I pushed in the U.S. House of Representatives to expand and improve the Department of Energy's carbon capture and storage (CCS) research and demonstration program. CCS will be critical to helping us continue to use our vast domestic sources of coal while also working to address rising greenhouse gas emissions.

I should add that the development side of R&D is critically important, though sometimes lost in our efforts to find the next big discovery. Development is the first step towards commercializing a product and getting new technology int the hands of Americans, both in our homes and businesses. I believe development includes creating a workforce capable of managing these technologies.

There is much more we can do to move this effort forward.

Recently, NREL joined with our state's research universities—University of Colorado, Colorado State University, and Colorado School of Mines—to form the Colorado Renewable Energy Collaboratory. This partnership has already combined the best from universities and the national labs to work with the state government and private businesses on furthering research, development, and commercialization on new renewable energy technology.

I believe Colorado's Collaboratory provides a example of the partnerships we need to encourage to move our energy economy forward.

I am looking forward to hearing from today's witnesses about the future of energy R&D and what we in Congress can do to help advance that work.

STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator MURKOWSKI. Thank you, Mr. Chairman, and I appreciate the hearing this morning. I also want to welcome you, Dr. Chu, Secretary Chu.

This is the first time you've been before us since the confirmation hearing. I've had a couple opportunities to discuss issues with you, and I appreciate your openness and your being here this morning.

I've got lots of questions over a variety of issues including questions about the Administration's view on the renewable electrical standard. If we have some time I'd like to get into those. But very hopeful that this Committee will have the opportunity perhaps at another hearing with Administrative witnesses to talk about those issues and perhaps some others.

The legislative proposal that we're considering today, not only reauthorizes the research and development components of the Energy Policy Act of 1905. But it doubles the authorization funding from 2009 to 2013, hopefully countering the drop in government funding for energy research and development efforts that we've seen since the 1970s. This increase in my mind anyway, is a necessary one.

All of our goals to become a more energy efficient nation and to be less dependent on unstable, foreign sources of energy rely on advances in technology advances in the know how. If we're going to be the leader in energy technology investment, in R and D, is a must. The two are certainly not mutually exclusive.

On another front as we get into the details of energy efficiency, alternative fuels and other specifics of energy policy, it can be easy to overlook the people power that are needed to make this work. It's an issue that we recognize that we can't neglect. Half of electric utility workers and oil and gas workers are eligible and likely to retire in the next 2 to 5 years. The subsurface geotechnical work force faces a similar challenge. Our challenge then is to figure out how we attract, how we retain new workers in those fields.

The legislative proposal we're looking at seeks to support programs that provide this training from secondary schools and trade schools on up to graduate programs. So what we're trying to do is figure out how we grow the work force. We know that the workers are going to be needed. The jobs certainly in this economy are needed. So hopefully with the support of this proposal we'll be able to bring the two together to meet our future energy work force needs.

I've expressed my support for reauthorization of the R and D programs and expansion of the work force development pieces. I have been looking at the proposal. I've got some level of concern about the Grand Challenges Research Initiative.

Not because I don't support the idea or the concept. But because of the funding mechanism that is to be used. So I just throw that out there as a concern for discussion. But I think the proposal that we have before us is a very good starting point, not yet a final product but I look forward to hearing from the witnesses from our second panel on their perspectives, ways to improve the product.

Again, Secretary Chu, welcome to the committee.

The CHAIRMAN. Secretary Chu, go right ahead. We're glad to have you testify today. Please give us any thoughts you have.

STATEMENT OF HON. STEVEN CHU, SECRETARY, DEPARTMENT OF ENERGY

Secretary CHU. Chairman Bingaman, Ranking Member Murkowski and members of the Committee, thank you for the opportunity to appear before you today. During his address to the joint session of Congress last week, President Obama reiterated his commitment to reducing our dependence on oil and sharply cutting greenhouse gas emissions. I'm looking forward to working with others in the Administration, this Committee and the Congress to meet the President's goal of legislation that places a market based cap on carbon pollution and drives the production of more renewable energy in America.

Such legislation will provide the framework for transforming our energy system, making our economy less carbon intensive and America less dependent on foreign oil. In the near term President Obama and this Congress have already taken a key step in passing the American Recovery and Reinvestment Act of 2009. This legislation will put Americans back to work while laying the groundwork for a clean energy economy.

I'd like to highlight a few of the energy investments in that law.

First, the Recovery Act will put people to work making our homes and offices more energy efficient. It includes $5 billion to weatherize the homes of low income families. A $1,500 tax credit to help homeowners invest in efficiency upgrades. $4.5 billion to green Federal buildings including reducing their energy consumption and $6.3 billion to implement state and local efficiency and renewable programs.

The Recovery Act also includes $6 billion for loan guarantees and more than $13 billion in tax credits to finance assistance instruments that may leverage tens of billions in the private sector investment in clean energy and job creation. This will help clean energy businesses and projects get off the ground in these difficult economic times. The investments in key industries such as $2 billion in advanced battery manufacturing and the $4.5 billion to jump start our efforts to modernize the electrical grid.

Getting this money into the economy quickly, carefully and transparently is the top priority for me. I know that your constituent States, cities and businesses are eager to move forward and are seeking more information on how to access this funding. I've met with many of them already and we will have much more detailed information in the coming weeks.

With that, I would like to turn to a topic that's near and dear to my heart. How can we better nurture and harness science to solve our energy and climate change problems? I strongly believe that the key to our prosperity in the 21st century will lie in our ability to nurture our intellectual capital in science and technology.

Our previous investments in science led to the birth of the semiconductor, computer and biotechnology industries that add greatly to our economic prosperity. Now we need similar breakthroughs on energy. We're already taking steps in the right direction, but we need to do more.

First we need to increase funding. It's part of the President's plan to double Federal investments in the basic sciences. The 2010 budget provides substantially increased support for the Office of Science, building on the $1.6 billion provided in the Recovery Act for the Department of Energy's basic science programs.

We also need to refocus our scarce research dollars. In April a more detailed FY 2010 budget will be transmitted to Congress. This budget will improve science research development and deployment at the DOE by developing science and engineering talent, by focusing on transformational research, by pursuing broader, more effective collaborations and by improving connections between DOE research and the private sector energy companies.

Several years ago I had the honor and privilege of working on "Rising Above the Gathering Storm", a report commissioned by Chairman Bingaman and Senator Alexander. One of the key recommendations was to step up efforts to educate the next generation of scientists and engineers. The FY 2010 budget supports graduate fellowship programs that will train students in energy related fields. I will also seek to build on DOE's existing research strengths by attracting and retaining the most talented scientists.

The next area that I want to discuss is the need to support research on transformational technology. What do I mean by transformational technology? I mean technology that's game changing as opposed to being incremental.

For example, in the 1920s and 1930s when AT & T Bell Laboratories was focused on extending the life of vacuum tubes, another much smaller research program was started to investigate a completely new device. This device was based on revolutionary advances in the understanding of the quantum world, quantum mechanics. The result of this transformational research was the transistor which transformed communications, allowed the commuter industry to blossom and changed the world forever.

DOE must strive to be the modern version of the old Bell Labs in energy research. Because of the payoffs in transformational research are both higher risk and longer term, government investment is critical and appropriate. As this committee knows we have funded three bioenergy research centers. One at Oak Ridge National Laboratory, one led by the University of Wisconsin in close collaboration with Michigan State University and one led by the Lawrence Berkeley National Lab. Each of these centers is targeting breakthroughs in biofuel technology development that will be needed to make abundant, affordable, low carbon biofuels a reality.

We need to do more transformational research at the DOE to bring a range of clean energy technologies to the point where the private sector can pick them up.

This includes gasoline and diesel like biofuels generated from lumber and crop waste and non food crops.

Automobile batteries with two or three times the energy density that can survive 15 years of deep discharges.

Photovoltaic solar power that is five times cheaper than today's technology.

Computer design tools for commercial and residential buildings that will enable reductions in energy consumption of up to 80 percent with investments that will pay for themselves in less than 10 years.

Large scale energy storage systems so that variable, renewable energy resources such as wind and solar power can become base load power generators.

This is not a definitive list or a hard set of technology goals. But it gives a sense of the types of technologies and bench marks I think we should be aiming for.

DOE also needs to foster better research collaborations both internally and externally. My goal is to build research networks within the Department, across the Government, throughout the Nation and around the globe. We will better integrate national, lab, university and industry research. We will seek partnerships with other nations. For example, increased international cooperation on carbon capture and storage technology could reduce both the cost and time of developing the range of pre and post combustion approaches that will be needed for cost effective carbon capture and sequestration.

While we work on transformational technologies the DOE must improve its efforts to help deploy demonstrated, clean, technologies at scale. The Loan Guarantee Program will be critical in these efforts by helping to commercialize technologies. The Recovery Act funding for weatherization and energy efficiency block grant programs will accelerate the deployment of energy efficient technologies.

I'm excited about the prospect of improving DOE's clean energy research development and deployment efforts. I thank you and would be glad to answer your questions at this time.

[The prepared statement of Secretary Chu follows:]

PREPARED STATEMENT OF HON. STEVEN CHU, SECRETARY, DEPARTMENT OF ENERGY

Chairman Bingaman, Ranking Member Murkowski and Members of the Committee, thank you for the opportunity to appear before you today to continue the conversation we began at my confirmation hearing.

During that hearing, I touched on the enormous challenges and threats we face—to our economy, our security, and our climate. In the 20th century, America's economic engine was powered by relatively inexpensive domestic fossil fuels. Today, we import roughly 60 percent of our oil, draining resources from our economy and leaving it vulnerable to volatility in oil prices. Additionally, the potentially adverse effects of global greenhouse gas emissions and their cost to the world economy were not widely realized until the end of the past century but are well-established today.

If we, our children, and our grandchildren are to prosper in the 21st century, we must decrease our dependence on oil, use energy in the most efficient ways possible, and decrease our carbon emissions. Meeting these challenges will require both a sustained commitment for the long-term and swift action in the near-term.

During his address to the Joint Session of Congress last week, President Obama reiterated his commitment to reducing our dependence on oil and sharply cutting greenhouse gas emissions. I look forward to working with others in the Administration, this Committee, and the Congress to meet the President's goal of legislation that places a market-based cap on carbon pollution and drives the production of more renewable energy in America. Such legislation will provide the framework for transforming our energy system to make our economy less carbon-intensive, and less dependent on foreign oil.

In the near term, President Obama and this Congress have already taken a key step by passing the American Recovery and Reinvestment Act of 2009. This legislation will put Americans back to work while laying the groundwork for a clean energy economy.

AMERICAN RECOVERY AND REINVESTMENT ACT

I would like to highlight a few of the energy investments in that law.

First, the Recovery Act will put people to work making our homes and offices more energy efficient. It includes $5 billion to weatherize the homes of low-income families; a $1,500 tax credit to help homeowners invest in efficiency upgrades; $4.5 billion to "green" federal buildings, including reducing their energy consumption; and $6.3 billion to implement state and local efficiency and renewable programs.

The Recovery Act also includes $6 billion for loan guarantees and more than $13 billion in tax credits and financial assistance instruments (grants and cooperative agreements) that may leverage tens of billions in private sector investment in clean energy and job creation. This will help clean energy businesses and projects to get off the ground, even in these difficult economic times. The bill also makes investments in key technologies, such as $2 billion in advanced battery manufacturing, and $4.5 billion to jumpstart our efforts to modernize the electric grid.

Getting this money into the economy quickly, carefully, and transparently is a top priority for me. I know that your constituent States, cities, and businesses are eager to move forward, and are seeking more information about how to access this funding. I have met with many of them already, and we will have much more detail in the coming weeks.

I know the Title XVII loan guarantee program is of great interest and concern to this committee. We are already in the process of making improvements to this important program that I believe will satisfy many of these concerns.

RESHAPING ENERGY RESEARCH, DEVELOPMENT, AND DEPLOYMENT

With that, I would like to turn to a topic that is near and dear to my heart: how we can better nurture and harness science to solve our energy and climate change problems. I have spent most of my career in research labs—as a student, as a researcher, and as a faculty member. I took the challenge of being Secretary of Energy in part for the chance to ensure that the Department of Energy Laboratories and our country's universities will generate ideas that will help us address our energy challenges. I also strongly believe that the key to our prosperity in the 21st century lies in our ability to nurture our intellectual capital in science and engineering. Our previous investments in science led to the birth of the semiconductor, computer, and bio-technology industries that have added greatly to our economic prosperity. Now, we need similar breakthroughs on energy.

We're already taking steps in the right direction, but we need to do more.

First, we need to increase funding. Dan Kammen of U.C. Berkeley has conducted studies showing that while overall investment in research and development is roughly three percent of gross domestic product on average, it is roughly one-tenth of that average in the energy sector. As part of the President's plan to double federal investment in the basic sciences, the 2010 Budget provides substantially increased support for the Office of Science, building on the $1.6 billion provided in the Recovery Act for the Department of Energy's basic sciences programs.

We also need to refocus our scarce research dollars. In April, a more detailed FY 2010 budget will be transmitted to Congress. This budget will improve energy research, development, and deployment at DOE: by developing science and engineering talent; by focusing on transformational research; by pursuing broader, more effective collaborations; and by improving connections between DOE research and private sector energy companies.

Developing Science and Engineering Talent: Several years ago, I had the honor and privilege of working on the "Rising Above the Gathering Storm" report commissioned by Chairman Bingaman and Senator Alexander. One of the key recommendations was to step up efforts to educate the next generation of scientists and engineers. The FY 2010 budget supports graduate fellowship programs that will train students in energy-related fields. I will also seek to build on DOE's existing research strengths by attracting and retaining the most talented scientists.

Focusing on Transformational Research. The second area that I want to discuss is the need to support transformational technology research. What do I mean by transformational technology? I mean technology that is game-changing, as opposed to merely incremental. For example, in the 1920's and 1930's, when AT&T Bell Laboratories was focused on extending the life of vacuum tubes, another much smaller research program was started to investigate a completely new device based on a revolutionary new advance in the understanding of the microscopic world: quantum physics. The result of this transformational research was the transistor, which transformed communications, allowed the computer industry to blossom, and changed the world forever.

DOE must strive to be the modern version of the old Bell Labs in energy research. Because the payoffs from research in transformational technologies are both higher risk and longer term, government investment is critical and appropriate.

Here is an example of current DOE transformational research. As this Committee knows, we have funded three BioEnergy Research Centers—one at the Oak Ridge National Laboratory in Oak Ridge, Tennessee; one led by the University of Wisconsin in Madison, Wisconsin, in close collaboration with Michigan State University in East Lansing, Michigan; and one led by the Lawrence Berkeley National Laboratory. Each of these centers is targeting breakthroughs in biofuel technology development that will be needed to make abundant, affordable, low-carbon biofuels a reality. While these efforts are still relatively new, they are already yielding results, such as the bioengineering of yeasts that can produce gasoline-like fuels, and the development of improved ways to generate simple sugars from grasses and waste biomass.

We need to do more transformational research at DOE to bring a range of clean energy technologies to the point where the private sector can pick them up, including:

1. Gasoline and diesel-like biofuels generated from lumber waste, crop wastes, solid waste, and non-food crops;
2. Automobile batteries with two to three times the energy density that can survive 15 years of deep discharges;
3. Photovoltaic solar power that is five times cheaper than today's technology;
4. Computer design tools for commercial and residential buildings that enable reductions in energy consumption of up to 80 percent with investments that will pay for themselves in less than 10 years; and
5. Large scale energy storage systems so that variable renewable energy sources such as wind or solar power can become base-load power generators.

This is not a definitive list, or a hard set of technology goals, but it gives a sense of the types of technologies and benchmarks I think we should be aiming for. We will need transformational research to attain these types of goals. To make it happen, we will need to re-energize our national labs as centers of great science and innovation. At the same time, we need to seek innovation wherever it can be found—the new ARPA–E program will open up research funding to the best minds in the country, wherever they may be. I pledge to you we will have this program up and running as soon as possible.

Broader, More Effective Collaboration.—DOE also needs to foster better research collaboration, both internally and externally. My goal is nothing less than to build research networks within the Department, across the government, throughout the nation, and around the globe. We'll better integrate national lab, university, and industry research. We will seek partnerships with other nations. For example, increased international cooperation on carbon capture and storage technology could reduce both the cost and time of developing the range of pre-and post-combustion technologies needed to meet the climate challenge.

Speeding Demonstration and Deployment.—While we work on transformational technologies, DOE must also improve its efforts to demonstrate next-generation technologies and to help deploy demonstrated clean energy technologies at scale. The loan guarantee program will be critical to these efforts by helping to commercialize technologies, and the Recovery Act funding for weatherization and energy efficiency block grant programs will accelerate the deployment of energy efficient technologies.

CONCLUSION

I am excited about the prospect of improving DOE's clean energy research, development, and deployment efforts. The Nation needs better technologies to fully meet our climate and energy challenges, and DOE can be a major contributor to this effort.

We already have ample technology to make significant, near-term progress toward our energy and climate change goals. The most important of these is energy efficiency, which will allow us to reduce costs and conserve resources while still providing the same energy services. The potential there is huge, as is the potential to increase the use of existing technologies such as wind, solar, and nuclear. We will move forward on all of these fronts and more, as we invest in the transformational research to achieve breakthroughs that could revolutionize our Nation's energy future.

Thank you. I would be glad to answer your questions at this time.

The CHAIRMAN. Thank you very much. Let me start with a couple of questions. I know one of the issues that you have been focused on and that we've also heard a lot about in this committee is the gap between basic research and applied research and development and how that can be bridged and more effectively dealt with.

Sandia Livermore has a combustion research facility that has tried to address this in something of an ad hoc fashion by getting funding from the Office of Science also getting funding from EER and E, the vehicles program there and also working with industry. We've tried to figure out a way through legislation to promote that kind of an effort in other technology areas. That's this Grand Challenges Program that is in the draft bill that we submitted.

I'd be interested in any thoughts you've got as to whether this would be helpful or if there's a better way to do this or is this something that can't be done legislatively and just has to be done administratively? What's your thought about how we bridge this gap between basic and applied R and D?

Secretary CHU. As I've said in the confirmation hearings and in my discussions with you. I think that is a major focus in how we can link the basic research that's done in the Office of Science and in universities around the country. The Office of Science supports both universities and national labs and how we can better link that research with things that actually get out into the marketplace, the more applied research that leads to innovation.

We're completely aligned in terms of using, for example, the bioenergy fuel centers as an example of a very successful program. In the details of the FY2010 budget you will hear about our plans to do that. So I do want to ask for some flexibility in these programs, but the nature of where we're going is very much in line like that.

I think from what I've already seen in the bioenergy institutes that is a very good way of focusing attention and really bringing together a cluster of scientists to work on these problems. I do feel though it's best if it comes from the Department of Energy. But you'll see that we're very, very closely aligned, almost perfectly aligned.

The CHAIRMAN. Ok. Very good. Let me ask about ARPA–E.

I believe you were a part of the National Academy's panel that recommended the establishment of ARPA–E. We authorized that as part of the Competes Act in the last Congress. We funded that at $400 million as part of the Stimulus bill. Could you give us your thoughts as to how/what topics or what objectives you see being pursued through ARPA–E and how that would be managed?

Secretary CHU. The way it's going to be managed is we are in the process of trying to identify a director. That director will be reporting directly to me. There will be a very lean set of contract people under that director.

The philosophy of ARPA–E is that if you look at what either industry or venture capitalists are willing to pick up there is a gap. There are innovative things that have too high a risk for investors to be willing to put in. So just like the old DARPA program invested in things that do have a risk of failure but they also have a higher probability of bringing on those transformational technologies.

So we will be investing in that very short time scale, 2 or 3 years and see what's going to happen. If it doesn't look promising one pulls the plug and moves on. If it looks promising there could be another tranche of money.

But ARPA–E will have a very similar philosophy to what DARPA has been doing. In the end the success of this program really depends on the success of the program managers and the quality of the program managers. The good news is that if it's a very lean organization that has a lot of freedom and authority, I think we can attract those program managers to this program because it's very exciting possibility to be investing that kind of money to actually lead to something truly transformational.

The CHAIRMAN. Ok. Let me ask one other question. We provide in this draft bill that we've had put on the website funding levels for energy research and development authorization levels. It essentially calls for a doubling of that funding over the 4-year period.

Are the levels we're talking about here consistent with what you are going to try to accomplish in the Administration? I mean we've got sort of three things that happen here. The Administration gives us their proposals in the budget. Then we try to, in some cases at least, authorize a certain level. Then we try to appropriate a different level to the extent we can I'd like to try to get those in sync.

Are what we have in this Authorization bill, proposed Authorization bill consistent with what you think the Administration would want to see?

Secretary CHU. I'm not going to—I applaud the authorization levels. Let me be very frank about that. It really depends on what Appropriations will actually appropriate.

But I think I cannot overly impress upon this committee, upon the Nation the critical need to do energy research. The good news is that many of the most talented scientists in the country are realizing our energy problem and all it facets. It's one of the most important things that science and technology has to solve.

Because of that we're beginning to see extraordinarily talented people, mid-career people who are shifting their fields. Say I've got to work on this problem. We're seeing a lot of young people with an idealism, quite frankly, I haven't seen since the 1960s and 1970s. They are saying I've got to work on this problem. They want to enlist. So the increases in funding that are being authorized are the instrument that will allow us to open up recruiting stations and allow them to volunteer for this task.

The CHAIRMAN. Senator Murkowski.

Senator MURKOWSKI. Mr. Chairman, I'm going to defer to Senator Barrasso who has got to get upstairs for a tribal blessing in Indian Affairs.

The CHAIRMAN. Alright. Senator Barrasso.

Senator BARRASSO. Thank you very much, Mr. Chairman. Thank you, Senator Murkowski. Mr. Secretary, thank you for being here with us today.

I have 3 questions. One has to do with small businesses. To me, small businesses are the engine that drives our economy and in these economic times they want to be involved in this. We come from a number of different States, long distances away. I believe that small businesses can also be very involved in the innovation of the technologies where we're working on this.

You had said that you were going to be putting, in terms of the stimulus funding, putting together a release of details for allocating some of that money. Could you give us a little bit of information about what competitive processes may be available so that all of our States are able to be involved in that competitive process, so our small businesses have an opportunity?

Secretary CHU. Sure. I mean, we're planning on being very transparent in requests for proposals and in the feedback of the proposals. But really to get it out there, we will have web-based information that anyone can look up and apply. We are going to be setting up essentially help lines, if you will, frequently answered questions to help people apply for that money.

So we're in the process of changing the way we actually solicit proposals to be much more transparent and much more what I call, customer friendly. So if there are questions, and this is not only is in the grants that we will be giving out in contracts, but also in the Loan Guarantee Program. So we intend to help everybody try to learn what it takes to make these applications.

So I agree with you by the way. Small businesses in many respects are really the engine of true innovation. That, you know, results in some of the out of the left field approaches.

Senator BARRASSO. Right. Let me get next to clean coal technology. The Chairman and others of us met with former Prime Minister Tony Blair the other morning to talk about what's coming online in China in the next 10 years, coal fired power plants equal to two and a half times the amount of coal fired power plants that we have now in the United States.

So as you look forward, as we look forward to your research and development and really the transformational technology that you talk about. In your confirmation hearings you said you wanted to work very hard to extensively develop clean coal technology. You're hopeful and optimistic that we can figure out how to use coal in a clean way.

I believe very much, we need to do that. Do you have some thoughts on how you're going to work toward that goal?

Secretary CHU. Yes. First I'd like to thank Congress for the Economic Recovery Act. We have $3.4 billion in that stimulus package for piloting clean coal technologies another essentially billion dollars for that.

So I've begun to look very seriously at how to best allocate those funds. Once you start building pilot plans, the costs build up. So I've already started engaging discussions with foreign ministers, science ministers, energy ministers abroad and have gotten a good response.

The European Union is thinking of 10 to 12 clean coal demonstration experiments, if you will, or pilot projects. China is thinking of them. What I would like to see, and we're moving in this direction, is to have a truly international alliance that we'd look at all these technologies.

We do not know currently what the best technology is. But we do know that if we don't get this one, the environmental risk is incredible. China, India and the United States will not turn their back on coal. So we've got to get it right.

There's a realization internationally how important that is. What that means is—think of this as a common goal, that all countries around the world can really align themselves with and collaborate. So that means intimate sharing of knowledge.

You know what needs to be done is to invest in this. Get the pilot plants going. Really see what are the lessons that are learned? What can work? As you go down this learning curve and drop the price of this, all countries will benefit.

So it's a completely shared intellectual property. The good news is you don't buy a coal plant like you buy a car or refrigerator. Most of that investment is done locally.

It's like a building. So if we all develop these technologies then each country as they apply this, the benefit of that intellectual property, if you will, will go to servicing that country. The entire effort will be going to helping us conquer this problem.

Senator BARRASSO. Thank you, and Mr. Secretary, just finally there's a Department of Energy facility in Wyoming, the Rocky Mountain Oil Field Testing Center. I was going to alert you of that and maybe supply a question in writing because my time is up.

But thank you, Mr. Chairman. Thank you, Senator Murkowski for allowing me to get in front. Thank you.

The CHAIRMAN. Senator Udall.

Senator UDALL. Thank you, Mr. Chairman. I want to acknowledge the leadership you're providing to hold this important hearing today. Secretary Chu, great to see you again.

I wanted to acknowledge that the last time you appeared before the committee we had a short conversation about the Rocky Flats Environmental Technology Site in my home state and the Federal Government's obligation to address the health impacts and needs of the former workers there at that nuclear weapons complex. I look forward to continuing to work with you on that important challenge. I want to thank you again for your commitment to work with those of us in Colorado and frankly, more broadly in the nuclear weapons complex.

I did also want to note the excitement I felt when you mentioned that people are lining up to enlist in this important work to create a new energy economy. There's a saying that's been making the rounds over the last few years which is, "Green is the new red, white and blue." In other words one of the most patriotic things we can do is to develop this new energy economy. Maybe we'll see you soon on a poster Uncle Sam needs you because this is so important. There's such great opportunity presenting itself to us.

Let me build if I could on Chairman Bingaman's question about the opportunity that applied research presents to us. But also the need for the longer term R and D investment in R and D work in the context of the national labs. It's clear to me that they will play an increasing role.

I wanted to ask you to think out loud with us a bit about how do we ensure that we strike the right balance in the roles and in the funding in this diverse group of national laboratories. Between the science we require for the long term, the applied science and the critical commercialization and deployment of clean energy technology which we know that we need today. Could you speak to that?

Secretary CHU. Sure. I think we really need a balanced portfolio of things. There are a number of technologies we already have today that we should be getting out there, especially on the energy efficiency side. We know a lot about energy efficiency. The Department of Energy will increase its efforts to help grease the wheels to get that stuff deployed.

Then there's near term research and development where it might be on the cusp of getting picked up by the private sector. Those things, again, we will be working very hard. One of the things to remember is that when you go from very basic, out of the box, research to more applied research to development and piloting, each time you go up the chain the price increases sometimes by a factor of 5, sometimes by a factor of 10.

So once you start piloting commercial scale, now you're talking billions of dollars, hundreds of million dollars for smaller pilot plans. So the portfolio that I really believe is important is that on the more basic side, you should be trying really new, innovative, essentially crazy stuff. It doesn't cost much.

But you have to, on the flip side, on the development and deployment side, you have to show that as you approach commercial scale that when you're asking for the private sector to invest billions of dollars they have to have some comfort that they won't lose their shirt. So I think everywhere in between there has to be this balanced approach. Yes, the Department of Energy has to invest in some of these larger pilot scale plants.

So, I feel very committed to this balanced portfolio. It is absolutely essential. One of the weaknesses, previously in the Department of Energy is that there was a gulf between the really great science that the Department of Energy supports and the development and transformation of that science into things that look like they might fly.

So again, with the ARPA–E, we need the integration of the applied science side with the basic side. We're setting up a structure now where undersecretaries will have to share some money. That they don't have total budget control and in order to share a significant amount of that money they have to both agree on it. They have to both say that this is worthy.

This is the only way I see one can really integrate this gulf between the basic science and the applied science. So those structures are being designed today.

Senator UDALL. I also assume that there's even more work in regards to the outreach to the private sector to the VC leaders to the other private capital interest on the part of the DOE. I hear more about it from lab directors. Those who know the private sector will eventually, hopefully soon, lead the way because that's where the great reservoirs of capital lie.

Would you care to comment on that as well?

Secretary CHU. I think, you know, in my history when I was at Stanford I was the Scientific Advisor for one of the venture capital firms and an incubator firm. When I became a lab director, of course, I couldn't do that anymore. But I know a lot of the people in these startup companies.

I have to say that these people work 70, 80 hours a week. They are totally devoted to what they're trying to do. The Department of Energy and the Federal Government should be assisting.

ARPA–E is a mechanism for doing this. A lot of the sections in the more applied areas can be a way of helping them. In certain cases where they might be cash limited we could see about helping them boot up and get there faster so that instead of having 12 people working in a garage they can have 24 people working in a garage.

But I think when I see this total dedication, living, eating, breathing what they want to have happen. That is really money well invested. So I'm a big fan of that.

Senator UDALL. Thank you, Mr. Secretary.

The CHAIRMAN. Senator McCain.

Senator MCCAIN. Thank you, Mr. Chairman. Thank you Doctor for being here. We're all very impressed and appreciative of your credentials and your willingness to serve in this very important position.

Doctor, according to a report by the Department of Energy, Report of Subcommittee, the Basic Energy Science Advisory Committee, it says that as important as solar is that it would still only provide approximately 5 percent of the carbon free energy by the year 2015. Do you agree with that assessment?

Secretary CHU. By 2015.

Senator MCCAIN. Yes. I've only got 5 minutes.

Secretary CHU. I'm a little bit more optimistic than that.

Senator MCCAIN. A little bit more.

Secretary CHU. Yes.

Senator MCCAIN. But it certainly wouldn't be nearly the contribution that some envision, unfortunately. I come from a State where it's very important.

Secretary CHU. The potential, it really depends on the timeline that we're talking about.

Senator MCCAIN. Is it not somewhere around 5 percent? Ten percent? Let's say 15 percent.

Secretary CHU. By 2015.

Senator MCCAIN. Ok.

Secretary CHU. Yes.

Senator MCCAIN. That means that clean coal and nuclear power, it seems to me then, are far more important than maybe some people appreciate today, right?

Secretary CHU. I agree with that in the short term.

Senator MCCAIN. Good. Then did you agree, is it true that the Department of Energy's spokeswoman told Bloomberg that President Obama and you, "have been emphatic that nuclear waste storage at Yucca Mountain is not an option, period."

Secretary CHU. That's true.

Senator MCCAIN. That's a true statement. So now we're going to have spent nuclear fuel sitting around in pools all over America. Also tell the nuclear power industry that we have no way of either reprocessing or storing spent nuclear fuel around America. We expect nuclear power to be an integral part of this nation's energy future.

What's wrong with Yucca Mountain, Dr. Chu.

Secretary CHU. We have learned a lot more in the last 20, 25 years since Yucca Mountain.

Senator MCCAIN. I know that. What is wrong with Yucca Mountain, Dr. Chu.

Secretary CHU. I think we can do a better job.

Senator MCCAIN. Where?

Secretary CHU. But going to your original question about what to do with the spent fuel. The Nuclear Regulatory Agency has said that we can solidify the waste at the current sites and store it without substantial risk to the environment. So while we do that we——

Senator MCCAIN. Has any nuclear power plant made any plans for solidification of the nuclear waste?

Secretary CHU. Yes. They have. There are solidification plans going on today.

Senator MCCAIN. There are plans going on? Also you don't see any—is there any plans for reprocessing of spent nuclear fuel?

Secretary CHU. There is—well, I support reprocessing research. I think it's an important part of the nuclear——

Senator MCCAIN. Why would we need research when we know the Europeans and the Japanese are already doing it in a safe and efficient fashion?

Secretary CHU. I believe the Europeans and the Japanese are doing it, but they're doing it in a way that lends to risk of proliferation, nuclear proliferation. The Japanese have already said——

Senator MCCAIN. You balance that risk of proliferation verses spent nuclear fuel sitting around in pools in nuclear power plants all over the country and telling industry that we may do some research on reprocessing?

Secretary CHU. Let's separate the issues. First——

Senator MCCAIN. I don't think they are separable. I think they are inextricably tied because it's clear that industry today is not interested in construction of nuclear power plants because we have no place to store it and we have refused to adopt what is already a proven technology of reprocessing.

Secretary CHU. The storage of waste, the interim storage of waste, the solidification of that waste is something we can do today. The NRC has said that it can be done safely. That buys us time to formulate a comprehensive plan in how we deal with the nuclear waste.

The recycling, which I think in the long term is very beneficial. It has the potential for greatly reducing the amount of waste is something that we have to press on. But the time scale of the recycling development is different such that we have a couple of decades, quite frankly in my opinion to figure that one out.

Senator MCCAIN. I couldn't disagree more strongly, Doctor. But I certainly have the greatest respect and admiration for your work and your knowledge and background. Nuclear power has got to be an integral, vital part of America's energy future if we're going to reduce greenhouse gas emissions. To say that after 20 years and nine billion dollars spent on Yucca Mountain, that there's not an option, period to me is remarkable statement.

I'm running out of time here. But I just want to say another great disappointment that I have is that we're going—the President's budget assumes nearly $650 billion in revenue from a cap and trade system for controlling greenhouse gas emissions. I'm proud to have been one of the first to propose cap and trade to support it. Be deeply concerned about the issue of climate change.

So now I see cap and trade, not to be used to encourage technology or development of other technologies, but or frankly to be fundamentally a reason to reduce greenhouse gas emissions. The budget submission now is for $650 billion in revenue into general revenues. You're not going to get support by a lot of us in that kind of proposal.

I deeply regret it. Because when business people all over America who are struggling today who are going to see if they engage in cap and trade, those revenues will just be another tax source for the Federal Government. I think it's a significant mistake.

I'd be glad to hear your views of using $650 billion in revenue from a cap and trade system when we should be using it not for revenues, but to developing technologies and specifically devoted off budget to technologies that will reduce greenhouse gas emissions. I know that my time is expired. I thank you, Mr. Chairman.

The CHAIRMAN. Did you wish to respond to the latest comment?

Secretary CHU. Very briefly.

The CHAIRMAN. Go ahead.

Secretary CHU. Very briefly the President's proposed budget allocates $15 billion per year for research and development of new green technologies. So that is putting back that money into developing better solutions. The rest of it as you know is to offset in the poorest sectors of the population some of the consequences of that.

The CHAIRMAN. Senator Shaheen.

Senator SHAHEEN. Thank you, Mr. Chairman. Welcome, Secretary Chu. I have two questions for you. One is not exactly on point for energy research and development, but since that seems to be an option this morning I guess it's ok. It's a little parochial.

The $5 billion that was included in the Economic Recovery and Reinvestment Act for weatherization, I think is a very important investment. Certainly agree with your comments about the significance of energy efficiency. I met with some folks from New Hampshire at one of our community technical colleges where they actually have a degree in energy efficiency and energy services. They were talking about their concerns that as we're trying to do the weatherization and use the money effectively that's in the bill, that we don't have the number of people trained to do that that we really need to make the most effective use of those dollars.

So what's DOE doing to help States as we're trying to effectively spend those dollars in a way that makes the best use of weatherizing homes for the future?

Secretary CHU. What we're doing is we're looking at the inventory of people that can do proper energy audits that—so with those energy auditors and looking at the training programs and how you can get intense training programs going this spring and early summer. With those energy auditors—and this is replicating in many instances what is already on the ground today, but in greater numbers. They can help specific homeowners spend the dollars most wisely.

It's certainly very important to us that all those dollars are spent not only to create green jobs, but actually reduce the energy consumption and reduce the energy bills as much as possible. So we are very keenly aware of the need for training a larger corps of energy auditors. I've begun these discussions.

Senator SHAHEEN. A related concern in talking to our community action agencies which are the folks in New Hampshire who are doing the low income housing weatherization. They expressed a concern about the cap on the amount that can currently be used to weatherize homes. We have a lot of old housing stock in New Hampshire.

A $6,500 cap is a challenge for many of those homes. You can't adequately do the work that you need to have done. Are you willing to or have you given any thought to increasing that cap to say $10,000 which is what they tell me would be most effective in New Hampshire?

Secretary CHU. In all honesty I don't know what the limitations of the statues that have been passed. I would certainly look into that.

[The information referred to follows:]

The American Recovery and Reinvestment Act of 2009 (P.L. 111-5) by statute, changed the program's average state cost per unit from $2,500 to $6,500. DOE does not have the authority to grant waivers to statutory changes made by Congress.

Senator SHAHEEN. Thank you. I think that's two questions. But I actually have a third.

I want to follow up on Senator Udall's question about venture capital and how do we better leverage the private sector as—I appreciate your commitment to the research that can be done through the Energy Department and through our own government laboratories. But how can we better leverage private capital to help with what the government is going to be spending to encourage energy research.

Secretary CHU. I think there are a number of tools that have been proposed by the Administration. I think renewable energy standards is a way to draw on and to encourage the investment because it creates a market. I think tax credits are also a way to encourage the market.

The research and development is a way to essentially push from below because you're inventing new things that could look to be more promising than what we have today. So both the draws and the pushes and the assistance in loan guarantees, all those instruments are going to be used.

Senator SHAHEEN. Thank you.

The CHAIRMAN. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman. Secretary Chu I wanted to follow up with Senator McCain's comments on nuclear because when the budget blueprint, the FY2010 came out your DOE press office put out a statement that said, the new Administration is starting the process of finding a better solution for management of our nuclear waste. I will certainly share the concerns of my colleague that after decades and millions and billions of dollars that have gone toward Yucca to know that it is considered not an option. To know that where we're starting the process is concerning.

We've got, as you know, we've got a good handful of applications that are out there to move forward new projects within the industry. But boy, if I were looking to advance a new nuclear facility these comments from the Administration that we're starting the process of finding a better solution would be very disconcerting. I don't know what we have done to our nuclear renaissance that Senator Domenici worked so hard to advance by pulling the plug on Yucca.

Can you give me any kind of a timeline? Can you speak to what you feel the Administration will be doing to advance this so that we're not in this limbo so that you don't have an industry that is absolutely necessary and essential? As you have stated before this committee and the President has stated, nuclear has got to be part of the solution as we work to reduce our emissions.

Secretary CHU. First we are finalizing or certainly moving as fast as we can on the $18.5 billion loan guarantee program for nuclear reactors. That we'll get first.

As I said before as we know a lot more than we did 20, 25 years ago. There is now becoming a very strong possibility that with fast neutron reactors, a small fraction being fast neutron reactors, one can actually burn down the nuclear waste. So based on what we know today I think it is prudent to step back and say, let's develop a comprehensive policy toward how we reduce the amount of nuclear waste, how we store it. It will probably be a mixture of short term, interim waste followed by essentially permanent storage.

Senator MURKOWSKI. But we're already doing the short term. It is happening. But we recognize that it is not the long term solution that we will need that that permanent facility.

Secretary CHU. I was talking short term in a sense that gives the option of taking that back as we get the recycling and the ability to burn down some of that waste to split the long lived actinide nuclei to make it very much shorter lived to recover a lot of that energy. So short term in that sense. Then after that one can think of repositories that are essentially, you would say, we don't ever want to recover it.

Senator MURKOWSKI. No.

Secretary CHU. So I would say the time scale I think would be this year to get a really esteemed bunch of people to look at this based on what we know today and to think of what is going on. Other countries I think would participate in this fresh look.

Senator MURKOWSKI. I would urge a level of expediency and absolute urgency. Because otherwise we will as a country by shutting the door on nuclear which I think would be irresponsible. It's one thing to convene smart people together to look at the problem. It's another thing to make it a commitment of the Administration that we need to resolve this issue otherwise we will not be able to resolve, meaningfully, the issue of our carbon emissions.

I wanted to ask one question to you about the renewable electric standard. You've stated and I would agree with you that we've got some challenges with meeting a 20 percent RPS due to the intermittent nature of what we have with renewables. I think you made a statement that during the snowstorm this winter in the Pacific Northwest we had a situation where the wind didn't blow for three straight weeks. So we recognize we've got some issues there.

Can—and I'd ask you to address two things. First, the transmission infrastructure and whether you acknowledge that we're just woefully behind or the transmission infrastructure right now is inadequate to allow us to achieve a 20 percent standard by the 2021 requirement. Then how we deal with the multiple States.

There's 29 States plus the District of Columbia that have some kind of clean energy requirement right now. Each one of these States has different targets. They've got different definitions of resources. In fact every one of the States that has a program has at least one eligible resource that wouldn't qualify under this Federal RPS program definition.

How do you reconcile dealing with the different mandates from 30 different areas?

Secretary CHU. First let me say that I agree with you that the transmission system, as it is today, is not suitable for getting the renewable energy to the parts of the population centers in the United States. So this is something we have to concurrently build up. The United States is blessed with incredible renewable energy resources but they are localized in certain areas in the upper Midwest and the Pacific Southwest when solar becomes economically viable.

So we have to start building that. By 2020 I hope we would be well along in getting the line sited, getting agreements in local communities and States. We will be building up this transmission system.

We will have to look at the financing mechanisms for the transmission. Right now my understanding is that the transmission lines are paid for by point of origin of energy production. That was based on a time when we produced and used energy very locally.

But now we recognize in order to take full advantage of renewable energies which will take some time, we—this is a national issue. So we need a comprehensive plan nationally to port energy around and it does take time. So—and what was the other part?

Senator MURKOWSKI. The second one was how you deal with the 30 some odd States that have different mandates?

Secretary CHU. This is the way our country works that in many times our States have their rights as States to have these mandates. I look upon it as the States have been a good laboratory in many instances for what eventually is done federally. They can try what works or what doesn't work for them.

In the end, yes, I think we need to develop more comprehensive policies. But historically if I think of a lot of issues that the country has dealt with like clean air, clean water, those things; the States actually did take the lead and develop things that then became national standards, appliance standards similarly.

So it's essentially the way our country has been working over the last century.

Senator MURKOWSKI. Mr. Chairman, I'd have some follow up, but I have well exceeded my time. So I will——

The CHAIRMAN. Senator Risch has not had a chance to ask questions. Go ahead, please.

Senator RISCH. Thank you, Mr. Chairman. Secretary Chu, I know you're familiar with the Idaho National Laboratory and its two missions of obviously research and of clean up. The Department of Energy very wisely has separated those two over the last decade or so.

We've—and you also know that the State has had some difficulty with the Department. In fact we litigated the issue of the clean up over at the laboratory. I'm wondering if you're familiar with the agreement that was entered into and was court approved that resolved the issue of clean up over at the INL site in Eastern Idaho?

Secretary CHU. No, I'm not familiar with the details.

Senator RISCH. Secretary let me—you're not going to be able to answer my questions then. But I'm going to ask you to follow up on it.

[The information referred to follows:]

At your request, I have followed up on the agreement entered into with the State of Idaho that was court approved and resolved the issue of cleanup of the buried waste at the INL site in Eastern Idaho. My staff has provided me with detailed information which I will briefly summarize here. On July 1, 2008, the United States Department of Energy (DOE) and the State of Idaho announced their Agreement to implement the United States District Court Order of May 25, 2006, in coordination with the ongoing Superfund cleanup of the area. The Agreement marked the end of 6 years of litigation related to interpretation of the 1995 Settlement (or Batt) Agreement. Implementation of this Agreement will satisfy DOe's commitment to Idaho to remove waste containing transuranic and other contaminants that was buried at Idaho National Laboragtory (INL) several decades ago.

Under the 2008 Agreement, DOE and its contractor will continue retrieving drums of radioactive waste and hazardous chemicals from the burial ground. The transuranic waste is repackaged and sent to the Waste Isolation Pilot Plant—DOE's deep geologic transuranic waste repository in Carlsbad, New Mexico. The other targeted waste, which may contain volatile organics and uranium, is being shipped out of Idaho to other licensed or permitted disposal facilities. The Department intends to excavate 5.69 acres and remove a minimum of 6,238 cubic meters of targeted radioactive and hazardous waste over the life of the buried waste cleanup.The Agreement requires that all targeted waste retrieved by December 31, 2017 be shipped out of the state by December 31, 2018, and all waste retrieved after that be shipped within one year of retrieval. I also recognize that through February 2009, DOE has excavated about 15% of the 5.69 acres, retrieved over 2,500 cubic meters of targeted waste, and shipped in excess of 500 cubic meters of the waste out of the State of Idaho. Our plans include continuation of this significant progress to ensure we meet the obligations in the Agreement to Implement with the State of Idaho.

Senator RISCH. Let me tell you briefly after a considerable amount of litigation the State and the DOE entered into an agreement whereby the DOE would remove the—all of essentially the nuclear waste that was left over from the cold war. The INL played a role just as Rocky Flats and Hanford and all the other sites did. We're the only one with an agreement.

The DOE agreed that they would remove the waste. They're doing well. They're keeping up with the contract. The waste is being removed to the wip site.

Unfortunately there's material that is not qualified for the wip site and it was anticipated that that would go into Yucca Mountain. Now I understand in answer to Senator McCain's question you indicated that the United States has no plans to activate Yucca Mountain. So the question I have for you which I suppose you can't answer at this point is what are you going to do about the contract that requires you to remove materials that are of such a level that they can't go into the wip site?

Secretary CHU. This goes to the sense of urgency that Senators McCain and Murkowski talk about in terms of developing an approved approach to dealing with high level nuclear waste. So it's certainly going to be—we'll be looking at this very intensely over this next year.

Senator RISCH. Secretary, with all due respect, I appreciate that. But I can tell you that this contract is very clear. It is in the form of a court order that it has to be moved.

Do you have any thoughts right now as to where, if you're not going to go to Yucca Mountain. This whole thing with Yucca Mountain not going to be used is a relatively new thing. Certainly when somebody made that decision, when the new Administration made that decision, somebody must have had some thoughts as to where—how you were going to keep your agreements on removing the high level stuff from places like Idaho where you are required to by court order.

Secretary CHU. In addition to that I should also add that we have obligations to the utility companies for similar disposition of their waste. So I hope——

Senator RISCH. But with the utility companies all you have to do is pay a fine. That's been going on for some time. Not so with the Idaho contract. You've got to move it.

So what was going through people's mind when they said we're not going to use Yucca? Where you thinking you're going to go?

Secretary CHU. I think, as I said before, that there are other options that we will have to look at. Quite frankly I think there would be better options. But at this time I'm not willing, again I would want to seek the advice of some deeply knowledgeable people on this.

Senator RISCH. Will these options you refer to—can you tell us what these options are so that we can be thinking about them too?

Secretary CHU. I think it would—first, it's going to be a mixture of short term sites. There are several layers of short term sites of longer term and then finally, final disposition. I think it probably will have to be geographically distributed in some way other that you know, one location, one site will probably not work.

Senator RISCH. But these are sites that you have not located or identified or——

Secretary CHU. That's correct.

Senator RISCH [continuing]. Gotten at this point.

Secretary CHU. That's correct.

Senator RISCH. Ok. Have you got an idea of how long this is going to take because you're under some real time constraints in the Idaho agreement?

Secretary CHU. As I said that we will be assembling this and getting a report sometime this year. I agree there are real time constraints.

Senator RISCH. Ok, thank you. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you. Senator Risch, let me just ask. My impression was that the obligation to move that waste under the Idaho agreement was effective in 2035. Is that wrong?

Senator RISCH. That is incorrect. There is a series of deadlines that have to be met in that.

The CHAIRMAN. Ok. Alright. Let me ask another question then I believe Senator Murkowski had another question or two and maybe Senator Udall, I'm not sure.

I just wanted to ask one of the issues that you and I have discussed before and you know is near and dear to my heart is the whole issue of the role of our NNSA laboratories, Los Alamos, Sandia and Lawrence Livermore in particular. The involvement of those laboratories in the scientific work that is pursued the basic scientific work that's pursued in the Department of Energy. I'd appreciate it if you could just give us a short statement as to your thoughts as to the appropriateness of them being involved in that scientific work.

Secretary CHU. I think the—first their core function of our National Nuclear Security intimately depends on having an intimate coupling with science. The stockpiled stewardship is a science based program. It is essential that the science connection with our nuclear weapons be kept, maintained, possibly even strengthened as you go into these, an aging arsenal.

In addition to that the scientific expertise has become quite useful in non proliferation work. It's been quite useful in the interpretation of intelligence gathered by the United States. So again anything that threatens the science component of those NNSA laboratories I would be very much opposed to.

The science component of those laboratories actually was a mechanism for attracting some of the best scientists into our National Security programs. Again, I think that's a vital component of particularly those 3 weapons laboratories. This is as tradition goes way back to the very beginning with Robert Oppenheimer. It has served the country well.

So any discussions about how those labs evolved should not sever that intimate tie. The weapons labs are an important national asset, not only to our nuclear security, but to our science in general.

The CHAIRMAN. Thank you very much. Let me call on Senator Murkowski for her additional questions.

Senator MURKOWSKI. Thank you, Mr. Chairman. Secretary Chu I wanted to follow up with the question that we were discussing about the RAS and what is happening out in the respective States. I think the word that you used was that the States are good laboratories. I would certainly agree with that.

They look to their resources. They figure out what is possible within their areas. Many of these States have moved forward with setting their own standards and working toward them.

But we recognize that all sources of energy in terms of their location are not equal. In my State we're about 20, almost 25 percent renewable if we're allowed to count the definition of hydro. So, so much of this comes down to the definitions.

I just received a letter, actually the Chairman and I received a letter signed by 13 members here, 11 of them Democrats urging us as we look toward a national renewable electricity standard to expand the definition to include ways to energy. As we debate how we define renewables can you give me some of what you consider to be the parameters? I have a difficult time understanding why we would not include hydro as renewable.

I have a difficult time understanding why if our goal with an RES is to move toward reduced emissions why we would not include nuclear in the definition. So could you just speak to that issue because I think it is incredibly important as we discuss the RES? Then if you could also address the concept, if you will, of regional standards as opposed to a national standard?

I understand that what we have in the Northwest is entirely different than what we have in the Southeast. Can you address both of those, please?

Secretary CHU. I was not part of the discussion of the definitions of renewable.

Senator MURKOWSKI. I understand that.

Secretary CHU. I would certainly work with this committee to look at it. I agree that anything which greatly reduces carbon emissions is something that we should nurture. Anything that would increase the reduction of carbon emissions, new hydro is something we should nurture. But I will be perfectly happy in wanting to work with the committee in looking at how these things are defined.

Senator MURKOWSKI. Can you speak a little about just a regional concept as opposed to a national standard and where you might fall on that?

Secretary CHU. I certainly know, again I agree with you that the amounts of renewable energy, like wind and solar, vary greatly in different regions. So again one could look at that. The Southeast does not have one resource it has biofuel resources, but not wind resources. One has to look at this with a finer eye to really see what are going to be the consequences.

Again I will be working with the committee on this.

Senator MURKOWSKI. We do want to work with you on this. It is an issue that one thing I've determined it's not partisan. It really is much more regional issue.

Those parts of the country that aren't blessed with sufficient renewable resources are looking at this and saying this is troubling to us because what it will be for all intense and purposes is a tax on us. Because we're not blessed with as much as the East has or the North has. It is something that I think we've got to really focus, not only on the definition but what the goal is.

If our goal is reduced emissions than we need to be making sure that what we are doing is encouraging just that. If our goal is to get more wind turbines erected, if our goal is to get more solar panels up, than that's completely different than the goal of working to reduce our emissions. So we want to work with you on this to make sure that we're not unduly hampering efforts in certain parts of the country or challenging them in a way that is going to financially unfair.

Thank you, Mr. Chairman.

The CHAIRMAN. Senator Udall, did you have additional questions?

Senator UDALL. Mr. Chairman, I do have a brief final question. I'm reluctant to have the last word here. So I hope you and Senator Murkowski will feel if you need to say more you can and should.

I've been listening with real interest to Senator Murkowski's points that she's making. I think we are undertaking a challenging process here, one where in the end we perhaps arrive at a hybrid energy policy much like we want us to develop a series of hybrid energy systems all over the country. I think we do have a dual goal, Senator, which is to promote renewable energy technologies that have emerged over the last 10 years but also to reduce carbon emissions.

All of these technologies perhaps are at worse distant cousins of each other and perhaps are siblings. But I take seriously your concerns in the important questions that you're raising here today. In that spirit, Dr. Chu, I'll submit for the record a question about the hydrogen R and D.

I feel like I've been, some cases whip sawed by the excitement about hydrogen and then those who say that's not realistic. I do know you have, I think, a billion dollars plus in your budget to do R and D. There's some recent reports that suggest we should refocus on hydrogen, not in the short term, perhaps not even the medium term, but in the long run that may be where we land in 50 to 75 to 100 years. So if I might, I'd submit that question about the use of those dollars and what you foresee.

One final comment. I listened with interest to Senator McCain's questions about solar. One of the dynamics here that we should acknowledge is that there may be and this is an overused term these days, but it's effective term and there may be game changers. As you note in your statement if you develop photovoltaic solar power that is five times cheaper than today's technology and more efficient as well if we raise the efficiency levels from 12, 13 percent to 18 or 19 or 20 you get exponential gains.

That technology may well be much more deployable, much less expensive and therefore make up a bigger portion of our energy needs. So I just want to note that for the record as well that there are advances that we can't even foresee. I believe that when we make this investment at the Federal level, make this investment internationally and this is why this is such an exciting field. It is why I'm so excited that you're leading the Department of Energy at this important time in our history.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much. Secretary Chu, thank you for spending this time with us. We will stay in close touch as we try to proceed to develop some legislation in this area.

Why don't we excuse you and bring forward the second panel?

Secretary CHU. Thank you.

The CHAIRMAN. Thank you.

On our second panel let me just introduce folks as they are taking their seats at the table here.

Dr. George Crabtree is a Senior Scientist and Associate Division Director at Argonne National Laboratory in Illinois. We appreciate him being here.

Mr. Bob Fri is a visiting scholar with the Resources for the Future. Thank you for being here.

Dr. Jim Bartis is Senior Policy Researcher with RAND Corporation. Thank you.

Ms. Deborah Wince-Smith is President of the Council on Competitiveness.

Professor Mike Corradini is Director of the Wisconsin Institute of Nuclear Systems. Originally hails from Albuquerque which we wanted to note for the record. But he's at the University of Wisconsin in Madison.

So why don't we just take—if each of you would take maybe about 5 minutes and tell us the main points you think we need to be aware of on this set of issues. We will include a full statement, any full statement you have in the record as if read. But Dr. Crabtree why don't you start and we'll hear from all of you. Then we'll have some additional questions.

STATEMENT OF GEORGE W. CRABTREE, SENIOR SCIENTIST, ASSOCIATE DIVISION DIRECTOR and DISTINGUISHED FELLOW, MATERIALS SCIENCE DIVISION, ARGONNE NATIONAL LABORATORY, ARGONNE, IL

Mr. CRABTREE. Chairman Bingaman, Ranking Member Murkowski and members of the Energy and Natural Resources Committee, I'm grateful for the opportunity to contribute to the national discussion on the role of science and technology in meeting America's energy, environmental and economic challenges. Let me begin by expressing my thanks to the members of the Senate present today and to the entire Congress for their strong support of basic science and technology. The crises we face today are a perfect storm of unpredictable energy supply, global warming and severe economic recession.

Translational basic science and technology are essential to meet these demands. A single number captures the magnitude of the energy challenge, $700 billion per year. That's the cost of imported oil at last summer's peak prices. That money is removed from the

United States economy where it cannot turn over and stimulate additional economic activity.

Even at today's prices imported oil will remove about $200 billion a year from the United States Beyond cost however, lies a serious security threat. We import nearly 60 percent of our oil making us vulnerable to interruption caused by natural disasters, terrorist acts or interim political decisions in producer countries.

Carbon dioxide emissions are an equally serious threat. The evidence for global warming is unequivocal. The United States is the second largest carbon dioxide emitter behind China. We need to regain international leadership in tackling this important global threat.

There's an opportunity hidden in these challenges. Next generation energy technologies will not only solve our own energy and environmental problems but also create a new export market of enormous capacity and enduring strength. The world faces the same energy and economic and environmental challenges that we do. Meeting these global needs with next generation technologies exported by U.S. companies will generate long term economic growth that can protect the economy from stagnation or recession and reverse the drain of imported oil.

Next generation energy technologies are an unprecedented, global economic opportunity. The question for us is whether the United States will be buying them or selling them. The report the New Science for a Secure and Sustainable Energy Future here issued recently by the Department of Energy's Basic Energy Sciences Advisory Committee outlines the transformational opportunities to address these challenges and recommends a path forward.

We know what many of the next generation sustainable energy technologies will be carbon sequestration, high efficiency coal and nuclear electricity, renewable solar, wind and geothermal power generation, solar fuels and biofuels, solid state lighting, energy storage and high temperature superconductivity for a 21st century electric grid. Why have we not deployed these technologies? The answer is simple. The current versions of these technologies do not perform well enough to compete with conventional fossil energy alternatives.

The performance road blocks to next generation sustainable technologies are extremely challenging. Otherwise they would have been solved by the extensive research and development already devoted to the energy sector. Some of the most important challenges are inexpensive catalyst ten times more active than platinum, electrodes for batteries that accept and release large quantities of lithium to increase the energy density, new superconductors that operate at twice the temperature of the current generation for long distance transmission with solar and wind electricity.

The materials and chemistry that overcome these performance road blocks will be much more complex than those in use today. High temperature superconductors contain four or five elements instead of the usual one or two for conventional superconductors. The best battery electrodes have intricately nanostructured surfaces that promote the injection and release of lithium.

The catalytic activity of platinum can be increased by a factor of ten by altering its subsurface composition in subtle and still largely unexplored ways. The lesson of the last 10 years of materials in nanoscience research is clear. Greater complexity enables higher performance.

Thomas Edison gave us a wonderful model when he said, Genius is 2 percent inspiration and 98 percent perspiration." These words motivated the technology of his day and described his remarkable success with the light bulb, the phonograph and the movie camera. The complexity of today's materials in chemistry however, is much greater than it was in Edison's time.

It's no longer possible to try one variation after another and eventually hit the jackpot. Instead we need to raise the inspiration quotient significantly. Instead of 2 percent inspiration we need at least 50 percent inspiration to dramatically reduce the perspiration of perfecting the new energy technologies.

This inspiration can come only from basic science. We need to understand the why and how of materials. Why they do what they do at nano scale dimension and ultra fast time scales that are beyond the reach of the human eye. This knowledge of how and why is the tipping point for creating new materials and chemistries that will change the performance equation of sustainable energy.

What are the basic science challenges we need to solve? They're laid out in 12 basic research needs workshop reports and summarized by this new science report. They provide the road map for investments in inspirational basic science that will transform the energy game.

The energy frontier research centers proposed by the DOE Office of Basic Energy Sciences are a first step in promoting a new level of inspiration. These centers will launch dream teams of the best scientists drawn from diverse institutions working in interdisciplinary teams, using the most advanced tools and focused on the most important problems outlined in the Basic Research Needs workshops and the New Science Report. These dream teams are a new concept on the energy research landscape representing not only the will but also the critical mass to overcome the materials and chemistry road blocks to competitive sustainable energy performance.

But the Department of Energy must do more than establish dream teams and EFRCs. It must recruit the next generation of talented scientists, post docs and early career scientists to inspire them to become tomorrow's energy innovators. The challenges we face dependence on imported oil, carbon dioxide emissions and growing ourselves out of the recession are among the most serious that we have faced in 6 decades. The solution will require basic science inspiration on a grand scale and a new generation of energy scientists to achieve it.

Thank you again for the opportunity to provide testimony. I'll be pleased to answer questions at the right time.

[The prepared statement of Mr. Crabtree follows:]

STATEMENT OF GEORGE W. CRABTREE, SENIOR SCIENTIST, ASSOCIATE DIVISION DIRECTOR AND DISTINGUISHED FELLOW, MATERIALS SCIENCES DIVISION, ARGONNE NATIONAL LABORATORY ARGONNE, IL

Chairman Bingaman, Ranking Member Murkowski, and members of the Energy and Natural Resources Committee. I am grateful for the opportunity to contribute to the national discussion of the role of science and technology in meeting America's energy, environmental and economic challenges.

Let me begin by expressing my thanks to the members of the Senate present today and to Congress for their strong support of basic science and technology. Basic science and technology have given us remarkable innovations that have dramatically raised the quality of our personal lives, increased the productivity of our businesses, and created long term economic growth. However, the combined challenges of energy, environment and the economy that we face today are greater perhaps than at any time in the last six decades. They will require a new generation of inspirational breakthroughs from basic science to replace the economic recession with economic growth, to replace uncertain and costly imported oil with a secure and sustainable energy supply, and to reduce carbon dioxide emissions that threaten global climate.

Congress has taken a bold step toward meeting these economic, energy and climate challenges with the recent passage of the American Recovery and Reinvestment Act. Along with the pending FY09 Omnibus Appropriations Act, these acts have the power to transform science and technology into the vibrant and aggressive engines of change envisioned by the America COMPETES Act passed by Congress in 2007.

But such daunting goals cannot be achieved in a year. A sustained and aggressive investment in basic scientific research, manpower and infrastructure is needed, like that triggered by Sputnik or devoted to the Manhattan project. Today's combination of energy, environment and economic challenges is much greater than either of these landmark historical events.

Energy and Environmental Challenges

A single number captures the magnitude of the energy challenge: $700 billion/yr, the cost of imported oil at last summer's peak prices. That money is removed from the U.S. economy, where it cannot turn over and stimulate additional economic activity. Even at today's prices, imported oil will remove about $200 billion/yr from the U.S. economy, a significant drain on the economic recovery. Last year we imported nearly 60% of our oil, used primarily to power our cars and trucks. Imported oil has become the lifeblood of our transportation system, making us vulnerable to interruptions caused by natural disasters, terrorist acts or internal political decisions in producer countries. Our energy security requires markedly reducing this dependence on imported oil.

Carbon dioxide emissions are an equally serious threat. The evidence for global warming cited by the Intergovernmental Panel on Climate Change is unequivocal: rising average temperatures and sea levels, shrinking polar ice and snow cover in the northern hemisphere, and pole-ward migrations of animals and plants to maintain their preferred habitat. The U.S. is the second largest carbon dioxide emitter behind China, but we have remained remarkably passive in addressing this issue. We need to regain international leadership by tackling this global threat.

There is a transformative opportunity hidden in these challenges. Next-generation energy technologies not only solve our own energy and environmental problems, but also create a new export market of enormous capacity and enduring strength. The world's energy and environmental problems reflect our own—a reliance on uncertain imported oil and the threat of climate change. Meeting these global needs with next-generation technologies exported by U.S. companies generates long term economic growth that can protect the economy from stagnation or recession and reverse the drain of imported oil. Next-generation energy technologies will be developed—the question is whether the U.S. will be buying or selling them.

The Path Forward

The report New Science for a Secure and Sustainable Energy Future*, issued recently by the Department of Energy's Basic Energy Sciences Advisory Committee, outlines the opportunities to address these challenges and recommends a path forward. We know what many of the next-generation sustainable energy technologies are: carbon capture and sequestration; high-efficiency coal and nuclear electricity; renewable solar, wind and geothermal power generation; solar fuels and biofuels; solid state lighting; energy storage for plug-in hybrid and battery electric cars, and high-temperature superconductivity for a 21st century electric grid. Many of these technologies have been proven in principle in the laboratory or in small scale demonstrations. Why have we not deployed them? The answer is remarkably simple and universal: the current versions of these technologies do not perform well enough to compete with conventional fossil energy technologies.

The performance roadblocks to next-generation sustainable technologies are extremely challenging—otherwise they would have been solved by the extensive re-

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* See Appendix II

search and development already devoted to the energy sector. Inexpensive catalysts ten times more active than platinum are needed for producing electricity in hydrogen fuel cells that operate without emitting pollutants or carbon dioxide. Electrodes that accept and release large quantities of lithium are needed for high energy density batteries to enable plug-in hybrids and all-electric vehicles. New superconductors that carry high current at low loss are needed for long-distance transmission of solar and wind electricity from remote generation sites to population centers.

The materials and chemistry that will overcome these performance roadblocks will be much more complex than those in use today. High-temperature superconductors contain four or five elements instead of the one or two of conventional superconductors. The best battery electrodes have intricately nanostructured surfaces that promote injection and release of lithium. The catalytic activity of platinum can be increased by a factor of ten, by altering its sub-surface composition in subtle and still unexplored ways. The lesson of the last ten years of materials and nanoscience research is clear: greater complexity enables higher performance.

The complexity demanded of next-generation materials is so great that conventional trial and error approaches to their discovery and development are failing. Edison gave us a wonderful model when he said "Genius is 2% inspiration and 98% perspiration." These words motivated the technology of his day—and described his remarkable success with the light bulb, the phonograph and the movie camera. The complexity of today's materials and chemistry, however, is much greater than in Edison's time. The number of possible variations is enormous. It is no longer possible to try one variation after another and eventually hit the jackpot. Instead, we need to raise the inspiration quotient. Instead of 2% inspiration we need at least 50% inspiration to dramatically reduce the perspiration of perfecting new energy technologies. This inspiration comes from basic science. We need to understand why and how materials do what they do, at nanoscale dimensions and ultrafast time scales beyond the reach of the human eye. The basic science of how and why materials behave as they do is the inspiration for developing new materials and chemistries that will change the performance equation of sustainable energy.

The Basic Science Solutions

What are the basic science challenges we need to solve for next-generation energy technologies? They are laid out with remarkable clarity and detail in the twelve Basic Research Needs Workshop reports that are summarized by the "New Science" report. Each of these workshops selected a sustainable energy challenge such as electrical energy storage, solar energy, advanced nuclear power, superconductivity, solid state lighting, or catalysts for energy. Each workshop then convened a group of 100 or more experts drawn from universities, national laboratories, industry and foreign countries to identify the materials and chemistry challenges in the selected field and the promising research directions to overcome them. These workshops and reports are textbooks for next-generation sustainable energy technologies. They provide the roadmap for investments in inspirational basic science that will change the energy game.

The importance of basic science inspiration for next-generation sustainable energy technologies cannot be overemphasized. History has shown that breakthrough materials and chemistries, once found, are quickly snatched up by entrepreneurs looking for a competitive opportunity. The laser, digital electronics, and fiber optics communication are all examples of materials advances spawning new technologies. These technologies flowed from basic research. Try to imagine, for example, the information revolution based on vacuum tubes.

In the rush to do something about the daunting problems of imported oil and carbon dioxide, we often emulate Edison's emphasis on perspiration—redoubling our efforts on technologies based on existing materials and chemistry. These efforts often improve technologies incrementally, but just as often they miss the opportunity for game-changing breakthroughs to an entirely new material or chemistry that dwarfs the old approaches. The big solutions come from high risk-high payoff basic science on new materials and chemistries—catalysts for fuel cells, electrode materials for batteries, superconductors for electricity transmission. These basic science inspirations are the tipping points that create the next-generation energy technologies that will replace imported oil, reduce carbon dioxide emissions, and grow us out of the recession. To have the biggest effect, we must go after the biggest challenges, and that means investing in basic science.

Energy Frontier Research Centers

The Energy Frontier Research Centers (EFRC) proposed by the DOE Office of Basic Energy Sciences are a model for promoting inspiration. These centers will create “dream teams” of the best scientists, working with the best tools and focused on the most important problems outlined in the Basic Research Needs Workshops and the “New Science” report. The EFRCs are basic science inspiration machines, examining how complex materials and chemistry work at nanometer length scales and ultrafast time scales. The scientific knowledge and understanding they generate will be the basis for overcoming the materials and chemistry roadblocks to next-generation sustainable energy technologies.

The scientific community has responded enthusiastically to the concept and opportunity of EFRCs. The Office of Basic Energy Sciences has received approximately 260 proposals representing 3800 senior investigators from 385 research institutions in 41 States and the District of Columbia. The proposals reflect an unusually high degree of interdisciplinary cooperation—the average proposal has nearly 15 senior investigators from 4.8 institutions. The EFRCs will deliver the “dream teams” needed to overcome the challenging performance roadblocks to next-generation sustainable energy technologies.

The Department of Energy must do more than establish “dream teams” and EFRCs. It must recruit the next-generation of talented early career scientists and inspire them to become tomorrow’s energy innovators. The challenges we face—dependence on imported oil, carbon dioxide emissions that accelerate global warming, and growing ourselves out of the recession—are the biggest we have faced in six decades. The solution will require basic science inspiration on a grand scale—and a new generation of energy scientists to achieve it.

Thank you again for the opportunity to provide this testimony and I will be pleased to answer any questions.

The CHAIRMAN. Thank you very much.
Mr. Fri.

STATEMENT OF ROBERT M. FRI, VISITING SCHOLAR, RESOURCES FOR THE FUTURE

Mr. FRI. Thank you, Mr. Chairman, Senator Murkowski.

Although I’m a visiting scholar Resources for the Future, I’m here today representing the National Research Council where I participated in a number of energy studies and served as the vice chair of the Council’s Board on Energy and Environmental Systems. As you know the Council is nearing the end of its major energy project, America’s Energy Future and reports from the first phase of that study will soon be available to the Congress. But for today’s purposes I’m going to draw on some background of a series of energy R and D studies we have conducted over the years together with the first product of the America’s Energy Future project, a summary of the National Academy’s Summit on America’s Energy Future held a year ago.

Now my task today, as I understand it is to try to distill from these reports and my own experience some lessons that may be useful as you consider the programs that you are in the process of reauthorizing. In that regard I only want to make 3 points.

The first is a familiar one. Taken together all of these studies forcefully remind us that it is still too early to pick winners in our search for energy technologies that will adequately address the challenges of energy security, economic viability and climate change. For this reason the fundamental objective for the research programs that this committee is considering remains the same. To sustain and advance a portfolio of technology options from which the Nation can ultimately select those that best meet our energy goals.

Now, and this is the second point. Although the importance of a broad energy portfolio is a familiar observation, these Council reports also strike a new theme that the Nation is getting closer to the point at which we can, in fact, distinguish a few winners and losers. For the essential next step in several key fossil, nuclear and electric grid technologies is to build them at a scale that will demonstrate their cost and performance for commercial deployment. Integrated gasification combined cycle plants, carbon capture and storage, the next generation of nuclear plants and the so called SMART grid are at this point in their development.

Now the Summit report also underscores the importance of getting on with these programs with a real sense of urgency. Many speakers asked whether the urgency being expressed by the public and by policymakers is sufficient. Now in my view the year since the Summit has seen our collective sense of urgency grow substantially.

Nevertheless it is important to realize that there is no benefit in delaying the demonstration of these key technologies. We need to know. Industry needs to know how these new fossil, nuclear and grid technologies perform and an especially important target for research, we need to get them on the experience curve of continuing efficiency improvement. Waiting will not answer these questions. It will only make more difficult applying the answers when we finally get them.

Finally as important as these first commercial projects are they will not be the final answers to our energy problems. We will depend, as the Secretary has said, as Dr. Crabtree has said, on innovations as yet unknown to create technologies that are even more efficient and environmentally friendly. My own analysis of technology innovation convinces me that basic research is the foundational source of this needed innovation.

Moreover basic research is the conical example of a public good that won't get done unless government does it. A vigorous basic research program is an essential part of an energy research portfolio. I applaud the committee's support of this crucial program.

Those are my brief remarks, Mr. Chairman. I'd be happy to answer your questions later.

[The prepared statement of Mr. Fri follows:]

STATEMENT OF ROBERT M. FRI, VISITING SCHOLAR, RESOURCES FOR THE FUTURE

Good morning, Mr. Chairman and members of the committee. I am Robert Fri, a Visiting Scholar at Resources for the Future. Today, however, I am representing the National Research Council, where I have been active in a succession of Council studies of energy and energy R&D over the last decade. I currently serve as vice-chair of the Council's Board on Energy and Environmental Systems.

As you know, the National Research Council is nearing the end of a major energy project, America's Energy Future. Reports from the first phase of that study will soon be available to the Congress. For purposes of today's discussion, however, I want to draw on three other Council projects—our retrospective and prospective assessments of the benefits of fossil fuel and energy efficiency R&D programs at the Department of Energy; an evaluation of the nuclear energy research program at DoE; and the first product of the America's Energy Future project, the summary of the National Academies Summit on America's Energy Future held a year ago. Thank you, Mr. Chairman, for joining us at the Summit last March. For the record I have included summaries of these three reports.

My task today is to distill from these reports, and from my own experience with energy research and development, some lessons that may be useful as you consider the programs that your committee is in the process of reauthorizing.

The first lesson is a familiar one. Taken together, all of these studies forcefully remind us that it's still too soon to pick the winners in our search for energy technologies that will adequately address the challenges of energy security, economic stability, and climate change. For this reason, the fundamental objective for the research programs this committee is considering remains the same—to sustain and advance a portfolio of technology options from which the nation can ultimately select those that best meet our energy goals.

Although the importance of a broad research portfolio is a familiar observation, these Council reports also strike a new theme—that the nation is getting closer to the point at which we can in fact distinguish a few winners and losers. For the essential next step in several key fossil, nuclear, and electric grid technologies is to build them at a scale that will demonstrate their cost and performance for commercial deployment. Integrated gasification combined cycle (IGCC) coal-fired power plants, carbon capture and storage (CCS) technology, the next generation of nuclear power plants, and so-called smart grid technology are at this point in their development.

The Council's analyses of prospective benefits of the IGCC and CCS technologies suggest that the benefits of government investment in critical research areas greatly outweigh the costs. Specifically:

- Our assessment of gasification technology suggests that federal investment in research to improve the efficiency of the process—especially of the carbon capture step—would yield on the order of $4-7 billion in net present value of economic benefit under almost any scenario of deployment. If natural gas prices rise, this benefit could be several times larger.
- Similarly, federal investment in the development of carbon sequestration technology could yield discounted economic benefits on the order of $2-4 billion. This result assumes only a modest acceleration of the availability of the technology, recognizing that the private sector would have a strong incentive to develop carbon sequestration in the event of a national policy to reduce net carbon emissions. Under some scenarios, the benefit could be much larger.

In addition, the Council's evaluation of the DoE nuclear R&D program assigns the highest budget priority to the NP2010 program and to research in support of the commercial fleet of nuclear power plants. The report on the Summit on America's Energy Future is one of several sources stressing the centrality of the electric grid in delivering economic and reliable electricity. Furthermore, the so-called "smart grid" is essential to realizing the potential for energy efficiency, to bring renewable energy on line, and to managing carbon and other emissions.

The Summit report also underscores the importance of getting on with these programs with a real sense of urgency. To quote the Summit report, "many speakers . . . asked whether the urgency being expressed by the public and by policymakers is sufficient". In my view, the year since the Summit has seen our collective sense of urgency grow substantially. Nevertheless, it is important to realize that there is no benefit in delaying the demonstration of these key technologies. We need to know how new fossil, nuclear, and grid technologies perform, and we need to get them on the experience curve of continuing efficiency improvement. Waiting will not answer these crucial questions, only make more difficult applying the answers when we finally get them.

But as important as these first commercial projects are, they will not be the final answers to our energy problems. We will depend on innovations yet unknown to create technologies that are even more efficient and environmentally friendly. My own analysis of technology innovation convinces me that basic research is the foundational source of this needed innovation. Moreover, basic research is the canonical example of a public good that won't get done unless government supports it. A vigorous basic research program is an essential part of the energy research portfolio, and I applaud committee's support of this essential program.

Finally, the Council's research, and especially our retrospective study of DOE's energy R&D programs, provides some insight into managing the energy research enterprise successfully.[1]

As noted earlier, fossil, nuclear, and grid technologies are at the point of conducting demonstration that will provide information that the private sector needs to invest in commercial plants. As such, government research needs to be surgically targeted on removing market failures that inhibit private sector investment. As an example, consider the large benefits that our studies assigned to research into carbon capture technologies. The major reason is that the private sector does not now have a strong incentive to develop this technology, and will not until a carbon price is established. Yet current IGCC technology pays a stiff economic premium because

[1] The discussion of managing DOE's energy research is based on views I have developed from Council studies and other research. A more complete summary of my conclusions is available in the Fall 2006 issue of Issues in Science and Technology (http://www.issues.org/23.1/fri.html)

of the inefficiency of the carbon capture step. Federal investment can accelerate improvements in this very specific process step that, in turn, will make the IGCC technology more affordable sooner when a carbon control regime is finally established.

The history of energy research developed in our retrospective study shows that government programs with clearly focused goals can yield substantial benefits. The converse is true, as well; a lack of focus is often associated with lackluster results. While in its early days, DOE programs often lacked this focus, in my opinion it has improved greatly. I commend the Climate Change Technology Program strategic plan as an excellent roadmap for actions that DOE and other departments can constructively take.

Managing basic research is an entirely different matter, of course. Unlike the applied research discussed above, basic research cannot be tied to specific technologies. On the other hand, it has to have some relevance to national energy goals. A good way to walk this line is to identify the physical limits that must be overcome to create technologies that are more efficient and less polluting than exist today. The report of DOE's Basic Energy Sciences Advisory Committee New Science for a Secure and Sustainable Energy Future is an admirable example of this kind of thinking. Similar thinking should be extended to the application to energy issues of scientific disciplines not usually thought of as energy research. The committee's consideration of the Grand Challenges Research Initiative seems to be in this spirit.

That conclude my remarks, Mr. Chairman, and I would be happy to respond to the committee's questions.

The CHAIRMAN. Thank you very much.

Dr. Bartis, go right ahead.

STATEMENT OF JAMES T. BARTIS, SENIOR POLICY RESEARCHER, RAND CORPORATION, ARLINGTON, VA

Mr. BARTIS. Mr. Chairman, distinguished members, thank you for inviting me to testify on the future of fossil energy R and D and the challenges that must be addressed. My remarks today are based on my own experience in energy policy and technology development including some recent research carried out by the RAND Corporation.

In shaping the overall energy R and D program the greatest emphasis is now being given to reducing greenhouse gas emissions. Fossil fuels, namely petroleum, coal and natural gas are associated with about 90 percent of the greenhouse gas emissions of the United States. The magnitude of the energy transformation that we are about to embark on is enormous. As we go forward with this transformation enhanced support to R and D directed at how we produce and use fossil fuels is crucial to maintaining our goals for reducing greenhouse gas emissions while at the same time assuring our national security and economic well being.

If the only option available to reduce greenhouse gas emissions is to eliminate coal use and turn our backs on this energy resource, consumers in the United States will pay a heavy price. Not only will our electricity rates rise much higher than they would otherwise, but also the price of natural gas will rise dramatically. These higher prices will affect all users including residential and commercial customers. High natural gas prices will also cause certain industries to move production to outside the United States.

In my written testimony I have provided the committee with 13 areas where in my judgment R and D in fossil energy addresses essential national needs. I give highest priority to establishing the technology base so that we can use fossil fuels for electricity generation and greatly reduce greenhouse gas emissions. Most important is enhanced funding and staffing for large and long duration demonstrations of the geologic sequestration of carbon dioxide.

Additionally for both new and existing power plants, R and D needs to be directed at advanced approaches that enable simultaneously carbon dioxide capture and high efficiency electricity production. Considering both research and demonstration needs of the next 10 years. In my judgment, at least two billion dollars per year is a prudent estimate for the annual Federal investment directed at the future of fossil powered generation.

Next I would like to say a few words about a resource that could fundamentally change the game for the United States. Under elevated pressures and low temperatures natural gas forms a solid complex with water known as a methane hydrate. These conditions of pressure and temperature occur off shore and in the Arctic regions including Alaska.

We don't know much about this resource, but we should. Because some of the estimates of the United States resource base are enormous, enough to supply the United States with natural gas for hundreds of years if not longer. If R and D can successfully show the way to develop methane hydrates the national benefits are overwhelming. Greenhouse gas control costs in the power sector would likely be reduced by more than 50 percent.

For energy security both oil shale and coal derived liquids offer the opportunity to significantly enhance our posture without increasing and more likely decreasing greenhouse gas emission as compared to importing crude oil. But this opportunity can, of course, can only be realized if carbon dioxide sequestration can be demonstrated to be commercially and environmentally viable highlighting again, the importance of Federal support for early, long term, long duration demonstration. We have in the United States an enormous oil shale resource, roughly 800 billion barrels. But moving forward with commercial development requires research directed at understanding and mitigating or preventing adverse environmental impacts.

Coal derived transportation fuels are another important opportunity for energy security. RAND's recent work in this area shows that with carbon dioxide capture and sequestration hybrid systems, they use a combination of coal and biomass, offer very large reductions in greenhouse gas emissions at costs that are much lower than using only biomass. For coal derived liquids R and D priorities should center on gaining early, albeit limited, commercial experience. Furthering the technology base for coal biomass hybrid systems is another important research opportunity.

In my written testimony I've also highlighted the importance of strengthening the management of energy technology development providing a stronger role for our research universities in establishing an overall framework that promotes private sector investment in energy R and D. This concludes my remarks. I'd be pleased to answer any questions that you might have.

[The prepared testimony of Mr. Bartis follows:]

PREPARED STATEMENT OF JAMES T. BARTIS[1], SENIOR POLICY RESEARCHER, RAND CORPORATION, ARLINGTON, VA

RESEARCH PRIORITIES FOR FOSSIL FUELS[2]

Mr. Chairman and distinguished Members: Thank you for once again inviting me to testify before this committee, on this occasion to address critical research and development (R&D) needs and opportunities associated with fossil energy. I am a Senior Policy Researcher at the RAND Corporation and specialize in energy technology and policy issues. My doctoral degree is in chemical physics, granted by MIT.

When I joined the U.S. Department of Energy 31 years ago, the challenge was energy security. Although energy security remains an important problem, we now also have a compelling need to reduce greenhouse gas emissions. Each year, the United States releases the greenhouse gas equivalent of over 7 billion metric tons of carbon dioxide. Almost 90 percent of these emissions are associated with the production and use of petroleum, coal, and natural gas, in order of decreasing contribution. So, of course, there is a clear need for research on technologies that allow us to use less of these three fossil fuels, as well as research on other energy sources, such as solar and nuclear energy, that lessen our dependence on fossil fuels. We all hope for a future in which we will depend much less on fossil fuels while simultaneously maintaining our goals for national security and economic well-being. My goal today is to make the case that the path to that future crucially depends on enhanced federal support to research and technology development directed at how we produce and use fossil fuels.

Currently, over 77 percent of the nation's electric generating capacity is based on fossil fuels. Coal plants alone meet nearly 50 percent of our electricity demand. The good news is that we have plenty of coal, more than any other nation. We also have reasonable amounts of natural gas. From an energy security perspective, the electric power sector is today in fairly good shape. From an economic perspective, the costs of generating power from coal and natural gas are quite attractive. But the bad news is that these fossil-fuel power plants account for almost a third of the greenhouse gas emissions released within the United States. If the only option available to reduce greenhouse gas emissions is to eliminate coal use and turn our backs on this energy resource, consumers in the United States will pay a heavy price. Not only will electricity rates rise higher than they would otherwise, but also the price of natural gas will rise dramatically and these higher prices will affect all users, including residential and commercial customers, and will cause industries that depend on natural gas to build plants outside the United States.

Highest Priority: Low-GHG Power Production

For these reasons, our highest priority in fossil energy R&D should be to establish a technology base so that we can use fossil fuels for power production at greatly reduced greenhouse gas emission levels. Such a program needs to be directed at four major goals:

1. Establish the technical, environmental, and commercial viability of geologic sequestration of carbon dioxide in United States, as well as public acceptance of it. The fundamental challenge is developing the knowledge base required to confidently select underground locations that will store large amounts of carbon dioxide for many hundreds of years. This is a daunting challenge. The U.S. Department of Energy has underway an R&D and demonstration program to capture and sequester carbon dioxide emitted by new and existing power plants. In my view, this program has been grossly underfunded at every level of research, from basic studies to demonstration. While considerable progress has been achieved, the planned tests are neither large enough nor of long enough duration sufficient to establish the viability of geologic sequestration. If this program is shortchanged, either with regard to funds or staffing, there is a real possibility that the public will neither gain confidence in the technology nor trust the Department to execute sequestration projects competently. We cannot

[1] The opinions and conclusions expressed in this testimony are the author's alone and should not be interpreted as representing those of RAND or any of the sponsors of its research. This product is part of the RAND Corporation testimony series. RAND testimonies record testimony presented by RAND associates to federal, state, or local legislative committees; government-appointed commissions and panels; and private review and oversight bodies. The RAND Corporation is a nonprofit research organization providing objective analysis and effective solutions that address the challenges facing the public and private sectors around the world. RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

[2] This testimony is available for free download at http://www.rand.org/pubs/testimonies/CT319/
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afford to have the Department's efforts in geologic sequestration of carbon dioxide follow the path the Department took with Yucca Mountain.

2. Develop advanced power-generation technology that enables both carbon dioxide capture and highly-efficient power production from new power plants. We have a problem with current technology, including even our advanced combined-cycle systems. Capturing carbon dioxide and preparing it for transport drains energy from the power plant, increasing coal or natural gas requirements, raising power costs, and increasing the amount of carbon dioxide requiring geologic sequestration. Expanded federal R&D efforts should be considered, especially R&D directed at high-risk, high-payoff opportunities for cost reduction and improved efficiency and environmental performance. Fruitful areas for longer term R&D include advanced high-temperature fuel cells, oxygen production at reduced energy consumption, improved gas-gas separation technologies, higher temperature gas-purification systems, and reduced or eliminated oxygen demand during gasification.

3. Develop carbon capture technology that can be retrofitted onto existing power plants. About 800 GigaWatts of electric generating plants powered by fossil fuels currently operate in the United States. Representing over 77 percent of total electric generating capacity, these are the plants responsible for about a third of U.S. greenhouse gas emissions. Replacing these existing plants will require an investment of many trillions of dollars. Approaches are available for capturing the greenhouse gas emissions from these plants. The R&D challenge is to discover and bring to the market carbon dioxide capture systems that drain less power from the plant and cost less to install and operate.

4. Develop new markets and uses for captured carbon dioxide. If we are going to capture carbon dioxide, it would preferable to put it to some good use. One opportunity already exists, namely, using carbon dioxide to extract crude oil that remains in place after normal petroleum pumping operations cease. Considering advanced methods for enhanced oil recovery, one recent study sponsored by the Department of Energy suggests that as much as 200 billion barrels of petroleum might be recoverable while simultaneously sequestering billions of tons of carbon dioxide. A longer term option is to use captured carbon dioxide to support the production of renewable liquid fuels from sunlight. For example, carbon dioxide can be used to promote rapid growth of algae that is genetically engineered for high-yield oil production.

Increasing Natural Gas Supplies

When it comes to greenhouse gas emissions, not all fossil fuels are equal. When burned, coal yields the greatest amount of carbon dioxide per unit of energy released, while natural gas yields the least. In particular, for the same amount of energy, natural gas releases about 56 percent of the carbon dioxide that would be released using coal. Moreover, because natural gas is an ashfree fuel, it can be used at much higher energy efficiencies than coal. The bottom line: Substituting natural gas for coal generally will halve greenhouse gas emissions. But it would be shortsighted to believe that natural gas can displace coal in power generation without serious adverse economic consequences, unless technology development efforts can greatly expand the amount of natural gas supply resources that can be recovered in North America. Under higher pressures and lower temperatures, natural gas forms a solid complex with water that is known as a methane hydrate. These conditions of pressure and temperature commonly occur offshore and in the arctic regions of North America, including Alaska. At present, we do not have a good understanding of how much natural gas is available to us in the form of these methane hydrates. But we ought to, because some of the estimates of the U.S. resource are enormous, enough to supply the United States for thousands of years.

The National Methane Research and Development Act of 2000 authorizes a federal research program to determine the potential of this resource to contribute to our energy needs. Equally important, that Act also provides the basis for research directed at the potential adverse environmental consequences of these resources. Although the intent of that Act was reconfirmed in the Energy Policy Act of 2005, this research area has never seen adequate funding. In 2007, the Federal Methane Hydrate Advisory Committee reported its findings to Congress.[3] They emphasized the "critical need for more funding" and the detrimental effects of the current level of funding (about $10 million per year) on R&D progress. I fully concur with this find-

[3] Federal Methane Hydrate Advisory Committee, "Report to Congress, An Assessment of the Methane Hydrate Research Program and an Assessment of the 5-Year Research Plan of the Department of Energy," June 2007

ing, as well as with their recommendations for program emphasis, which I quote directly:

> 5. "Field testing of concepts and technologies for producing hydrates economically." Production tests are essential for developing data required for further scientific progress. Here we have an opportunity to build on promising work occurring abroad, especially work done under the support of the government of Japan.
>
> 6. "An accurate assessment of the economic viability of marine hydrates, which exceeds the permafrost resource by several orders of magnitude." Present estimates are extremely speculative. Better estimates are required, especially so we can understand whether this resource can provide the United States and other Nations with a means of deeply cutting greenhouse gas emissions at much lower costs than would otherwise be the case.
>
> 7. "A quantifiable assessment of the environmental impact of possible leakage of methane from uncontrolled hydrate decomposition." Compared to carbon dioxide, methane has a twenty-fold greater greenhouse gas effect. Understanding mechanisms that lead to methane leakage, especially from permafrost, must be a high priority research topic, especially in light of recent observations of methane releases in Arctic regions.

One of the reasons methane hydrate research has not been adequately funded in the United States is the view that any research in this area should be fully carried out and funded by the oil and gas industry. While the oil and gas industry is participating and making R&D investments in methane hydrate research, their investment levels are small, as they should be, given the high risks of success, the uncertainties of obtaining access to the resource, and the long time span required to realize profits. Methane hydrate research should not be viewed as a subsidy to fossil fuel production, but rather as an integral part of the federal strategy to reduce dramatically greenhouse gas emissions.

The Department of Energy also has underway research directed at extracting natural gas from unconventional formations. However, I have not recently had the opportunity to familiarize myself with the details of this program, and therefore suggest that the committee turn to another expert qualified to make a recommendation about critical R&D opportunities or needs in this area.

For Energy Security: Unconventional Liquid Fuels

Over the past few years, RAND has examined opportunities for the United States to produce liquid transportation-quality fuels from abundant domestic resources, in particular oil shale and coal. If carbon dioxide sequestration can be demonstrated as commercially and environmentally viable, our findings indicate that the very large oil shale and coal resources located within the United States offer the potential to produce strategically significant amounts of liquid fuels while not increasing, and more likely decreasing, greenhouse gas emissions as compared to fuels produced from imported crude oil.

Oil Shale.—RAND's work on oil shale was supported by the National Energy Technology Laboratory. The largest known oil shale deposits in the world are located in the Green River Formation, which covers portions of Colorado, Utah, and Wyoming. We estimate that this resource base may eventually yield between 500 billion and 1.1 trillion barrels of useful fuels. The mid-point of this range is 800 billion barrels, which is more than triple the oil reserves of Saudi Arabia.[4] The richest and thickest oil shale deposits are on Federal lands. Protecting the public interest in these oil shale lands is important, considering both environmental issues as well as the potentially profound impact on federal revenues and energy security. Oil shale development falls squarely on the dual purview of this committee: Energy and Natural Resources.

Two weeks ago, the prospects for successful development of oil shale in the United States increased as a consequence of the announcement by the Department of the Interior of a second round of research, development and demonstration leases. This will allow additional small tracts of federal lands to be made available for developing and demonstrating advanced oil shale extraction technologies. The private sector is clearly willing to invest in research directed at the economic extraction of oil shale. For this reason, it is important that any government-supported R&D be directed at areas where the public stake is highest. For these reasons, our recommended priorities for federally sponsored oil shale research are as follows:

[4] For further information, see James T. Bartis, Tom LaTourrette, Lloyd Dixon, D.J. Peterson, and Gary Cecchine, Oil Shale Development in the United States: Prospects and Policy Issues, Santa Monica, Calif.: RAND Corporation, MG-414-NETL, 2005.

8. Conduct research required to understand and mitigate or prevent the adverse impacts of oil shale development. This includes research directed at better understanding of the subsurface environment, assuring safe disposal of spent shale, reducing the uncertainties associated with ecological restoration, protecting water supplies, demonstrating carbon dioxide sequestration in the vicinity of the Green River Formation, and promoting higher recovery yields.

9. Develop the information base required for a federal leasing strategy. This includes regional air quality monitoring, assessments of water availability and quality, and evaluation of governance mechanisms for managing federal lands and meeting infrastructure requirements in anticipation of large industrial development.

10. Provide federal incentives for early commercial experience. The most promising oil shale technologies are not yet ready for large-scale commercial development. Advancing any one of them will require technology development and demonstration efforts costing in the range of hundreds of millions of dollars. While the terms of accessibility to federal lands is important, there are many other instruments, such as investment tax credits for first-of-akind commercial plants, that the federal government should consider to encourage continued private sector investment in advanced oil shale technologies.

Oil shale development is an area where continued policy analysis is required to protect the public interest. At present, oil shale resources have little value. The key to monetizing this publicly owned asset requires that the government put in place a federal land leasing and management framework, and possibly an investment incentive system, that assures that private firms that successfully develop commercially and environmentally viable oil shale technologies be rewarded commensurate with the considerable risk and expense of their efforts.

Coal-derived liquids.—As is the case oil shale, the United States leads the world in the quality and quantity of its coal resources. Dedicating only 15 percent of recoverable coal reserves would yield roughly 100 billion barrels of liquid transportation fuels, enough to sustain three million barrels per day of fuel production for over 90 years.

A few months ago, RAND published its findings on a comprehensive examination of the prospects and policy issues associated with producing liquid fuels from coal in the United States.[5] This work was supported by the National Energy Technology Laboratory and the Air Force. The study showed that coal-to-liquid (CTL) production facilities would emit very large volumes of carbon dioxide and that the viability of a CTL industry in the United States depends crucially on the successful demonstration that carbon dioxide can be sequestered in multiple locations in the United States. Our results show that for CTL facilities, capture and sequestration of carbon dioxide does not add significantly to liquid fuel production costs.

Another important finding of RAND's work on CTL is that liquid fuels produced using a combination of coal and biomass, when combined with capture and sequestration of carbon dioxide emissions, yield lifecycle greenhouse gas emissions that are much lower than those associated with conventional petroleum-based fuels. For example, we found lifecycle greenhouse gas emissions using a transportation fuel from a production facility using 75 percent coal and 25 percent biomass (on an energy input basis) would be roughly 60 percent less than the same fuel derived from conventional petroleum.

These considerations support the following recommendations for research in coal-derived liquids:

11. Promote early, but limited commercial operating experience. Modern CTL technology is ready for initial use in commercial production facilities. The government should consider subsidizing early production experience from a limited number of CTL plants. These early plants should include approaches for managing greenhouse gases. Gaining early experience will facilitate post-production cost improvements, and posture the private sector for the possible rapid expansion of a more economically competitive CTL industry.

12. Develop the technology for combined gasification of coal and biomass. At present the design base for combined use of coal and biomass is weak. Here we are recommending a short duration (roughly, five years) engineering development program involving materials testing and the design, construction, and operation of a few test rigs.

[5] James T. Bartis, Frank Camm, and David S. Ortiz, Producing Liquid Fuels from Coal: Prospects and Policy Issues, Santa Monica, Calif.: RAND Corporation, MG-754-AF/NETL, 2008.

If the United States government decides to promote early investment in CTL production, it should also consider expanding long-term R&D efforts directed at advanced technologies for producing liquids from a combination of coal and biomass. In my judgment, the most fruitful of the R&D opportunities for advancing liquids production are the very same ones that are appropriate for advanced power production, namely lower cost and more energy-efficient means of gasifying coal and biomass, as listed in my second recommendation dealing with low-GHG power production.

Leading the Transition: Hybrid Systems

For automobiles, the concept of a plug-in hybrid vehicle provides a path by which advances in electric vehicle and battery development can immediately be put to use; so also may be the case with power generation. Specifically, the combined use of fossil and solar or nuclear technologies may make for cost-effective and environmentally superior approaches.

For example, one approach to making electricity from sunlight involves building an array of parabolic troughs that heat a working fluid to about 750 degrees F. That working fluid is pumped through a heat exchanger that makes steam in the range of 650 to 700 degrees. This steam drives a steam turbine with the result being electric power. There are two problems with this system. First, the sun isn't always shining. Second, the steam cycle is inefficient because the steam temperature is too low. A possible solution is to use a combination of a solar and fossil energy. In this hybrid concept, the fossil fuel, say natural gas, would be used to raise the temperature of the steam to about 1000 degrees F, which allows much greater efficiency at possibly much lower overall costs.

Another example is nuclear energy. The Department of Energy does not know whether hybrid plants that include both nuclear and fossil technologies can lead to lower cost, more efficient power production. It doesn't know this because of the way that the Department separates and isolates its various technology development efforts. This leads to my final technical recommendation.

> 13. Fossil energy R&D should include exploiting opportunities that promote renewable and nuclear power generation. This area of research is especially appropriate as the amount of intermittent power entering the electric transmission and distribution grid increases.

Strengthening the Management of Energy Technology Development

The foundation of a successful national energy R&D program requires more than sound goals and a financial commitment from Congress. Measures need to be taken to strengthen the management of federal energy technology development efforts.

In the past, the Department of Energy has shown a tendency to downplay the scientific challenges associated with technology development efforts. Congress, the public, and the senior leadership in the Department itself are often provided with program plans with schedules that are too fast, with unrealistically low funding requirements, and with unduly optimistic technology development goals. A consequence of this tendency is that R&D funds are too often directed at large projects that are more "show and tell" than dedicated to advancing technical progress. Quick engineering fixes are attempted while the important research necessary for progress, such as materials research and applied research dedicated to truly understanding problems and developing sound solutions, is left under funded, or in many cases, unfunded.

To remedy this problem, I urge the committee to consider steps to assure that the Department has adequate scientific and technical talent at all levels involving the management or oversight of R&D and technology development. Further, all technology development programs should be required to demonstrate that they are sufficiently addressing the fundamental research issues and materials development issues associated with their efforts.

Our energy technology managers also need to be aware of extensive R&D efforts underway in other nations. In some cases, cost-shared efforts may be highly cost effective and productive. But to bring this wealth of information back to the United States and to afford technology transfer to our firms, Department of Energy technology managers must be able to travel internationally when R&D program needs so dictate.

Strengthening the Institutional Framework for Energy Technology Development

I would like to address briefly the important role that our research universities should have in energy technology development. In my judgment, not enough of the technology development budget has supported university-based research. Moreover, much of the funding that universities do receive is through contractual instruments that undercut the main values that universities offer to the program: creativity, scientific and engineering excellence, and education.

The main reason so little funding goes to universities is that so little of the technology development program funds are devoted to fundamental research issues, as I have previously discussed. Taking care of this problem should move more funding towards our research universities. But to get the most of those funds, energy R&D program managers must take the longer view and build their relationships on grants and other flexible contractual instruments. I urge this committee to take measures so that the energy technology development programs are empowered to and expected to interact with our research universities in this more productive manner.

The central pillar is, of course, the private sector. It will be private firms that will be responsible for manufacturing, distributing, selling, and maintaining the energy systems that will emerge from our national investment in energy R&D. Their participation in the federal program has always been important, but it will be stronger and more focused the sooner the Federal government clearly signals whether or not there will be a price on emitting greenhouse gas emissions, and if so how much; and whether or not the price of automotive fuels will include costs that reflect infrastructure requirements and energy security.

In closing, I thank the committee for inviting me to testify today.

The CHAIRMAN. Thank you very much.

Ms. Wince-Smith, go right ahead.

STATEMENT OF DEBORAH WINCE-SMITH, PRESIDENT, COUNCIL ON COMPETITIVENESS

Ms. WINCE-SMITH. Chairman Bingaman, Senator Murkowski and members of the committee, thank you for inviting me to testify on the critical importance of research and development to addressing America's energy and climate challenge, change, responsibilities and opportunities. The Council on Competitiveness is the only group of corporate CEOs, university presidents and labor leaders committed to achieving United States competitiveness in the global economy. For the past 18 months we have focused on the dual challenges of energy security and sustainability called out in our National Innovation Initiative over 4 years ago.

Even as a Nation with an immense wealth of natural resources we face soaring energy demand, price volatility and supply instability. At the same time pressure is mounting around the world to mitigate greenhouse gas emissions from fossil fuels with the prospect of a 45 percent increase by 2030 driven almost entirely by demand in developing countries. The current trajectory of global energy trends is unsustainable, environmentally, socially and economically.

We know energy and its efficient use is at the heart of industrial production, global supply chains, transportation modes and how we build and use the constructed environment. For this reason the Council launched an ambitious Energy Security Innovation in Sustainability Initiative. Our goal is to shape a private sector/public sector partnership for sustainable energy solutions while supporting the creation of new industries, global markets and skilled jobs here in America.

This work is led by the CEO of Caterpillar, James Owens, the President of Rensselaer, Shirley Ann Jackson and the President of the United Workers of the Utility Union of America, Mike Langford with the steering committee of over 40 leaders from industry, academia and labor. We're very honored that Secretary Chu served on this committee during his tenure at LBL. Our initiative has asked these questions.

What enabling conditions are needed to spur private sector, demand driven innovation in investment?

In essence what is the business case for energy transformation and sustainability?

In September the Council released 100 day Energy Action Plan for the next President named, Prioritize. A copy of which is appended to my testimony. We've outlined a set of interrelated recommendations from energy efficiency, supply diversification, regulatory reform, R and D and work force investments at the frontier. I will focus on the one central to our hearing today that we must spur technological innovation and entrepreneurship by ramping up R and D in its commercialization.

One of the areas that we strongly support are creating regionally based R and D test beds and large scale commercial pilots for deploying new energy technologies and systems. These test beds must address issues from the knowledge and application continuum all the way to industrial process of scale and scope. We want to solve the big game changing problems, next generation storage, battery density, carbon capture sequestration, solving clean coal and nuclear waste and storage.

These test beds should be multidisciplinary, stakeholder and really be focused at the region. We have to be ready. Be poised to deploy innovations.

Now we know of course that America is famous for being the laboratory to the world but we also want to be the place that captures the manufacturing of these new innovations. We remember how in the 1970s through the 1990s we lost our flat panel display market while we created all the underlying technologies. We certainly don't want that to happen in our energy transformation.

Manufacturing right now is on the cusp of a tremendous transformation. Manufacturing and services are emerging. We have production and distribution networks spanning the globe, digitally infused manufacturing operations and science based manufacturing. Clearly we want to ensure that we use the tools of science and the tools of technology that support these challenges.

So the graph I've put up really shows the critical importance of our government's high performance computing capabilities that support our research, our government missions and industrial competitiveness. We know that high performance computing presents a huge, competitive advantage to our companies as well as to solving these problems, the Nation that out computes will out compete. Other nations are rapidly using these capabilities but still the United States and Japan are the leaders in both the production of HP systems and using them for competitive advantage.

So I would urge the committee as we go forward to really invest in the R and D. That we accelerate our high performance computing tools, we use this to solve these problems and we ensure that America will be, not only the R and D leader, but the manufacturing powerhouse of the world in the energy transformation. Thank you very much. I'm pleased to answer questions.

[The prepared statement of Ms. Wince-Smith follows:]

PREPARED STATEMENT OF DEBORAH L. WINCE-SMITH, PRESIDENT, COUNCIL ON COMPETITIVENESS

Chairman Bingaman, Senator Murkowski and members of the committee, thank you for inviting me to testify today on the critical importance of research and development to addressing America's energy and climate change challenges.

I'd like to start by providing a little background about the Council on Competitiveness—who we are, and how we operate—and on our Energy Security, Innovation & Sustainability Initiative, a top Council priority. The Council on Competitiveness is the only group of corporate CEOs, university presidents, and labor leaders committed to enhancing U.S. competitiveness in the global economy. Our scope of issues reflects many factors that affect a nation's ability to compete—ranging from the business environment for innovation and advancing key enabling technologies, to building a world-class workforce and igniting regional innovation through entrepreneurship.

We have been fortunate to have some of America's best executives as Council leaders. Our current chairman is Chad Holliday, chairman of DuPont. The Council carries out its agenda, and shapes the debate through several mechanisms:

- We analyze emerging challenges.
- We convene leaders who can envision and implement solutions.
- We catalyze and organize action.

We strive to represent the voice of competitiveness and innovation in a wide range of technology, economic, trade, education, and international decision-making fora. For the past 18 months, we have focused this voice on the dual challenges of energy security and sustainability. These challenges were called out in the Council's National Innovation Initiative four years ago and the urgency for action has only grown in that time.

ENERGY SECURITY, INNOVATION AND SUSTAINABILITY

The Council believes that energy security and sustainability are two of the defining and intertwined challenges of our time. For virtually every country, access to affordable energy is a basic need for economic growth, social development, improved standards of living, and increasingly for national security. However, neither an affordable nor a reliable supply of energy is a given for any country. As committee members well know, even as a nation with an immense wealth of natural resources, we face soaring energy demand, price volatility, and supply instability. At the same time, pressure is mounting around the world to mitigate greenhouse gas emissions from fossil fuels—with the prospect of a 45% increase in emissions by 2030, driven almost entirely by developing countries.[1]

Without access to cost-effective cleaner energy solutions, developing economies will have no alternative but to increase their dependence on the most rudimentary fossil-fuel technologies, contributing significantly to increased pollution and environmental damage. To summarize, the current trajectory of global energy trends is unsustainable—environmentally, socially, and economically. They are impacting:

- the fundamental ability of American industry to compete in the global economy
- the political ability of our government to play an international leadership role
- the capacity of our military to carry out its missions

Energy security and sustainability are now first-tier economic, national security, and competitiveness concerns. It is, therefore, inevitable that the world will undergo a systems transformation in the way we use and produce energy. As this country moves toward sustainable energy policies and programs, the Council does not believe there is an unavoidable trade-off among economic growth, energy savings, and environmental interests. Indeed, the pending systems transformation offers an opportunity to integrate energy security, sustainability, and competitiveness.

For this very reason, the Council has launched an ambitious Energy Security, Innovation & Sustainability (ESIS) Initiative. Our goal is to shape an action agenda to drive private sector demand for sustainable energy solutions, while supporting the creation of new industries, markets, and jobs. This initiative is led by James Owens, CEO of Caterpillar; Shirley Ann Jackson, President of Rensselaer Polytechnic Institute and Vice Chair of the Council on Competitiveness; Mike Langford, President of the Utility Workers Union of America; and a steering committee of 40 CEOs, university presidents, labor leaders and national lab directors, the ESIS is focused on:

[1] International Energy Agency, World Energy Outlook 2008, IEA/OECD, Paris (2008).

- The critical link between energy security and national competitiveness
- Identifying drivers of private sector investment in sustainable energy
- Clarifying and publicizing the business case for changing how the private sector thinks about and uses energy
- Examining what leading companies are doing to integrate energy security and carbon issues into their business strategies for productivity and competitive advantage

Most importantly for today's discussion,

- developing a policy and regulatory framework that will unleash American investment and innovation across all sectors of the economy

We know:

- here is no "silver bullet"
- There is no single technology that can solve the problem
- There is no one policy or regulatory measure that will transform our energy system, protect the environment and mitigate climate change
- We will need every resource we have—coal, oil, gas, nuclear, solar, wind, biomass, ocean and hydropower—AND increased energy efficiency to meet future energy demand.

We also know that we have a tremendous opportunity before us. In fact, these challenges have created a perfect storm for innovation. We can move to a new era of technological advances, market opportunity, and industrial transformation if we can successfully unleash the investment and innovation potential of the private sector to meet the challenges and seize the opportunities arising from these new public-private partnerships.

The ESIS initiative has engaged over 200 of the nation's leading experts from a wide range of perspectives and asked them what enabling conditions are needed to exist to spur private sector innovation and investment. This work led to the September release of the Council's 100-Day Energy Action Plan for the next President and Congress named Prioritize, a copy of which is appended to my testimony.

Prioritize includes 18 specific recommendations, many of which are relevant to this committee's jurisdiction, but I will focus on one that is central to today's hearing: America must spur technological innovation and entrepreneurship by ramping up investment in energy R&D and commercialization. This means at least tripling the current federal investment in basic and applied energy R&D; enhancing public-private partnerships with baseline federal funding—to be matched by state and private sector investments—and creating regionally-based R&D test-beds and large-scale commercial pilots for new energy technologies.

Central to this recommendation is the idea that we must be poised to deploy new ideas and innovations that come from the significant new investment in energy research into scalable products, goods and services. Research must be viewed as encompassing basic, applied, development and test beds. If we do not have in place the infrastructure to reap value from our investment, you can rest assured another country will. When that happens, the jobs and intellectual property will be lost; as well as the component subsystems leading to a hollowing out of the innovation enterprise.

AMERICA MUST NOT BECOME JUST THE LABORATORY TO THE WORLD—RENOWNED FOR OUR IDEAS, BUT BLEEDING AWAY JOBS, INDUSTRIES AND OPPORTUNITY.

As we enter a new era of technological innovation, driven by the twin challenges of energy security and climate change, we must be vigilant in ensuring that we support these nascent industries here at home. We do not want to repeat the errors of our past when despite having achieved scientific and technology breakthroughs in liquid crystal, plasma and other flat panel display technologies, we ceded market leadership to countries like Japan and Korea, as they rapidly scaled up their high quality manufacturing ability and captured the global display market.

We have learned that we cannot divorce our investments in R&D from our efforts to support each stage of the manufacturing continuum. We must design-in manufacturing considerations upfront in the innovation process. We must ensure that we have the appropriate regulatory and financing framework in place to allow our entrepreneurs to move agilely from testing and pilots to manufacturing and large scale system deployment.

THE EVOLUTION OF MANUFACTURING

As the 20th century drew to a close, rising global competition and the broad opening of global markets challenged U.S. manufacturers. As a result, there has been continuing concern about the offshoring U.S. manufacturing and the loss of U.S. manufacturing jobs.

With the growing strength of newly-developing low-cost competitors such as China, there are many who fear that U.S. manufacturing will spiral into further decline. It is becoming increasingly clear that the United States cannot compete with commodity products and low-wage mass production systems.

Nevertheless, I believe we must put aside the growing perception that America will inevitably lose its manufacturing edge. Instead, prepare for a shift in manufacturing that embraces:

- production and distribution networks that span the globe
- digitally-infused manufacturing operations, and
- science-based manufacturing

These could form a new foundation to support a revitalized manufacturing base, and U.S. competitiveness in the very highest-value production activities.

Long-term national and economic security in the United States critically depends on our having innovative and agile manufacturing capabilities. Current economic conditions and energy security challenges have only heightened the need to accelerate competitive advantages for U.S. manufacturing companies in the global marketplace. Manufacturers can maintain their global leadership position only through technological differentiation, not through labor cost advantage.

While energy-saving investments must compete for scare capital often against near-term priorities, the potential for substantial returns over the long run is real—lower production costs, lower environmental compliance costs, reduced waste, and improved productivity when production inefficiencies are eliminated.

Then there are the rewards of helping customers control their own costs by redesigning products to reduce the energy they consume Revenues from GE's Ecomagination line of energy efficient, environmentally-friendly products and services have grown to $17 billion (in 2008) since it was launched 2005. The company invested $1.4 billion in cleaner technology research and development in 2008 and recently reported that its portfolio of 70 Ecomagination-certified products is four times the number of products it offered in 2005. Still, too many U.S. companies remain underinvested in energy efficiency, and few have adopted strategies that treat energy as a vital dimension of business.[2]

Wal-Mart launched a new green-packaging scorecard in February 2008. By August of last year, the scorecard software system included over 8,000 vendors and more than 170,000 products. Because Wal-Mart is one of the most powerful forces in the world's supply chains, this initiative is a potential game changer in the design of packaging.[3]

Yet, conventional wisdom holds that manufacturing is characterized by the four D's—dirty, dumb, dangerous and disappearing. Nothing could be further from the truth. Modern American manufacturing, which has dramatically changed from its earlier definition, is growing—in size, complexity and market importance. For the past 50 years, the value of manufacturing output has increased by 3.7 percent per year.[4] Modern American manufacturing profits have outperformed those of other sectors and manufacturing productivity increased faster than the national average.[5] In other words, a great many American manufacturers have made major adjustments to the changing needs of the marketplace and are doing very well. But they cannot do it alone.

American public officials, opinion leaders and investors also need to understand and vigorously support these changes if we are to regain and retain our international leadership position. If America fails to adapt, we risk losing this critical underpinning of our economy and failing to reap the value from the investments in next generation energy technologies. America's edge lies with forward looking, high-value manufacturing that looks well beyond traditional assembly and fabrication of products. Consider the new paradigms of manufacturing:

Mass Production has evolved to Mass Customization.—As more countries enter the global marketplace, the competition has shifted rapidly to new kinds of added value that require new kinds of skills. Just as basic product design has moved beyond the work of draftsmen with pencils and T-Squares to highly sophisticated com-

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[2] "GE's 2008 Ecomagination Revenues to Rise 21%, Cross $17 Billion," GE News Center, October 21, 2008. http://www.genewscenter.com/content/Detail.asp?ReleaseID=4266&NewsAreaID=2

[3] Connolly, Kate Bertrand. "Wal-Mart's Scorecard Drives Sustainable Packaging," FoodProcessing.com, August 2008. http://www.foodprocessing.com/articles/2008/371.html

[4] Strauss, William A. "Is the U.S. Losing Its Manufacturing Base?" Presentation at 61st Annual Meeting of the Midwestern Legislative Conference, Chicago, IL, August 21, 2006.

[5] Ibid.

puter driven Cad-Cam programs, more of the value-add within manufacturing began to come from the activities integrally associated with production: marketing, financing, customer service and managing quality, variety, customization, innovation, convenience, novelty and speeded operations. Each of those affects not only the quality of the product being made and its competitive price, but its value to customers as well. All of which are key elements in the process of modern manufacturing.

Services and Manufacturing have merged.—The Council's National Innovation Initiative highlighted this convergence. Surveys by Deloitte Research found that the average profitability of service operations is more than 75 percent higher than overall business unit profitability. The most profitable service businesses (the top 25 percent) are more than three times as profitable as the average business unit. Across the manufacturing companies that were studied, what have traditionally been considered service revenues average just over a quarter of total revenues but deliver 46 percent of the profits.[6] For many producers, there would be little or no profitability without the so-called service business. In other words, modern manufacturers have actually integrated elements of the service sector into the manufacturing process in order to maximize their competitiveness, and public policy must recognize and encourage that process.

High Value Jobs.—Another way to look at this change is that approximately 75 percent of jobs in the United States are classified as service sector jobs, but a significant portion of these jobs, in reality, remain part of the extended manufacturing enterprise.[7] As manufacturing companies restructured—outsourcing (not offshoring) functions that could be provided most cost-effectively outside the company—many jobs that did not directly deal with fabrication were simply reclassified as service jobs even though they remained as essential parts of the modern manufacturing process. It is also essential to note that in different areas of the country new jobs in the modern manufacturing sector have been created as new small and medium-sized companies are established to fill continuing and growing needs. America's data collection systems, a relic of an industrial economy, simply do not capture or reflect this integration of services and manufacturing. Knowing the importance and the changed nature of manufacturing are critical steps for policymakers, but not the whole story. As we stand ready to tackle the challenges of energy security and sustainability, we must ensure that America's federal investments in research and development and America's premier research capabilities are leveraged to provide the strongest possible outcomes. A primary example of this is the U.S. Government's high performance computing (HPC) capabilities.

THE CRITICAL AND TRANSFORMATIONAL ROLE OF HPC IN MANUFACTURING

The use of high performance computing for modeling, simulation, and analysis has already provided a competitive advantage for many of the manufacturing Fortune 50. These companies employ in-house advanced computing and have access to high performance computing hardware, software, and technical resources through partnerships with national laboratories. Many of these companies recommend that adoption of modeling, simulation, and advanced computing be accelerated throughout the U.S. manufacturing sector. For example, Pioneer Hi-Bred, a DuPont company, uses HPC to manage and analyze massive amounts of molecular, plant, environmental and farm management data, allowing them to make product development decisions much faster than by using traditional experiments and testing alone. For Pioneer, the result has been faster improvement in new seed products, staying ahead of the competition, a major jump in innovation and productivity, and the ability to help meet some of the world's most pressing demands regarding the availability of food, feed, fuel, and materials.[8]

The Transition to "Simulation-Based Manufacturing".—A substantial effort toward wider adoption of modeling and simulation requires the commitment of intellectual capital, computer hardware and software for complex problem solving, and other resources from among the diverse advanced computing assets spread across the nation's regions, States, and advanced computing centers. This truly successful national initiative will leverage these vital resources from a new public-private partnership to bolster the U.S. manufacturing sector.

New Manufacturing "Call to Action" on the 21st Century Manufacturing Enterprise.—To these ends, the federal government should issue a "call to action" to U.S. manufacturing sector leaders and create a national manufacturing initiative enabled

[6] Koudal, Peter. The Service Revolution in Global Manufacturing Industries, A Deloitte Research Global Manufacturing Study, (2006). www.deloitte.com

[7] Council on Competitiveness, Thrive: The Skills Imperative, Washington, D.C. (2008).

[8] 9 Interviewed Mark Cooper, Pioneer Hi-Bred International, Inc., and Lane Arthur, DuPont, in June 2008.

by advanced computing. These leaders in advanced computer-enabled design and manufacturing should be asked to leverage their expertise in modeling, simulation, and analysis and partner with the federal government to improve U.S. manufacturing competitiveness. The outcome of this call to action will be to accelerate and broaden the use of modeling and simulation, to increase penetration of these tools into smaller companies (pushing these tools further down into the supply chain), to solve the biggest complex problems with the latest techniques, and compete through innovation.

Through the national laboratory system, the federal government offers the greatest scientific and engineering resources, computer assets, and research software to be deployed for the initiative. Importantly, the United States and Japan are the only significant manufacturers of HPC machines—an incredible advantage that must be utilized for economic growth. To succeed, the initiative should also call upon, bring together, and leverage (all of) the nation's most advanced computing resources—state to state, region to region, center to center.

COMMITTEE DRAFT LEGISLATION

Thank you also for the opportunity to comment of the draft legislation on Energy Research and Development. We strongly endorse the proposal to double funding for applied energy research and development. The Council further urges the committee to act upon the recommendations made in Prioritize to triple both basic and applied energy research and development.

The Council applauds the energy workforce development provisions as proposed by the committee, as they also are closely aligned with the intent of our recommendations in Prioritize. We urge the Committee/Congress to go further by adopting the Council's recommendations to create a $300 million Clean Energy Workforce Readiness Program. This program should be specifically designed to foster partnerships between the energy industry, universities, community colleges, workforce boards, technical schools, labor unions, and the U.S. military, with the goal of attracting, training, and retaining the full range of skilled workers for America's clean energy industries.

At the very least, the Department of Labor should be required to assess, classify and widely publicize the demand-driven needs for energy-related occupations. It should also be required to align federal workforce investment programs and state-directed resources to support skills training and career path development in energy fields for American citizens.

With regard to the scholarships and fellowships proposed, the Council would urge the committee to consider making these portable (controlled by the student) to ensure the maximum flexibility for the students to follow the most current thinking and technologies in these areas.

Under the section on Grand Challenges Research Initiative, the Council would propose that a requirement for small businesses representation in the consortia be included.

CONCLUSION

Thank you again for this opportunity to provide testimony on this important topic for American competitiveness. The committee's support for research and development, including the enactment of the America COMPETES Act and recent increases in the stimulus package speaks to the forward-looking vision of the Senators sitting on the dais. I would only urge that you dedicate the same passion to ensuring the infrastructure exists and is utilized to generate value in the form of jobs, new businesses and new opportunities from these critical investments.

The CHAIRMAN. Thank you very much.

Professor Corradini.

STATEMENT OF MICHAEL L. CORRADINI, CHAIR, NUCLEAR ENGINEERING AND ENGINEERING PHYSICS, UNIVERSITY OF WISCONSIN, MADISON, WI

Mr. CORRADINI. Thank you, Mr. Chairman and members of the committee for inviting me today. I'm currently chair of Nuclear Engineering Program at University of Wisconsin, Madison. I am from New Mexico originally, so thanks for remembering.

In 2007 I was a member of the National Academy's review of the DOE's Office of Nuclear Energy and recommendations for future R and D activities. So today I'd like to address the committee on this particular issue. I'll note that Bob Fri was the chairman of the committee. So if I do it wrong, he'll tell me.

Growing energy demands, emerging concerns about carbon dioxide emissions in a sustained period of successful operation of the existing fleet of nuclear power plants really have gained a renewal of interest in nuclear power in the United States. Clearly I think nuclear energy can be an important component in addressing these issues. But we have to ensure that our nuclear R and D investments are aligned to the technological challenge associated with deploying new plans and developing a sustainable nuclear fuel cycle.

The Office of Nuclear Energy in the United States DOE has been the major agent of the government's responsibility for advancing nuclear power. Parenthetically if you look back 10 years ago, it was zero in terms of R and D research. Now we're sitting at about 400 million in the current, pending Omnibus Appropriations bill.

In FY2006, the President's budget requested that funds be set aside for a study by the National Academy to conduct a review of nuclear energy and to recommend priorities among the programs given constrained budget levels. The programs to be evaluated were NP 2010 or Nuclear Power 2010, the Gen IV Reactor Development program, Nuclear Hydrogen Initiative and the Advanced Fuel Cycle Initiatives as well as Idaho National Labs facilities. I believe its recommendations are still very relevant in the prioritization and phasing of nuclear R and D investments. I'd like to review some of these and give you some personal comments.

First, NP 2010, the Nuclear Power 2010 program was established by the United States DOE in 2002 to support the near term deployment of new nuclear power plants. NP 2010 is a joint government industry 50-50 cost share with very clear objectives. It's actually achieved a very good working relationship between DOE and industry.

The selection of the projects funded is really appropriately market driven. There's really a strong focus on demonstrating a regulatory process, finalizing and standardizing the advance LWR reactor designs and implementing the 2005 Energy Policy Act Standby Support Divisions. This has lead to a large number of combined license submittals to the NRC.

Our committee concluded that successful completion of the NP 2010 program should be the Office of Nuclear Energy's highest priority. I'd only emphasize that very strongly. We need to continue success in the present to guarantee success in the future of nuclear power.

DOE has also begun to evaluate the need for a reinvigorated R and D program to improve the performance of existing and advanced light water reactor power plants. The National Academy Study supports such an R and D program as a shared cost effort separate from NP 2010. For example, the life after fifty focus for plant life extension is a good example of a research focus.

For Gen IV, DOE has engaged in other government wide ranging efforts to develop advanced, next generation nuclear energy systems, so called generation IV or Gen IV systems. During 2002 to

2005 time period, the Gen IV program's primary goal was to develop the next generation nuclear plant which focused on high temperature process heat, an innovative approach as to produce energy products that might benefit the transportation and chemical industry. I included a figure.

I don't have a chart, but you have a figure in the testimony that actually identifies in detail the gas cooled, graphite moderated reactor concept. Both the reactor at the plant and the advanced fuel is being considered. The NGNP program has well established goals, decision points and technical alternatives.

The program requires predictable and steady funding. Our committee recommended that the nuclear energy sustain a balanced R and D portfolio beyond just the NGNP, but for other advanced concepts. Again, I included a figure. For example, funding and prioritization for grid appropriate reactors, that is smaller reactors that could be in various other markets both in the United States and abroad.

Since 2002 the United States has also been conducting a program of spent fuel reprocessing R and D in a program called the Advanced Fuel Cycle Initiative or AFCI. In 2006, the National Academies Committee was established. DOE at the same time, about, unveiled GNEP, the Global Nuclear Energy Partnership as a broad initiative to facilitate worldwide expansion. The AFCI Research Program was absorbed into GNEP with an additional component of rapid deployment of commercial reprocessing/recycling facilities.

The overall concept has many positive features especially in the international arena at a time when many nations are actively considering expanded their nuclear energy portfolio. However the committee was not persuaded that the GNEP was worth pursuing as presented to the committee at that time. We felt the program was premised on an accelerated deployment strategy creating large technical and financial risks and premature narrowing of technical options. Also we felt there was insufficient external input and peer review.

Nonetheless the committee believes and I continue to believe that the program similar to the original AFCI research program is very worth pursuing. Such a program should be paced by national needs including economics, technological readiness, energy security and other factors. The committee recommended a more modest, long term program where engineering efforts including new research scale experimental capabilities that can reveal innovative approaches to nuclear fuels, materials, modeling. We had others on the panel even mentioning high performance computing, power systems and reprocessing.

Finally to end off let me talk about the human infrastructure. Our success in addressing all of these challenges will ultimately be predicated on our ability to educate and train the next generation of nuclear scientists, engineers and nuclear related technicians. There's good news. Undergraduate enrollments continue to increase in several new programs.

In my third figure I gave you essentially a little histogram of how we've grown substantially in nuclear engineering related fields, both at the undergraduate and graduate level and a growth in nuclear engineering departments around the country. A good half dozen have started in the last few years. However the Federal funding from a Federal funding standpoint, the last few years have been a period of significant uncertainty.

DOE, in 2006, completely eliminated the Nuclear University Research Programs. Since that time Congress has added back funding in the Appropriations process and ultimately shifted a significant portion to the Nuclear Regulatory Commission. I parenthetically say that's primarily with the support of many of the members on this committee, including you Mr. Chairman.

Last year DOE committed to allocate 20 percent of its R and D funding for work to be performed at universities. Most recently in the pending Omnibus Appropriations bill, the integrated university program structure has been created which provides DOE, NNSA and NRC to collaborate in funding both mission directed research, jointly coordinated programs that support the overall discipline as well as infrastructure such as research reactors. This—I really feel that Congress should continue this structure and support stable funding portfolio.

So in closing let me just say that the programmatic building blocks already exist for a strong, relevant portfolio of research, investment in nuclear R and D. Congress should build on these existing programs in a stable, predictable manner and hopefully avoiding precipitous changes in funding. Ultimately no matter what one's position is on the issue, the fact is in my view and it's a strong view that nuclear energy will be a prominent fixture of our energy, environmental and national security activities for the foreseeable future.

So I'm open to questions as you see fit.

[The prepared testimony of Mr. Corradini follows:]

PREPARED STATEMENT OF MICHAEL L. CORRADINI, CHAIR, NUCLEAR ENGINEERING AND ENGINEERING PHYSICS, UNIVERSITY OF WISCONSIN, MADISON WI

Good morning, Mr. Chairman and members of the committee. Thank you for inviting me here today. I am currently chair of the Nuclear Engineering and Engineering Physics program at the University of Wisconsin, Madison. I am also involved in a number of national activities in nuclear energy for the National Academies, the Department of Energy and the Nuclear Regulatory Commission. In 2007, I was a member of the National Academies review of the DOE Office of Nuclear Energy and recommendations for future R&D activities in nuclear energy. Today, I would like to address the committee on this particular issue of nuclear energy R&D as well as human resources related to nuclear science & engineering.

Growing energy demands, emerging concerns about carbon-dioxide emissions from fossil fuel combustion, and a sustained period of successful operation of the existing fleet of nuclear power plants have resulted in a renewal of interest in nuclear power in the United States. Clearly, nuclear energy can be an important component in addressing these issues. However, we must ensure that our nuclear R&D investments are aligned to the technological challenges associated with deploying new plants and developing a nuclear fuel cycle that is sustainable as well as proliferation-resistant.

The Office of Nuclear Energy (NE) of the U.S. Department of Energy (DOE) has been the major agent of the government's responsibility for advancing nuclear power. One consequence of the renewed interest in nuclear power has been rapid growth in the NE research budget. NE R&D funding has increased from less than $5 million in Fiscal Year 1998 to almost $400 million in the pending FY 2009 Omnibus Appropriations Bill.

In FY 2006 the President's Budget requested that funds be set aside for a study by the National Academy of Sciences to conduct a review of the Nuclear Energy research programs and budget, and to recommend priorities among the programs given the likelihood of constrained budget levels in the future. The programs to be evaluated were Nuclear Power 2010, the Generation IV reactor development program, the Nuclear Hydrogen Initiative, the Advanced Fuel Cycle Initiative (which temporarily evolved into the Global Nuclear Energy Partnership—GNEP), and the Idaho National Laboratory facilities program. I served as a member of this committee and I believe its recommendations are still very relevant in the prioritization and phasing of our future nuclear R&D investments.

NP 2010 PROGRAM

The Nuclear Power 2010 (NP 2010) program was established by the U.S. Department of Energy (DOE) in 2002 to support the near term deployment of new nuclear plants. NP 2010 is a joint government—industry 50/50 cost-shared effort with clear objectives. A good working relationship exists between DOE and industry. The selection of the projects funded is appropriately market driven and there is strong focus on demonstrating the regulatory processes, finalizing and standardizing the advanced reactor designs, and implementing the 2005 EPACT standby support provisions, all of which are essential activities and have led to a large number of Combined License submittals to the NRC. Our committee concluded that successful completion of the NP 2010 program should be the Office of Nuclear Energy's highest priority. DOE should also immediately initiate a cooperative project with industry to identify problems that experience shows can arise in actual construction and startup of new plants and define best practices for use by the industry.

Recently, DOE has also begun to evaluate the need for a reinvigorated R&D program to improve the performance of existing nuclear plants. The NAS study supports such an R&D program in a cost-shared effort separate from NP 2010.

GENERATION IV PROGRAM

DOE has engaged other governments, in a wide-ranging effort for the development of advanced next generation nuclear energy systems, known collectively as "Generation IV" (or Gen IV). The goals of Gen IV are to widen the applications of nuclear energy; enhance the economics, safety and physical protection of new reactors; and improve the fuel cycle waste management capability and proliferation resistance in the coming decades.

During the 2002 to 2005 time period, the Gen IV program's primary goal was to develop the Next Generation Nuclear Reactor (NGNP) focusing on high-temperature process heat and innovative approaches to produce energy products that might benefit the transportation and chemical industry, such as hydrogen. The current design focuses on a gas-cooled and graphite-moderated reactor. (Figure 1)*

The NGNP program has well-established goals, decision points and technical alternatives. The 2005 EPACT identified two key decision NGNP points; licensing by the NRC and plant operation no later than 2021. A major risk in this program is that the current business plan does not match government funding. The program requires predictable and steady funding, and its goals and timetable should be in harmony with available funding.

Our committee also recommend that NE sustain a balanced R&D portfolio in new Gen IV advanced reactor development concepts; e.g., funding and prioritization for grid-appropriate reactors (Fig. 2).

ADVANCED FUEL CYCLE INITIATIVE AND GNEP

Since 2002, the United States has been conducting a program of spent fuel reprocessing research and development in a program called the Advanced Fuel Cycle Initiative (AFCI). In March 2006, after the National Academies committee was established, DOE unveiled GNEP, a broad initiative intended to facilitate a worldwide expansion of nuclear energy while minimizing the risks of proliferation. GNEP would require the US to be an active participant in the community of nations that recycle fuel in order to meet the fuel and waste disposal needs of other "user" nations.

Thus, the AFCI research program was absorbed in GNEP along with rapid deployment of commercial reprocessing, recycle facilities and fast reactors. The overall concept has many positive features, especially in the international arena. At a time when many countries are actively expanding their nuclear energy portfolio, there are strong energy and national security arguments for continued U.S. leadership in the field. However, the committee was not persuaded that the GNEP program was worth pursuing, as presented to the committee by DOE. We felt the program was premised on an accelerated deployment strategy, creating large technical and finan-

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*Figures 1–3 have been retained in committee files.

cial risk, and premature narrowing of technical options. Also, there was insufficient external input and independent peer review.

Nonetheless, the committee believes that a program, similar to the original AFCI research program, is worth pursuing. Such a program should be paced by national needs, including economics, technological readiness, national security, energy security, and other factors. It should not include construction of large demonstration or commercial scale facilities. Rather, the committee recommended a more modest and longer term program of applied research and engineering effort including new research-scale experimental capabilities that reveal innovative approaches for fuels, materials, modeling, power systems and reprocessing.

UNIVERSITY NUCLEAR SCIENCE AND ENGINEERING INFRASTRUCTURE

Our success in addressing U.S. nuclear R&D challenges—whether its nuclear energy, nonproliferation, or detection-will ultimately be predicated on our ability to educate and train the next generation of nuclear scientist, engineers.

There is good news—undergraduate enrollments continue to increase and several new programs have been created (Figure 3). However, from a federal funding standpoint, the last few years have been a period of significant uncertainty. In 2006, DOE proposed the complete elimination of nuclear university programs. Since that time, Congress has added back funding in the appropriations process (with the support of many members of this committee, including you, Mr. Chairman), and ultimately shifted a significant portion of the program to NRC. Last year, DOE committed to allocate 20 percent of its R&D funding for work to be performed at universities. Most recently, in the pending Omnibus Appropriations Bill, an Integrated University Program structure has been created, which provides DOE, NNSA, and NRC with funding to support both mission-directed research, and a jointly coordinated program that supports the overall discipline and infrastructure such as research reactors. The Omnibus language, combined with DOE's "20% Solution," is a strong package of on-going stewardship. Congress should continue this structure, with stable funding portfolio.

OVERSIGHT

As a counterbalance to the short-term nature of the budget process, we also recommended that DOE adopt an oversight process for evaluating the adequacy of program plans, evaluating progress against these plans, and adjusting resource allocations as planned decision points are reached. The senior advisory body for NE was the Nuclear Energy Advisory Committee, and a modified committee seems the obvious starting point for reestablishing proper oversight; to ensure its independence, transparency, strategic issues.

The CHAIRMAN. Thank you all very much for your excellent testimony. I'll ask a few here. I'm sure the others will as well.

Dr. Crabtree, let me start with you. You talk in your testimony about this energy research frontier centers as a way to bring together industry and universities and national laboratories to address fundamental energy research hurdles. Could you describe what you think is needed there?

I mean, we've got work, for example in the area of solid state lighting. We've got work going on I know at Sandia National Laboratory. I'm sure they're probably going on at other national laboratories as well and in universities.

What more do you see that would be useful for us to do in that area or any of the other areas you're focused on here?

Mr. CRABTREE. So that's actually an excellent question and an excellent topic, solid state lighting. You may know that the incandescent light is 5 percent efficient, fluorescents are 20 percent efficient and solid state lights can be 50 or even 70 percent efficient. So the payback in terms of energy efficiency is huge.

The—when you consider that 22 percent of electricity goes for lighting, you see that the amount is huge. The impact may be very, very large. The road blocks to solid state lighting are really to produce white solid state light.

So we can already produce red solid state lights with 75 percent efficiency. The trick is to make it white. To make it white you have to add three colors together, red, blue and green.

So we have to develop the blue and the green solid state lighting. That's mainly a matter of adjusting the composition of semiconductors with up to, say, four or even five elements present to make the band gaps correct for emitting these red—the blue and the green light. You have to do this without sacrificing the structural perfection and the electron mobility which leads to the high efficiency. So that's why it's such a difficult problem.

But there are also engineering problems associated with that as well. You have to make a package in which all three of these semiconductor elements can be put in the same package and extract the light in the right ratios to make white light. Now that's a very practical engineering point of problem.

So it's a challenge that really lends itself to basic materials research to understand the structure in band gaps. Also to engineering research to make the package that includes all three of these semiconductor elements and allows the light to come out. There's an industrial side, of course. You have to bring it to market.

So the EFRCs in that example could combine these three sectors of research. So the basic research which could come from universities and national labs, engineering which could come from national labs and industry and industry to do the deployment to really solve the problem. It's within reach. The progress has been dramatic in the last 10 years. I think with continued effort it will certainly yield.

The CHAIRMAN. Very good. Mr. Fri, let me ask you. As you point out you're involved in this current study which is being done about our energy needs, our energy challenges at the National Academy.

Do you see that study as concluding significant changes in policy that we ought to consider adopting here in Congress or are these—is this just much more a prioritizing of funding areas or what do you see coming out of that study? We're in the awkward circumstance of getting ready to write an energy bill. In the process of trying to write an energy bill and not knowing whether or not it's going to be in sync with what the National Academy thinks ought to be happening in this area.

Mr. FRI. Mr. Chairman, the study has two phases. The first phase is the one that is about—is in the final throws of being completed and made available. The first phase is what you might just call a truth telling phase.

To look at all of the range of technologies, to understand on a comparable basis their cost performance and reasonable expectations for deployment over two time periods, a near term time period, the next 10 years or so and then a 10 or 15 year time period after that. So it provides, I think, a framework of reasonable expectations for technology around which a research program and a deployment program can be built. The key policy issues are meant to be addressed in the second phase of the study which so far as I know has not been fully put together yet.

But the kinds of questions that the Congress may have are, in part at least, intended to be addressed.

The CHAIRMAN. What is the timing on that second phase? When would that be completed?

Mr. FRI. I don't think it's—I don't know is the answer to that question.

The CHAIRMAN. Alright. We have a very impatient President. I just thought I'd mention that. I have noticed that, myself.

Mr. FRI. We've noticed that.

The CHAIRMAN. Yes.

Mr. FRI. I know that Dr. Blair who is sitting behind me is very sensitive to the need for expedition in this regard. On the other hand those of us who've done this business for a long time also know that if you get some decent facts on the table and some careful analysis it will be always valuable. That's what the Academies are trying to do.

The CHAIRMAN. I agree with that. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman. Dr. Bartis and Professor Corradini, this is probably directed toward you. As we think about how we encourage young people to go into different fields and get them excited.

It was encouraging to hear Secretary Chu say that there is a real level of enthusiasm for the jobs that are being created, the new green jobs. I think that the term he used was, you know, they're joining the service. That's great. It's important. It has to happen.

But do you have concerns, whether it's in nuclear or whether the oil and gas industry that while the excitement to join, kind of, the energy of the future, the renewables, the greens, is going to leave nuclear behind? It's going to jeopardize our ability to get the clean coal technology, the carbon sequestration because it will be viewed as those dying fields or those areas where you've suggested Professor Corradini that university nuclear research programs are cutting back in there. If we're not sending the right signals from on high from the government that these are areas that we want to encourage our best and our brightest.

We want our engineers to go there. Are we going to lose the energy, the enthusiasm in these particular areas? I know that when I was out a year or so in California looking at some wind turbine operations we were talking about well, is it difficult to recruit and retain?

They said, well basically we're taking all the engineers from the petroleum engineers. I'm going up North and the folks up there are saying we can't get people to do the engineering work that we need here. Are we seeing this shifting and leaving behind in certain energy sectors?

Mr. CORRADINI. Do you want to go first or do you want me? Ok. So, I'll give it a shot.

I guess my—so a little history. I was actually in front of this committee in 2000 I think. I talked about actually the human infrastructure there about nuclear engineering.

At the time all the numbers were about one fifth the size that I show you on the graph. In fact I actually went all the way back to that time period. So we've seen a tremendous growth, a factor of four or five in terms of enrollments in the discipline.

But I think in some sense we're a leading indicator in that power engineering, energy engineering in general, has been at a very low ebb. We're seeing now growth in all areas. So I think that if the—and I'll—so that's observation one.

Observation two is young people are really smart.

Senator MURKOWSKI. Yes.

Mr. CORRADINI. They don't need me to tell them what to do. They ignore me most of the time when I'm in the classroom. So there's no point in—so I think that if signals are given and they are not thought through carefully, you could get a problem exactly as you've characterized.

I do hope and if they listen a little bit, I try to explain to them the underlying fundamentals of physical sciences and engineering kind of cross boundaries. As well, if they're well trained and educated they can move with it. So that's part of the reason when you noted that some people hire here and they then shift over here, always occurs.

But I do think that we have to be careful. That's the reason that I emphasize the need to continue without and I'll pardon the expression, in a herkey, jerkey, up and down, up and down that we continually support at a broad level all areas of energy engineering. So that's kind of a quick answer to your question.

Senator MURKOWSKI. I appreciate that. Dr. Bartis.

Mr. BARTIS. I think you have raised a very important point. First I'd like to just comment on your geosciences initiative. I think that's really a very appropriate direction.

I've been very concerned over the last couple of decades about what's been going on in our mining schools. Safety is such an important aspect of mining. You really need people to be able to see the whole picture there in mining. So I think your geosciences initiative is going very much in the right direction. Of course that adds on to the importance of geologic sequestration, better petroleum recovery here at home.

My overall view is that the Department of Energy hasn't given adequate funding and the right kind of funding to universities. I'm hoping that your committee could rectify this. I think the university funding levels have not been as high as they should be, especially from the technology development programs.

They need to be investing in university research to make sure that they have that level of wisdom that they can call on. That level of expertise that they can call on because these programs generally do have problems. Other than that I think a good scientific education, a good engineering education does allow all of our students to have that flexibility to move during their careers to other fields of endeavor.

I mean we can't predict the future. So it's that solid engineering and science background that's essential here. But again it takes Federal support.

Senator MURKOWSKI. Thank you.

The CHAIRMAN. Senator Udall.

Senator UDALL. Thank you, Mr. Chairman. I do think the Senator from Alaska makes a very good point. It relates to the overall energy policy that I think the Chairman has proposed and advocated for as has the Senator from Alaska which is, we have to throw the kitchen sink at this.

We need a comprehensive energy proposal. Somebody quipped to me, Mr. Chairman, that there's no silver bullet. Maybe there's a lot of silver buckshot and it includes renewables, includes efficiency, includes the traditional fossil fuel technologies. We have to do it all including nuclear as well.

Dr. Crabtree if I might turn to you. You talked about some of the overarching challenges with next generation sustainable fuels. Many of these technologies work in the labs, but they're not economical on a larger scale.

Beyond increasing the funding for such programs what are other policy actions that the Congress could take to encourage, not just the development, but the deployment of these technologies?

Mr. CRABTREE. So that's a very broad question because you have, certainly have to have before you're ready to deploy, you have to have a workable, sort of demonstrated and viable technology. I think the reason that a lot of the technologies haven't hit the target and been deployable is simply that they don't look economically attractive. That's a performance question.

That performance question is—the solution to that performance question lies really in the materials and the chemistries of these sustainable energy technologies. So we've talked a lot actually about solar. It was mentioned earlier in this hearing that when Secretary Chu was here, that we need to get the cost down by a factor of 5.

That's the thing that I think will induce the commercial side to invest and to deploy solar. Getting the cost down, but getting that cost down is really a scientific issue. We have to understand why semiconductors do what they do and what's limiting the efficiency.

I just returned earlier this week from Japan, a meeting on innovative solar energy, photovoltaics. They're looking at efficiency as 50 percent or more, nothing less. That's the intended goal of their program. It's a 5-year program.

That's the kind of innovation that is going to get the price down, cost of electricity down, solar electricity and make it deployable. So in my view the issues really are fundamental at the materials and chemistry level. We need to understand that and do those things better. The rest will come.

It will be a sort of tipping point when it finally becomes competitive with let's say coal to electricity, it will happen. I'm not sure that it's wise to force it to happen before that time. We really should concentrate on the fundamentals.

Senator UDALL. Any other members of the panel care to comment. Particularly on sustainable fuels, alternative liquid fuels and what more we might do to encourage the development and deployment of these technologies. I've read increasingly that many scientists think this is where you may see developments that we can't even predict today, with all due respect to the exciting potential news about PV technology.

But in the alternative liquid fuels arena we don't necessarily know what feed stocks might work. There's a lot going on. There are those who think this really could see developments that we can't forecast here today.

Anybody else care to comment?

Ms. Wince-Smith.

Ms. WINCE-SMITH. I'll just add to the comments also on the deployment issues. You know in addition to refining and understanding some of the underlying science we really have to look at the whole risk/reward continuum of the investment both on the debt and equity side. The built in infrastructure that often acts as a barrier for the deployment of these new systems and the replacement cost.

In the case of the liquid fuels area you know one of the other partners for collaboration was the Department of Energy. I think the new Secretary and the new Administration is going to really look at these activities in a systemic way is the Department of Defense. They're already working very aggressively to try and develop, you know, alternative liquid fuels for of course, military applications.

The extent of which we can really mirror both the industrial as well as the defense as we've done in other very important game changing technologies that changed the world. That's another very, very critical path on deployment.

Senator UDALL. Others?

Mr. Fri.

Mr. FRI. The short answer is put a price on carbon. Not just because of the usual reasons. But the innovation process in this country is a messy, recursive process. It's not some sort of linear, start here and get there.

So the way it works best is to get a lot of people working on it. The way you get a lot of people working on it is put a price out there that incents them to go work on it. I know that's a very difficult thing to do. But at the end of the day that's the thing that will really stimulate the innovation process.

Senator UDALL. Dr. Bartis.

Mr. BARTIS. I want to—I certainly agree with that, putting a price on carbon. Unfortunately the Department of Energy in its program has tried to narrow prematurely. I think you talked about the problem of narrowing prematurely its choices on biofuels.

This is a program that should be—have a very broad scope. It needs to be looking at lots of different opportunities out there. The focus on cellulosic alcohol, it may be ready for some scale up, but it should not be done at the expense of all these other opportunities, these longer term, much higher pay off potentially, opportunities.

The place to do that research is in the national labs and the universities. It's fairly basic stuff that has to be investigated.

Senator UDALL. Mr. Chairman, thank you. I think we may be coming to the end of the hearing. But if I might I'd like to direct some additional questions to the panel for the record on coal to liquid technology, on oil shale which Dr. Bartis you've written at great length. I think in a compelling and thoughtful and rational way.

So thank you Mr. Chairman, for this important hearing.

The CHAIRMAN. Alright. Thank you very much. I think Senator Murkowski had another question.

Senator MURKOWSKI. Just very quickly Ms. Wince-Smith. You mentioned just the investment and recognizing that the current investment markets are in pretty tough shape. I guess the question that I would have of you.

Are we seeing the government become the main source of long term technology investment? Is this a good thing, a bad thing? Is it healthy? Is it sustainable? Does it hinder us in any way as we move forward on R and D?

Ms. WINCE-SMITH. I certainly think that the government's primary role in supporting the underlying, basic research, the frontier research, through the applied continuum is very important. You know we've all worked so hard to get the American Competes Act that's just at the heart of that. But having said that, you know, as we move to really, for instance, be the place in the world that solves and commercializes some of these battery storage challenges that R and D barriers.

We have to involve industry right there in the process. We have to have financing mechanisms that are sustainable and long term. Quite frankly a lot of people think that the venture capital world, you know, will be the place that will finance the startups that who knows where they will go.

But the scale is so big that there has to be a way to pool these different investment sources together. One of the initiatives that the Council on Competitiveness pushed very early, it's in our Prioritize. We're very pleased it's being addressed by this committee and the Congress is the Clean Energy Bank.

I mean, XM is still financing and accessing capital markets for United States products, innovative products, to be sold overseas. What about having those capabilities and resources and guarantees to deploy and develop them here in the United States as well? So I think the financing area with loan guarantees, debt networks, is a very, very critical area that will supplement and add to what the government's core role is in the basic applied and some of the demonstration products.

You have to have both of those together.

Senator MURKOWSKI. I agree. Appreciate that statement.

The CHAIRMAN. thank you all very much. I think it's been useful testimony. We appreciate it. That will conclude our hearing.

[Whereupon, at 11:39 a.m. the hearing was adjourned.]

APPENDIXES

APPENDIX I

Responses to Additional Questions

RESPONSE OF ROBERT M. FRI TO QUESTION FROM SENATOR BINGAMAN

Question 1a. Given that any new energy technologies that are developed must be accepted and adopted by an already well-established energy industry, what role should these industries play in public-private R&D partnerships?

Answer. The most efficient role for industry in public-private R&D partnerships depends on a variety of factors, such as the relative maturity of the technology on its path to widespread commercial viability, the unit scale of its likely ultimate deployment, or the accompanying maturity of so-called "balance of system" features necessary to demonstrate the technology at commercial scale. For example, it is less important for industry to be leading early stage investigations of fundamentally new areas of inquiry, e.g., novel solar cell concepts, such as high-efficiency organic and polymer solar cells or nano-particle devices (distributed junction solar cells) that use different nanostructures for solar conversion. But for technologies closer to commercial scale development, industry leadership is essential, such as in demonstrating at commercial scale carbon capture and sequestration or next generation nuclear power generation.

Question 1b. For example, ARPA–E: Should these research teams be industry led? "University led with significant industry input?

Answer. If ARPA–E is to be true to its model-the "old" DARPA-the the leadership should be guided by the problem and the necessary expertise, which could be either industry or academic teams depending on the project. In introducing the idea in 2006 following the release of the Academy report, Rising Above the Gathering Storm, Steven Chu, who served on the Academy Committee that prepared the report, expressed the committee's view as "ARPA–E could fund research at universities start-ups, established firms and national laboratories for similar focused goals. ARPA–E may be especially useful in funding projects whose success will require coordinated efforts from several fields of science. It would also meet the nation's need for transformational, high-risk, high payoff R&D that would be a challenge for today's electric utilities, petroleum companies, and large energy equipment manufacturers to address and which are not very attractive to the entrepreneurial world . . . Anyone could compete for funding from ARPA–E including universities, industry, businesses, and national laboratories or ideally, a consortia of these organizations. Those managing the process would need to be very independent and not favor one group over another."

Question 1c. Within these partnerships, how do we balance industry's inherent need for short-term results with the longer timeframe often required to achieve scientific breakthroughs?

Answer. ARPA–E is but one component in the portfolio of R&D mechanisms. ARPA–E is designed to focus on "for transformational, high-risk, high payoff R&D" that has been underserved by other government funding mechanisms. Yet results from ARPA–E could serve either short-or long-term R&D objectives.

RESPONSES OF ROBERT M. FRI TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective.

As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. As technologies are commercially demonstrated the need for a government role becomes less and less important, but it is sometimes difficult to make the determination that government support is no longer needed. The clear signals are in the measurement of scale and scope of R&D progress and as demonstrated benefits become marginal and incremental it is time to move on. We have not assessed the current portfolio, but, as an example, one of the Academy reports I referred to in my testimony, Energy Research at DOE: Was It Worth It?, concluded that magnetohydrodynamic electricity production, a technology that was identified as a potentially efficient method for generating electricity from domestic coal, continued to be funded long after the technology was found to be too costly and complex for widespread use. A systematic review of the portfolio today along the lines of that report's analysis would likely yield similar examples.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent-there is no such thing as a monopoly on good ideas.

What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. Higher education in the United States, especially the graduate schools, remains generally the envy of the world. U.S. Technical training in trade schools and, of course, at K-12 level science and mathematics is not so envied and indeed lags other nations by a considerable margin. We have not analyzed the energy education and workforce programs in the U.S. and overseas per se, but there may be applicable lessons from more general analyses. I refer you to Academy studies such as Science Professionals:

Master's Education for a Competitive World (2008), Policy Implications of International Graduate Students and Postdoctoral Scholars in the United States (2005), Enhancing the Community College Pathway to Engineering Careers (2005), or Preparing Chemists and Chemical Engineers for a Globally Oriented Workforce - A Workshop Report to the Chemical Sciences Roundtable (2004).

Question 3. Yesterday, the National Association for Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of the energy industry workforce are nearing retirement and will need to be replaced.

What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. Many universities and colleges are reporting renewed student interest in energy-related disciplines by students. If the stimulus package reflected in the American Recovery and Reinvestment Act of 2009 is implemented successfully and expanded investments in energy technology research, development and deployment, as reflected in the FY09 appropriations bill just passed, take shape quickly, demand for skills in energy related fields will gain momentum relatively quickly as well. However, we are in the midst of a deep and likely prolonged recession and industry may be conservative in making decisions to build the skill base to implement those activities. As examples, Congress and the Department of Energy could play at least two roles in overcoming industry reluctance: (1) support for university programs that are tuned to the needs of industry, i.e., “impedance matching” the skills needed with the skills delivered by universities and (2) expansion of support for “work study” programs that build student relationships with industry as early as possible.

Question 4. In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans require the higher pay found in specialty care.

As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. If you mean within energy fields, I'm not sure student loans alone would explain major shifts among fields, since other considerations would likely dominate, such as perceived job market considerations. Perhaps they have an effect on the margin. Nonetheless, in the current economic conditions the burden of student loans or, perhaps the lack thereof or of alternative sources of support, will likely contribute to the trends observed recently in student decisions among institutions, such as decisions less expensive public rather than private colleges and universities, which regionally could have an equivalent effect of selecting among fields. In graduate education, research assistantship support (perhaps sometimes combined with loans) is crucial for maintaining a healthy pipeline and if such support is plentiful in one field over another and job market conditions are similar, the market will, of course, favor the funded field.

Question 5. We tend to live in society that expects and demands instantaneous results and action—from instant messaging and the internet, to being reachable electronically around the globe 24-hours a day, seven days a week. Yet most research and development takes years to achieve results and even then it may not be a marketable product.

In today's economy, what are the challenges to demonstrating the long-term applicability and economic viability of energy research and development programs?

Answer. I think the answer can be illustrated with the historical experience of the energy R&D portfolio. For example, I referred in my testimony to the Academy report, Energy Research at DOE: Was It Worth It?, which, in looking back as far as 1978, examined 17 DOE R&D programs in energy efficiency and 22 programs in fossil energy and found that those programs yielded economic returns of an estimated $40 billion from an investment of $13 billion. Perhaps more importantly, however, the study found that a few key programs delivered benefits many times over the total amount invested, but that it was essentially impossible to predict a priori which part of the portfolio would yield the most important benefits. To demonstrate economic viability the portfolio must be held accountable for producing results. However, the challenge is striking the right balance between high risk and potentially high benefit options and options with lower risk but more likely more incremental benefit.

RESPONSE OF JAMES T. BARTIS TO QUESTION FROM SENATOR BINGAMAN

Question 1. Given that any new energy technologies that are developed must be accepted and adopted by an already well-established energy industry, what role should these industries play in public-private R&D partnerships?

For example, ARPA–E: Should these research teams be industry led? University led with significant industry input?

Within these partnerships, how do we balance industry's inherent need for short-term results with the longer timeframe often required to achieve scientific breakthroughs?

Answer. If the objective of the effort is short term and directed at the development of a new product, such as a lower-cost PV panel, the effort should be industry led and include significant cost-sharing by industry. If the objective of the effort is to advance technical progress more broadly, combined teams involving universities, national laboratories, and industry are appropriate. In this case, it may be highly appropriate that the overall effort, or significant components of the effort, be university led.

More generally, I recommend that all major energy research programs should be implemented through a process that involves broader participation of the public, the scientific and technical community, and industry. By this means, universities, national laboratories, non-governmental organizations, and industry can collectively contribute to the formulation of research plans.

The greater the level of industry cost-sharing, the greater will be industry's need for short term results. To promote industry participation in programs that involve longer-term efforts, I suggest that Congress reduce the requirements for industry cost-sharing.

RESPONSES OF JAMES T. BARTIS TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective.As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. This is an excellent question, and one that is too infrequently asked. I assume that the question concerns technology development efforts, as opposed to basic research. With that assumption, I suggest focusing on technologies that are well-established in the private sector and where government efforts to introduce improved systems might weaken private initiative. For example, technology for enhanced petroleum recovery is well-established within the private sector. Unless the main purpose is carbon dioxide sequestration, I suggest low priority for technology development (but not basic/fundamental research) on this topic. Likewise, the private sector has extremely strong financial motivations to develop advanced batteries and is investing in this area. Portable computers and hybrid vehicles are two applications that clearly indicate the value of successful product development. Again, government-sponsored R&D should be limited to fundamental and basic studies; otherwise, the government will simply be de-motivating private investment. A third example might be wind energy systems. Considering the number of firms active in wind power development, sponsoring the development of an advanced wind system is likely to be counterproductive. More relevant would be research on advanced materials and fabrication systems.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent—there is no such thing as a monopoly on good ideas.

What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. I am not familiar with this topic and regretfully am unable to provide you with an informed judgment on this question.

Question 3. Yesterday, the National Association for Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of the energy industry workforce are nearing retirement and will need to be replaced.

What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. In my judgment, an important goal of a college education is to provide students with the flexibility to respond to future employment opportunities. The marketplace already provides clear signals—through hiring and compensation—as to where those opportunities are. Government efforts to promote college graduates to enter the energy workforce independent of these marketplace signals could lead to an oversupply and lower salaries, which would simply negate the intended benefits.

That being said, there is a role for continued improvements in K-12 education and, in particular, science and technology (S&T) education. Any efforts to improve S&T education should increase the potential labor pool for college-trained persons capable of entering the energy workforce.

Question 4. In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans require the higher pay found in specialty care.

As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. This issue is outside my area of expertise. I have no basis by which I can provide you with an informed answer to the question.

Question 5. You mentioned in your testimony that retrofitting existing plants with carbon capture technology represents a parasitic load on those plants. To replace that lost energy we will need to build more plants or burn more fuel. Certainly carbon capture technologies would not be deployed if there were a net increase in emissions but it does bring up the impact of plant efficiency.

Could you comment on the relative benefits of research and development directed at improving plant efficiency overall and how that would compare to the expenditures needed for carbon capture and sequestration to have an equivalent impact?

Answer. In my spoken remarks before the committee, I suggested that at least $2 billion per year over the next 10 years is required so that we can use fossil fuels for power generation at greatly reduced greenhouse gas emissions. While my highest priority is multiple early demonstrations of carbon dioxide sequestration in the United States, the funding for such demonstrations should represent well below half of the $20 billion minimum funding level that I suggested.

In my judgment, the majority of these funds should be directed at developing advanced power-generation technology that enables both carbon dioxide capture and highly efficient power generation from new plants. Significant funding is also required to develop technology that might allow carbon dioxide capture from existing generating units.

A number of older power plants operate at energy efficiencies in the 30 percent range. Technology is available to upgrade these plants. For example, if these plants are upgraded (or replaced) with plants operating at the current state of the art (about 40 percent for coal), fuel use and greenhouse gas emissions would decline by 25 percent.

For three reasons, however, I do not recommend government support of research that would raise generating plant efficiency but not allow carbon capture. First, technology is already available for upgrading the efficiency of power plants. This upgrade technology is not being applied in the United States because the current economic benefits—lower coal costs—of improving efficiency do not support the required investment costs. If Congress passes legislation that places a price on emitting carbon, power plant operators may opt for efficiency improvements. Second, a collateral consequence of progress in developing advanced power generation cycles for new plants will likely be efficiency-enhancing technology that might be retrofitted onto existing plants. Third, considering the magnitude of the reduction in greenhouse gas emissions that appears to be needed over the next 40 to 50 years, a 25 percent reduction from power plants is not sufficient.

RESPONSES OF JAMES T. BARTIS TO QUESTIONS FROM SENATOR UDALL

Question 1. Two years ago you testified before this committee on the topic of oil shale development. In your statement, you said at the time, "In my judgment, establishing a broad-based commercial leasing program within the next five years is not necessary and, in fact, may be detrimental to oil shale development." You also made the following recommendation:

> Rescind the requirement to establish final regulations for a commercial leasing program within six months of completing the programmatic EIS. As discussed above, within the next few years, it is unlikely that adequate technical, economic, and environmental information will be available to formulate fair and equitable leasing regulations.

Late last year the Bush Administration finalized a commercial leasing program, which has been criticized by many, including myself, for having a host of deficiencies.

Has anything changed in the intervening two years to change your views as expressed in your statement of April, 2007?

Answer. No. To the contrary, the actions by Department of the Interior over the past two years to establish a commercial leasing program have strengthened my conviction that insufficient information is available to formulate fair and equitable leasing regulations. In particular, the "programmatic" EIS published in September of 2008 clearly illustrates how little information is available on the environmental performance of prospective technologies for commercial development of oil shale. Likewise, lack of information on the economics of prospective oil shale technologies resulted in rules for royalty rates and diligence requirements that do not take into account the public stake in the prudent development of oil shale resources.

Rather than a "commercial" leasing program, I suggest consideration of an oil shale leasing program that is specifically designed to encourage private investment in advanced oil shale technology development and demonstration. I refer to this alternative as a "pioneer" oil shale leasing program, since it is directed at the small number of firms that are pioneering new and better (economically and environmentally) oil shale technology. The low-cost leasing of small parcels for RD& D can be viewed as one component of such a pioneer leasing program. But firms will not make the $100 million plus investments required for oil shale technology development and demonstration unless they are confident that success will reap rewards commensurate with the size and risks of investing in RD&D. Basically, they need to know that if they pass environmental muster, they will be able to build a pioneer commercial facility on public lands and pay fairly low royalty rates for the initial operating period of that commercial facility.

Given the richness of the oil shale resources that are of greatest commercial interest, access to a fairly small amount of public land for a commercial operation may be more than adequate to incentivize private investment. Considering the risks of building pioneer production facilities and the vicissitudes of the world oil market, it may be appropriate for the Department of the Interior to be highly flexible regarding royalties, including the option of foregoing royalties for the first 10 or 15 operating years of a pioneer oil shale operation.

These special considerations would be limited to the few pioneer facilities that might be candidates for commercial production over the next 10 to 15 years. The design and operating experience from these pioneer facilities would form the basis of formulating a broader-scale commercial leasing program that could be put in place in the 2020 to 2025 timeframe.

Question 2. Secretary Salazar last week announced that he was halting the Bush Administration's solicitation for a new round of oil shale research, development and demonstration (RD&D) leases. He also stated that he planned to offer a new round of solicitations after he had heard from the public and had an opportunity to review the program.

In your statement two years ago, you suggested that, "the federal government direct its efforts at a list of "early actions" listed in the RAND oil shale report, viewing those actions as priority measures for developing oil shale as a strategic resource for the United States." Your recommendations included additional research on the impact of oil shale development on climate change and our environment, as well as development of technology.

Would you make the same suggestions to the Interior Department for its next round of RD&D leases, and would you add any issue areas that you think need to be explored before we venture off into a commercial development program?

Answer. In my written testimony submitted on March 5, I repeated my recommendation that the government support research required to understand and mitigate or prevent the adverse impacts of oil shale development. I also highlighted the importance of research directed at establishing the information base required to prepare a federal leasing strategy. Since publication of the RAND report on oil shale development in 2005, it is my understanding that negligible, if any, federal R&D funding has been directed at these issues. While industry may be conducting important work in certain environmental areas, the public interest requires that non-interested researchers also be involved. Moreover, environmental issues that are critically important to a sustainable oil shale industry, as opposed to a single facility, are not being addressed. These include infrastructure requirements, water requirements and availability, potential air quality impacts, and disposition of greenhouse gases.

A forthcoming round of RD&D leases provides the government with an opportunity to rectify the inadequate federal funding directed at protecting the public interest in oil shale development. Moreover, if demonstration facilities are built, they will provide an important opportunity for independent researchers to gather important environmental information such as how the subsurface environment responds to chemical and physical changes induced during in-situ retorting. To allow this research, the RD&D lease provisions should allow for the government to secure limited site access by independent researchers, along with provisions to protect company proprietary information.

If a federally-sponsored oil shale research program is to be established, I recommend that the implementing agency take steps to assure broader participation in the formulation of research priorities and in the overall oversight of the program. Since the results of this research will weigh on future decisions regarding the governance of oil shale development, it is important that interested parties, especially the state of Colorado, local governments in the vicinity of the Piceance Basin, non-governmental organizations, and industry, be consulted.

Question 3. I know you authored a RAND report on coal-to-liquid fuels last year. What are your thoughts on the water needs for CTL refineries and the limitations that might put on wide scale development of this technology?

Answer. Water is an important issue for CTL development in the Mountain States, particularly Wyoming, Montana, Colorado, and New Mexico. For CTL production facilities built in locations with abundant water supplies, between 200 and 400 gallons of water will likely be consumed for each barrel of transportation fuel produced. CTL plants can be designed to use much less water, possibly as low as 65 gallons per barrel of fuel produced. Moreover, CTL plants might be able to use water sources that are unsuitable for other purposes, such as agriculture. But given the CTL design information that is publicly available, the cost implications of such low-water designs is highly uncertain.

Overall, I anticipate that water limitations will not seriously impede CTL development in the Midwest and Appalachian regions. The extent that water limitations will impede CTL development in the Mountain States remains an open issue. Early commercial operating experience in CTL plants built in the Mountain States should provide important insights into this problem.

RESPONSE OF GEORGE W. CRABTREE TO QUESTION FROM SENATOR BINGAMAN

Chairman Bingaman, Ranking Member Murkowski, Senator Stabenow and members of the committee: thank you for the opportunity to respond to these questions concerning my testimony before the Senate Energy and Natural Resources Committee. Please find my responses below. I will be happy to supply more information on these or other questions at your convenience. I would appreciate your inserting your questions and my responses into the formal record.

Question 1. Dr. Crabtree, in your testimony you support the formation of Energy Frontier Research Centers (EFRC's) that are focused towards making fundamental scientific breakthroughs to enable the development of competitive and sustainable energy technologies. We have seen several other proposals for 'innovative' R&D models to enable the development of breakthrough technologies: ARPA–E, the Brookings proposal of Energy Discovery-Innovation Institutes, and, as I have just put forth—a Grand Challenges Research Initiative.

What are your thoughts on the ability of each of these models to achieve the technological breakthroughs that we need? Do we need more than one of these models? How would you envision these models complementing one another?

Answer. These are important questions and I will answer at some length. The energy, environmental and economic challenges we face can be captured by a few simple objectives: we must reduce our dependence on imported oil and other fossil fuels, reduce our carbon dioxide emissions to slow climate change, and create and export next generation sustainable energy technologies to grow our way out of the recession. The routes to achieving these objectives, however, are considerably richer and more diverse than the simple statement of the challenges suggests. The solutions include, for example, sequestering carbon dioxide in geologic formations, generating electricity in coal and nuclear power plants at twice their current efficiencies, producing power from renewable solar, wind and geothermal sources, replacing oil and gasoline with biofuels and solar chemical fuels, electrifying transportation through increased use of plug-in hybrids and battery electric vehicles, and replacing fossil fuels with hydrogen produced by splitting water renewably. Many of these more sustainable energy technologies require a 21st century electricity grid with the capacity, reliability and efficiency to move energy long distances, and efficient methods to store electrical energy to accommodate the intermittent production of wind and solar electricity.

The roadblocks to these sustainable energy technologies are severe, otherwise they would have been solved by the significant resources already devoted to the applied energy sector. They cannot be overcome by incremental improvements of present energy technologies. Transformational change is needed if we are to reduce our dependence on imported oil and other fossil fuels and lower our carbon dioxide emissions sufficiently to slow climate change.

Basic and Applied Science Challenges.—To achieve viability of sustainable energy technologies, transformational breakthroughs are needed at many points along the research and development chain. Serendipitous discovery of new phenomena has always played a key role in generating new technologies, by creating qualitatively new opportunities where none previously existed. The record-shattering discovery in 1986 of superconductivity at temperatures ten times higher than ever observed before is in this serendipitous category, allowing transformational change of the capacity, reliability, and efficiency of the electricity grid that have now been demonstrated and are beginning to be exploited.

Equally important as serendipitous discovery is use-inspired basic research to understand and control known but unexplained phenomena, such as how plants use sunlight to transform water and carbon dioxide into fuel, or how catalysts increase the rates of targeted chemical reactions by factors of one million or more. Understanding these mysteries of nature requires the steady development of theoretical insights and observational tools, often at ultra small length and ultrafast time scales that are beyond the reach of the human eye and beyond our present capability. Once understood and controlled, these phenomena can be applied to create new energy technologies such as recycling waste carbon dioxide to produce fuel using sunlight, or transforming the high density energy of chemical bonds to useful electricity by electrochemical conversion without combustion.

Understanding known phenomena like photosynthesis and catalysis for energy are challenges that respond to strategic scientific research. These two challenges, for example, have been examined by Basic Research Needs workshops convened by DOE's Office of Basic Energy Science (http://www.sc.doe.gov/bes/reports/list.html). The workshop reports on Solar Energy Utilization and on Catalysis for Energy outline the current status of each field, the scientific roadblocks to sustainable energy applications, and the promising research directions for overcoming the roadblocks. Understanding and controlling these phenomena are basic science challenges that will produce the necessary transformational energy technologies. Like other basic science challenges, they will be solved by creative, out-of-the-box thinking, bottom-up idea generation, and by following promising research directions wherever they lead.

Beyond basic science challenges, there are a host of applied science and technology development challenges that also require transformational change to overcome. Unlike basic science challenges, these applied science challenges exploit phenomena that are largely understood, connecting them together to produce a complete energy chain, such as plug-in hybrid cars or wind farms to produce electricity. These are primarily engineering challenges, with the same richness, creativity and transformational potential as basic science. Unlike basic science challenges, however, applied science and technology development challenges respond to top-down management, a focus on performance, and on meeting pre-set milestones needed to make the technology viable.Energy Frontier Research Centers.—Because the transformational challenges needed for next generation energy technologies lie along the entire research and development spectrum, more than one kind of program is needed to meet them. Energy Frontier Research Centers (EFRCs) meet the basic science transformational challenges, overcoming roadblocks in understanding and controlling the basic phenomena of sustainable energy. EFRCs will operate as basic science research consortia at the $5M level, creating dream teams of the best scientists from multiple institutions to work in interdisciplinary collaboration using the most advanced tools and focused on the most critical and basic obstacles. EFRCs are designed to solve the scientific challenges in understanding and controlling the phenomena of sustainable energy. Despite the high impact of EFRCs in solving major scientific roadblocks to sustainable energy development, their cost is relatively small compared to the cost of applied energy programs.

EFRCs offer an approach to basic science energy research that is tuned to the level of the challenge—bigger and broader than individual investigators but small enough to be scientifically nimble and responsive to new opportunities created by scientific discovery. Many of the challenges outlined by the twelve Basic Research Needs workshops and reports issued by the Office of Basic Energy Sciences require this level of effort. EFRCs provide interdisciplinary coordination among top scientists using resources from different institutions but do not add the layers of administration and management that technology development requires. Many of the most serious roadblocks to sustainable energy are knowledge based—we need to understand and control the fundamental phenomena of sustainable energy production, storage and use. EFRCs are designed to build the required knowledge base quickly.

ARPA–E presents another model, locking onto specific high-risk high-payoff ideas that, if successful, will enable specific transformative changes in energy technologies. The concept of DARPA, on which ARPA–E is modeled, is to act quickly, usually within 18 months or 3 years, to decide if a particular high risk idea is close enough to fruition to pay off in the near term. If not, the idea is dropped and attention is diverted to the next idea. The ARPA–E concept works well for ideas that face near term technical roadblocks that can be overcome in less than three years and that are not being considered seriously by industry because the risk is too high. ARPA–E would assume the risk and, if possible, bring these projects within industry's development horizon. The rapid development of specific transformational changes for sustainable energy through ARPA–E would build on the basic science foundation produced by EFRCs. The two programs are highly complementary.

Energy Discovery Innovation Institutes.—The Brookings Institution's Energy Discovery Innovation Institutes offer a much grander vision (http://www.brookings.edu/reports/2009/0209__energy__innovation__muro.aspx). The Brookings report takes the bold step of looking at the entire energy enterprise, not just within DOE but also across the national landscape, including all agencies of the government, research universities and industry. Many of their observations are on target: the problems of energy and climate are severe, long term, and require transformational change in our national way of doing business; solutions will be interdisciplinary across research fields and require coordination of science and engineering internal and external to DOE; an interagency approach is needed to coordinate energy research across the federal government; and the magnitude of the total investment in energy research from government and industry must increase significantly, by as much as a factor of four or five.

While the Brookings analysis of the energy landscape frames many of the issues at an appropriately large scale, its plan for Energy Discovery Innovation Institutes requires much further study before it can be accepted for action. The largest institutes would be led by universities or national labs, but on strictly separate tracks—a feature that discourages, rather than encourages, close cooperation among these two pillars of energy research. The size of the largest Energy Discovery Innovation Institutes is recommended to be $200M/year, much larger than many other energy research organizations. Although a commitment of this size can be justified (as the Brookings report does well), the structure, management style, and scope of these institutes are much less well examined. A bottom up approach is needed for basic science, a top down approach for applied science and technology development. Experience shows that it is challenging—there may be no successful examples at this scale—to combine management, scientists and engineers embodying both world-class basic science and world-class applied science and technology development in one organization. We need to gain experience at managing basic and applied research in a single structure, such as with the Helios program at Berkeley, before launching much larger initiatives on all fronts.

The Brookings study recommends NSF as the lead agency for the Energy Discovery Innovation Institutes, yet NSF has little experience at managing large projects and no intellectual foundation in energy research. DOE has the required management and oversight experience through its strategic network of scientific user facilities such as the Spallation Neutron Source, the four light sources, the Electron Beam Characterization Centers and the five Nanoscale Science Research Centers—over $800M/year in operations management—and it has a strong and unique intellectual foundation in energy through its series of twelve Basic Research Needs workshops and related reports issued since 2002.

At the scale envisioned in the Brookings report the Energy Discovery Innovation Institutes would be the dominant energy research organizations in the country. They would consume much more than all of the projected growth in federal spending on energy. To create a new structure of unprecedented size and scope to manage such a large investment that duplicates or supersedes much of the energy structure and intellectual momentum already in place is very likely to be unwise. We need to build on what we have, perhaps refining it to better meet the monumental challenges of energy, environment and economy that we now recognize; we should not duplicate, or worse, relegate to the side lines the present energy structure. Given the depth of the financial crisis, we need to make the best use of the resources we have, not create new ones that bring parallel and possibly competing strategic, administrative and funding structures into existence.

Grand Challenges Research Initiative.—The Grand Challenges Research Initiative proposed in the draft legislation of the Senate Energy and Natural Resources Committee has many admirable features that could address the twin challenges of energy and environment. The draft legislation captures key elements needed for a successful program, including consortia addressing the grand scientific and energy challenges described in the twelve Basic Research Needs workshop and related reports issued by the Office of Basic Energy Sciences or in the Grand Challenges for Engineering report issued by the National Academy of Engineering, coordinating basic and applied science, and contributing to scientific understanding. There are, however, a few features of concern in the proposed initiative that are briefly mentioned below.

Page 44, line 22 of the draft legislation refers to " . . . the Challenges described in the Grand Challenges report of the Basic Energy Sciences Advisory Committee of the Department of Energy . . . ". The Grand Challenges report is just one of twelve reports describing the basic science energy challenges. The text should be revised to specifically include "the Basic Research Needs and Grand Challenges reports issued by the Office of Basic Energy Sciences."

Page 46, line 22 of the draft legislation refers to " . . . assisting industry in overcoming the Grand Challenges described in subsection (c)." Industry is an important component in developing new technologies, but the strong focus on industry leadership is too restrictive. Industry is generally too risk-averse to aggressively pursue solutions to grand energy challenges. Because most industry decisions are driven by obtaining financial gain in the short-term and capturing the exclusive use of the intellectual knowledge base they produce, they would not likely be interested in working on the big picture grand challenges. Most of the grand challenges blocking sustainable energy are so high risk, so generic and require such a long-term commitment that their payoffs are beyond industry's planning horizon. In many (even most) cases, the initiative and the leadership of tackling grand challenges should reside with the basic science partner, namely national laboratories and universities. Industrial participation may be a crucial element for eventual success, but requiring industrial leadership in all instances is likely to leave many of the grand challenges on the table and unaddressed by this program.

Industry will lead when a solution to a grand challenge emerges as promising. Before reaching that point, the risk is too high and the guaranteed payoff too low for industry to take a leading role. The grand challenges described in the twelve BES Basic Research Needs workshop reports and many of those called out in the Committee's Grand Challenges Research Initiative are in the realm of basic science, and require dream teams of the most creative and energetic scientific talent to succeed. The leadership of these grand challenges should reside in basic research organizations including universities and national laboratories.

Page 48, line 8 of the draft legislation states that "The amount of an award provided to a consortium selected by the Secretary under this subtitle shall be not less than $50,000,000 for each fiscal year." A consortium funded at this level must have considerable administrative structure, diluting the research funds available to actually solve the grand challenges. This size is larger than most national laboratory divisions and university departments, and it would require the overhead costs and structures appropriate to a large organization, typically as much as 50% of the total funding. To be effective, such an organization would ordinarily require a building, an issue not addressed in the legislation. The legislation should address how the funding will be spent, whether it would create a stand-alone organization with administrative and physical structures, or whether it would leverage the administrative and physical structures of existing research organizations.

At the proposed level of funding, $50,000,000 or more per consortia, the Grand Challenges Research Initiative would require adding several hundred million dollars to energy spending for promoting applications and technology deployment. The cost of this program, however, could diminish the basic science resources needed to solve the fundamental problems blocking sustainable energy development. Investments in the basic science of sustainable energy, through EFRCs and other mechanisms, must be enhanced if we are to produce a more sustainable energy landscape. The cost of the proposed legislation should not come at the expense of reducing the doubling of basic physical sciences funding laid out in the America COMPETES Act. For example, funding only six centers of the Grand Challenges Research Initiative at the minimum $50 million a year would require an additional $300 million a year—more than the proposed increase in the Office of Science budget and 7% of the Office of Science's total funding in FY08.

Page 50, line 5 of the draft legislation seems to allow non-competitive awards of $50M or more to consortia. If a non-competitive approach is intended, this approach is fraught with problems. It would not be in keeping with the transparency of the scientific enterprise, and experience shows that non-competitively awarded consortia typically perform well below the level of competitively awarded consortia. The non-competitive aspects of the legislation should be re-examined and excluded.

Page 50, line 20 of the draft legislation seems to allow information produced under this funding to be embargoed from publication for five years. Such a restriction will severely limit the participation of academic and national laboratory scientists whose careers depend on publication of their research results in peer reviewed journals. This provision should be eliminated or severely revised to include specific protections of the right to publish in those consortia that are solving pre-competitive scientific grand challenges. Most of the grand challenges outlined in the twelve Basic Research Needs workshop reports fall in this category. The American public benefits when research discoveries are openly disseminated. This not only furthers a basic principle of the scientific enterprise of sharing information, but also greatly increases the likelihood that the research will be developed and commercialized.

RESPONSES OF GEORGE W. CRABTREE TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective.

As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. Peer review, the lifeblood of science, maintains the quality of the scientific enterprise. The scientific community rigorously reviews the scientific papers published in its journals. The more prestigious journals that carry highly cited papers and are the most important for career advancement impose the most severe reviewing requirements. This is evident in their rejection rates: Physical Review Letters, the pre-eminent physics journal, rejects 65% of the papers it receives, Nature and Science, interdisciplinary science journals, reject over 90% of the papers they receive.

The standards of scientific peer review apply equally to research grants: rejection rates for Office of Science and NSF new proposals approach or exceed 90%. Initial grants in the $100 K range are scrutinized by up to eight reviewers, collaborative grants of $2-5M receive mail reviews and in-person site visits by teams of six to twelve reviewers. The full review process is repeated every three years, so that high performance must be maintained continuously or funding will be cut. Phasing out research grants is common, it is the primary mechanism by which new talent is brought into the scientific community. The scientific funding agencies are themselves regularly reviewed by "Committees of Visitors" whose task is to evaluate their performance in funding the highest quality proposals and phasing out those whose quality no longer meets the standard.

Using the above procedures, the scientific community takes a pro-active role in phasing out scientific programs that no longer meet the quality mark. Additional funding allocated to science and administered through competitive grants will normally maintain its quality and its usefulness indefinitely. Individual projects and principle investigators will change frequently to keep the funding focused on the frontier of research and to insure that only the highest quality projects are active.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent—there is no such thing as a monopoly on good ideas.

What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. Other countries are not standing still. Europe and Asia have dramatically increased the quality and effectiveness of their science enterprises in the last two decades, to the point that the U.S. can no longer assume with confidence that it is the pre-eminent scientific leader in the world. Germany reorganized its national laboratory system under the new name Helmholtz Association in 2001, with national strategic planning and coordinated funding across all laboratories replacing the former fragmented and laboratory-centric system. In energy research, this has been a sweeping change, bringing coordination among basic and applied components and across formerly independent research laboratories, and review at the highest strategic levels by foreign scientists. The impact of the reorganization in preparing Germany to solve its energy challenges and market next generation energy technologies to the rest of the world (one of their stated strategic goals) has been significant. In implementing this reorganization, training of graduate students in national laboratory settings is a major new component.

Japan is looking well beyond incremental advances in energy research to, for example, efficiencies greater than 50% in innovative multi-junction solar cells. Their program, launched in 2008 and called Solar Quest, coordinates four teams of scientists from three institutions with international collaborators to design and create the complex semiconductor materials and architectures that will deliver high efficiency solar electricity at competitive cost. This program is advanced basic science, well beyond the risk limit of industry but well within the reach of sophisticated materials science. This consortium will build on the new world record for solar cell efficiency established in January 2009 by the German Fraunhofer Institute of Solar Energy Systems, 41.1%.

Workforce issues are critical to the future US competitiveness in science and technology, and especially in energy. Training the next generation of innovators in energy is key to our future national health. The response to the question below elaborates this theme.

Question 3. Yesterday, the National Association for Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of the energy industry workforce are nearing retirement and will need to be replaced.

What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. The energy and environmental challenges have captured the imagination of students and early career scientists across many disciplines. For the last two years, the American Physical Society has held a one-day Energy Research Workshop on the Sunday before its March meeting, limited to 65 participants and presented by leading basic energy researchers. The response has been overwhelming—in each of the two years, the Workshop has been oversubscribed by a factor of two. The "energy" at the workshop was palpable-lively and creative questions from the participants, intense informal exchanges among students and lecturers during breaks and at lunch and a buffet dinner. The same interest is seen at other major energy events, such as the MRS Energy Forum, a one-day event before the annual Spring meeting of the Materials Research Society in 2008. Over 300 participants filled a room designed for 150, mostly students and early career scientists, sitting on the floor in the aisles and along the walls.

There is an overwhelming interest among students and early careers scientists in energy, an unusual situation that we as a nation can use to our strong advantage. Young scientists are eager to attack the energy and climate challenges, driven in part by the desire to use their scientific talents to solve societal problems. The best and the brightest of the students know that energy is the place to be, expecting career-building opportunities like those of information technology in the last two decades and nanoscience in the last ten years.

We are not equipped to accept, guide and mentor this eager flood of budding energy research scientists. We need major new graduate fellowship programs, five year early career energy research awards, an organized program of regional and national symposia on energy to promote networking across traditional disciplinary boundaries for early career energy scientists, and a set of senior mentors to advise technically and professionally the coming generation of energy scientists. Their careers will be unlike any others, because energy requires much more interdisciplinary research than any other field. There is no "department of energy" in universities; instead energy is diffused over physics, chemistry, biology, materials, engineering, economics and sociology. We need to give the next generation of energy scientists a much broader base and much wider vision than we were given; we are not currently prepared to do this.

The resources of the national labs, working collaboratively with university partners, offer a scale and dimension to energy workforce training that anticipates conditions in the larger community. These experiences for students, postdocs and early career scientists can be major components in their training.

Consistent, sustained and balanced funding for research is critical for workforce development. Students who see faculty continuously stressed over funding will not be encouraged to proceed with energy research careers. Funding should support scientific research generally, rather than try to pick winners and losers. Funding bubbles that encourage a temporary overproduction of workers in a particular area are not helpful to the long-term needs of science, engineering or the economy.

Question 4. In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans require the higher pay found in specialty care.

As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. Unlike in health care, graduate education in the physical sciences, biology and engineering is supported by fellowships that make it possible to earn a graduate degree without going heavily into debt. This removes some of the incentive to steer energy research careers to the highest paying areas. We should strive to maintain this positive feature of energy education.

Question 5. I am struck by your note that the cost of imported oil at last summer's prices would be $700 billion/year. That's pretty close to what the President and Congress just spent on an economic stimulus plan. At a time when we are racking up record levels of debt that will be passed on to future generations, concern about spending fatigue needs to be kept in mind.

The proposal before us would double energy research and development funding. Is this justifiable?

Answer. Federal spending on energy research and development is far smaller than the stimulus bill or the cost of imported oil. In FY2007, the federal expenditure for energy research and development was approximately $2B[1], 0.25% of the $787B spent on the stimulus bill in 2009.

Today's federal spending on energy R&D is one fifth of the expenditure on energy R&D of the early 1980s (in constant dollars). Including approximately $2.4B spent by industry on energy R&D, the total energy R&D spending is $4.4B, approximately 0.35% of the $1300B gross output of the energy sector in the U.S. By contrast, the health sector spends 2% of its gross output on health R&D, and agriculture spends 2.3% of its gross output on agricultural R&D. Across all sectors, R&D spending is 2.7% of GDP.

Given the magnitude of the energy and environmental challenges and the transformational change needed to meet them, many experts in and out of government conclude that the U.S. is significantly underfunding energy R&D.[2] Even a doubling would not bring energy R&D spending to near the average intensity of R&D spending for other sectors.

There is an important return on energy R&D expenditures that must be considered when we calculate the cost: the outcome of some of this spending is a reduction in the cost of imported oil. If energy R&D spending produces a 10% gain in the efficiency of automobiles (a goal that everyone, even auto manufacturers, agrees is within reach) we cut the cost of imported oil by $20B/year—$70B/year. The payback to the U.S. economy in one year is much more than the total cost of the R&D to achieve it.

Innovation is what drives our economy. The only way to recovery from the economic downturn we currently face is to grow and innovate our way out of it. That requires investment in basic science, and now is the critical time to increase those investments. Other nations are investing in the development of energy technologies.

[1] Federal R&D Funding by Budget Function: 2007–09, NSF, http://www.nsf.gov/statistics/nsf08315/

[2] International Energy Agency, "Energy Technology Perspectives 2008;" President's Council of Advisors on Science and Technology (PCAST), "The Energy Imperative: Technology and the Role of Emerging Companies" (Washington: Executive Office of the President, 2006); National Academy of Engineering, Engineering Research and America's Future; National Academies, "America's Energy Future: Technology Opportunities, Risks and Tradeoffs" (Washington: National Academies Press, 2008).

If the US does not keep pace we will become the consumers of these foreign-developed and produced energy technologies instead of the sellers.

Question 6. You describe in your testimony the magnitude of the energy R&D challenge before our country in terms of the Manhattan project or the Saturn program. I am glad to see that you also refer to an important barrier to adoption of new developments—economics. Economic competitiveness is a challenge that neither of these earlier programs faced.

While we focus on the need for basic energy R&D what do we need to do to foster the engineering development needed to promote the commercial adoption of promising new discoveries? This wouldn't be a role of the DOE's energy frontier research centers would it?

Answer. A primary strength of the U.S. economic system is its entrepreneurial nature. When new opportunities arise, entrepreneurs are quick to take the opportunity to market. The market for sustainable energy in the U.S. and the world is obvious, and the profit motive is as robust as ever. The bottleneck for entrepreneurial commercialization of sustainable energy is the fundamental science roadblocks to competitive performance. These roadblocks are not new, they have been known for years or, in some cases, decades. The fact that they have not been solved despite the resources and efforts of the entrepreneurial community shows that they require breakthroughs in understanding and control of complex materials and chemical phenomena that can only come from basic science. The required breakthroughs, and the promising basic science research directions to achieve them, have been outlined in the twelve Basic Research Needs workshops and reports organized by DOE's Office of Basic Energy Science. Once basic science provides the understanding and control of these phenomena, often using nanoscale techniques, entrepreneurs can translate the opportunities to the marketplace as competitive next generation energy technologies.

This system worked well for Bill Gates and Steve Jobs, two towering entrepreneurial figures who capitalized on new ideas and opportunities enabled by faster, smaller, cheaper semiconductor electronics. Similar opportunities await on the sustainable energy frontier, as basic science develops the understanding and control of sustainable energy materials and chemical phenomena. Entrepreneurs need a new opportunity, the basic science of sustainable energy materials and chemistry provides the opportunity.

Although Energy Frontier Research Centers are primarily oriented toward the basic science of sustainable energy, the proposals submitted include industrial participation, and in some cases leadership by industrial firms. This close connection of basic research and industrial development is key to rapid progress in sustainable energy technology. Industrial partners who participate in the basic research of materials and chemistry of sustainable energy will be in the best position to appreciate and exploit new opportunities before they become widely known. This bridging feature of EFRCs is a key link between basic and applied research for sustainable energy and an opportunity to pursue basic to applied translational research.

RESPONSES OF GEORGE W. CRABTREE TO QUESTIONS FROM SENATOR STABENOW

Question 1. Federal Collaboration.—The energy challenges facing my state of Michigan and others require everyone on deck—not just engineers and scientists but public policy experts, business leaders and economists. What steps would you recommend to link public policy and science at the federal government level? What initiatives could be shared among agencies—DOE, EPA, Department of Transportation, etc.—to best address the multiple energy challenges facing our country?

Answer. Energy is a highly interdisciplinary enterprise, spanning not only science and technology, but also business, economics, sociology and public policy. An interagency approach is very appropriate, such as the existing interagency initiatives in nanoscience, high performance computing, and climate change. Such an approach will bring many of the major players together and get the most value from federal resources. It is important to engage the policy makers in the discussion as well, such as the Secretary of Energy, the White House coordinator for Energy and Climate Change, the President's Science Advisor, and the chairs of the President's Council of Advisors on Science and Technology.

Question 2. Congressional Role.—Besides additional federal dollars, what is the single greatest action that Congress can take to stimulate additional energy R&D? What would be most effective in assisting regions, such as the Midwest, to transition to new industries built on alternative energy technology?

Answer. Energy and carbon dioxide are monumental, long-term challenges that need participation from every sector of society-government at all levels, industry, the science community, and citizens. The "reaction time" of the energy and climate systems is long, giving time for market forces to play a significant role if they can be properly motivated. The single biggest factor determining the course of energy and climate research and development is economics. One of the reasons we face such monumental problems today is that fossil fuels have always been relatively cheap and plentiful—there was no business or economic imperative to develop alternatives or to consider the cost of cleaning up their environmental and climatic impact.

The same economic factors that created the present energy and environmental challenges can be turned to our advantage to help meet the challenges. Consumers of imported oil and other fossil fuels can be asked to pay the true cost of their use, reflecting not only the price set by supply and demand, but also the cost of developing sustainable alternatives, reducing their greenhouse gas emissions, and cleaning up the pollutants they release into the environment. The effect of raising the price of fossil fuels has been demonstrated twice, in the oil crises of 1980 and 2008. In each case, dramatically rising prices motivated us to use less and to seek lower cost alternatives. This dynamic operated effectively at all economic levels-businesses and consumers became creative proponents of finding alternative energy. Because the price of oil dropped following both crises, the financial incentives to develop alternatives disappeared, and we resumed business as usual with fossil fuels.

Congress, however, can change the economic equation going forward. Finding a way to charge commercial and private consumers the true cost of fossil fuels gives us financial incentives to find sustainable alternatives. There are many ways to fold the true cost of fossil fuel use into their price, through taxes or a system of carbon cap and trade, for example. Finding the most societally acceptable way of charging the full cost of fossil fuel consumption is a complicated political and sociological task that is best achieved by Congressional negotiation.

RESPONSES OF DEBORAH L. WINCE-SMITH TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Given that any new energy technologies that are developed must be accepted and adopted by an already well-established energy industry, what role should these industries play in public-private R&D partnerships? For example, ARPA–E: Should these research teams be industry led? University led with significant industry input? Within these partnerships, how do we balance industry's inherent need for short-term results with the longer timeframe often required to achieve scientific breakthroughs?

Answer. The Federal government must maintain its traditional role as the funder of long term basic research but the importance of public/private sector partnerships is critical if the United States is to meet the twin challenges of energy security and sustainability. The Council's Energy Security, Innovation and Sustainability (ESIS) Initiative is grounded in the belief that the demand-side of the equation must be adequately addressed since government cannot and should not mandate new technology adoption. Industry is as a key reality check and commercializer of new ideas and needs to be at the table early in the process. But, industry can be a longer term thinker as demonstrated by the Department of Energy's INCITE program that grants industry access—on a peer reviewed basis—to the nation's greatest high performance computing capability in order to tackle some very fundamental scientific challenges.

Question 2. Could you discuss what you see as the main reasons that the U.S. often invents but fails to capture the production of technologies like flat panel displays, photovoltaics, and advanced batteries?

Answer. As I discussed in my testimony, the United States must be poised to deploy the new ideas and innovations that arise from our research enterprise. To do otherwise is to fail to capture value in the form of new jobs and new industries from the billions of tax dollars we spend each year on research. The oft-discussed valley of death—where funding dries up between basic research and commercialization—remains a significant challenge; as does the perception that we don't "make anything" in America anymore. Overcoming both these challenges means investing in our advanced manufacturing capacity as well as basic and applied research. The manufacturing processes of the 21st century—such as desktop and nano fabrication—are just as cutting edge as the research they seek to commercialize, but no less complicated or in need of study.

The other point I would make is that the technology transfer process in our nations universities and labs remains spotty at best often suffering from too narrow a focus on licensing fees and/or patents. The technology transfer process must be viewed appropriately in its larger regional innovation context where success is measured by new companies, jobs increases to the tax base and overall regional economic growth.

Question 3. Throughout your testimony you state that new public-private partnerships are needed to translate our advances in energy R&D into a competitive manufacturing and economic advantage for the United States. Can you comment further on how these public-private partnerships might be structured? Should we establish and make available Manufacturing Science Centers at each of our National Labs that manufacturers could partner with to develop and test new processes and technologies?

Answer. I am hesitant to suggest that a new research bureaucracy is necessary to overlay the current federal research enterprise. Rather, consistent with the recommendations included in the Council's 100-Day Energy Action Plan, Prioritize, I would urge the committee to explore better leveraging the federal research assets that currently exist by creating regionally-based R&D test-beds and large-scale commercial pilots for new energy technologies.

Question 4. Could you comment on the role that both regulatory and tax policy can play in driving the establishment of new domestic manufacturing? For example, both Spain and Germany have become leaders in solar and wind technology production, respectively—a result that many believe stems from these countries' aggressive renewable energy production incentives.

Answer. The Council put forward two recommendations in this area in its competitiveness agenda released last fall. The first argued that it is critical to put all energy sources on equal footing with respect to federal subsidies and regulatory treatment. Secondly, the Council proposed a series of tax changes to encourage corporate investment in the United States. These include: a reduction is the corporate tax rate; a short term allowance for repatriation of foreign earnings; and making the R&D tax credit permanent.

Question 5. The Federal Government currently has several programs through NIST, DOE and SBA that aim to increase the competitiveness of U.S. manufacturers. How can we better leverage and integrate these programs to reach more manufacturers and enable them to develop high-value manufacturing?

Answer. The Council first addressed this issue in its Innovate America report in 2004 when we called for NIST to refocus its manufacturing work on 21st century advanced manufacturing opportunities rather than trying to perpetuate the jobs and industries that were not coming back. I would also reiterate my earlier point regarding better use of the federal government's HPC capabilities by a broader cross section of America's industries. Advanced being made in modeling and simulation will literally transform the way, and at what cost, innovations are brought to market.

Question 6. In your testimony you make the point that our classification of what constitutes a manufacturing job is outdated. If we instead use your classification system, how do the manufacturing employment trends of the past 10 years change?

Answer. As American firms restructured optimize for efficiency, manufacturing firms often outsourced (not off-shored) certain functions to specialty firms: contract research, design or engineering, logistics and distribution or marketing and branding. Once these jobs were performed outside the company, the jobs would typically be reclassified as service jobs—even though they support competitiveness in the manufacturing sector. Indeed, the fastest growing source of manufacturing revenues is in associated services that are tied to the product. Our position is that the current classification misses this synergy between production and services which is now at the heart of high-value manufacturing.

RESPONSES OF DEBORAH L.WINCE-SMITH TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective. As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. The Council has not proposed the specific elimination of any programs, though as discussed in my testimony, the federal government must do a better job of leveraging the research assets it has.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent—there is no such thing as a monopoly on good ideas. What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. I am not personally aware of any such programs.

Question 3. Yesterday, the National Association for Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of the energy industry workforce are nearing retirement and will need to be replaced. What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. The Council's 100 Day Energy Action Plan calls for:

- The Secretary of Labor to create a $300 million "Clean Energy Workforce Readiness Program," augmented by state and private sector funding, to foster partnerships between the energy industry, universities, community colleges, workforce boards, technical schools, labor unions and the U.S. military to attract, train and retain the full range of skilled workers for America's clean energy industries.
- All federal agencies to commit 1 percent of their R&D budgets to competitive, portable undergraduate and graduate fellowships in energy-related disciplines for American students.
- The Secretary of Labor to assess, classify and widely publicize the demand-driven needs for energy-related occupations and align federal workforce investment programs and state-directed resources to support skills training and career path development in energy fields for American citizens.

Question 4. In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans require the higher pay found in specialty care. As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. The Council's research confirms both the tremendous need and opportunity in the energy field for skilled, technically trained workers. Importantly, many of these high paying jobs do not require a 4-year college degree, so the debt burden could be significantly less. What is critical is for States, regions, businesses, academic institutions and labor unions to be better coordinated in matching the workforce needs of a region to the available education and training.

RESPONSES OF DEBORAH L. WINCE-SMITH TO QUESTIONS FROM SENATOR STABENOW

Question 1. Federal Collaboration.—The energy challenges facing my state of Michigan and others require everyone on deck—not just engineers and scientists but public policy experts, business leaders and economists. What steps would you recommend to link public policy and science at the federal government level? What initiatives could be shared among agencies—DOE, EPA, Department of Transportation, etc.—to best address the multiple energy challenges facing our country?

Answer. As stated in my testimony, the one federal research asset that is currently underutilized as a drive of economic growth, cuts across departments and agencies and is almost the sole purview of the United States is our high performance computing capacity. If we are going to address some of the great scientific challenges facing the public and private sectors in the energy and climate change arenas, HPC must be brought to bear and diffused further into our economy.

Question 2. Congressional Role.—Besides additional federal dollars, what is the single greatest action that Congress can take to stimulate additional energy R&D? What would be most effective in assisting regions, such as the Midwest, to transition to new industries built on alternative energy technology?

Answer. The single greatest action beyond additional investment in research and development is to recognize that this is not enough by itself. The Council's 100-Day Energy Action plan includes several recommendations to achieve energy security and sustainability through the creation of new industries, new innovations and new jobs. Rather than repeat them here, I would note that the full report was included in the hearing record and can be found at www.compete.org.

RESPONSE OF MICHAEL L. CORRADINI TO QUESTION FROM SENATOR BINGAMAN

Question 1a. Given that any new energy technologies that are developed must be accepted and adopted by an already well-established energy industry, what role should these industries play in public-private R&D partnerships?

Answer. A team approach in any new energy technology development is crucial. New technologies are being developed by innovative individuals, whether at universities or companies, all the time. From my perspective, the technologies that are successful in taking a new science/engineering concept and being able to translate them into a new product and/or process is always a team-effort. I would expect established industries to be part of a team but not necessarily lead a team. I am not sure that I have answered your question adequately, but let me give you some examples (case studies) that show success and failure of new science/technologies for energy and environmental issues:

- Molten Metal Technology (early 1990's)—waste remediation
- Virent (early 2000's)—bioenergy
- NuScale (2007)—modular nuclear power plants

Question 1b. For example, ARPA–E: Should these research teams be industry led? University led with significant industry input?

Answer. Consistent with my comments above, I would allow either industry or universities to lead a team and let the team of top-notch, smart and motivated individuals develop the proposals. These motivated, energetic folks would form themselves in a small business startup and they would take the risks. I would encourage ARPA–E to be a modified version of a public Venture Capital company investing in new energy technologies based on their ability to deliver a new product or process in a time-scale that is longer (5+yrs compared to 2-3yrs) than private venture capital companies (like Kosla Ventures or Vulcan Corp or Vinrock Inc). But I would not change the historically successful model where individuals form a team based on their own skills and ideas and the team then makes the proposals to the ARPA–E model. I am not an expert in these sort of business arrangements, but I would be quite willing to get you in touch with those that are at VC firms and or successful small companies.

Question 1c. Within these partnerships, how do we balance industry's inherent need for short-term results with the longer timeframe often required to achieve scientific breakthroughs?

Answer. I completely agree with your vision, that timescale is the important determinant. I firmly believe that ARPA–E should be focused on shorter-term goals (?5yrs). The normal R&D funding from the DOE Office of Science would handle the longer term research with scientific discoveries. Given the Bayh-Dole act of 1980, the discoveries from such research has a natural avenue to create new businesses.

RESPONSES OF MICHAEL L. CORRADINI TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective.

As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. I cannot argue with the idea that certain programs should have a sunset clause or be "deauthorized". However, Energy R&D has been so severely underfunded for the last two decades, I would have a hard time giving you immediate examples. This lack of investment has caused the energy infrastructure to deteriorate and we are suffering for it now and will for many years. Nuclear Energy R&D is a good example of this point, and only in recent years has this changed. With this disclaimer, let me point out that the reorientation of the GNEP program, back to what it was in 2005, to a more stable and steady R&D effort is a useful effort.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent—there is no such thing as a monopoly on good ideas.

What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. Let me address this question with nuclear science and engineering as the theme. The Japanese have been very aggressive in reviewing and reorienting their nuclear science and engineering programs. The name of the effort is GoNERI and Prof. Y. Oka has been a real force in reorganizing their educational efforts. That is one good example. Another example can be found in France, where the CEA is sponsoring masters programs to bring young people back into the field from other disciplines.

Question 3. Yesterday, the National Association for Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of the energy industry workforce are nearing retirement and will need to be replaced.

What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. I have just completed testimony at the Nuclear Regulatory Commission (NRC) about this particular topic and would be happy to send you my presentation. The short answer is that the NRC inherited the former DOE program and their approach to developing the human infrastructure for nuclear is excellent. John Gutteridge, formerly at DOE, has developed this program. Because of this success, the DOE is now working with the NRC and the NNSA to develop a comprehensive effort. This would be a good model for other energy fields.

Question 4. In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans require the higher pay found in specialty care.

As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. No, I have not seen this to be the case.

Question 5. I am glad to hear that you believe pursuing advanced fuel cycle research is worth pursuing, particularly since the administration has already announced its intention to abandon our current spent fuel management strategy. I am concerned though that spent fuel recycling is often described in terms of long term R&D. In the past we have seen R&D funding for nuclear technology dwindle to nothing, as it did during the Clinton administration.

What is the best way to ensure a consistent level of fuel cycle R&D over what may be several administrations so that we don't find ourselves without alternatives twenty years from now?

Answer. This is a very difficult question and is more policy than technology. Continuing fuel-cycle R&D is an easier part of this issue, in the sense that the more we can learn from R&D the more technology options we can provide to policy-makers in the future. I think the harder question is what institutional structure can be created that would provide stable stewardship of fuel-cycle R&D, spent fuel storage, recycle, and eventual disposal of some part of the material (something will have to be geologically disposed of). In my view there is nothing wrong with Yucca Mountain as a disposal site for high-level waste, but there is also no rush. This Institutional structure should be the focus of a "Blue-Ribbon Panel".

RESPONSES OF HON. STEVEN CHU TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Given that any new energy technologies that are developed must be accepted and adopted by an already well-established energy industry, what role should these industries play in public-private R&D partnerships?

For example, ARPA-E: Should these research teams be industry led? University led with significant industry input?

Within these partnerships, how do we balance industry's inherent need for short-term results with the longer timeframe often required to achieve scientific breakthroughs?

Answer. Public-private R&D partnerships are critical tools to increase industry engagement in activities that spur energy technology innovation and the development of entire new industries. The Department engages with industrial partners through a variety of programs that focus on different points in the life cycle of technology development, recognizing that different industrial partners have different needs and varying tolerances for the risk associated with scientific research.

One example of public-private R&D partnerships occurs through the Office of Science's Bioenergy Research Centers (BRCs), which provide a variety of mechanisms for industrial entities to advise and collaborate in the Centers' research projects. Two of the three BRCs are led by DOE national laboratories. All of the BRCs have industry representatives on their advisory boards; all are cultivating close relations with industry; and two of the three have industrial partners that actually collaborate in the fundamental research.

Another example occurs through the Office of Energy Efficiency and Renewable Energy's Photovoltaic Technology Incubator program, which has awarded funding to a range of small-to-medium sized firms to promote the development of a diverse set of laboratory-proven photovoltaic technologies that target a variety of markets, including residential, commercial, and utility power generation.

Finally, the Office of Fossil Energy's Plains CO_2 Reduction (PCOR) Partnership, one of seven regional technology demonstration partnerships under the Regional Carbon Sequestration Partnership Program, has brought together more than 80 eighty state, federal, industrial, and non-profit entities to perform test injections of carbon dioxide in lignite coal seams in North Dakota. Numerous other Fossil Energy programs have successfully partnered with industry and academia on public-private R&D, such as the Advanced Turbine Systems program, which developed advanced, higher efficiency combustion turbines, and the Solid State Energy Conversion Alliance (SECA) program. This focuses industry teams and core technology program participants on developing low-cost solid state fuel cells.

These examples illustrate a variety of mechanisms to promote public-private R&D partnerships in energy-relevant technologies and highlight some of the key roles our national laboratories continue to play in these types of programs. Our laboratories also play a significant role in private-public R&D partnerships through their technology transfer activities with industry, such as cooperative research and development agreements, reimbursable work for the private sector, and licensing of laboratory developed technology. The laboratories can also offer to the public-private partnership model their knowledge and experience in conducting longer-term research programs focused on providing scientific breakthroughs.

The Department recognizes that industry is also critical to the success of ARPA-E. At this early stage in its development, ARPA-E can be expected to establish teams led by any of the important R&D sectors—academia, industry, federally funded entities, and other not-for-profit entities. The Department is not imposing rigid structures on ARPA-E partnerships, preferring instead to allow flexibility in the formation of the partnerships and then follow the progress of varying models closely.

Question 2. How do you intend to execute the contracts that will be required to be put in place, or modified, to implement the American Recovery and Reinvestment Act? How will you plan on obtaining the necessary staffing to implement these increased funds?

Answer. The Recovery Act requires agencies to follow government-wide procurement laws and regulations for awarding contracts under which Recovery Act funding will be obligated unless otherwise authorized by statute. Accordingly, the Department will follow all applicable legal, regulatory and policy requirements governing the award and administration of contracts and modifications of contracts that will be funded with Recovery Act appropriations. Additionally, the Recovery Act prescribes new requirements that necessitate the inclusion of special terms and conditions in contracts to ensure added transparency, reporting, administrative controls and oversight. Pending the issuance of final government-wide guidance and rulemakings, including new or amending Federal Acquisition Regulations provisions, the Department has developed and issued interim terms and conditions for use in contracts to ensure proper implementation of Recovery Act requirements. In addition, each Departmental program has developed contract-specific execution strategies to ensure the expeditious and proper obligation of funds consistent with the requirements and objectives of the Recovery Act.

With respect to ensuring that appropriate and qualified staff are in place to properly obligate and administer Recovery Act funds, the Department is pursuing both short-term and long-term strategies. Consistent with the objectives of the Recovery Act to expedite the obligation of funds, the Department is utilizing its existing acquisition workforce, including leveraging contracting and program personnel that support programs that are not directly impacted by the Act, as well as existing information technology systems that will speed the solicitation, evaluation, and award of contracts. As necessary and appropriate, the Department also intends to supplement its existing acquisition workforce with temporary contractor support. To ensure that appropriate Federal personnel are in place to manage and oversee the expenditure of Recovery Act funding, the Department has identified essential staffing needs, in both acquisition and program. The Department is pursuing filling those needs through expedited hiring strategies and approaches, including direct-hire authority, the Department of Veterans Affairs' Veterans and Disability Program, and the Reemployed Annuitant program.

RESPONSES OF HON. STEVEN CHU TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. Congress tends to authorize a large number of programs, but we are not as successful in deauthorizing programs that are no longer needed, or are ineffective.

As we are looking at doubling the authorization level for energy research and development programs, are there some programs that could be deauthorized?

Answer. The Department of Energy implements and oversees a wide range of programs in every stage of energy research and development (R&D) as well as in energy technology deployment, demonstration, and technology transfer phases. While the current priority is the expeditious and responsible disbursement of funds made available by the American Recovery and Reinvestment Act, the Department will continue to review existing programs to determine both their effectiveness in achieving desired objectives and their efficient use of taxpayer money.

Question 2. As we work to grow our future energy workforce needs, I am reminded that multinational companies are global shoppers of talent—there is no such thing as a monopoly on good ideas.

What energy education and workforce development programs are there overseas that we might be able to emulate?

Answer. We certainly must be open to learning from the world's best practices in developing our future workforce. Working closely with the National Science Foundation and others, the Department's Office of Science's Workforce Development for Teachers and Scientists (WDTS) program is responsible for providing a continuum of opportunities to our students and teachers of science, technology, engineering and mathematics. As part of their work, they monitor and interact with programs around the world including participation in the international Lindau Nobel Laureates meeting, which annually attracts 600 of the best graduate students and 30 Nobel Laureates to a week long meeting in Germany. This year will focus on climate change and renewable energy. WDTS also works with other DOE offices, including EERE, to monitor international programs and model exemplary programs from overseas.

Question 3. Yesterday the National Association of Colleges and Employers reported that 66% of companies surveyed are either hiring fewer new college graduates in the Spring, or not hiring at all. The report also shows a 37% decline in hiring of professional services, which includes engineering. At the same time, large segments of energy industry workforce are nearing retirement and will need to be replaced.

What role should Congress and the Department of Energy play in highlighting energy workforce needs for college students?

Answer. The Department of Energy (DOE) is committed to meeting its workforce needs in energy careers for college students through recruitment programs tailored at the entry-levels. The Student Career Experience Program (SCEP), Student Temporary Employment Program (STEP) and the Federal Career Intern Programs (FCIP) are some of our programs offering students exposure and hands-on experience in science and technology.

While some of these students will clearly move on to energy careers, the main missions of the Department of Energy are focused on energy and science research and development activities, nuclear security and environmental cleanup. Inasmuch as the research awards assist colleges and universities in the education and training of our next generation of energy workers, the Department of Energy stays within its mission and contributes to this workforce growth.

In the health care field, many medical students turn to a specialty practice rather than general healthcare, where there is a huge need, because overwhelming student loans, require the higher pay found in specialty care.

Question 4. As we look to grow the energy workforce, does the burden of student loans move students toward one particular field over another?

Answer. The Department is not expert in education related matters, but has not observed any such trend in energy-related fields. That said, the Department does use recruitment incentives and student loan repayment flexibilities when appropriate to attract candidates by helping to minimize their financial burdens. For example, while engineers, physicists, computer scientists, and mathematicians made up 18 percent of DOE's Federal employee hires last year, this group accounted for nearly 30 percent of the Department's recruitment incentives. As the Federal workforce continues to age, we expect to continue the use of human capital flexibilities like recruitment and retention incentives and student loan repayment to attract and retain America's best and brightest scientific professionals.

Question 5. Shortly following the release of the FY2010 Budget Blue Print, your DOE press office put out a statement which said "the new administration is starting the process of finding a better solution for management of our nuclear waste". I am happy to hear this since the administration has been unambiguous in its oppositions to the current solution in the form of Yucca Mountain.

Since the language we are considering today includes increased authorizations for nuclear energy R&D, which includes the Advanced Fuel Cycle Initiative, do you agree that there is a need to increase fuel cycle R&D to support this process?

For the record, can you provide a more detailed description of the process the administration plans to follow? What other agencies may be involved and what is the timeline?

Answer. The President has highlighted the need to address the key issues of security of nuclear fuel and waste, waste storage, and proliferation. To this end, the Department will continue to work with the Department of State, the National Security Council, the Environmental Protection Agency, and Congress to resolve technical and policy issues associated with proliferation-resistant technologies.

Question 6. The legislation we are considering today provides top level authorizations for broad ranges of R&D programs in nuclear, fossil, and renewable energy and fundamental science. In your testimony you also list a number of clean energy technology examples in need of transformational research.

Can you be more specific regarding what transformational research would be needed in these different areas and how increased R&D funding would be used?

Answer. The Department needs transformational research to bring a range of clean energy technologies to the point where the private sector can pick them up. Some examples include:

- Automobile batteries with two times the energy density of today's Lithium-ion batteries, that can be recharged in minutes, that can survive 15 years of deep discharges, and that cost one-third as much as current devices;
- Transportation fuels generated in a biorefinery from biomass feedstock like forest wastes, crop wastes, municipal solid wastes, algae, and non-food energy crops. In addition, transformational technologies are needed to reduce the cost of higher-value bioproducts that can replace petrochemicals in the chemicals and materials markets;
- Photovoltaic solar power that has installed costs of one-third as much as today's technology;
- Advanced materials for building shells (walls, windows, roofs) and advanced equipment for lighting and heating and cooling, together with computer-controlled design and operations tools for commercial and residential buildings to enable reductions in energy consumption of up to 80 percent and lower costs of ownership; such technologies, together with onsite power generation using renewable energy sources like photovoltaics, will truly provide net-zero energy buildings;
- Large scale energy storage systems that will allow utilities to accept high levels of variable renewable energy sources such as wind and solar power, with an incremental cost of just $0.01/kWh to $0.02/kWh

This is not a definitive list, or a hard set of technology goals, but it gives a sense of the types of technologies and benchmarks for which DOE should be aiming. The Department will need transformational research to attain these breakthrough goals. DOE must re-energize its national laboratories as centers of great science and innovation and at the same time must reach out to universities, our Federal partners, and other research entities for collaboration and innovation wherever it may be.

Transformational research will also be needed to make carbon capture and sequestration safe, cost-effective, and secure for hundreds of years. One area of immediate importance is research into potential technology breakthroughs for carbon capture from the existing fleet of power plants which will be critical in meeting any greenhouse gas stabilization scenario.

Question 7. As you know, Congress expanded the Renewable Fuel Standard to 36 billion gallons in 2007. A submandate of 16 billion gallons was put in place for cellulosic biofuels, starting with 100 million gallons in Calendar Year 2010. To encourage the development of these fuels, we've appropriated funds for a wide range of research and development programs, including the Bioenergy Research Centers you mentioned in your testimony. But even with those commitments, most agree there is almost no chance that the submandate for cellulosic biofuels will be met when it kicks in next year.

Do you believe the biofuels R&D programs we have in place are adequate, given the volume of biofuels Congress mandated in 2007? In terms of both supply and demand, are the targets set by Congress achievable and realistic? Are there any further actions that you would recommend to facilitate the transition from corn-based ethanol to next generation biofuels?

Answer. Cellulosic biofuels technologies involve the creation of an entirely new industry that will produce liquid transportation fuels. As you know, cellulosic processes must be competitive in a high volume and highly volatile fuel market. Several factors have led to unanticipated reductions in the near-term pace of growth of the cellulosic ethanol industry, including the economic recession, severe oil price drops, and the reduction of credit available to investors who wish to invest in these technologies. The Department believes that meeting the 2010 cellulosic biofuel target set by the 2007 Energy Independence and Security Act (EISA) will be challenging. However, EISA does provide Environmental Protection Agency (EPA) authority to adjust the cellulosic targets.

The Department shares your concern that the U.S. needs to transition from corn-based ethanol to next-generation biofuels. That is why the DOE Office of Science's Bioenergy Research Centers are performing fundamental research on next-generation bioenergy crops to provide the transformational breakthroughs that can contribute towards more efficient cellulosic biofuel production and development of other advanced cellulosic biofuels. Moreover, DOE deployment projects focus mostly on cellulosic or other non-food feedstocks to produce advanced biofuels. The DOE Biomass Program has developed public-private partnerships to share the risk of deploying first-of-a-kind cellulosic biorefineries to produce biofuels. Cellulosic biofuels facilities are also eligible to apply for loan guarantees under DOE's Title XVII program.

Question 8. During your confirmation you expressed your support for nuclear energy and the administration has stated that nuclear energy will be "part of the mix". Yet, in the list of clean energy technologies you describe in your testimony there is no example of nuclear energy. Also, in the 2010 budget there is little mention of nuclear energy outside the reduction in Yucca Mountain funding.

What assurance can you or the administration provide that nuclear energy will actually receive equitable benefit from increased R&D funding relative to other clean energy technologies?

Answer. Nuclear power currently supplies nearly 20 percent of the Nation's electricity and approximately 70 percent of its greenhouse gas-free electricity. It is unlikely that the U.S. can meet its aggressive climate goals if nuclear power is eliminated as an option, but as industry moves forward with expansion, the federal government must continue to address the key issues of security of nuclear fuel and waste, waste storage, and proliferation. These priorities are supported in the administration's FY 2010 budget overview, released February 26, and will be described further in the forthcoming detailed Congressional budget request.

Question 9. You mentioned in your statement that you have spent much of your career in research labs—and I particularly noted you mentioned your time as a student.

In your opinion, throughout your career in the energy arena—from student to Secretary of Energy, has the government kept up in helping to attract students to the energy sector? What could we be doing better?

Answer. Attracting bright students and inspiring them to devote a career to tackling our most challenging energy and climate needs are matters of great importance to me. Energy security and climate sustainability are priorities not only for the United States but indeed for the entire global community. For the United States to meet these challenges and achieve the transformational breakthroughs needed, a large, highly focused, highly trained technical workforce must be developed.

Government has achieved some successes in attracting talented students to the energy sector. DOE programs support undergraduate researchers, graduate students working toward doctoral degrees, and post-doctoral researchers. The R&D workforce developed by DOE and its national laboratories provides scientific talent in areas of fundamental and applied research and also provides talent for a wide variety of private technical and industrial sectors. In addition, the DOE scientific user facilities provide outstanding hands-on research experience to many young scientists. Thousands of students and post-doctoral investigators conduct experiments at DOE-supported facilities each year.

And, building on our achievements, we see this as a time of increased opportunity. DOE programs complement the changing demands of the energy workforce through their support of career-intern programs, research and development opportunities, scholarships, and support for post-doctoral associates to continue to help them develop advanced research and management skills. The Department utilizes a variety of intern programs to attract students to professional and scientific careers in government. The Federal Career Intern Program, Presidential Management Fellows Program, Student Career Experience Program, Student Temporary Employment Program, Student Partnership Program, and DOE Scholars program all provide professional development to students while allowing us to build our workforce pipeline. Workforce pipeline development and talent acquisition strategies are effective when government has the right people with the right tools to facilitate that pipeline.

Energy is not an area of fleeting relevance. It will continue to be essential to our economy, our national security, and our environment for decades to come. There is huge growth potential in clean, renewable, sustainable energy as our Nation seeks to overcome dependence on foreign oil and reduce carbon emissions by improved conservation measures and the commercial expansion of renewable technologies. We cannot afford for this potential to be limited by a labor shortage; however, experience has shown that students are well aware of the areas where their greatest employment potential lies and gravitate to those fields. Having an ample workforce with diverse technical skills is critical to an effective transition in the energy sector, and the ongoing leadership of the Administration can help signal that these areas are high potential for new graduates.

Question 10. I applaud the Administration's support for graduate fellowship programs that will train students in energy-related fields in the FY2010 budget request. But in order to have successful graduate programs, there needs to be a pipeline of students interested in energy-related fields starting in high school and on through undergraduate programs.

What support will there be for these programs in the FY2010 budget?

Answer. Every year the Department of Energy engages in a variety of capacity building programs in an effort to maintain the strength and vitality of the Department's workforce pipeline beginning at the high school level. In FY 2010, the Department will continue its efforts to attract both high school and undergraduate participation. DOE has supported the development and expansion of high school outreach and pipeline programs for many years. Approximately 91 percent of the participants in our science, technology, engineering and mathematics (STEM) related outreach and education programs belong to the K-12 demographic. One of the Department's leading STEM programs is the National Science Bowl, which DOE has sponsored since 1991. This program is designed to encourage high school students to excel in science and math, and was expanded in 2002 to include a separate national competition for middle school students.

Recognizing the growing diversity of our Nation coupled with the underutilization of some key segments of the population, DOE has designed programs to ensure that under-represented high school students have access to DOE facilities and information. For example, DOE partnered with non-profit organizations to sponsor a series of seven Hispanic Youth Symposia across the country. While encouraging students to pursue higher levels of education, these symposia showcase the importance of STEM education, research, and careers with DOE while supporting the Executive Order on Education Excellence for the Advancement of Hispanic Americans.

At the collegiate level, DOE supports the National Solar Decathlon and will continue to work in programs that enhance the President's vision on clean energy and reduced dependence on foreign oil. DOE is committed to providing opportunities for college students and recent graduates to experience R&D firsthand through fellowships, internships and entry-level hiring programs. DOE currently has 38 Presidential Management Fellows, 166 Federal Career Intern Program interns, and 141 Student Career Experience Program interns hired at the entry-level, which provide opportunities for conversion to permanent career positions. DOE also has 277 Student Temporary Employment Program interns currently on board and is funding 70 DOE Scholars. These are in addition to the regular cadre of student summer interns which DOE sponsors annually. This short-term summer intern program provides participants both a salary to help them stay in school and real hands-on experience with careers in the Federal Government.

The Department's FY 2010 budget supports graduate fellowship programs that will train students in energy-related fields. In the energy sector, recruitment needs to increase three to fourfold in the years ahead, both to meet increasing demand and also to replace an aging current workforce. The FY 2010 budget support transformational research to re-energize our national laboratories as centers of great science and innovation.

RESPONSES OF HON. STEVEN CHU TO QUESTIONS FROM SENATOR STABENOW

R&D SPENDING

Question 1. The Recovery Bill in February included $2.5 billion for Energy Efficiency and Renewable Energy R&D. What are the Administration's priorities for rolling out grant applications and new program regulations to fulfill the vision of our Recovery bill R&D priorities? We are enthusiastic about the opportunities—Michigan we will be among those first in line to receive such grants, given our strong research and manufacturing capacity, and our commitment work to connect researchers, entrepreneurs and industry to bring about a strong, green economy.

Answer. The Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) is working to develop projects as directed by the Recovery Act. These projects are being closely reviewed to ensure that they meet the priorities of the Act, the energy priorities of the Administration, as well as requirements for integrity and transparency.

The Department understands the need to issue Recovery Act funds quickly and will be making announcements on R&D funding opportunities that span the energy efficiency and renewable energy industries.

EXPEDITED DEPLOYMENT OF ADVANCED MANUFACTURING TECHNOLOGIES

Question 2. Large turbine component manufacturing is done on the same tooling machinery that was in use in the 1960's. What can DOE do to help insure that advanced manufacturing technologies that will speed production and lower cost are deployed as soon as possible in the U.S.? For large competitive solicitations that are forthcoming from the DOE, such as the grants that will be available for battery manufacturing, how has the DOE prepared (in terms of staffing and operational support) to respond to the solicitations, and what is the expected turnaround time for agreements to be announced? Also, under the new processes DOE has developed, how quickly will contracts to be finalized once agreements are announced?

Answer. The Department of Energy (DOE) is partnering with the Department of Commerce to ensure that resources and capabilities available to both agencies are best targeted to support rapid expansion of the U.S. wind energy technology supply chain, including support for development and deployment of advanced manufacturing technologies. While this partnership is just beginning, DOE is currently supporting an advanced manufacturing project for wind blades in collaboration with the state of Iowa. DOE has also received a number of applications for industry projects in wind technology manufacturing advances through a solicitation that closed on March 5 and expects to announce selections in early May. DOE will continue to provide technical expertise and resources as available to contribute to expanding and speeding production, retooling for needed industrial capabilities, and lowering the cost of U.S. wind energy technology manufacturing to keep pace with the rapidly growing markets for renewable energy.

DOE is assessing staffing and operational support needs. Additional Federal staff and appropriate support personnel will be acquired to enable the department to solicit, evaluate, and award agreements for battery manufacturing. The department has and will continue to issue vacancy announcements to acquire necessary Federal staff, reassign existing federal staff from lower priority activities on a limited basis where possible, and hire support personnel through existing support contracts. For instance, the Advanced Battery Manufacturing solicitation was released March 19, 2009 and will be open for 60 days. The Department expects contracts to be awarded (finalized) by September 30, 2009.

Question 3. Efforts of States. As a general matter, how does the Department view states' efforts to collaborate with potential applicants, and will the use of state dollars as non-federal match provide any preference as the Department awards funding under the Recovery Act?

Answer. Cost share requirements vary based on particular solicitations, and applicants' leveraging of Federal funds is highly encouraged. Direct funding for States is primarily through formula grants. DOE provides guidance to States that focuses on the principles that should guide their project planning, including encouraging States to support programs and projects that will provide substantial, sustainable and measurable energy savings and that will have job creation and economic stimulus effects and to give priority to programs and projects that leverage Federal funds with other public and private resources.

RESPONSE OF HON. STEVEN CHU TO QUESTION FROM SENATOR BARRASSO

Question 1. What is the Department of Energy's long-term plan to extend the operation and production of the Rocky Mountain Oilfield Testing Center and ensure its continued success as a research and education resource?

Answer. DOE expects production to continue to naturally decline because NPR-3 is largely comprised of stripper wells—wells whose production has slowed to 10 barrels a day or less. The President must authorize continued production every three years, and production is currently authorized until April 2012. For FY2010, production activities will continue at NPR-3, while testing activities proceed at the Rocky Mountain Oilfield Testing Center (RMOTC). DOE is studying options concerning RMOTC once NPR-3 production operations are no longer economically feasible, including options for becoming a self-sustaining user facility.

RESPONSES OF HON. STEVEN CHU TO QUESTIONS FROM SENATOR SHAHEEN

RECOVERY ACT WEATHERIZATION IMPLEMENTATION

Question 1. Continuing with my question from the hearing regarding the Weatherization program and the funding included in the economic recovery bill, can you tell me what steps the DOE is taking to ensure states make best use of these weatherization monies? We have twin goals of getting this money into our economy quickly while at the same time achievable the important goal of weatherizing homes and reducing energy costs for consumers. What guidance are you or will you be giving states to help guide them through this process? Would the DOE be willing to hold workshops in various regions, like the Northeast, to bring together stakeholders to trouble shoot, problem solve and talk through these issues?

Answer. The Department of Energy (DOE) has made it a priority to make the funds under the Recovery Act available to the weatherization grantees as quickly as possible, while making the use of funds transparent and accountable. DOE published the Funding Opportunity Announcement (FOA) which contains program guidance regarding the use of these funds and its programmatic goals to all grantees. This FOA and Guidance can be read in its entirety at http://apps1.eere.energy.gov/wip/pdfs/wap__recovery__act__foa.pdf

DOE is taking a number of actions to ensure effective use of the funds. First, DOE is increasing the level and scope of the evaluation of state plans submitted as part of the application for funds. Plans must demonstrate that states and local weatherization agencies have identified and have satisfactorily planned to meet the need to increase the number of workers, equipment, auditors, trainers and supervisors. Second, DOE intends to obligate the Recovery Act funds based on a stage gate system with progress reviews as follows:

- 10% of total allocation at time of initial award
- 40% of total allocation upon DOE approval of a State Plan (due within 60 days after FOA issuance)
- Balance of total allocation (20% to 30% at a time) based on DOE review of progress of the states in obligating the funds, complying with all reporting requirements, and creating jobs. If progress reviews reveal deficiencies, such as funds not disbursed, jobs not created, insufficient technical monitoring, or failure to meet reporting requirements, DOE reserves the right to place a hold on current balances and withhold further funding until deficiencies are corrected.

Third, DOE will increase the frequency of monitoring and oversight of the states and local weatherization agencies, including announced and unannounced visits. The DOE/Energy Efficiency and Renewable Energy Project Management Center offices in Morgantown, West Virginia and Golden, Colorado field staff are assigned to conduct oversight monitoring of state operations. These offices will bring on additional support to ensure that monitoring will be conducted on a timely and thorough basis.

DOE headquarters and field management staff conduct weekly conference calls to address ramp up, obstacles to achieving goals, funding, and accountability. The 2009 National Training Conference, scheduled for July 21-23, will work to ensure that the weatherization network is trained to meet the programmatic goals established under the Recovery Act. DOE is considering holding regional workshops or using any other mechanisms to spot and solve problems and discuss issues as they arise.

RECOVERY ACT WEATHERIZATION FUNDING CAP

Question 2a. We raised the statutory cap in the Recovery bill from a maximum of $2,500 worth of weatherization improvements on a single home to $6,500. Can you please clarify for me, does the cap apply to an average of homes or a single home?

Answer. The cap applies across all homes weatherized in the state, not to individual homes.

Question 2b. In my conversations with the New Hampshire Community Action Association, which actually implements New Hampshire's weatherization money, they are concerned that $6,500 may not be enough and are advocating for a $10,000 cap on each home. The thinking goes, rather than making relatively modest weatherization improvements to many homes, with a $10,000 cap, they could actually fully weatherize a lot of homes. Do you have any thoughts on changing the cap to a higher level?

Answer. The Recovery Act, by statute, changed the program's maximum average cost per unit from $2,500 to $6,500. Any subsequent changes would have to be made through statute. Investments in homes are made on the basis of a cost effectiveness assessment under which the most cost effective measures are performed first. Each incremental measure is less cost effective than those that precede it.

Question 2c. In addition, is the DOE considering giving some flexibility to state agencies, like the New Hampshire Community Action Association, in administering these dollars and what is prioritized when improving these homes? More flexibility may help expedite the expenditure of these funds and help get the money into our economy more quickly, a key goal of the Recovery bill.

Answer. DOE encourages innovation in program implementation within the statutory and regulatory framework. Proposed new approaches should be fully described in the plan that the State submits to allow DOE to make a thorough and considered review to assess the impact on quality control, cost effectiveness and other critical program requirements.

Question 3. Of the six Gen IV nuclear power technologies proposed by the US in 2000, DOE Idaho National Labs have been pursuing two—(1) high temperature gas-cooled reactors for hydrogen production, and (2) sodium-cooled fast reactors for waste burning. Separately, liquid-fluoride thorium reactor research is ongoing at UC

Berkeley, MIT, Redstone Arsenal, and in other countries including France, Japan, and Canada.

As the Department analyzes advanced reactor designs, can you tell me if the liquid-fluoride thorium reactors are under consideration? What are the benefits of liquid-fluoride thorium reactors? What are the drawbacks or downsides of liquid-fluoride thorium reactors? How does power generated from liquid-fluoride thorium reactors compare, on a price per kilowatt hour, with power generated from the current coal generation fleet in the United States? As we confront our nation's energy and climate challenges, what role might these types of reactors play?

Answer. The "liquid-fluoride thorium reactor," otherwise known as a molten salt reactor (MSR), where molten salts containing fissile material circulate through the reactor core, is not part of the Office of Nuclear Energy's research program at this time. Some potential features of a MSR include smaller reactor size relative to light water reactors due to the higher heat removal capabilities of the molten salts and the ability to simplify the fuel manufacturing process, since the fuel would be dissolved in the molten salt. One significant drawback of the MSR technology is the corrosive effect of the molten salts on the structural materials used in the reactor vessel and heat exchangers; this issue results in the need to develop advanced corrosion-resistant structural materials and enhanced reactor coolant chemistry control systems. In addition, operational practices would have to address the fact that the liquid salts solidify between temperatures of 300 C to 500 C, thereby requiring the use of special heating systems when the reactor is not operating. From a non-proliferation standpoint, thorium-fueled reactors present a unique set of challenges because they convert thorium-232 into uranium-233 which is nearly as efficient as plutonium-239 as a weapons material. A cost per kilowatt hour estimate has not been developed.

APPENDIX II

Additional Material Submitted for the Record

STATEMENT OF JOHN R. DEAL, CHIEF EXECUTIVE OFFICER, HYPERION POWER GENERATION, INC.

Hyperion Power Generation is the spin-out and commercialization vehicle for a small (70 MWt) transportable reactor invented by Dr. Otis (Pete) Peterson while he was on staff at Los Alamos National Laboratory.

The Hyperion Power Module has several key attributes that make it a compelling solution to providing remote, independent, secure power generation in a variety of applications (see below)*.

A small business, based in Los Alamos New Mexico, Hyperion is funded entirely by venture capital, and mentored by Technology Ventures Corporation, a non-profit business assistance and economic development company. Hyperion is the only privately-owned company commercializing reactor technology from the U.S. Department of Energy.

Hyperion is exactly the kind of innovative firm doing the "crazy stuff" that American industry and government (according to DOE Secretary Chu at the hearing on March 5) need to pursue to help provide cleaner, cheaper, more secure power generation for the nation and the world at large.

The Hyperion Team has successfully commercialized technologies invented at DOE facilities for over 15 years. Several on our team served as Los Alamos staff. Since taking on the commercialization of the Hyperion reactor technology over two years ago, Hyperion management and staff have become immersed in U.S. public policy as it relates to new energy technology, and more specifically, U.S. policy on nuclear power generation.

We believe the committee can support the expansion of safe, clean, and secure nuclear energy by enacting a few initiatives. All of these are consistent with President Obama's commitment to a new energy economy built on innovation, and also to the committee's charter and legislative agenda.

1. The U.S. must close its civilian nuclear fuel cycle. This is a political dilemma, not a technical problem. Although various attempts have been made, it is critical Congress provide funding to create definitive methods for recycling uranium, and securing other fission products and waste in long term storage. France recycles nuclear fuel. Is the U.S. incapable of doing something the French take for granted? As you know, over 90% of so-called "nuclear waste" can be recycled. This valuable fuel can generate massive amounts of electricity for generations to come. While we support the overall goals of the Global Nuclear Energy Partnership (GNEP), we think Congress should focus funding on the recycling and waste treatment aspects of the U.S. GNEP program instead of on creating new commercial reactor designs. If a company as small as Hyperion, and firms as large as Westinghouse, can invent and manufacture new reactor designs, the U.S. government does not need to spend taxpayer dollars doing so.

2. If President Obama is sincere about not funding further development of Yucca Mountain, Congress must enact new legislation to shut down that project and to put taxpayer dollars toward finding a new long term storage site. Although the Yucca Mountain project has been built on solid science, it has been plagued by bad PR and been mismanaged from a public policy perspective. To continue the project now, in the face of Congressional, Administrative, and local opposition, will just waste additional taxpayer funds. We implore Congress look to a more remote location, and suggest the U.S. commonwealth of the Northern Marianna Islands; Tinian comes to mind. The local work force is accepting of

* HPM Report has been retained in committee files.

nuclear energy, and the region desperately needs additional industry. They would welcome such as project. Transportation to CNMI would be completely safe since such a repository would be for civilian (non-weapons grade) waste only.

3. We need a Department of Energy focused on energy. The U.S. weapons complex has enormous responsibilities. Their focus, rightly, is on the maintenance and safety of the weapons stockpile. A smaller, separate, and more efficient weapons complex would eliminate the conflicts inherent at the DOE labs and allow the vast majority of personnel to focus on energy innovations and infrastructure. A Department of Energy focused on civilian energy innovation is necessary in order to meet our national challenges.

4. Congress must be pragmatic and intellectually honest and include nuclear power generation in all so-called "clean," "green," and "renewable" energy categories. All energy generation is really energy conversion, and each has a waste stream. The critical issue is the impact each waste stream has on the planet. Nuclear energy is the only part of the energy industries that can truthfully assert it has contained 100% of its waste stream. The waste streams from all other energy generation methods are simply diluted into the atmosphere. This not only poisons the entire planet, but gives citizenry a false sense of security. It has led many in the U.S. to believe that solar or wind generation can solve our baseload energy requirements (they can't) and that a veritable "free lunch" exists (it doesn't).

5. Lastly, the committee should see that Congress continues its support for small businesses, especially those companies contributing to national energy security, physical homeland security, and alternative energy technologies. The Small Business Innovation Research (SBIR) grants should be streamlined to minimize the time between proposal and funding, and new methods of technology maturation--outside the inefficient Laboratory complex-- should be established to get innovations "off the bench" and into the hands of industry as fast as possible.

I appreciate the committee's interest in our national energy security and in its commitment to increasing U.S. economic security through technical innovation and small business development.

STATEMENT OF GEORGE CRABTREE, SENIOR SCIENTIST AND DISTINGUISHED FELLOW, MATERIALS SCIENCE DIVISION, ARGONNE NATIONAL LABORATORYARGONNE, IL

NEW SCIENCE FOR A SECURE AND SUSTAINABLE ENERGY FUTURE

SUMMARY OF A REPORT OF THE DOE BASIC ENERGY SCIENCES ADVISORY COMMITTEE

The Energy Challenge

For a secure and sustainable energy future, the United States must reduce its dependence on imported oil, reduce its emissions of carbon dioxide and other greenhouse gases, and replace the economic drain ofimported oil with economic growth based on exporting a new generation of clean energy technologies.

The cost and uncertainty of imported oil ($700B/yr at the peak, about $200B/yr currently) are major threats to the U.S. economy. Developing new competitive renewable energy resources will help solve our energy problems at home and create economic opportunity to market our solutions to the world.

The Science and Technology Solution

Changing our decades-long dependence on imported oil and unfettered emission of carbon dioxide requires fundamental changes in the ways we produce, store and use energy. This report identifies three strategic goals required to meet these challenges: (1) making fuels from sunlight, (2) generating electricitywithout carbon dioxide emissions, and (3) revolutionizing energy efficiency and use.

To meet these strategic challenges, the U.S. will have to create fundamentally new technologies with performance levels far beyond what is now possible. Such technologies, for example, may be able toconvert sunlight to electricity with triple today's efficiency, store electricity in batteries or supercapacitors at ten times today's capacity, and produce electricity from coal and nuclear plants at twice today's efficiency while capturing and sequestering the carbon dioxide emissions and hazardous radioactive wastes.

Development of these advances will require scientific breakthroughs that come only with fundamental understanding of new materials and chemical processes that govern the transfer of energy between light, electricity, and chemical fuels. Such breakthroughs will require a major national mobilization of basic energy research. A working transistor was not developed until the theory of electronic behavior on semiconductor surfaces was formulated. Lasers could not be developed until the quantum theory of light emission by materials was understood. Similar breakthroughs can be achieved for sustainable energy, but only if we invest in basic research now.

Basic science stands at the dawn of an age in which matter and energy can be controlled at the electronic, atomic, and molecular levels. Materials can now be built with atom-by-atom precision, and advanced theory and computational models can predict the behavior of materials before they are made—opening new horizons for creating materials that do not occur in nature and are designed to accomplish specific tasks. These capabilities, unthinkable only 20 years ago, create unprecedented opportunities to revolutionize the future of sustainable energy. Transformational solutions to reducing imported oil dependency and carbon dioxide emission-from solar fuels, renewable electricity and carbon sequestration to batteries, solid-state lighting and fuel cells-require breakthroughs in the fundamental understanding and control of materials and chemical change.

Recommendations

To achieve these essential breakthroughs we need to fund a bold new initiative focused on solving the critical scientific roadblocks in next-generation carbon-free energy technologies. The solutions are within reach, using advanced materials and chemical phenomena that control matter and energy at the electronic, atomic and molecular level. To develop these solutions, we must recruit the best talent through workforce development and early career programs. We must establish “dream teams” of the best researchers and provide them the resources to tackle the most challenging problems.

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