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FUTURE ENERGY NEEDS

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED TENTH CONGRESS

SECOND SESSION

TO

RECEIVE TESTIMONY ON THE CHALLENGES TO MEETING FUTURE ENERGY NEEDS AND TO DEVELOPING THE TECHNOLOGIES FOR MEETING INCREASED GLOBAL ENERGY DEMAND IN THE CONTEXT OF THE NEED TO ADDRESS GLOBAL CLIMATE CHANGE

JUNE 25, 2008

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FUTURE ENERGY NEEDS

Wednesday, June 25, 2008

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

The committee met, pursuant to notice, at 9:36 a.m. in room SD–366, Senate Dirksen Office Building, Hon. Jeff Bingaman, chairman, presiding.

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

The CHAIRMAN. OK. Thank you all for coming. We have a hearing on the challenges of future energy needs that we should be pursuing in order to address our energy needs and the issue of global climate change as well.

Nearly 20 years ago, James Hanson was before this same committee testifying that global temperatures had risen beyond the natural range of variability and since then, in the last 20 years, I think it's now clear to everybody that we should have been seriously pursuing development of low carbon energy technologies.

We've done some work in this area but at least from my perspective, we have failed to sustain the support that was needed for many promising technologies that could have decreased our dependence on fossil fuels.

Today, we're at a crossroads. We have high fuel prices. We have growing energy demand. We have global greenhouse gas emissions on a trajectory to unacceptable levels. It's clear that we need new policies and strategies here in the United States and we have an opportunity, I believe, to develop the technologies that will break the world's dependence on fossil fuels.

I hope that today's testimony will begin a serious effort at developing a robust long-term energy strategy that will ensure not only our energy security, but our economic and climate security in the future.

Two weeks ago, a little over 2 weeks ago, the International Energy Agency put out a comprehensive and provocative report dealing with the mix of technologies that we need to develop and deploy in order to meet our energy needs and to reduce greenhouse gas emissions.

We've invited Dr. Hirst from the IEA to talk about the findings contained in that report. In my view, it's an excellent and sobering report which I would encourage everyone to read. I'm in the process of reading it. It's not light bedtime reading, but it's quite comprehensive.

Transforming our economy from one that's based on fossil fuels to one that's based on clean energy will require significant investment in the range of $45 trillion, I think, between now and 2050 is the estimate. It will require that we develop and deploy a whole range of clean technologies now in development, from carbon capture and storage to concentrated solar power, and will require that all nations, particularly the nations in the developing worlds, participate wholly with the United States and other OECD countries in making these changes.

The final message of the report is that the goal of a 50 percent reduction in greenhouse gases by 2050 is attainable but this is an extremely ambitious and difficult goal to attain.

Our task here is to apply the report's findings, to chart a path forward. I think there are lessons here for us to learn in the United States. It is to ensure that the policies are in place that will take us down the necessary technology development pathways toward dealing with these challenges.

We need to encourage private sector investment obviously. We have a chance here in the Congress with our energy tax incentives to do that. Second, we need to prioritize and sustain support for promising energy technologies over the long term.

Today, our funding for energy technology is about half what it was 25 years ago. The policies——

Senator DOMENICI. What was that statement?

The CHAIRMAN. I said today, our funding for energy technology is only half what it was 25 years ago.

Policies must be developed which capture the extensive research and development knowledge that's generated in the United States and ensure that the technologies that are spun out of that knowledge are manufactured and deployed here and we create domestic jobs and wealth in the process.

Lastly, we need to engage other nations in developing these technologies and I hope we can see a way clear to do that.

I look forward to the testimony this morning. I thank all witnesses for being here.

Before introducing our first panel, let me defer to Senator Domenici for his statement.

[The prepared statements of Senators Salazar and Barrasso follow:]

PREPARED STATEMENT OF HON. KEN SALAZAR, U.S. SENATOR FROM COLORADO

Mr. Chairman and Ranking Member Domenici, thank you for holding this hearing on the challenges we face as a planet and as a nation in developing and deploying the energy technologies necessary to satisfy growing global energy demands in the face of global warming.

The energy crisis that we currently face is dominating the minds of many citizens. While many are feeling the pain of high gas prices that is only the most visible symptom of a much deeper and more systemic set of problems. The price of energy is reflected in every aspect of our economy—the price of our food, the cost of the goods and services that we purchase, the cost of travel, manufacturing, mining, water and sewage treatment, etc. etc.. But the price of energy is also embedded in the billions of defense dollars we spend each year to monitor our global oil supply chain, and the billions of dollars we send every day to hostile oil-backed regimes. And the potential future costs of global climate change may be too vast to comprehend. This week the intelligence community published its first classified report on the national security implications of global warming. Clearly the environmental, economic, and national security threats that our current energy portfolio poses are deeply sobering.

Yet, in the face of these threats our nation still struggles with an energy policy for the 20th century instead of embarking boldly on an energy policy for the 21st century. Last week the President stated in the Rose Garden at the White House that our country desperately needs to maximize domestic production of fossil fuels. I was struck by the fact that in the seven and a half years since this Administration took office—since 9-11 and the rise of oil-funded Islamic terrorists, since the IPCC's conclusive reports heralding the dire threat of global warming, and since our current energy crisis—the President's disposition towards energy has not changed one iota. Simply put, this country has suffered a colossal lack of leadership, insight, and dedication to tackling our essential energy challenges.

I am raising these broader issues in the context of today's hearing because I truly believe we are at a watershed moment in our nation's energy policy. We can either continue to clutch the fossil fuel dependencies that we have nourished over many decades or we can seek to forge a new energy economy founded on the exploitation of clean, low-carbon energy technologies. If we turn away from our current energy crisis to the old embrace of fossil energy, we will ignore our myriad security threats.

The topic of today's hearing is thus the essential piece to the puzzle. We must do everything we can to capture the environmental, economic, and national security benefits of low-carbon technologies for the long term. This quest is three-fold. First, we need to invest in projects that can provide proven energy gains and savings today and in the near term. Investing in renewable energy is one of the surest paths to reducing U.S. carbon emissions while creating good-paying jobs in these globally-expanding industries. Passing the energy tax package before the Senate is a critically important step in this direction.

Second, we need innovative public-private partnerships to accomplish the early commercial-scale demonstration projects that will prove the viability of carbon capture and sequestration, geothermal energy, and advanced coal technologies, and other capital-intensive technologies. Third, we need to embrace a "Manhattan Project"-inspired intensive R&D approach to developing the transformative energy technologies that will contribute new and unforeseen long-term solutions to our energy and environmental security challenges.

The IEA report that Dr. Hirst will present today makes clear that time is already running short. Achieving global carbon emissions reduction goals may require an unprecedented level of cooperation between developed and developing nations to ensure low-carbon energy technologies become cost-effective and widespread as quickly as possible. The high standard of living we enjoy in the U.S. is intimately related to our longstanding dedication to promoting and capitalizing on technological innovation. I believe that our innovation infrastructure holds the key to solving our energy crisis, and I look forward to discussing the policies that are needed to ensure the global transformation to a low-carbon energy future with this distinguished panel.

Thank you, Mr. Chairman.

PREPARED STATEMENT OF HON. JOHN BARRASSO, U.S. SENATOR FROM WYOMING

Thank you Mr. Chairman.

We need to develop the technologies we need to meet our future energy needs.

This hearing today is reviewing that issue in the context of the addressing global climate change.

Energy demand is going up across the globe.

China and India are emerging economic powers with burgeoning middle classes. Their people are demanding more energy now than ever before.

They need the power to provide running water, lighted streets, and heated homes in the heartland of their countries. They also need the power to provide the manufacturing base that is driving their economy.

In the United States, our energy demand is growing too. We need energy to power our homes and to power our economy.

Unfortunately for us, the price of energy is going through the roof.

It costs $4.00 a gallon to fill up your gas tank. That impacts moms and dads trying to get to work, pick up the groceries, and drop their kids off to school.

It costs hundreds more to pay heating and air conditioning bills. Oil prices have soared to $135 dollars a barrel. Natural gas prices have nearly doubled since last year.

It costs hundreds more to buy groceries each month for average Americans, with the price of fuel impacting the cost of producing food on our farms.

Many industries across the United States are looking to lower their energy costs by shipping jobs overseas.

Airlines are canceling flights because they can't afford the price of jet fuel.

The current status quo is unacceptable. Americans are demanding more energy for now and for their children's futures.

Now let us consider the status quo in the context of global climate change.

The best way to address climate change is to have cleaner, more affordable energy.

We need to lower energy prices for all Americans. Any solution to climate change that does not do that is not worth pursuing.

Proposals that suggest a cap and trade approach to solve climate change do just the opposite, they dramatically raise energy prices.

The very premise of these approaches is to make carbon intensive fossil fuels so expensive that energy companies and consumers will make a radical shift to non-fossil fuel sources.

The bottom line is energy prices are already high, and Americans are demanding action. We do not need to make them higher for Americans to get the point.

They know we need abundant, affordable, clean energy to power our economy and to address climate change.

Then the question is how to get there. For that, I believe we need to use all our energy resources—clean coal, natural gas, wind, solar, nuclear, geo-thermal.

We need to develop all of these resources using new technologies that make them cleaner and yes, more affordable.

My home State of Wyoming is blessed with vast deposits of coal. Coal is perhaps America's most abundant resource.

It would make no sense to not include coal in our energy future.

Reduction of greenhouse gas emissions from coal-fired power plants will be possible through first capturing the carbon dioxide emissions and then sequestering it underground.

Both will take time and money.

In order to achieve this challenge the federal government and private industry must partner in funding research and technological innovations.

Timing is critical.

America needs to make a serious and substantial investment in research and developing commercial technology.

In order to achieve energy security and a clean environment, the federal government must demonstrate its commitment with targeted, up-front financial support.

We must show leadership, not merely dictate unreasonable and unworkable policies and hope for the best.

What does this mean? . . . If Congress mandates reduced emissions, it is incumbent upon us to also provide the policies to allow our economy to succeed.

Proven, commercially available, cost-effective technologies must be developed with respect to carbon capture and sequestration.

These technologies must be efficient, effective, and allow America to continue to compete globally.

It for this reason that I filed an amendment during the climate change debate on the floor to provide $50 billion in revenue from emissions allowances:

- $40 billion for the demonstration and deployment for carbon capture technologies and;
- $10 billion for large-scale geologic carbon storage demonstration projects.

This is an enormous investment, but we must take aggressive steps.

This is one approach that will help meet the global demand for energy. But it's going to take an investment in a number of energy methods to develop affordable, commercially viable clean energy sources.

Federal funding will also be needed to get the first new modern nuclear power plants online.

With any major new technology, the first few commercial scale models are always the most expensive. With the help of the federal government, we can help lower the costs of the initial plants, and therefore make future plant construction much more cost effective.

Lower construction costs means lower energy costs for constituents.

With the development of new technologies, the Untied States can be the leader in the development of the next generation of coal and nuclear power plants.

Such technology can also help spur the development of cleaner energy plants across the globe and help address climate change.

I thank the Chairman and look forward to the testimony.

STATEMENT OF SENATOR PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

Senator DOMENICI. Thank you very much, Mr. Chairman, fellow Senators. I'm glad to see so many senators here.

There's no question that the issue before us is a major one, of great significance to our children and our grandchildren.

First I want to ask, Mr. Chairman, would you put my prepared statement in the record?

The CHAIRMAN. Glad to do that.

Senator DOMENICI. I just want to make sure that you have read the Albuquerque Journal from this past Sunday. If you haven't, I want to talk with this committee and you in particular about the Journal's editorial, which I believe most succinctly states the problem that our country has at this point in our history.

When we have two great problems confronting America at the same time. One is carbon dioxide emissions, which we want to try to control because we have the long-term problem of global warming. We have a second problem that whether we like it or not, there's a growing energy dependence, which I have chosen to say causes me to have the greatest fear for our country's future that I have ever, ever had.

I was quite pleased to see this editorial which is titled, "It takes black gold to get to green future." Now you might say, is that some kind of wacky right wing newspaper? Not at all. It's a right down the middle newspaper that has rather good editorial policies that are realistic. The conclusion in this Journal editorial is as follows, and let me read you a few things that are better than I can do.

"With all due respect to Al Gore," it starts, "there is an urgent new inconvenient truth." Continuing, "Unless Congress acts quickly to expand domestic oil supplies, the Nation could face economic destruction long before it sees the environmental fall-out of global warming."

Now I know a lot of people don't want to hear that statement, but I believe that is the way it is, and that's true, and that's why I'm fearful for our country because, as this editorial starts, "we have a new inconvenient truth." Remember, Al Gore had inconvenient truth. We have a new one, and that is we are going to have economic ruin if we do not find a way to diminish our dependence upon crude oil imports.

It goes on to say that "for decades it has been easy for most Americans to dodge the truth about our foreign oil dependence and just keep driving—but $4 a gallon gas has finally snapped the trance. Reality is sobering: The United States has put its economic survival in the hands of unstable foreign powers and volatile commodities markets. At any time, a major disruption in foreign supply could bring the enormous transportation-based U.S. economy to a standstill. The U.S. trade deficit jumped to its worst level in more than a year in April, driven primarily by oil imports. Not only does this empower anti-American regimes, it siphons off money consumers could be spending or saving or investing."

Then the best statement in this editorial, it quotes me.

[Laughter.]

Senator DOMENICI. It says next, "'I have never been more frightened for America's future than I am right now,' Senator Pete

Domenici said last week, urging Congress to remove the ban on offshore drilling and open the Arctic National Wildlife Refuge to oil companies."

Now I can go on and I will tell you, Mr. Chairman, that you are not left out. The editorial proceeds and says to you, "As chairman of the Senate Energy Committee, Bingaman will be a key player on both fronts of the effort to chip away at America's dangerous level of dependence on foreign oil."

What I want to say is, my staff and I have reviewed the IEA report. If we followed the path for technology that this report might suggest, and we go out 50 years and we have CO_2 under control, the problem is that at that point, they say we will still be dependent on crude oil to the same degree that we are today.

Now I guarantee you that that cannot happen. It won't work. If we had the wherewithal to follow that approach, we would be bankrupt before we got to the new technology for CO_2 capturing 50 years from now.

So I believe I'm going to put this editorial in the record, if you'd let me, Mr. Chairman.

The Chairman. No, I'm glad to have that in the record.

ALBUQUERQUE JOURNAL

EDITORIALS.—IT TAKES BLACK GOLD TO GET TO GREEN FUTURE

Sunday, June 22, 2008.

With all due respect to Al Gore, there is an urgent new "inconvenient truth." Unless Congress acts quickly to expand domestic oil supplies, the nation could face economic destruction long before it sees the environmental fallout of global warming.

For decades it has been easy for most Americans to dodge the truth about our foreign oil dependence and just keep driving—but $4-a-gallon gas has finally snapped the trance. Reality is sobering: The United States has put its economic survival in the hands of unstable foreign powers and volatile commodities markets. At any time, a major disruption in foreign supply could bring the enormous, transportation-based U.S. economy to a standstill.

The U.S. trade deficit jumped to its worst level in more than a year in April, driven primarily by oil imports. Not only does this empower anti-American regimes, it siphons off money consumers could be spending or saving or investing.

"I have never been more frightened for America's future than I am, right now," Sen. Pete Domenici said last week, urging Congress to remove the ban on offshore drilling and open the Arctic National Wildlife Refuge to oil companies.

President Bush—in a speech laced with counterproductive partisan rhetoric—called on Congress last week to open up several domestic oil, fields that have been off-limits since the 1980s. ANWR could yield 27 billion barrels; the Atlantic and Pacific coasts contain 17 billion barrels, and the Gulf Coast could produce another 72 billion. There is strong evidence this can be done in an environmentally responsible way.

Democratic presidential candidate Barack Obama has so far ignored polls that show a majority of Americans rallying around calls for domestic drilling. He continues to argue that the answer to foreign oil dependence lies in wind, solar and nuclear technologies. The inconvenient truth, however, is that climate-friendly technologies will take decades to develop We look forward to the day when we can all plug our green cars into an electrical grid powered by something other than coal.

Until then, we're going to have keep buying gas. Even if we achieve a dramatic 20 percent reduction in oil consumption, some experts estimate that oil will still cost $200 a barrel by 2012. So here's another ' inconvenient truth: New drilling isn't about returning to cheap gas. It's about economic survival.

The United States needs to organize a Manhattan Project for alternative energy, addressing the threats from both global warming and foreign dependence. We need to vigorously pursue those, along with a crash course in conservation.

These are monumental undertakings, and to succeed they must transcend party lines or individual egos. Sen. Jeff Bingaman was on-target Wednesday when he faulted President Bush for injecting "election-year politics" into the Rose Garden speech. As chairman of the Senate energy committee, Bingaman will be a key player on both fronts of the effort to chip away at America's dangerous level of dependence on foreign oil.

The way ahead is not easy. Fuel costs are impacting food and retail prices. Truckers are parking their rigs. School bus operators and closing up shop. Airlines are laying off thousands and perhaps are heading for prices that will put air travel out of reach for the middle class. The idea of the family flying to Disneyland, for example, would be out of the question. Even a family vacation by car could look like a luxury.

Americans have never backed down from a challenge, however. Once we know the truth, no matter how inconvenient it may be, we like to get to work. In this case, the work involves a drilling rig, and the self-Confidence to use it.

Senator DOMENICI. I will say that I believe we have not faced up to this issue the way this editorial says. For instance, if we are going to apply a new technology, Dr. Orbach, or even an old technology that the Germans used in the Second World War, to turn coal to liquid diesel fuel, we would immediately have those who are worried about CO_2 say no, no, no, that increases global warming.

This editorial says you better not throw that approach away because you are substituting a barrel of domestic produced diesel fuel for a barrel of foreign oil and you are minimizing the destruction path for the American economy. You cannot throw that approach away in fairness to your country's future and your grandchildren. You have to follow the bridge to the future, which is reducing crude oil demands of America.

I thank you, and I hope the hearing goes on well. Thank you, Mr. Chairman.

[The prepared statement of Senator Domenici follows:]

PREPARED STATEMENT OF HON. PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

Thank you, Mr. Chairman, for calling this hearing to discuss the challenge posed by the need to provide the energy that fuels our economy, while at the same time addressing global greenhouse gas emissions. This hearing gets to the very heart of the difficult debates that Congress has conducted over the past several weeks since it forces us to again consider the short-term actions we must take to build a bridge to a secure, sustainable energy future. While it is simple to agree that we must develop a sustainable economy that produces significantly less greenhouse gas emissions 40 or 50 years from now, it is difficult to agree on what options we should pursue to achieve that goal and at what cost.

The Energy Technologies Perspective 2008 report recently published by the International Energy Agency shows the complex and multifaceted nature of the problem before us. After considering the projections provided in this report, though, I am impressed that really the challenge is three fold. Not only must we address our growing future energy needs while reducing our carbon emissions, but first, and I believe most importantly, we must address the immediate danger in which our continued dependence on foreign sources of energy places us. I have made no secret of the deep-seated fear I have regarding the future of our Nation if we continue to export our wealth abroad in exchange for foreign oil.

This is an issue that we must address, no matter what course we pursue with regard to carbon emissions. Despite the assertions of many who support reducing our carbon emissions, the Energy Technology Perspectives 2008 report makes it clear that reducing carbon emissions, by itself, will not significantly impact our dependence on foreign oil. Even under the most aggressive CO_2 cutting scenarios described in this report, oil is projected to remain a substantial portion of the world energy mix by 2050. While world oil use is projected to decrease under these aggressive scenarios it is still projected to remain at 60-70 million barrels a day by 2050 compared to approximately 80 million barrels a day in 2005. What is most notable in these projections is that the amount of oil obtained from OPEC sources is projected to be the same in 2050 as it is today. It is the oil obtained from other sources, including our own domestic production, that is projected to decline.

I have said on many occasions in recent weeks that I believe domestic oil production is a bridge to the future. This is an example of why I make that statement. Are we to accept a future in which we continue to send billions of dollars overseas to purchase oil, or will we build a bridge with increased domestic oil production to a future of new, cleaner technologies? I suggest that our best interests are served by decreasing our dependence on foreign sources of oil—and we should start now.

There are many “inconvenient truths” that we must contend with today. First, the effort required to reduce our domestic CO_2 emissions in the decades to come will be extremely difficult and if not done correctly will be very costly. Second, no matter how successful we are in limiting our carbon emissions, oil will remain an essential part of our domestic energy mix. Third, the immense wealth we expend to purchase oil from foreign sources increases our trade deficit and leaves us economically disadvantaged and strategically vulnerable.

Mr. Chairman, I believe we must keep these truths in mind as we listen to today’s testimony. Certainly we must aggressively address the issue of global greenhouse gas emissions but we must do so while keeping the economic well being of our country in the forefront of our thinking. I believe this can be achieved by taking advantage of the many technological alternatives we will hear about today while ensuring the maximum utilization of all of our domestic sources of energy.

Again, thank you Mr. Chairman, for convening this hearing. I look forward to hearing the testimony of the witnesses that have joined us today.

The CHAIRMAN. Thank you very much. Let me introduce our first panel. We have two witnesses. Dr. Neil Hirst, who is Director of Energy Technology and Research and Development at the International Energy Agency in Paris, and also Dr. Ray Orbach, who is the Director of the Office of Science in our Department of Energy, and is a fairly frequent witness before this committee.

We’re going to deviate from the normal procedure here and give these witnesses, particularly Dr. Hirst, additional time to go through some of the findings of his report since this report, I think, is a very major addition to our understanding and so why don’t you take about 20 minutes, if you would, and summarize the main points of your report. Then, Dr. Orbach, you can take any time that you think is appropriate and then after both of you have finished your testimony, we’ll go ahead with questions.

So Dr. Hirst, thanks for coming.

STATEMENT OF NEIL HIRST, DIRECTOR, ENERGY TECHNOLOGY AND R&D, INTERNATIONAL ENERGY AGENCY, PARIS, FRANCE

Mr. HIRST. Mr. Chairman, Senator Domenici, members of the committee, thank you for the opportunity to appear before you today to discuss the International Energy Agency’s recent publication Energy Technology Perspectives 2008. It’s a great honor to be here.

I’ve submitted a written statement which includes a copy of the full executive summary of this report and I ask that that be included in the record. Thank you.

The CHAIRMAN. We will be glad to include that.

Mr. HIRST. As requested by the committee staff, I’ve put together a set of approximately 20 charts and graphs that summarize key findings and I hope that’s accessible to members in my remarks this morning. I will refer to these charts and graphs.

The CHAIRMAN. Yes. I think everyone has a copy of those at their place.

Mr. HIRST. Some of the most important of them will also appear on our stand over here.

At the Gleneagles Summit in 2005, the leaders of the G8 addressed the issues of climate change, clean energy and sustainable development, and they asked us at the International Energy Agency to provide scenarios and strategies for a more sustainable energy future and they also asked us specifically to report back in time for this year's summit on the Japanese chairmanship in Hokkaido in July.

Energy Technology Perspectives 2008 is a response to that request. It shows how we can use energy technology to achieve really deep cuts in global CO_2 emissions and also in the medium and longer term, how we can ease the pressures on international energy markets.

The work is based on extensive analytical and modeling work at the IEA and draws on the work of many experts, including U.S. experts, who participate in our International Technology Network.

In Energy Technology Perspectives, we examine what it would take to bring global CO_2 emissions back to their current levels in 2050, referred to as the "ACT" scenarios, but we also examine, and this for the first time, what would be required for the world to halve the level of current emissions in the same period.

According to the Intergovernmental Panel on Climate Change, we need cuts at least this deep in order to contain global warming within the range of two to three degrees Centigrade, and the book has some important messages.

First of all, in our business as usual case, only about one-third of global CO_2 emissions in 2050 come from the developed OECD world and the other two-thirds are from the developing countries. So even if all the emissions of OECD countries were eliminated, we still would not meet the target of a 50 percent reduction. A global effort is required.

In order to bring CO_2 emissions back to current levels in 2050, all options are required at a cost of up to $50 per ton of CO_2 saved. To do this, we need to achieve very large improvements in energy efficiency across all sectors of the energy economy, industry, buildings, transport, appliances, and, in addition, we need to substantially decarbonize power generation.

But this may not be enough. If we are to halve emissions in 2050, all options up to a cost of $200 per ton of CO_2 will be needed and even this is based on fairly optimistic assumptions for technology development, and the less optimistic assumptions, we might need options costing up to $500 per ton of CO_2, and as you've already said, Mr. Chairman, we have estimated the incremental costs, incremental investment needed in technology deployment between now and 2050 at $45 trillion. That is just over 1 percent of average global GDP during the period.

It's important to understand a large part of this investment is on the demand side. A lot of this investment is consumer investment in low carbon homes, appliances and especially vehicles.

But as I will explain later, a large part of the sum, this amount of additional investment, will subsequently be recovered as a result of the lower fuel costs that will be incurred subsequently. So there is a return.

Indeed, the energy security benefits, this is relevant to what Senator Domenici was saying, the energy security benefits of such a development would also be substantial. By 2050, oil demand—excuse me—would be 27 percent below the level of 2005. This is the first time the IEA has been able to project scenarios in which global oil demand would actually decline to 2050.

Nevertheless, massive investment in remaining oil reserves will still be needed to make up the shortfall as low reserve oil provinces are exhausted.

There should be no doubt meeting the target of a 50 percent cut in CO_2 emissions represents a formidable challenge. We would require immediate policy action and technology transition on an unprecedented scale. It would essentially require a new global technology revolution which would transform the way we produce and use energy.

Now let me turn to the slides that you have. The first slide simply says who we are at the International Energy Agency. The second slide I've referred to already, the Gleneagles Summit, and I want to go directly to the fourth slide, figure 4 in your chart. It's displayed here. Thank you very much.

This slide summarizes the technologies that we need. The upper boundary of the colored area shows the business as usual case for carbon emissions, rising from 28 giga tons of CO_2 today in 2005 on the left-hand side to 62 giga tons in 2050.

That is actually a slightly greater level of emissions than we projected back in 2006 when we last did that. That partly reflects robust growth in the developing world but it also partly reflects indications of a switch toward coal in the energy sector which is, of course, a more CO_2-emitting fuel.

The lower boundary of the colored section shows what we call our BLUE case. The pathway that we would need to follow to reduce CO_2 emissions to half their count level in 2050. What I want you to note is that the amount of the reduction that we need to achieve against baseline in 2050 is actually greater than total global CO_2 emissions today. It's a huge amount and you see the breakdown there. I will refer to that very briefly.

The biggest element, I don't think anyone will be surprised, is energy efficiency. Thirty-six percent of those savings come from energy efficiency. Then we have carbon capture and storage. Power generation also for industry. Renewables play a big part, 21 percent, and nuclear power plays a big part. The contribution of nuclear power is rather underestimated here because this is against the baseline and there's quite a big contribution for nuclear in the baseline case itself.

Now if I can go on to figure 5, the next one, this is the same chart, but instead of technology, it just shows it by power sector. It shows the sector of the economy. It just shows that all sectors of the economy have to contribute, power, transport, industry, buildings, in that order, but all very big contributions.

I'd like to go on to the next figure, figure 6. Thank you very much. We also have it here on the stand.

The purpose of figure 6 is to make more real the investment required in power generation. This is investment to decarbonize power generation. If you look at this chart for each row, on the left-hand side, the red section is the current level of investment in giga watts per year. So you can see in the very top there's very little investment at the moment in coal-fired carbon capture and storage. This is actual plant. This isn't R&D, this is actual plant.

Then the blue section, the dark blue section shows what we would need to get back to current levels of CO_2 emissions, the ACT case, and the pale blue is the incremental investment needed for the 50 percent reduction case which we call the BLUE case.

I just highlight that for nuclear power, instead of showing current investment where the amount of capacity added in recent years is very low, we've instead given peak investment which took place in the 1980s when the development of nuclear power was at its height.

What you see is a measure of the task. On average, we would need to build 35 coal plants with CCS every year between now and 2050. We would need to build 32 nuclear plants, one giga watt nuclear plants, every year between now and 2050, and we would need to install 14,000 onshore wind turbines every year between now and 2050.

The point I want to emphasize, there isn't a choice here. We need to do all of these if we're to achieve that target. When I say that, for individual countries, there is a degree of choice as to the balance of these technologies that they use.

If I could go on now to figure 7 which also we have here?

This chart shows how the marginal costs of CO_2 abatement will increase as we seek to make deeper and deeper cuts in global CO_2 emissions and there's a slight health warning. This is a great simplification, but I think it's helpful to understand the key trends.

What you see on the X axis is reductions, cuts in CO_2 emissions against our base case in 2050, and on the Y axis, you see the marginal costs, dollars per ton of CO_2. So if you start toward the left-hand side of the chart, you see that there is a lot of potential for carbon abatement through energy efficiency measures which actually have either zero or negative economic cost. The barrier here is not economics. The barrier here is institutional, regulatory, perhaps even cultural.

Then we have an intermediate section where we're talking about decarbonizing power generation. You can see there that the power options have a positive cost but on the optimistic side of this chart, and I should explain that the blue area is the range of uncertainty that we see in the costs. So taking the lower side of the blue area, we see options for decarbonizing power that could be in the range of up to $50 per ton of CO_2 saved and that simply takes you to what we're calling the ACT case, getting back to current levels of CO_2 emissions in 2050.

But beyond that, if you're seeking to halve CO_2 emissions, the options become more challenging and more costly. You have to achieve really deep cuts, going beyond conventional energy efficiency in industry and in transport, and so, for instance, you might have to have carbon capture and storage for the most heavily emitting industries and you will have to have alternative transport fuels. I'll come on to that, but this is the area where you're introducing electric vehicles and/or hydrogen- powered vehicles as well as increasing biofuels.

Could I go on to figure 8? This chart shows what happens in the various scenarios to the demand for key fuels, and I want you to focus, first of all, please, on the oil columns. It takes a little explaining, this chart.

If you look at the oil columns, the left-hand blue column is current or 2005 global oil demand and there's a space because the other columns are forecasts or projections. Next column shows where we would be on our baseline projection in 2050.

Now I have to say that opinion varies on whether that level of oil supply can be provided in 2050. What is certain is that it's the case where there would be a lot of tensions and pressures on international energy markets.

Then we have the ACT case in which oil demand is very significantly less than in our baseline case but still significantly above the level today, and then, finally, we have the BLUE case where we're illustrating that oil demand is 27 percent below the current level of oil demand, actual reduction in oil demand.

Can we move on now to figure 9? Because an important feature of this study is that we have identified 17 key technologies or probably it would be fair to say areas of technology that are needed for the BLUE case. They're listed here on figure 9, and we have developed roadmaps. I think it would be fairer to say we have made a first attempt at roadmaps as to how these technologies need to be deployed, developed and deployed globally in order to achieve the results that we're looking for in the BLUE case.

Can we go on to the next figure, figure 10? This is simply an example, slightly condensed example, of the roadmaps. This is for carbon capture and storage. It shows in very general terms what we think the global deployment might be, gives some of the key milestones for research and development and deployment of this technology. The colored section shows in time the different cases, how soon it needs to move beyond the research stage to demonstration, then to deployment, and then to full commercialization.

I just give this one example because there is headline conclusion in this case which is that globally, we need to commit to 20 full-scale carbon capture and storage demonstration projects with coal by 2010. That's a very tough target. We think it is necessary on the pathway to a low carbon world and it's a target that has been specifically endorsed by the G8, G8 Energy Ministers at their meeting in Amori, Japan, just a couple of weeks ago. We have similar roadmaps for others.

Now since time is running a little short, I'd like to go direct to figure 13. Figure 13 illustrates government research and development spending in OECD countries and it's just to highlight that, and I have to say in presenting this, of course, the U.S. is a world leader, arguably the world leader, in the research and development of many of these key energy technologies and by far the majority of this spending is taking place in the United States and in Japan.

However, the global trends have been unfavorable and while we don't set extremely concrete targets for global R&D spending because we think you have to look at it from the point of view of the technologies and what they need rather than coming up with sort of headline numbers, it's clear that this trend has to be reversed if we're going to bring in the advanced technologies that we will need by 2050.

If I could go to figure 14, this shows the mix of power generation in 2050 in our BLUE case. Now what I would like to highlight here, if you look at the right-hand column, it shows the total mix, and you see, for instance, that 46 percent of global power is coming from renewables. If you break that down, hydro, wind and solar, solar photovoltaics and solar collecting are the biggest players in that. Other technologies taken together make up the equivalent of the final quarter.

This chart also gives a more realistic impression of the role of nuclear. Nuclear in this chart accounts for about something like a quarter of global power generation, so it does play big part, but so does coal with carbon capture and storage and gas with carbon capture and storage.

I'd now like to move on, if I still have a moment or two, to figure 16. A characteristic of the BLUE case, if you are looking for really deep cuts in global CO_2 emissions, as I said before, you have to begin to address fundamental technology change in vehicle fuels, and we have to be honest and say we don't know at this stage which will be the dominant technologies in 2050.

It may be that it will be fuel cell vehicles. It may be electric vehicles. It may be a combination of the two. We also believe that biofuels will play a significant part, although they are restrained, will always be restrained by resource, and so we develop a range of—we offer in this study a range of cases, of which I suppose our central case is the MAP case which is the third column across from the left, and here we're seeing a combination.

This is the market share of new vehicles in 2050 and there are no conventional internal combustion light—this is light vehicles in this case. What we're seeing there is a combination of hybrids, of plug-in hybrids, of electric vehicles, and fuel cell vehicles.

These technologies need a lot more research and development before they can be regarded as genuinely commercial technologies. We believe that even with that development, they will be relatively high cost in terms of dollars per ton of CO_2 saved, but if we want very deep cuts in CO_2, it is vital to press ahead with those technologies.

Now I'm coming toward the end of this. If we could look for a moment at figure 19, this just illustrates possible trends in biofuels, and a major finding of this analysis is that if we're going for these very deep cuts in carbon emissions, it is not enough simply to address light vehicles, cars. We also have to address aviation and shipping and there, it's very difficult to find alternative technologies, but biodiesel represents a viable option for or will represent, we believe, a viable option for aircraft fuel and for shipping and therefore that needs to be a priority for the biofuels that are available in the longer term.

So that is why we see a trend toward biofuels, particularly biodiesel, converted, using advanced technology from non-food elements of biomaterials, straws and waste materials. We also see a very significant role for cellulosic ethanol as a fuel for light vehicles, for ethanol from cane.

We think that over a period, ethanol from grain, which is significantly less efficient from those conversions, will need to be phased out.

The CHAIRMAN. Perhaps you could go ahead and conclude, summarize your final comments, so that we can get to Dr. Orbach.

Mr. HIRST. Thank you very much. That basically brings my remarks to a conclusion.

We're facing an urgent challenge in the energy sector. We need a global solution. We've spelled out how we could stabilize emissions, how we could reduce emissions to 50 percent of their current levels, and what is required is a global technology revolution, a transformation of the way in which we produce and use energy.

Thank you very much.

[The prepared statement of Mr. Hirsch follows:]

STATEMENT OF NEIL HIRST, DIRECTOR, ENERGY TECHNOLOGY AND R&D INTERNATIONAL ENERGY AGENCY, PARIS, FRANCE

Mr. Chairman, ranking member Domenici, members of the committee, thank you for the opportunity to appear before you today to discuss the International Energy Agency's (IEA) recent publication: Energy Technology Perspectives 2008.

I have included at the end of this statement a copy of the full Executive Summary of the Report, as well as a number of additional charts and graphs that summarize the key points of the report.*

Introduction

At the Gleneagles Summit in 2005, the leaders of the G8 addressed the issues of climate change, clean energy, and sustainable development. They asked the IEA to provide "scenarios and strategies" for a more sustainable energy future, and they asked us to report back to this year's Hokkaido summit.

The Energy Technology Perspectives 2008 (ETP) study is a response to that request. The report shows how we can use energy technology to achieve really deep cuts in global CO2 emissions and also, in the medium and longer term, ease the pressures on energy markets. We describe the technologies required, how they could be deployed across the globe, and their costs.

The analysis is based on extensive analytical and modelling work at the IEA, and draws on the work of the many experts who participate in our international energy technology network. This study concerns CO2 emissions from the energy sector only—including energy use in the transportation and industrial sectors. This accounts for approximately 60% of all greenhouse gasses. Analysis of other sources, such as forestry and agriculture, is needed for a complete view of the potential impact on climate change. This is not the IEA's area of expertise and is not addressed in the ETP study.

At present, global CO_2 emissions are increasing steadily, and in our business as usual case (the "Baseline") this trend is accelerated by a rising share of coal in energy markets. By 2050, global CO_2 emissions could be 130% higher than they are today.

In Energy Technology Perspectives "ACT" scenarios we examine, as we have done before, what it would take to bring global CO_2 emissions back to their current levels by 2050. But we also examine, for the first time, what would be required for the world to halve the emissions from the energy sector, relative to 2005, by 2050. According to the Intergovernmental Panel on Climate Change, cuts at least this deep are required to contain global warming within the range of 2-3 degrees C. This 50% reduction case is referred to as the "Blue" scenario in ETP.

A global energy technology revolution is necessary to meet the Blue target, it is both necessary and achievable; but it will be a tough challenge. ETP 2008 demonstrates the extent of the task.

Emissions Stabilisation—ACT

To stabilize global emissions in 2050 at today's levels we need to achieve very large improvements in energy efficiency across all sectors of the energy economy. In addition, we need to substantially decarbonize power generation.

The IEA has set out specific measures that we believe governments should take to enhance energy efficiency—and these represent the most cost-effective measures to reduce CO_2 emissions and as well as energy demand.

*Document and graphs have been retained in committee files.

Decarbonising the power generation sector can be achieved through renewables, nuclear power, and the capture and storage of CO_2 emissions from coal plants. There is a degree of choice, for each country, as to the balance of these technologies to adopt. These measures—improving energy efficiency and decarbonizing power generation could enable us to bring emissions back to current levels by 2050. We would need to use all abatement options with a cost of up to $50 per tonne of CO_2, and the total additional investment required is 7% higher than in the Baseline at $17 trillion between now and 2050. But as the IPCC has highlighted, this effort may not be enough.

Emissions Reduction by 50 Percent—Blue

The additional technologies required to halve current emissions—the "Blue" scenario—include buildings with near zero emissions and the more extensive capture and storage of emissions from industry. They also include the development of technologies for alternative transport fuels, such as electric or hydrogen fuel cell vehicles.

Emissions halving implies that all options up to a cost of $200 per tonne of CO_2 will be needed. And even this is based on a set of optimistic assumptions for technology development. Under less optimistic assumptions we might need to include options costing up to $500 per tonne. The total additional investment needs for research, development and deployment (RD&D) and commercial investments between now and 2050 are 18% higher than the Baseline and amount to $ 45 trillion, or 1.1% of average annual GDP over the period. That's about the GDP of Canada each year.

Much more research and development is required before some of these technologies are ready for the market. Governments, as well as industry, will need to raise their efforts in this area—we estimate the cost of additional research, development and demonstration to be $ 2—3 trillion.

The capacity additions in the power sector are a measure for the energy technology revolution that is needed. Investments in CO_2-free power generation need to rise from around 50 GW per year at present to around 330 GW per year in the period 2035 to 2050. Annual hydro capacity additions must be maintained at the level of today. Nuclear capacity additions must rise to 1.5 times their historical high. Wind capacity additions must increase five-fold, Solar PV by twenty-fold. New industries for CO_2 capture and storage, concentrating solar power and enhanced geothermal power generation systems must be developed. On average 35 coal-fired power plants with CCS must be installed per year between now and 2050. Given the challenges of establishing a single CCS project today, this is really an energy technology revolution. More importantly, it is not a matter of choosing one of these technology options, but doing all at once.

Transport Sector

The transport sector plays a key role and accounts for 78% of the oil savings. Half of these energy savings are accounted for by fuel efficiency measures, the other half by alternative fuels. In the Blue Map scenario, advanced biofuels, battery electric vehicles and hydrogen fuel cell vehicles each play a role of similar importance. These are the most expensive CO_2 saving options and account for the majority of the incremental investment required in the Blue case, they also are some of the most uncertain technology options.

Supply security benefits

So far I have focused on the CO_2 challenge, although there are other benefits from reduced local pollution from power plants, factories, and vehicles. But of course we have another urgent energy policy challenge-that of supply security and spiralling energy costs. ETP's Baseline scenario would require a massive expansion of fossil fuel production, to an extent that can be questioned. For example, as shown in Chart 4, oil production would have to rise from today's level of around 85 million barrel per day to around 135 million barrels a day in 2050 just to meet rising demand levels. Oil industry experts are divided if such an expansion is feasible.

In contrast, oil demand in Blue Map in 2050 is 27% below the level of 2005. Such a development would certainly ease the supply challenge and could be expected to have a significant impact on price. However, even this level of production will require massive investments in new supply in the coming years and decades as oil fields are depleted. Importantly, total fossil fuel demand in the Blue Map scenario in 2050 is the same as today. So in any case fossil fuels will remain a key pillar of our energy supply in the coming decades.

Of course the big investments in energy efficiency, renewables, and nuclear power also lead to fuel cost reductions. At a 3% "social" discount rate, these savings would not quite be sufficient to recover the incremental investment costs.

Roadmaps: The Transition

The study includes 17 energy technology roadmaps which explain how to get from today's situation to the target situation for 2050. We think that the development of internationally agreed technology transition paths and the use of indicators to monitor the progress on these paths will be crucial. The IEA and its technology collaboration network are ready to support this change.

R&D Investments

Government R&D spending has nearly halved in the last 25 years, to a level of USD 10 billion per year. Two countries, the United States and Japan, account for 80% of this investment. Energy R&D accounts for a mere 3% in total R&D. Clearly this trend is incompatible with energy policy ambitions and the need for an energy technology revolution. A very significant rise of research, development and deployment (RD&D) spending is needed, both in the public and in the private sector, and this change is urgent.

Conclusion

In conclusion, deep emission cuts are technically achievable. However a global energy revolution is needed where all countries and all sectors must participate. This change is urgent. Financing needs, capital stock turnover and the rate of technology development means that there is no time to lose. The IEA and its technology network stand ready to support such a transition to a brighter more sustainable future.

This concludes my statement, and I would be happy to answer any questions the committee members may have.

The CHAIRMAN. Thank you very much, and again I compliment you on the report. I think it's an excellent contribution to our understanding of the issue.

Dr. Orbach, we're anxious to hear your perspective on all of this.

STATEMENT OF RAYMOND L. ORBACH, UNDER SECRETARY FOR SCIENCE, DEPARTMENT OF ENERGY

Mr. ORBACH. Thank you, Chairman Bingaman, Ranking Member Domenici, and members of the committee.

I just would like to say that it's been a privilege to testify a number of times before this committee and now your invitation is very kind to talk on this very serious issue.

As you've heard from Dr. Hirst, and as you read in his report, and I'm going to quote, "It is essential to enhance the science base and its links with technology," That is the role that the Department of Energy has been pursuing; and, in my position as Under Secretary for Science, which this committee created, it's been my responsibility to pursue that direction.

We believe that with the investment that this committee has supported in basic research, one can imagine the following consequences. We believe that we can construct solar photovoltaics that exceed thermodynamic efficiency limits.

We believe that we can, by borrowing nature's design for capturing sunlight, photosynthesis, directly convert sunlight into chemical fuels. We believe that solar and wind can provide 30 percent of the electricity consumed in the United States.

We believe that a sustainable carbon neutral biofuels economy, capable of meeting a third of United States transportation fuel needs, without competing with fuel, feed and export demands, is feasible.

We believe we can close the nuclear fuel cycle, developing abundant fossil-free power with zero greenhouse gas emissions and minimal environmental impact. We believe that we can achieve safe and environmentally benign underground sequestration of CO_2 for millennia, and finally, through fusion energy, we believe that we can provide abundant energy without damaging our earthly environment by bringing the power of the sun and the stars to earth.

To inform this mission, the Office of Science has held over 15 workshops during this administration, covering such topics as carbon capture and sequestration. Here we are working with fossil energy to develop seven new sites for sequestration with science-based studies of what happens to the CO_2, where it goes, and what happens with underground chemistry.

We are working on electrical energy storage to improve the quality of batteries. We are working on bioenergy, with major new developments coming from our bioenergy research centers. We're talking about using ionic liquids to separate lignins and the hemicellulose and cellulose. We're using microbes to produce gasoline and diesel. We are looking at the way nature provides fuel to see if we can follow suit.

This committee understands that incremental improvements in our current technologies are not enough to meet the challenge of increased energy consumption, constrained by concern for the environment. We will need transformational breakthroughs in basic science, breakthroughs that provide the foundation for truly disruptive technologies that fundamentally change the rules of the game, and I believe we are succeeding because of your support.

This concludes my testimony. I would be pleased to answer any questions you may have.

[The prepared statement of Mr. Orbach follows:]

STATEMENT OF RAYMOND L. ORBACH, UNDER SECRETARY FOR SCIENCE, DEPARTMENT OF ENERGY

Mr. Chairman, Ranking Member Domenici, and Members of the Committee. Thank you for the opportunity to speak before you today about the technologies we need to meet increasing global energy demand, and to do so without adding unduly to atmospheric greenhouse gases. As you have heard from Dr. Neil Hirst, and as described in the International Energy Agency's report Energy Technology Perspectives 2008, the challenge we have before us is enormous.

Incremental improvements in our current technologies will not be enough to meet this challenge. We will need transformational breakthroughs in basic science to provide the foundation for truly disruptive technologies that will fundamentally change the rules of the game. This applies to renewables, nuclear, and CO_2 capture and storage as well as to promising technologies like fusion that are farther off.

The good news today is that we may be on the threshold of scientific and technological breakthroughs in the 21st century every bit as profound as those which transformed human life forever in the 19th. The scientific world today is changing and advancing with almost dizzying speed. Every year our capability to direct and control matter down to the molecular, atomic, and quantum levels is growing. This increasing ability to control the fundamental, nanoscale building blocks of both biological and non-biological matter holds out the promise of eventually forever transforming the way we generate, store, transmit, and use energy.

One of the chief missions of the DOE Office of Science has been to nurture and accelerate the development of this new fundamental science and these cutting-edge capabilities—capabilities that may transform our energy economy and ultimately provide answers to the great challenges we face in both energy and the environment.

Over the course of this decade, our Office of Basic Energy Sciences in the DOE Office of Science has held a dozen major "Basic Research Needs" workshops to assess basic research needs for energy technologies. These workshops have brought together scientific and technical experts from universities, national laboratories, industry, and government, from both here and abroad, to identify scientific roadblocks and determine research priorities. Each workshop has issued a major report. Together these reports define a bold and comprehensive research agenda.

Time and again we see the same themes: new materials design, development, and fabrication, especially materials that perform well under extreme conditions; control of photon, electron, spin, phonon, and ion transport in materials; science at the nanoscale and femtosecond; designer catalysts; structure-function relationships; biomaterials and bio-interfaces, and so on.

These are challenging and difficult scientific problems. That is why we refer to the problems we tackle in the Basic Energy Sciences program as "Grand Challenges." Late last year our Basic Energy Sciences Advisory Committee issued a report titled Directing Matter and Energy: Five Challenges for Science and the Imagination. The report summarized the work of the Basic Research Needs workshops by setting forth five grand challenges, as follows.

- Controlling materials processes at the level of quantum behavior of electrons
- Atom-and energy-efficient synthesis of new forms of matter with tailored properties
- Emergent properties from complex correlations of atomic and electronic constituents
- Man-made nanoscale objects with capabilities rivaling those of living things
- Controlling matter very far from equilibrium

These grand challenges span the Office of Science portfolio and define the tasks before us today and in the years ahead. I'd like to talk in a little more detail about our grand challenges in the field of energy—not just the barriers we face, but the opportunities before us. These opportunities provide more than hope for our energy future; they provide sustenance for us to imagine such things as:

- Solar photovoltaics exceeding thermodynamic efficiency limits
- Direct conversion of sunlight to chemical fuels
- A sustainable, carbon-neutral biofuels economy that meets over 30 percent of U.S. transportation fuel needs without competing with food, feed, or export demands
- A closed nuclear fuel cycle and abundant fossil-free power with zero greenhouse gas emissions
- Safe and environmentally benign underground storage of CO_2 for millenia
- Bringing the power of the sun and the stars to Earth with fusion energy

While as Under Secretary for Science I am responsible for advising on the entire R&D portfolio, my remarks today in response to your questions are focused on the Department's basic research portfolio aimed at transforming our energy future.

Solar Energy. Let's begin with solar energy. More energy from sunlight strikes the Earth in one hour than all the energy consumed by human activity on the planet in one year. This is abundant, carbon-free energy. Yet solar power today provides less than one-tenth of one percent of the world's primary energy. There are big challenges here, but also big opportunities. Silicon-based single crystal solar cells have reached efficiencies of 18 percent. Triple-junction cells with Fresnel lens concentrator technology are approaching efficiencies of 40 percent.

Imagine if we could develop solar photovoltaics that exceed thermodynamic efficiency limits.

Imagine, even more boldly, if we could borrow nature's design for capturing sunlight—photosynthesis—and directly convert sunlight into chemical fuels.

There are three ways we can use solar energy—by converting it to electricity, fuels, or heat. We are particularly interested in the first two: electricity and fuels. In both cases, there are three steps: capture, conversion, and storage. The challenge is reducing the costs and increasing the capacity for conversion of sunlight into electricity and fuels which can be stored and transported.

The Office of Science is pursing basic research in solar utilization to try to reach these goals. We are investigating new concepts for capturing energy from sunlight while avoiding thermalization, or heating, of carriers, such as multiple-exciton generation from a single photon. We are exploring "plastic" solar cells from molecular, polymeric, or nanoparticle-based structures that can provide flexible, inexpensive, conformal electricity systems. And we are trying to better understand defect formation in photovoltaic materials and self-repair mechanisms in photosynthesis, with the aim of developing defect tolerance and active self-repair in solar energy conversion devices, which would extend their lives.

We are also delving into artificial photosynthesis. We are working on the design and development of light-harvesting, photoconversion, and catalytic modules—bio-inspired molecular assemblies—capable of self-ordering and self-assembling into integrated functional units that can lead to an efficient artificial photosynthetic system for solar fuels. The photosynthetic reaction centers of plants are remarkably efficient, but we still have a lot to learn about their detailed reaction mechanisms.

We are also just beginning to discover the number and variety of light-harvesting molecules in Nature. For instance, Craig Venter's analysis of seawater samples taken from the Sargasso Sea identified 782 new rhodopsin-like photoreceptors, where only 70 were known before. (Rhodopsin is the photoreceptor that captures light in the mammalian eye.) There is great potential in this area for direct production of fuels from sunlight.

Electrical Energy Storage. Next, we turn to the related and vital area of electrical energy storage. To make an intermittent energy source such as solar effective for baseload electrical supply, major breakthroughs are required in electrical energy storage. This is a much-overlooked requirement for a range of renewable energy sources, including wind energy.

Electrical energy storage devices with substantially higher energy and power densities and faster charge times would also make all-electric and plug-in hybrid vehicles much more market attractive.

Imagine solar and wind providing over 30 percent of electricity consumed in the United States, and imagine roads where the number of all-electric/plug-in hybrid vehicles exceeds those running on gasoline.

Electrical energy storage devices such as batteries store energy in chemical reactants capable of generating charge. Storage devices like electrochemical capacitors store energy directly as charge. Fundamental gaps exist in understanding the atomic-and molecular-level processes that govern operation, performance limitations, and failure of these devices. Knowledge gained from basic research in the chemical and materials sciences is needed to surmount the significant challenges in creating radically improved electrical energy storage devices—whether improvements in weight, lifetime, and charge time and capacity for transportation use, or improvements that let us better store and use large but transient energy sources like solar and wind.

In pursuit of this knowledge, the Office of Science is supporting research in areas such as nanostructured electrodes with tailored architectures. For example, fundamental studies of the electronic conductivity of lithium iron phosphate (LiFePO4) led to the discovery of doping-induced conductivity increases of eight orders of magnitude. This discovery led to the DOE

Office of Energy Efficiency and Renewable Energy's funding development of the high power-density Lithium-ion batteries that power electric vehicles such as the Chevy Volt. The Office of Science is also looking at conversion reactions for batteries that yield more than one electron per redox center. New research on conversion reactions is looking at advanced materials that yield up to six electrons per redox center, allowing a large increase in power density. We are also investing in research on ultracapacitors, which complement battery power by allowing rapid charge and discharge cycles.

Bioenergy. A third area where we believe fundamental scientific breakthroughs can change the energy equation is biofuels. The development of biofuels—especially biofuels made from plant fiber, or lignocellulose, such as cellulosic ethanol and other fuels—represents a major scientific opportunity that can strengthen U.S. energy security while protecting the global environment.

Imagine a sustainable, carbon-neutral biofuels economy capable of meeting a third of U.S. transportation fuel needs without competing with fuel, feed, and export demands.

The capability to more efficiently tap into the energy contained in plant fiber or cellulose would give us the means to produce biofuels on a scale sufficient to create a nationwide biofuels economy. Unfortunately, our current means of converting cellulose, or plant fiber, to fuel is neither efficient nor cost effective. This is a tough problem. Plant fiber has evolved over the millennia to be extremely resistant to breakdown by biological or natural forces. The plant cell walls contain a substance called lignin that is tightly woven with the cellulose, forming a kind of "flexible concrete" which gives the plant its incredible strength. This "recalcitrance" of plant fiber forms the major cost barrier to making biofuels from plant fiber economically viable.

Nature, however, has evolved solutions to this problem. Termites, for example, are frighteningly efficient at converting cellulose and hemicellulose to fuel. They eat wood at an alarming rate, and convert the cellulose into energy. Using a systems biology approach to develop an understanding of the principles underlying the structure and functional design of living systems, the basic research supported by the Office of Science is focused on developing the capabilities to model, predict, and engineer optimized enzymes, microorganisms, and plants for bioenergy and environmental applications. A series of workshops led by the DOE Office of Biological and Environmental Research identified the basic research needs for such an approach.

The emerging tools of systems biology are being used to help overcome current obstacles to bioprocessing cellulosic feedstocks to ethanol and other biofuels—research tools such as metagenomics, synthetic biology, high-throughput screening, advanced imaging, and high-end computational modeling. In 2007, we launched three new DOE Bioenergy Research Centers, each funded at $25 million per year for five years, to pursue these research directions—the BioEnergy Science Center, led by Oak Ridge National Laboratory; the Great Lakes Bioenergy Research Center, led by the University of Wisconsin-Madison in partnership with Michigan State University; and the Joint BioEnergy Institute, led by Lawrence Berkeley National Laboratory. We believe that these Centers can crack Nature's code for cost-effective biofuel conversion.

The DOE Bioenergy Research Centers are focusing mainly on the use of enzymes and microbes to break down the lignocellulose or plant fiber into energy-rich sugars and synthesize these sugars into fuels. Ethanol is one focus, though the Joint BioEnergy Institute led by Lawrence Berkeley National Laboratory is also re-engineering microbes to produce hydrocarbon fuels—green gasoline, diesel, and even jet fuel. Of course, mankind has known how to make ethanol by fermentation for some time. Lignocellulose presents special challenges. First, the degradation process—the process of breaking through recalcitrance—typically produces chemicals that inhibit or endanger the microbes used for fermentation. Second, typically you get two types of sugar monomers, one type having 6 carbon atoms and the other type having 5 carbon atoms. The 5-carbon sugars are more difficult to ferment.

But once we've figured out how to degrade the lignocellulose and recover sugar monomers from it, there's another route to making fuel: chemical catalysis. The Great Lakes Bioenergy Research Center is devoting some resources to this alternative path. The major funder of this catalytic work within the Office of Science is our Office of Basic Energy Sciences, which has stewardship within the federal government for catalysis.

Catalysis offers several advantages over fermentation. First, researchers have shown that catalytic processes can be used to turn sugar into hydrocarbon fuels, fuels more like gasoline. Ethanol has certain disadvantages relative to gasoline. Ethanol has only about 70 percent of the energy content per gallon as gasoline. Ethanol is also water-soluble, which introduces problems of corrosion when shipped by pipeline or during storage. Also, today's vehicle engines need to be adapted for use with high concentration ethanol blends, such as E85; flex fuel vehicles can also carry a cost premium over ordinary gas-powered vehicles.

Catalysis may be able to yield biofuels that are essentially indistinguishable from gasoline, conventional diesel, even jet fuel. We may also be able to produce such hydrocarbon fuels via fermentation, by re-engineering microbes to produce them, and our DOE Bioenergy Research Centers are working on this. If we could produce gasoline from plant fiber—so-called "green gasoline"—we could move to a greener fuel supply without any major infrastructure changes. Our new Energy Frontier Research Centers initiative, which I'll talk about in a moment, will provide new funding opportunities for this important work in catalytic production of biofuels.

Nuclear Energy. Today, nuclear energy provides about 20 percent of the nation's electricity, with no greenhouse gas emissions or pollution. Nuclear energy could provide much more carbon-free, pollution-free energy. A key challenge to industry growth, however, is the need to solve the problem of spent nuclear fuel. Current "once through" nuclear reactor policy leaves spent fuel rods with long-term heat loads and radioactive decay, and a significant fission fuel content.

Imagine if we could close the fuel cycle; imagine abundant fossil-free electric power with zero greenhouse gas emissions.

Advances in basic science leading to new recycling technologies could in fact provide a major reduction in spent fuel—recycling the spent fuel for further use in fission reactors and reducing storage requirements by up to 90 percent. Performance of materials and chemical processes under extreme conditions is a limiting factor in all areas of advanced nuclear energy systems. The challenge is to understand and control chemical and physical phenomena in complex systems from femtoseconds to millennia, at temperatures to 1,000 degrees Celsius, and for radiation doses leading to hundreds of displacements per atom.

In 2006 and 2007, the Office of Science held three workshops designed to identify the basic science needed for the development of advanced nuclear energy systems and to close the fuel cycle. In addition to the Basic Research Needs workshops, two additional workshops were held in the area of nuclear physics and advanced scientific computing. Research areas identified in those workshops include: materials and chemistry under extreme conditions; actinide chemistry; separations science; nuclear theory; developing and scaling next-generation multiscale and multiphysics codes; and computational modeling and simulation of reactor and recycling systems.

Hydrogen. Most observers agree that there will be no "silver bullet" to solve our energy dilemmas. As we attempt to meet the energy and environmental needs of the 21st Century, we will increasingly rely on a portfolio of different energy sources. Hydrogen as fuel is a somewhat longer-term possibility, but it is a very attractive one.

Hydrogen has the highest energy content per unit of weight of any known fuel. Fuel cells powered by hydrogen are more than twice as efficient as internal combustion engines and produce only water. When hydrogen is burned in an engine, emissions are significantly lower than those from other alternative fuel technologies. Hydrogen can be produced from abundant domestic resources including natural gas, coal with sequestration, biomass, and even water, using nuclear energy or renewable energy sources such as solar wind, and geothermal.

Imagine an emissions-free energy future.

Combined with other technologies such as carbon capture and storage, renewable energy, and fusion energy, hydrogen fuel cells could make an emissions-free energy future possible. But this is an area that clearly requires some very fundamental research, in addition to applied research. Of particular importance is the need to understand the atomic and molecular processes that occur at the interface of hydrogen with materials in order to develop new materials suitable for use in a hydrogen economy. New materials are needed for membranes, catalysts, and fuel cell assemblies that perform at much higher levels, at much lower cost, and with much longer lifetimes. The breakthroughs needed to sustain a hydrogen economy will require revolutionary, not evolutionary, advances. Discovery of new materials, new chemical processes, and new synthesis techniques that leapfrog technical barriers is required. This kind of progress can be achieved only with highly innovative, basic research.

The Department through the Office of Science supports such research in five technical focus areas: novel materials for hydrogen storage; membranes for separation, purification, and ion transport; design of catalysts at the nanoscale; solar hydrogen production; and bio-inspired materials and processes. Funding within the Office of Basic Energy Sciences has enabled major advances in our fundamental understanding of hydrogen-matter interactions. Recent key accomplishments include: discovering atomic scale mechanisms in the reversible hydrogen storage within complex metal hydrides; developing novel micro-and nano-patterning syntheses for a new generation of fuel cell membranes with superior power output; theoretically predicting and experimentally validating new architectures and compositions of catalyst alloys for efficient hydrogen production from fossil fuels or biomass; synthesizing mixed metal oxide photoelectrodes for solar hydrogen production; and providing new insights into the development of oxygen-tolerant enzymes for bio-inspired hydrogen production. Such fundamental science accomplishments have significantly advanced our understanding of the behavior of hydrogen at the atomic level. They have also contributed significantly to shortening the knowledge gap between present-day hydrogen technology and commercial viability.

Carbon Capture and Sequestration. Coal provides almost 56 percent of baseload electricity produced in the U.S. and will likely continue to be a significant energy source globally over the coming decades. Carbon dioxide emissions from coal-fired power plants can be reduced by improving conversion efficiency and by co-firing coal with biomass, but the largest emission reduction potential will likely come from employing CO_2 capture and storage (CCS).

Imagine safe and environmentally benign underground sequestration of CO_2 for millenia.

While DOE's Office of Fossil Energy, in conjunction with many academic and industry partners, has worked to ensure that many components of CCS have been validated at an industrial scale and will soon conduct large scale field tests to determine the potential for the long-term safe storage of CO_2, full scale deployment of CCS requires an intensive science-based approach to understanding the long-term behavior of subsurface geological systems where CO_2 can be safely and securely stored for centuries to millennia. The scientific foundations must be laid for both firm regulation and public acceptance. This means we must be able to make the critical measurements of geological properties needed to design and build multiple, effective, stable, geological carbon sequestration sites; we must also improve our ability to predict subsurface properties from limited invasive sampling. Improved high-resolution geophysical monitoring and verification approaches are needed to observe subsurface processes in real time and to track processes at operating sequestration sites for validation of safety and security.

We must also develop a better understanding of the geochemical stability of deep potential storage sites, since CO_2 injection will introduce new reactive chemical components, and storage creates compositionally complex systems, potentially reactive chemical environments, and gradients in pressure and temperature. And we will need the computational modeling tools that can predict CO_2 plume movement and storage integrity for varied geological storage locations over large distances and long time scales.

Ultimately, we need to predict with confidence the transport and fate of CO_2. To do that, we need to learn how to better describe the fundamental atomic, molecular, and biological processes and to translate those microscopic descriptions to properties of materials and fluids. Sustained investment now in fundamental research in such areas as dynamic imaging of flow and transport of CO_2, fluid-induced rock deformation, understanding the complexities and dynamics of mineral-water interfaces, and biogeochemistry in extreme environments will enable the development of these capabilities.

Fusion. Finally, one of the most promising future energy solutions lies in fusion. Fusion is the energy that powers the sun and the stars. Fusion energy on earth will use deuterium from water and lithium to create tritium, fusing deuterium and tritium into helium and a fast neutron (14 MeV). Deuterium and lithium are abundant and cheap, the helium will escape from the earth's gravity, and the energy of the neutron can be captured to generate electricity or produce hydrogen. Fusion has the potential to provide clean, carbon-free energy for the world's growing electricity needs on an almost limitless scale. The key challenge is sustaining and containing the 100 million degree-plus fusion reaction on earth. Scientists have made progress containing fusion reactions using powerful magnetic fields for confinement.

Imagine a future of unlimited, emissions-free energy for humanity. Imagine a future where humanity ceases to struggle with the challenge of providing abundant energy without damaging our earthly environment.

The basic science needs to enable this technology include: fundamental understanding of plasma science; materials for the extreme thermochemical environments and high neutron flux conditions of a fusion reactor; and predictive capability of plasma confinement and stability for optimum experimental fusion power plant design. In November 2006, the United States signed an agreement with six international partners to build and operate an experimental fusion reactor, ITER, that will demonstrate the technical and scientific feasibility of a sustained fusion burning plasma. US scientists are working side by side with their counterparts from China, the European Union, India, Japan, the Republic of Korea and the Russian Federation in the ITER effort.

Energy Frontier Research Centers. If we are to realize this clean, abundant, and affordable energy future envisioned here today, we must engage the Nation's intellectual and creative talent to tackle the scientific grand challenges of transformational energy research. One way the Office of Science is seeking to do this is through Energy Frontier Research Centers, which we are asking Congress to authorize and fund in the Department's FY 2009 budget request. The funding opportunity announcement for the Centers was posted on our website on April 4, 2008. These Centers are intended to conduct innovative basic research to accelerate the scientific breakthroughs needed to create advanced energy technologies for the 21st Century. Assuming Congressional approval of Energy Frontier Research Centers, $100 million will be set aside for these Centers each year, with each Center receiving $2 to $5 million annually for five years. Universities, national laboratories, industry, non-profits, and partnerships among these groups are eligible to apply. The goal is to bring together our Nation's best minds to tackle formidable energy challenges in groups large enough to make a difference.

Conclusion. I want to thank you, Mr. Chairman, for providing this opportunity to discuss the fundamental research the Department of Energy is pursing to accelerate the scientific breakthroughs necessary to achieve not only for the United States but for all of our global neighbors the clean, secure, economic energy future we envision.

This concludes my testimony. I would be pleased to answer any questions you might have.

The CHAIRMAN. Thank you very much. Thank you both for your excellent testimony.

Let me start and we'll just do a 5-minute round of questions from any of the Senators here.

Let me ask, Dr. Hirst, your thoughts as to this whole issue of carbon capture and storage. You indicated that your conclusion is that by 2010, we have to have 20 full-scale projects underway or operating. Is that what I understand?

Mr. HIRST. Committed. Committed.

The CHAIRMAN. Oh, committed.

Mr. HIRST. Yes.

The Chairman. We need to have committed to 20 full-scale projects. I guess I'd be interested first in your view and then in Dr. Orbach's view as to whether or not the seven projects that he just mentioned—he mentioned seven new sites for carbon capture and storage that are committed to, I guess, already by the Department of Energy and through his office.

How does what he's talking about relate to what you're saying ought to be done by 2010?

Mr. HIRST. It relates very closely, chairman. There are other countries, also. The European Union is talking about aiming for 12 major projects. The United Kingdom, where I come from, is committed to competition for a full-scale CCS project.

So I think my answer to that is it sounds as though at the moment they're at the site development stage for the suitability of the sequestration and if those are indeed moving to become committed full-scale projects, that would be totally in accordance with the direction that we're saying we need to go.

The CHAIRMAN Dr. Orbach, did you have any thoughts as to how what you're doing relates to the goal that Dr. Hirst has articulated?

Mr. ORBACH. Mr. Hirst talked about the G8 Summit, the Energy Summit. We actually, together with the FutureGen announcement that was made yesterday, will have 10 sites by 2010 that meet half of the goal of the IEA.

I would like to——

The CHAIRMAN. These will not be demonstration sites. These will be full-scale——

Mr. ORBACH. They will be full-scale. There will be one million tons of CO_2 per year pumped into saline aquifers. We have 40 states that are participating and four provinces of Canada that are participating, and seven of these are going through the permitting process as we speak. We have developed the science protocol and the best practices manual for how the contractors who are going to pump the CO_2 will follow.

The CHAIRMAN. The report talks a lot about the potential for hydrogen fuel cell vehicles and I notice, at least in that one chart that you went over, that is projected to be a significant part of how we meet our transportation needs in the future.

My impression has been that this whole technology of hydrogen fuel cells for vehicles is something that is much further away than the development of electric vehicles or hybrid electric vehicles, and therefore I'm surprised to see the enthusiasm with which you sort of embrace it as a major part of the solution.

Do you have any comments on that?

Mr. HIRST. Yes, chairman. This is a subject on which I think we're very open in the report, that we actually do not know at the moment what may be the winning technology. You're quite right to imply that hydrogen fuel cell vehicles face a number of hurdles.

For instance, at the moment, the very high cost of the fuel cells in prototype form and there are issues about the storage, the on-board storage of the hydrogen, and there are also issues about the kind of infrastructure you would need to deliver the hydrogen to your filling stations. So there are indeed a lot of difficult issues around hydrogen.

But I think it would be wrong to imply that electric vehicles don't also face challenges. There are challenges around development of the kind of batteries that you would need to deliver electric vehicles at reasonable cost with fully comparable performance to current internal combustion vehicles.

I think it would be fair to say that in the sort of technology community, probably people have become slightly more, relatively slightly more optimistic about the outlook for electric vehicles over the last year or so because there has been some quite significant process, but we feel it's too soon to say that we know what the outcome of this will be and we need to pursue both of those, the research and development of both of those avenues in our view.

The CHAIRMAN. All right. My time is up. Senator Corker.

Senator CORKER. Thank you, Mr. Chairman, for holding this hearing, and I want to thank our witnesses for being here and for the great contribution you've made in the world arena as it relates to focusing on climate.

Mr. Hirst, I have to tell you, I felt a little incredulous, I guess, as I sat and listened to your presentation. How much time was put into the putting together of the facts and data to come up with the charts, if you will, that you just presented?

Mr. HIRST. This study is based on the model that the IEA's been developing over a period of 6 or 7 years. It's a 15 regional model and it contains a massive data on the costs and prospects of individual energy technologies.

The model built up on the costs and potential of technologies and the data that goes in there is not just from analysts at the IEA. Probably about 20 analysts at the IEA who have worked on parts of this but they're not quite full time on that, but most importantly, it's also based on the data and the advice that comes from the IEA's International Technology Network.

Now these are groups of experts from around the world, U.S. experts, but experts from other major countries around the world. There are 40 of these groups. There are probably thousands of experts who contributed in one way or another to this.

So I think, of course, I should perhaps emphasize this, these are scenarios. I put them in specific form because that makes them concrete. Of course there are enormous uncertainties around the future in these areas, but we do feel that this is based on in-depth analysis and taking extensive advice and guidance.

Senator CORKER. Let me say, and I wish that every member of the Senate could have seen that presentation and every member of the House could see that presentation.

I want to say that I generally have, I think, a very good nature here in the Senate and try to focus on bringing out the best in all of us to the degree that a human being can and also try to focus on being blunt and direct in asking questions and making statements.

I think that presentation, and I'm speaking to the presentation and not to you as a person, please, to me, does more damage to the discussion of climate change than almost anything that I've seen since I've been here.

I couldn't believe that this sort of command and control kind of discussion was taking place here and I have to tell you that if I were you, I would not—if the issue is trying to cause people to be interested in climate change, I would not make that presentation again.

So I just want to say to you, I'm stunned, and I think many of us up here have been stunned in watching this accumulation of experts talking about what the future will be and creating these kinds of scenarios. I don't think it's helpful.

But I would like to get back to the good nature component and say that there were some elements of your presentation that I found interesting. One of the things that we seem to not be able to do right now in this body is to bring the two groups of people together, folks who care deeply about our environment and folks, as Pete Domenici mentioned, who care deeply about making sure that countries around the world are energy secures, and it seems to me that we have a wonderful opportunity right now with people feeling so vulnerable to be able to do that.

I know that in your presentation, you mentioned the need to pursue nuclear and that it already was a great—there's much nuclear development already that takes place in our country and even more needed to take place.

I think you mentioned to some degree also increased investments in fossil fuels that are going to be necessary to meet demands, and I would like to say that while I thought the facts and the data that were presented were not helpful, I thought those two comments that you made were most helpful.

I have a meeting tonight with somebody in the environmental community to discuss just what you said and I wondered if you might expand a little bit on the opportunity that we have here in this world today with everybody feeling vulnerable to sort of take down the barriers that exist right now between these two communities and to be pragmatic as we use fossil fuels to some degree to be a bridge to the future, but at the same time create a tremendous sense of urgency, if you will, as it relates to moving toward new technologies that hopefully will solve many of the issues related to climate change.

I'd love for you to expand on that and please forgive me for my earlier bluntness.

Mr. HIRST. Senator, a couple of comments on that. I do want to emphasize the reason that we did this study is because we were asked to by the G8. They asked us for scenarios, literally for scenarios and strategies for a clean, clever, competitive energy future. I don't think we would have done this if we hadn't been asked to do this.

Senator CORKER. I would just say that I might not take on some of the things that G8 asked me to do in the future if that's the result.

Mr. HIRST. I think your second question is about the impulse that high energy prices today might give to change in the energy sector and whether that can awaken and bring together people from different parts of the community.

I think the answer is that will produce change, but in the absence of government policies, it won't necessarily change, produce all the changes that people want, because some of the responses to high energy prices will actually be through very high carbon responses, such as unconventional oil, whether it is oil sands or oil from coal. These are technologies which, in the absence of carbon capture and storage, are actually higher in carbon than conventional oil. Now they may also stimulate low carbon technologies.

The other point I would highlight, and this comes from—we presented these studies to a group of chief technology officers of 30 leading energy companies around the world, and their response was yes, this may be technically possible, but to make these changes, we need clear and predictable incentives for the future for these new technologies, and one of the problems with high energy prices right now is that investors won't necessarily assume or won't necessarily rely on prices remaining very high in the future when they make their investments, whereas they might respond if you have very clear predictable signals as to the carbon incentives that might be available in the future.

Senator CORKER. Mr. Chairman, I realize my time is up. Thank you very much for having this hearing and I apologize for some of the comments I made or having to make them actually.

Thank you.

The CHAIRMAN. Senator Salazar.

Senator SALAZAR. Thank you very much, Chairman Bingaman, and let me first say I think this is a very, very important hearing and I appreciate your leadership as the chairman to have this hearing on the issue of climate change and energy, and I would hope that one of the things that we might be able to do as a committee under your leadership is to move forward with our own bipartisan measures to try to address the issue of climate change.

I for one, a U.S. Senator, was not happy, frankly, with much of what we did in the global warming debate on the Floor a few weeks ago. I think it's an important debate that needs to be had, but I also know and we all know of how it is driven so much by what we do with our energy policy and it seems to me that this is the appropriate committee to try to deal with the issue.

Let me ask—I wanted just to make that comment to you.

A question that I have for you, Mr. Hirst, and also a question I'll have for Dr. Orbach, has to do with the technology options.

Now, I sense the disbelief from my colleague and friend Senator Corker. We also look at when you are looking out at 2050, you had to make some assumptions relative to the allocations of the different energy sources and what we're going to be doing on the demand side as well.

So if you look at your figure 9, you have the whole chart of the different energy sources on both the supply side and the demand side and making predictions about how that all will turn out in the year 2050.

How did you go about making the allocation that you make with respect to the different components of our energy equation? For example, how do you decide what percentage you're putting on nuclear versus what you're putting into coal and IGCC versus what you're putting into solar?

I ask that question in all sincerity because it seems to me that when we are talking about putting 500 megawatt power plants in the desert of Arizona that are CSB solar plants or 200 megawatts in Bakersfield, California, that some of this technology is so unfolding and so new, that it's very difficult to make these predictions at 2050.

So how did you come about the allocation of all these menus that are in the portfolio on both the supply side and the demand side?

Mr. HIRST. Senator, you're right, it is very difficult and there are uncertainties.

The way the model works is that it chooses the lowest cost options. So the model contains our best estimate of what you might call the supply curves in each of the 15 regions to which it relates. It contains our best estimates of what you might call the supply curves of each of these technologies, how much you could obtain at what cost, and then the model selects the technology which together produce the lowest cost solution for the level of CO_2 cuts, reductions, that you are seeking.

Now you're quite right to say there are lots of uncertainties in that and a key element of the model is what we call the learning curve. To what extent will the costs, some of which are very high on developing technologies, to what extent can they be reduced as the technologies——

Senator SALAZAR. Let me ask this question to push you a little bit. I've done a lot of litigation on the water models and I know that there are black boxes that you can spend months in litigation over.

Is this a model that's any good or is it just a piece of—you know, something to talk about? How good is this model?

Mr. HIRST. It's a good model. This is a topic on which there's quite a community of experts around the world and people have done, you know, analytical studies of the history of technologies, how in the past in motor vehicles and many other technology, they go through a well-established pattern.

Senator SALAZAR. Let me just say the trustworthiness of the model, dealing with, you know, 42-year output projections, is something that is a very important point, I think, for all of us.

I want to just ask a couple other questions, if I may. Carbon capture and sequestration, the use of coal. Coal is to us in the West, much like oil is, I think, to Saudi Arabia. You talk, both of you, Dr. Orbach and Dr. Hirst, with some optimism about where we are going, the announcement from DOE yesterday, Dr. Orbach.

How realistic is it that we're going to get there and that these projections that we have, Mr. Hirst, here on carbon capture and sequestration are going to be met? Dr. Orbach first and then Mr. Hirst for a minute.

Mr. ORBACH. Frankly, I'm somewhat optimistic. I believe that we know enough about underground geophysics and geochemistry to be able to predict what happens to the CO_2.

I would like to come back to the question you asked Mr. Hirst.

Senator SALAZAR. Let me keep pushing you a little bit on this carbon capture and sequestration.

Mr. ORBACH. Please.

Senator SALAZAR. Sam Bodman is a wonderful man and yet we've had these conversations about where we're going with carbon capture and sequestration and FutureGen and it's been delayed, and yet the reality of it is there are many of us that want to see how fast we can move forward with that and the dollars that have been out there have made it impossible for us to move forward with some projects that are demonstration projects.

Now you're saying 10 projects. How realistic is it from your point of view as the chief scientist in DOE that we're going to be able to move forward with those 10 projects? Are we going to run up against the fiscal walls again?

Mr. ORBACH. No, I believe we're going to go forward with those 10 projects.

Senator SALAZAR. OK. Now talk about your 20 comments about—your 20 demonstration projects for about 10 seconds. My time is up.

Mr. HIRST. Yes, now we do think it's—we're encouraging that G8—Energy Ministers across the G8 have committed themselves to this target which is—and we think that they can do it, yes.

Senator SALAZAR. Are the other G8 countries ahead of the United States or about in the same position still as an unknown with respect to——

Mr. HIRST. It's difficult to generalize, but I would not characterize them as being ahead, no.

Senator SALAZAR. Are they behind?

Mr. HIRST. They are doing different things, but they're in similar situations.

Senator SALAZAR. Thank you, Mr. Chairman. My time has expired.

The CHAIRMAN. Thank you.

Senator Craig.

Senator CRAIG. Mr. Chairman, thank you for the hearing, and Mr. Hirst, thank you for being here and making your presentation.

I'm sitting here in a couple of different thought processes at the moment, not unlike my colleague Senator Corker, but at the same time, going through a déjà vu with the International Energy Agency.

You were created in 1973, coming out of the OPEC oil embargo. The world was in a break point in hydrocarbons at that time, making fundamental changes in their thinking as developed nations versus undeveloped nations about what to do, and for this reason you were created.

I think it was the G5 or the G6 but maybe not the G8. The world has changed since 1973. You now come to us at what I call another break point in hydrocarbons for developed nations and developing nations. So stay with me for a moment because in the midst of this is a question as relates to your modeling and the realities of where we go in the future.

In 1973, 1970s, this nation was about 80 percent dependent on hydrocarbons, but following that, whether it was Great Britain, Western Europe, the developed nations, and the United States, we began to change. We changed for a lot of reasons. We changed because of policy and you've mentioned the need to drive that.

Out of that came CAFE standards which we had not heretofore had and we told the auto industry to make fundamental changes. Out of that came standards for electrical appliances that heretofore we did not have. For a period of time through the balance of the

1970s and the 1980s, we were a pretty forward-thinking nation as relates to energy and then we fell into the doldrums of a growing economy and a supply that was reasonably priced. So we leveled out, but we shifted from an 80 percent dependency to about a 40 percent dependency on hydrocarbons.

Now I'm not quite sure what the modeling was for Europe but that happened. Now we are at another break point, in my opinion, in energy, hydrocarbons, and oil. As a result of that, coming out of it over the next decade, we will act and think a great deal differently than we do today.

This Congress is wrestling with that. Dr. Orbach has talked about it. We were all moving in that direction but maybe not with the urgency that a $136 or a $140 a barrel oil will bring us and $5 gas at the pumps. That is a level of urgency and pain for us, but it is also true across all of the developed nations that are dependent on oil.

So my question relates to India and China, the emerging developing nations that are in the high percent of dependency on hydrocarbons. I think China's at about 90 percent coal and oil dependent at the moment. India's somewhere in that model also, they have the capability of responding differently than we did in the 1970s because they are not as affixed to the technologies that we were of that day.

By that, I mean, and you saw it happen last Thursday in China, China raised the tax on their hydrocarbons, a barrel of oil dropped in the world market, and the stock market went up. Why could they do that? They could do that because only one per thousand Chinese owns an automobile at this moment, not 500 per thousand. But some of the modeling that is being used by you and others would suggest that China's going to follow our pattern and that they're all going to develop. They're all going to go out and buy cars and so it's going to go from one to 10 to 50 to a 100 to a 150 to 200 per thousand Chinese owning an automobile.

But the Chinese, unlike us, can control that in a very different way. They didn't put copper lines between all of their towns to give everybody a telephone. They simply got them a cell phone and put up a tower. Why, they grabbed the technology of the moment and they adjusted and changed very rapidly. Something we could not do because we were simply the leaders of technology down through the decades as is true of Western Europe.

My point is, has the modeling that brought you today and brought the report incorporated the reality of markets that go through these kinds of dramatic changes based on costs that cause us to change?

We will be a very different country 10 years from now as relates to hydrocarbon dependency. Some modeling would suggest we will drop from 40 to 30, maybe less, based on the market forcing us to as much as policy.

Now the combination of successes coming out of the 1970s that created you were a combination of markets and policies. Today you come with policies and policy change proposals.

How reflective is your modeling of the markets that are rapidly changing at this moment in a relatively unforeseeable way?

Mr. HIRST. Senator, you're right, we are assuming in this that as we see continuing rapid economic development in China and India, and by the way, the study is based on fairly optimistic assumption about continuing economic growth, we have 3.3 percent average global economic growth between now and 2050, concentrated in these big developing countries, and we assume that, yes, as Indians and Chinese become more affluent, they will want to own vehicles, but we assume certainly in the more carbon-saving cases, first of all, that they will tend to own smaller and much more efficient vehicles in the coming decades and, second, that their cities may evolve on a pattern that involves higher opportunities for mass transit and public transport than some of them have in the past.

We do have those trends in there, but you're absolutely right, you know, that one of the big drivers in all this is the desire for personal transport by people in developing countries. We think that's inevitable and hard to question.

As far as the United States is concerned, yes, we have built in—we have assumptions about oil prices for the future and we have built in a response to those in terms of increasing efficiency in the economy as a whole and indeed in vehicle efficiency in the United States. Yes, we do expect a trend toward increasing vehicle efficiency.

It's interesting because it bears out exactly what you were saying. When we look back historically, we saw large energy efficiency gains in OECD countries in the 1970s and 1980s, but in the 1990s, a period when oil prices were relatively low, the rate of improvement almost halved and that's something that we have to—that, of course, is a bit of a lag between policies and results. So we don't yet see some of the results of the most recent policies the governments have been adopting.

Senator Craig. They're not factored into your modeling?

Mr. HIRST. Yes.

Senator CRAIG. Thank you. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Lincoln.

Senator LINCOLN. Thank you, Mr. Chairman, for holding this important hearing. We appreciate your leadership in this role, and I would associate myself with the comments from Senator Salazar in terms of the engagement of this committee in dealing with this issue as well as our frustration in the first attempt on climate change.

There seems to be so much more that we need to take into consideration. Certainly from the testimony you gentlemen bring, we hope we will.

I often speak on how we're going through a transition from an old energy economy to a new energy economy and that's exactly in my book how we have to look at this. I don't think we should be shocked or amazed at the unbelievable challenges that we're going to be faced with because it's going to mean not only changing our economy but in order to change that economy, we're going to have to change cultural ways among people and Americans do not change their cultural ways quickly.

I think one of my many main priorities as we continue the climate change discussion is making sure that all sectors of our economy have the right tools to meet the types of emission reductions that we are going to require in order that the disproportionate burden does not fall upon particularly low-income or those that live in disadvantaged areas, rural areas, and other.

It's clear that a wide range of energy efficiency technologies are going to be needed in this new energy economy in order to be successful in reducing the CO_2 emissions which you all speak about in terms of levels and cost-effective matters and a host of other things.

Just a couple of questions. One to what you had said, Dr. Hirst, was that predictable and dependable incentives. You know, I don't think we should be amazed that this is going to be challenging. We can't even pass the tax incentives for renewable energies in this Congress, and, you know, there's no doubt that if what we want to see happen is the investment in renewable technologies, we've got to incentivize it and it needs to be more predictable. It needs to be more dependable.

One of the questions I would have for you is you accommodate in your studies the technologies of more fuel-efficient vehicles. Do we speed that up? What happens when we make that rapid in terms of increased automobiles and fleets with fuel efficiency?

I mean, to me, it seems as if conservation, which his what that is in many ways, is the most immediate impact we can have and it seems as if, if we did more of that, we would see a quicker response with pain perhaps, if we provided the incentives that are there.

I guess just a couple questions that I would also have to the Department of Energy. You're aware of the process that's currently being developed to take advantage of animal waste. I come from a very rural and agriculturally productive state, but animal waste, such as chicken litter, as a primary feedstock for renewable fuels and energy.

What barriers exist in the implementation of that? I guess the other question would be on cellulosic biomass, you know. What is the role there? Algae-based fuels.

One of our biggest challenges is that, as you all point out, moving from these technologies which our constituents hear about and think that should be into practice the very next day. There's certainly a long spectrum of steps that have to be taken before we can get them to the consumer or even into a technology-based industry that can produce them, much less getting them deliverable to the consumers.

So algae-based biomass, animal waste, those issues, and to Dr. Hirst, I guess, a more rapid integration of technologies, particularly conservation measures and others, just would like to have your comments on those.

Mr. HIRST. Senator, I'll just comment on fuel efficiency in vehicles. First to say, yes, you're absolutely right. The issue is clear, predictable incentives. That's what business tell us again and again.

Senator LINCOLN. Sure.

Mr. HIRST. As far as the vehicle fleet is concerned, we believe that the technology potential exists with conventional vehicles to approximately double their fuel efficiency over the next 20 years and that could be quite a cost-effective transformation.

So we do support—you know, we're very aware that the U.S. is developing its fuel efficiency standards. We strongly support that, and we would like to see that progressively developed over the years because we think there's a lot more quite cost-effective potential there to increase vehicle fuel efficiency.

Mr. ORBACH. Senator Lincoln, your question is right on, and in particular, we believe that the farmer and the rural areas have a huge stake in energy. These are cash crops that we're talking about or use of agricultural waste.

You referred to animal waste, also rice stalk, corn stover. They all contain cellulose and that cellulose—well, the animal is different. That's an oil, but they contain fuel and the trick is to keep our options open. There are new technologies being developed as we speak that are very exciting. I don't know which one will be the most effective, but our investment in these new technologies is critical.

The way we look at it is to duplicate what nature does. Now, we're talking about using plants, about taking the cellulose that nature has created and producing fuel, gasoline as well as ethanol. But, why plants? Why not work directly with artificial photosynthesis? Do what plants do, only with molecular structures that we can create in the laboratory.

These are options that are very exciting. I can't tell you if they're going to work, but I can tell you that the country is electrified, students are pouring into universities, interested in energy because of these opportunities that are there.

So, I think you're going to see over the next couple of years some very exciting options that we have not even thought about in the past. You mentioned algae as one example. Biodiesel comes from algae, but you can also produce fuel directly from cellulose; and we're talking now about diesel and gasoline.

We have looked at the combustion side as well as the production side. We have a combustion research center which is working with people who are doing microbial development because gasoline comes from oil and the refiners make what they can out of it, but is that the most efficient fuel? If we can design the carbon chains for the most efficient combustion, will it come out to be the same? Will we have the same mixture of these organic compounds? I don't know.

So what you're seeing is that this energy crisis, as Senator Craig referred to, has really caused us to open the box, to think of opportunities that could conceivably be transformational, and my belief is that the person who will benefit most from this is the farmer. We are going to give the farmer a cash crop that is dependable, doesn't depend on the price of food, one that can use natural resources that are currently available, and not complete with food.

So I think we have an opportunity here that's very exciting.

Senator LINCOLN. Thank you. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman. Following up on Senator Lincoln's comments about the impact to the poor, the lower incomes, those on fixed incomes, we've got situations up north.

We're in full-blown energy crisis up there in a state that's got access to an awful lot and what we're seeing in Alaska, in some of our villages, some of the very remote, very small villages, is in an effort to be able to pay for home heating fuel, in an effort to be able to pay for the diesel that is the power- generating source, in an effort to put the fuel in the boat, families are not paying their water and sewer utility bills at a $126 a month. Those utilities are cutting them off and we are now going back to the days of the honey bucket where the human waste is carried outside and dumped in the ground.

That is, I would like to think, an extreme example of what happens when we haven't made that transformation. You are in a situation where all you're faced with are ever-increasing costs and the need for the resource is as acute as it is.

I wanted to ask both of you gentlemen, and I thank you for your testimony here this morning. Clearly, the need is a global effort, as you have both indicated. I think you referred to global technology revolution, that we have got to have the technological breakthroughs, but consistently, the terminology is on a global scale.

Give me more then in terms of how we get to that level of cooperation and collaboration globally. We're all looking at this. This is Alaska's interest. This is the United States' interest. This is India, this is China. How do we truly cooperate on this issue and therefore be able to make a difference globally?

Mr. HIRST. Senator, I'll comment rather generally, if I may, on that point because it is at the heart of the evolution that we're trying to achieve because you've talked about poor people in the United States, but, of course, very, very big players in this that you've mentioned are countries like India and China, and there's no doubt that their top energy priority is development, making, you know, affordable, clean energy available to very large numbers of people, people who are without it, and therefore any way forward on a global scale is going to have to integrate the concerns about affordable energy with concerns about security and these concerns about CO_2 emissions.

That's why I think we are looking for, you know, the lowest cost technologies that we can possibly find to solve these problems, but one has to be honest and say there are some additional costs and I guess it's for governments and societies to decide how these costs are going to be spread and how they can protect weaker people in society, but I don't think from the technology perspective, I can add very much to this.

Senator MURKOWSKI. Dr. Orbach.

Mr. ORBACH. Let me respond directly because it's a very important question that you've asked and this is a different kind of energy.

We think of oil and large refineries and huge centralized facilities; but the kind of energies that we're talking about, the energies from biomass, for example, are distributed. There's no reason why you need that huge investment; and in fact, in rural communities, small towns, it is feasible to think of a plantation of switch grass or poplar trees or some other vegetation which can be processed onsite to produce fuel for the community, to produce a product that can be sold. So, it's a different kind of energy. It offers a possibility of dealing with the rural environment that we've not had before.

There are technical issues that we are addressing right now; but I believe they can be solved. I think that they, frankly, are going to make a huge difference in rural environments where there aren't other resources available.

Senator MURKOWSKI. I would agree, and I think you get out to so many rural communities that are isolated. Alaska's a perfect example of a state where we don't have the transmission to move power from one community to another. Each village is its own free-standing unit and how you figure out how to power that village, whether it's through harnessing the wind or the ocean energy or the sap, the willow saplings that are growing up nearby, it's going to be these kind of mini projects, and they're prohibitively expensive right now, but I think otherwise what you're going to have is you're going to have these smaller communities who will not be energy sustainable and they will fold, moving people into the cities.

I'm not convinced that that's the best solution there, but it is how do you identify that energy source for the smaller particular areas? Mr. Hirst, you look like you want to jump in, but my time's up.

Mr. HIRST. May I just have a second because this is a most interesting topic. One of the activities that we're involved in is engaging with major developing countries on energy technologies and we said to them, well, here are the things we're working on. What are your priorities? Particularly South Africa led on this and said, well, our priority is what they call rural energization, which is exactly, I think, the topic that you're talking about.

We had a major workshop on this and there are a lot of technologies. They're not all prohibitively expensive, but it's very interesting what the suppliers and the industry can contribute and what they're really looking for is ownership in the community of these technologies. If you can find how the community themselves can own these quite diverse technologies and operate them and acquire the capability to manage them, then there are a whole range of technologies and that seems to be the real challenge in delivering these technologies, certainly in the major developing economies.

The CHAIRMAN. Thank you.

Senator Menendez.

Senator MENENDEZ. Thank you, Mr. Chairman. Thank you both for your testimony.

I appreciate that some of my colleagues have cause for concern in your presentation, but the reality is I appreciate the nature of the presentation because change is always a difficult challenge and I am concerned that we will rue the day that in fact we are unwilling to face the change that we need as we see even today the incredible floods that are taking place in Iowa and parts of the Midwest, as we see the incredible number of forest fires taking place in California, as we look at the erosion along the Eastern Seaboard of some of our coastal areas, and yet some of us cannot seem to come to the conclusion that the challenges we have will require significant leadership and a commitment to change. So I appreciate the efforts to have people realize the magnitude of the challenge before us and constantly place that out there.

Having said that, let me ask you, Dr. Hirst. The IEA Report makes it clear that annual solar power, solar energy dwarfs just about every other source of power. It says, "The amount of energy that hits the earth's surface in an hour is about the same as the amount of energy consumed by all human activities in a year."

It's a pretty significant statement, and you predict that under any emissions reductions scenario, solar power costs could drop to five cents per kilowatt hour or perhaps even less. That would be a deal to my constituents in New Jersey who are paying beyond that right now.

I want to understand, however, what policy changes we need in order to deliver on that promise.

Last year, I introduced legislation called The Solar Act, which would help eliminate interconnection and siting obstacles for solar panels.

What, in your view, are the primary obstacles to large-scale deployment of solar panels? What level of support is needed to develop and supplement the more widespread deployment of solar technology?

Mr. HIRST. Thank you, Senator. I just refer you quickly, if I may, to figure 14 which shows the share that we expect for solar in energy supply in 2050. It's one of the major components in renewables. I would think just from inspection, it looks as though it's something like, you know, 6 or 7 percent of global energy. It's a big contribution.

Obviously there's a big difference between the energy that's inherent in the sunlight or how much we can economically capture. But to come specifically to your point, there are two key areas for developing solar, solar power.

One is this is a technology that I would describe as being in the early stages of deployment. It's still expensive, but it is capable of mass deployment and experience shows that you make big economies in any technology as you begin to deploy it widely. This is because you get mass production, you get much more efficient ways of developing the materials, and business learns in all sorts of ways how to be more effective. So we need the deployment to bring the costs down. The costs have been coming down quite spectacularly in recent years, albeit they are still high in relation to conventional generation.

But we also need the research and development. Some of that needs to be government research and development. I know it's going on here in the States. It needs to be very closely ranked with the research and development that big energy companies are also conducting.

So I think those are the two areas, but we believe and we expressed it here, much more than we did 2 years ago, by the way, this is a technology that has the potential to come in and be competitive as a low carbon energy source.

Senator MENENDEZ. I appreciate that. The report talks about a global revolution, a dramatic shift in government policies.

Mr. Chairman, as you know from your efforts, we couldn't even seem to extend the tax credits for renewable electricity generation, and it's frustrating when we look at that in the context of the challenge.

Let me ask two last questions. Your report makes it clear that massive investments are going to be needed to meet rising global energy demand. Is there a danger of stranding capital in projects which exacerbate global warming if we don't have clear policies on carbon emissions?

Finally, Dr. Orbach, in your written testimony, you asked us to imagine the solar photovoltaics which exceed thermodynamic efficiency limits. While I'm not sure what that means, I'm glad that the Department of Energy is working on the next generation of solar panels.

I'd like to know what you're doing to reduce the costs of existing PV technologies and how much cheaper can you make solar, for example, over the next 5 years. If you both could answer those separate questions.

Mr. HIRST. Senator, the answer is yes, there is a danger of stranded, because we're going into a period where many countries around the world, I think including the United States, will need to make major refurbishment and replacements of, for instance, their electricity networks, electricity capacity, and that capacity that is built will be capable of running probably for a period of 50 or 60 years.

So if the wrong decisions are made now, the risk is of conflict later on with environmental policies and, indeed, in this BLUE case that we show, we have really substantial amounts, for instance, of coal-generating capacity that cannot be subsequently converted to having carbon capture and storage actually being phased out early because they're no longer economic in a low carbon environment.

Mr. ORBACH. In regard to solar, what we meant by that comment was we have one electron transfer now. If we can use two electrons, we get double the energy out. We're working on that and that, we believe, is a real possibility.

The actual cost driver right now on solar is more, as Mr. Hirst has indicated, a production issue. Can you really get this to mass production? But I would like you to think beyond solar panels because sun does a lot of things and we are looking at, for example, artificial photosynthesis.

Can we take sunlight that plants take and produce sugars that they live off of? Can we do the same molecular structure and produce fuels directly?

There's another aspect and that is hydrogen. Can we disassociate hydrogen and oxygen from water using sunlight? There are new methods we're looking at with various catalysts that use solar energy to derive hydrogen. So we look at solar on a much broader scale than just photovoltaics. They're very important now because they're an immediate capability.

We also believe that solar, just as you pointed out, is one of the great opportunities for energy for our country in the future. We're looking at all different ways of capturing that sunlight and turning it into energy.

The CHAIRMAN. Thank you.

Senator Barrasso.

Senator BARRASSO. Thank you very much, Mr. Chairman. Mr. Hirst, if I could, you talk about a need for a steep change in government policies, also closer international collaboration to address both the global energy demand as well as climate change, and I'm wondering how we're going to be able to accomplish that in such a way that we can reduce global energy prices.

I think you talked about a diminished demand for oil and things over the next several decades.

Mr. HIRST. The way we can do this is by going for the most economic technologies that we have and perhaps I should say when we wrote this book and we looked at energy price projections into the future, we have price projections in the range of $60 to $65 a barrel which is high but it's an awful lot less than current oil prices, and it's very interesting that, you know, you can convert some of the costs of the technology we're looking at.

For instance, when we say you need technologies up to $200 per ton of CO_2, say, that translates into about $80 a barrel on the price of oil. It's the same cost to the person using the oil.

So you can see that the price of oil that we have seen sort of takes us into the region where some of these clean technologies could already be competitive and could pay a plant in stabilizing prices.

The concern we have is that in the absence of low carbon technology, it may not be the low carbon alternatives that are preferred, it may actually be high carbon alternatives that are preferred. So that's how we see it.

Senator BARRASSO. The comparison you just did at $200 per ton of carbon, you said that equals to $80 per barrel of oil. That's in addition, on top of the current price of the barrel of oil? It's based on the 65 to 80?

Mr. HIRST. We did this when we were projecting $65 current money, $65 a barrel in 2050.

Senator BARRASSO. So that would add $15—the carbon component of that would add $15 to the base cost of the barrel of oil? That would take you from $65 to $80 or is it $80?

Mr. HIRST. No, no, no. It would add $80.

Senator BARRASSO. Add $80 to every barrel. All right. I just want to be very clear on that. Thank you very much.

Dr. Orbach, if I could, we're talking about coal and the amount that coal provides for the baseload electricity produced now in the United States and beyond.

We've heard a comment that we need 20 carbon capture and sequestration projects, I think, by 2010 at least started.

Mr. HIRST. Committed by 2010.

Senator BARRASSO. Committed by 2010, online by?

Mr. HIRST. 2020.

Senator BARRASSO. All right. Do either of you have a good estimate on how much government and private investment's going to be needed to really get the clean coal technology available at a commercial scale to really put it on?

Mr. HIRST. I can give ours. I mean, we estimate that the incremental cost of a full-scale—say you're talking about a 500 megawatt coal plant with carbon capture and storage. We estimate that the incremental—because obviously an element of that is the normal commercial investment in the coal plant, but the incremental investment at this stage for the demonstration plants, we estimate in the range of a $1 billion to $1.5 billion.

Senator BARRASSO. For each one? For the 20 or for each one?

Mr. HIRST. For each one.

Senator BARRASSO. For each one.

Mr. ORBACH. The IGCC, which is terribly important, is roughly about 20 percent more with CCS (carbon capture and sequestration) technology. But the beauty is that it enables you to capture the CO_2 before combustion.

The actual cost of sequestration, I don't know if anybody can really estimate that right now. We don't know enough about what happens underground in these saline aquifers. But if you're looking at carbon and CO_2, that's what you want to do, and that's what the purpose of our investment will be.

Senator BARRASSO. Mr. Chairman, I'm afraid I'm out of time. Thank you very much.

The CHAIRMAN. Senator Sessions.

Senator SESSIONS. Thank you, Mr. Chairman. You know, the communiqué from the Gleneagles G8 sets my priorities. It says it a little bit differently, but I believe we need to protect our national security when it comes to energy and transmitting $500 billion a year to foreign nations to purchase that oil is a matter that we've never seen before in the history of the world.

I believe we ought to improve our environment, particularly in SO_X and mercury and other things that get emitted. I certainly believe in that and air pollution is the phrase you use here, and we ought to eliminate greenhouse gases and the communiqué says reduce poverty. I say let's contain the cost of fuel. I think it's a world ideal, a good ideal, that energy be less expensive.

I understand where electricity is readily available, lifespan is twice that where it's not. So this is not something we want to deny the world, the ability to have low-cost energy, but so I'm worried and when you indicated, Mr. Hirst, that it would be $80 a barrel to support a $200 a ton tax or cost on carbon and then you indicated, I believe earlier in your remarks, that that 200 may not be enough and it may take $500 a ton, which would add $200 to the cost of a barrel of oil, which would have devastating impacts, I submit, on this economy, it cannot be limited to a one percent impact on GDP. I just can't imagine how it would.

I would also just express a concern of the concept that somehow a group of persons can meet in some salon in Europe and come up with a projection about exactly how it's all going to work out because you would admit really that technology is going to lead us the direction we'll go ultimately and there could be breakthroughs and failures that would make these projections not be very accurate, I guess, in 50 years. Would you agree with that?

MR. HIRST. Senator, of course. You're absolutely right. I think people are familiar with the scenario approaches. Everyone knows the world will not turn out exactly as we today think.

Senator SESSIONS. I think we're not masters of our universe to that extent that we can project how that would come out.

Mr. Orbach—excuse me. If you wanted to respond?

Mr. HIRST. Yes, I just wanted to say, you know, we believe that the impact of this BLUE case would actually be to reduce oil prices from what they would otherwise have been if we had not conducted this huge technology transformation, that's very important, and one way of looking at this transformation is that some of the resource which would have been used to import high-cost oil is actually used in engineering and technology development and technology deployment.

Senator SESSIONS I tend to agree with that. I think that's how we need to bring this fight back on oil company profits, fight back on OPEC demands on this economy, which amount to, in my opinion, a tax that's not related to the fair market value of oil because they contain the production to manipulate the price, and so this is something the Nation needs to do as a matter of security as well and it has the potential to benefit our CO_2 and our global warming concerns, also. It should do both.

Dr. Orbach, I've expressed some concern about the Department of Energy. Senator Domenici has expressed concern over the slow way of getting loan money out to innovative industries. I believe that you have tremendous amounts of information, looking at your website and other things, on all kinds of technologies.

I would like to see the Department of Energy come to us and tell us what they think would be the best prospects for loans, best prospects for subsidies. We get in Floor debate here and somebody's visited a plant in their home state, like I have, and I get all excited about it and I want to have you fund it and we need some real leadership to help us.

Do you think the Department of Energy can do a better job of helping us sift through the competing demands and make some recommendations for the best utilization of subsidies and loan monies?

Mr. ORBACH. Yes, sir. We are working as quickly as we can. It's a new process. We're setting it up. There's been a GAO review which we have been responding to. We hope that we can get that to Congress very shortly, both for renewables and for nuclear.

Senator SESSIONS. That's good. I'm going to offer some legislation that would require something like that and we're working on that, and I just believe that we need more than just you to house extensive research data and you need to develop policy and not be timid about it. We may not agree.

You mentioned biofuels, switch grass, wood, cellulose. I am very excited about that. In Alabama, I know of three projects, four counting the Auburn Portable Gasification Unit that was just brought up to Washington last week, they won a national award for it, where you heat cellulose wood, heat wood products, gas comes off, that gas can be converted to a liquid and it appears that that could come in less than, considerably less perhaps than the price of oil on the world market.

Do you—how do you feel about that potential?

Mr. ORBACH. First of all, I enjoyed seeing that exhibit at the Arboretum last weekend and you should be congratulated. That's a wonderful exhibit—one of the nice things was the age of the people who were running it. They were young and aggressive, and that's just the investment that we need.

The methods that they used—and there are other methods, chemical methods, of separating the lignins, the plant cell wall from the sugars that you want to get at—but the methods that they used are energy intensive. They had to use heat, called pyrolysis, in order to make the plant material available for the enzymes that would break it down.

We are looking at, as I mentioned earlier, at other ways of doing that separation. One way, of course, is to use ionic liquids; we're just exploring that. That will pull them apart without any energy being put in in the form of heat.

Another method that your state is very actively involved in with Oak Ridge National Laboratory is looking at the genetic structure of switch grass and poplar trees and trying to find out how to manipulate the genetic structure so that we can weaken the bond between the plant cell wall and the cellulose. We believe that in the future you will find in Alabama plantations of perhaps poplar trees that are so engineered that they can be processed with enzymes much more efficiently than we currently do it.

So for the future we are looking especially at states like Alabama that have so many water and land resources to grow special crops, that's not for food but for fuel.

Senator SESSIONS. We think, according to a report in a local paper, that the waste wood left in the forests after timber harvesting which is a nuisance to the landowner when it becomes time to replant, would amount to almost the entire state's utilization of fuel if it were converted to a biofuel and I think that's not—I'm past my time, Mr. Chairman.

I thank you for those comments and I do think there's potential. I hope the Department of Energy will seek to aggressively bring forth the ideas that are best for America so we can debate them.

The CHAIRMAN. All right. Thank you. Thank both of you. I think your testimony has been very useful. Dr. Hirst, thank you particularly for this report, and Dr. Orbach, thank you for your contribution today, too.

So why don't we dismiss this panel and go right to the next panel?

On this second panel, we have Dr. Thomas Wilson with EPRI, Senior Program Manager with EPRI in Palo Alto, California, Dr. Raymond Kopp, who's the Senior Fellow with the Resources For The Future here in Washington, and our third witness is Karan Bhatia, who is Vice President and Senior Counsel with General Electric.

Thank you all for being here. Mr. Bhatia, you have to be somewhere at noon or to leave here by noon, I'm told. Why don't you go first and then I'll ask any questions. Senator Sessions can ask his questions of you, if he has any, and then we'll dismiss you and go to the other two witnesses.

STATEMENT OF KARAN BHATIA, VICE PRESIDENT AND SENIOR COUNSEL, GENERAL ELECTRIC COMPANY

Mr. BHATIA. That's very kind. Thank you very much, Mr. Chairman, Senator Sessions.

On behalf of General Electric, I'm very pleased to be able to join you for this hearing on the Deployment of Cleaner Energy Technologies in response to the Challenge of Climate Change.

GE has been at the forefront of climate change for years, both in the public policy arena and in its commercial activities. GE is a founding member of the United States Climate Action Partnership which supports United States cap and trade legislation to achieve significant reductions of greenhouse gas emissions and a founding member of the International Clean Energy Alliance which supports global programs to promote the deployment of United States cleaner energy technology.

Commercially, GE has invested billions of dollars in its EcoImagination products and services, including wind turbines, coal gasification projects, advanced nuclear power plants, and aircraft engines, locomotives and gas turbines, which are significantly more efficient or lower emitting than traditional products.

While GE remains firmly committed to developing such products, we do face deployment challenges, particularly in developing economies which often lack the legal and policy structures to promote the adoption of such technologies but which account for an increasingly large share of the world's economy and greenhouse gas emissions, and my testimony, Mr. Chairman, which I will synopsize briefly but with your indulgence, I'd ask the full be entered into the record, the written version be entered into the record, focuses on this challenge, on how to ensure that these countries can and do participate in the deployment of cleaner energy technologies.

We believe that a comprehensive approach to this problem should include five elements.

First, as its top priority, the United States should renew its own renewable incentive programs, particularly the renewable energy production tax credit. Doing so, we believe, will assure a robust industry in the United States, capable of offering advanced technology products to the world.

Simultaneously, the United States should provide advice and assistance to developing countries in the creation and implementation of effective cleaner technology deployment incentives in their own countries.

Second, we believe there must be public funding supporting the deployment of new technologies in the emerging economies. In this context, we applaud the recent G8 Finance Ministerial commitment to establish a climate investment fund or funds to help combat climate change in developing countries as well as President Bush's request in fiscal year 2009 for a United States contribution to a clean technology fund.

Once created, we believe these efforts will be most effective if those funds are guided by four principles: (a) technology neutrality. The fund should be available to all technologies that have shown the potential to reduce, capture and/or store greenhouse gas emissions, (b) the majority of funds should be available to leverage funding from other sources, including export credit agencies, (c) the fund should act in a transparent and speedy manner on transactions brought to it by recipient countries and/or the private sector, and (d) the fund should employ a variety of eligibility criteria looking at both long-term high-impact projects as well as shorter turnaround projects.

The third initiative is we believe the IEA report makes clear continued innovation is going to be critical to addressing the climate change challenge in the years to come and key to innovation is rigorous intellectual property rights protection.

Recently, some have suggested compulsory transfers of cleaner technologies from the developed to the developing world in violation of the established intellectual property rights provisions. We believe this would be a fundamentally misguided concept that could immeasurably setback global efforts to combat climate change and we would urge they be strongly resisted.

In fact, we would urge that rigorous intellectual property rights protection should be a condition of eligibility participation in funding or other programs to promote cleaner technology deployment in the emerging economies.

Fourth, we support the elimination of Customs duties and other trade barriers to environmentally friendly goods and services, and we applaud a recent United States EU proposal to this effect. Eliminating such trade barriers will help to cut project costs and improve the rate of technology deployment.

Finally, a substantial focused United States Government effort to promote exports of cleaner and renewable energy goods and services, we believe, is required. We applaud efforts made by the Departments of Commerce, Energy and State in this area thus far and we urge that they be expanded and coordinated.

The Cleaner Export Programs established in the Energy Independence and Security Act of 2007 should be a core piece of the overall strategy. In sum, we believe that these five actions could form the foundation of a coherent, comprehensive United States strategy designed to engage the developing world in being part of the solution to global climate change. In doing so, we would not only be benefiting partners abroad but we would be supporting business decisions to expand United States investments in cleaner energy technology production, create United States jobs, and create a cleaner and more efficient array of energy options for our own domestic energy future.

Thank you very much.

[The prepared statement of Mr. Bhatia follows:]

PREPARED STATEMENT OF KARAN BHATIA, VICE PRESIDENT AND SENIOR COUNSEL, GENERAL ELECTRIC COMPANY

INTRODUCTION

On behalf of General Electric, I'm pleased to join you for this hearing on the deployment of cleaner energy technologies in response to the challenge of climate change. A key element in this effort will be engaging the world's emerging economies, which account for an increasingly large share of the world's economy and greenhouse gas emissions. My testimony today will focus on steps the United States can take to assist in the reduction of those emissions through the use of cleaner energy technologies. We recommend: 1) broad U.S. engagement to provide assistance to help developing nations establish public policies to incentivize cleaner energy technologies; 2) U.S. participation in multilateral funds or other mechanisms to provide direct financial support to offset the higher costs for cleaner energy technology; 3) continued protection of intellectual property rights as necessary to advance the development of technology; 4) elimination of trade barriers, including tariffs, to cleaner energy technologies; and 5) coordinated promotion of cleaner energy exports.

Action in each of these areas will support the partnership between government and industry that is essential to solve the global climate challenge.

OVERVIEW

The International Energy Agency report, "Energy Technology Perspectives 2008," provides a carefully documented analysis for the United States Senate to consider. The IEA's conclusions are that much of the technology to address climate change currently exists, but that that low and zero emission technology is currently more expensive than the alternatives and that achieving a 50 percent reduction in greenhouse gas emissions by 2050 will require considerable additional research, development and demonstration. General Electric agrees with each of these findings.

Climate change is one of the most compelling challenges facing the world today. This threat requires a concerted response from both governments and the private sector. Governments must provide a stable, long-term regulatory framework to reduce greenhouse gas emissions. To play our part in developing such a framework, GE is a founding member of the U.S. Climate Action Partnership (USCAP), which supports U.S. cap and trade legislation to achieve significant reductions of greenhouse gas emissions. GE is also a founding member of the International Clean Energy Alliance (ICE Alliance), which supports global programs to promote the deployment of U.S. cleaner energy technology.

The private sector also has a critical role to play. Given the right policy and legal framework, the private sector must make the investments and develop the business models that allow for a successful transformation to low carbon economies. It is GE's belief that this alignment of government and private sector interests and actions is the most—if not the only—effective way of addressing climate change. The result can be a true public-private partnership on a vast scale, in which private individuals and companies race to find innovative solutions, without the bottlenecks that can come with government-directed planning.

Through our Ecomagination initiative, GE is committed to making those investments. We will sell $20 billion of our Ecomagination products and services in 2009. Each of those products and services is significantly more efficient or lower emitting than traditional products. Our Ecomagination products include wind turbines, coal gasification projects, advanced nuclear power plants, energy efficient lighting, and the world's most efficient aircraft engines, locomotives and gas turbines. We recently announced the purchase of a thin film solar photovoltaic company to allow us to grow in the solar power area as well.

Just as importantly, we are investing in innovative technologies to break through to higher efficiencies and lower costs for the future. Our R&D for zero or lower emission and higher energy efficiency products and services reached $1.1 billion in 2007 and will increase to $1.5 billion by 2010.

U.S. greenhouse gas legislation is critically important because the United States represents approximately 20% of world greenhouse gas emissions. At the same time, China alone now emits more greenhouse gases than the United States, and emissions rates in emerging economies are growing far more rapidly than U.S. emissions. The deployment of lower emissions technologies in those economies is therefore essential to any effective response to climate change. The United States has the opportunity to export many of the needed products, services and technologies, providing benefits to both the recipient countries and to our own economy.

A further challenge to be addressed is the need to combat inflation in commodity prices. Many renewable and cleaner energy technologies rely on materials whose costs have soared in recent years because of increased demand. While the high price of oil encourages use of renewables, the high prices of carbon steel, aluminum, copper, and other materials pose an increasing challenge for the competitiveness of cleaner sources of energy. Developing countries that a year ago would have struggled to pay the higher price for cleaner technologies now find themselves facing a far greater challenge because of commodity inflation.

The solution around high commodity inflation is the same as the solution to our wider energy challenges: innovation and efficiency. Right now GE, supported by the renewable energy production tax credit (PTC), is developing more efficient wind turbines that can produce more electricity without increasing the amount of commodity inputs required. GE also is working on finding additional materials that can be substituted for high-priced commodities without sacrificing effectiveness. These innovations, and others in the future, will help combat high inflation in commodities and will work to keep the costs of cleaner technologies within reach of developing economies.

POLICIES TO PROMOTE CLEANER ENERGY DEPLOYMENT

While GE is firmly committed to developing lower-emissions, higher-efficiency products, we do face deployment challenges. These deployment challenges exist because traditional, higher emission technologies generally offer the lowest cost option. In developing economies, in particular, company decision makers have been understandably unwilling to pay for greenhouse gas reduction benefits, and governments have not wished to require such expenditures for cleaner and lower emitting technologies.

In international climate change negotiations, emerging economies have argued that the developed world has emitted most of the gases that are now causing climate change and should therefore bear the cost of reducing those emissions. In that context, some have even suggested mandatory transfers of cleaner technologies from the developed to the developing world. This is a fundamentally misguided concept that would immeasurably set back global efforts to combat climate change. It does, however, reflect the widespread recognition of the need for, and economic challenges associated with, cleaner energy technology deployment around the world.

Commercial mechanisms are highly efficient at ensuring the deployment of technology through the sale of products and services and through technology licensing. Yet for developing countries there are many competing demands on the capital available for investment, of which paying for cleaner but currently more expensive energy technologies is but only one. Moreover, developing countries feel little obligation to shoulder this additional cost, particularly when the United States itself has no national greenhouse gas legislation.

Absent the participation of the emerging economies, it is difficult to envision an effective solution to the global problem. It is therefore incumbent on the United States and other developed economies to offer constructive solutions to facilitate the deployment of cleaner technologies in the developing world. A comprehensive approach should include policy development assistance, funding for technology deployment, intellectual property protection, removal of trade barriers, and export promotion. Such a combination of initiatives will be essential to support the transition of emerging countries to a climate response program.

Policy Development Assistance

Cleaner energy solutions will be deployed when their recognized benefits to the owner exceed their cost to the owner by more than that of other energy sources. Because of the higher costs for cleaner energy technologies, public policies to provide incentives generally are required in order to make cleaner energy alternatives attractive. In the United States, for instance, the wind PTC has proven indispensable to the commercial development of wind farms. In years when the PTC has expired, wind project development has almost stopped in this country, and when it has been maintained for several consecutive years, wind development growth has accelerated.

As its top priority the United States should renew its own renewable incentive programs, particularly the renewable energy production tax credit. Doing so will assure a robust industry in the U.S. capable of offering advanced technology products to the world. Simultaneously, the United States should provide advice and assistance to developing countries in the creation and implementation of effective cleaner technology deployment incentives. Two models for this activity are the Asia-Pacific Partnership on Clean Development and Climate,[1] under which renewable and distributed generation policy ideas are being shared, and the U.S.-China Strategic Economic Dialogue,[2] under which the United States will help China adopt a NO_X emission trading program.

The ultimate goal should be to help develop a range of policies that work effectively together and are compatible with U.S. law and regulations so that they fit into an international emissions reduction program. The U.S. has a significant opportunity to lead by example and share the knowledge gained through the implementation of successful programs to spur innovative technology that increases energy efficiency and reduces emissions.

Funding for Technology Deployment in Emerging Economies

As the IEA report makes clear, the scale of required investment could be in the range of $400 billion to $1 trillion per year through 2050. That is a scope of investment beyond government capability. However, government funds and financing on a scale in the tens of billions of dollars can pave the way for private investment

[1] For additional information, see: http://www.asiapacificpartnership.org/.
[2] For additional information, see: http://www.ustreas.gov/initiatives/us-china/.

by demonstrating new technologies and achieving initial economies of scale and experience.

At their June 13-14 meeting in Japan, G8 Finance Ministers called for the establishment of climate investment funds to help combat climate change in developing countries.[3] The ministers stated their commitment to "helping developing countries address climate change in a way consistent with the development needs of their people." President Bush has asked for $400 million in FY 2009 as the initial U.S. contribution to one such fund, the Clean Technology Fund (CTF), and is seeking authorization for the U.S. to commit $2 billion to this multilateral fund over the next three years. The goal is for the CTF to reach up to $10 billion over the next three years, to be used to help developing countries in meeting the higher costs of deploying cleaner energy technologies.

These types of international funds offer a means to buy down the cost differential between existing technologies and cleaner alternatives. In GE's view, these efforts will be most effective if such funds follow four principles:

1. Technology Neutrality

The funds should be open to all types of technologies and projects having an impact on CO_2 and methane emission reductions. Given the magnitude of the challenge, the fund should be available to all technologies that have shown the potential to reduce, capture and/or store greenhouse gas emissions.

2. Leveraging Funding

The majority of the funds should be utilized to maximum effect by leveraging funding from other sources and should include:

- Premium payment cover for loan guarantees from Export Credit Agencies (ECAs), political risk insurance or credit insurance to backstop local companies' credit, thus allowing leverage of the Fund with commercial money; and
- Grants, including interest rate buy-downs, to offset higher costs of cleaner energy.

3. Usability

To ensure steady project implementation, the fund should act in a transparent manner on transactions brought to it by recipient countries and/or the private sector. Starting points for the approval process could be private sector bank and ECA procedures, as opposed to the processes used for specialized funds such as the Global Environment Facility. The Congress should also consider ensuring that the proportion of suppliers on funded projects reflects the contribution of the individual donor countries.

4. Eligibility Criteria

The fund administrators should evaluate proposals on several factors, including the following:

- Lowest cost per ton of carbon reduction;
- Total amount of potential carbon emission reduction;
- Reduction in emissions of other pollutants (SO2, NOX, particulates, mercury);
- Efficient use of water; and
- Removal of tariffs that would constitute a barrier to the introduction of technology imports.

Long term, high impact projects (such as low or zero emission baseload power plants) as well as shorter turn-around projects, should be considered on an equal basis under these criteria.

Intellectual Property Rights Protection

GE is convinced that further research and development, along with the economies of scale that can be realized by widespread deployment of existing technologies, are necessary to reduce the costs of addressing climate change. The IEA report makes clear that much of the technology to address climate change exists today, but public acceptance of those technologies will be far easier if there is little or no cost penalty associated with their adoption. For that reason, we should embrace all measures that promote innovation, foremost of which is the intellectual property right protection system, which has fostered two centuries of innovation in the United States.

[3] See http://www.mof.go.jp/english/if/su080614a.pdf.

Forcing the transfer of technology outside of normal commercial activity would stall the engine of innovation just when it is most needed.

At the same time, we should emphasize that the benefits of intellectual property protection are global. The United States, China and India are all centers of research activity. The next generation of GE patents on technologies to address climate change will be held by scientists in our facilities in Shanghai and Bangalore along with their colleagues in Niskayuna, New York.

It is also important to recognize that intellectual property right protection does not only promote the initial innovation. It also encourages commercial deployment of existing technologies. Companies will be careful to avoid licensing technology or even selling products to customers in countries where those customers could reverse engineer, take and use the intellectual property rights.

Rigorous intellectual property rights protection should be a condition of eligibility for participation in funding or other programs to promote cleaner technology deployment in emerging economies.

Trade Barrier Elimination

In looking for ways to accelerate the deployment of cleaner technologies, one mechanism immediately available to governments is to eliminate customs duties (tariffs) and other trade barriers to environmentally friendly goods and services. The United States and the European Union have proposed such an initiative in the World Trade Organization. Tariffs on wind turbines and components in most countries are in the 2.5 to 10 percent range. The United States is at 2.5 percent. These tariffs represent an additional cost that governments impose on the types of projects on which they are simultaneously offering incentives to support. GE supports the tariff elimination proposed by the United States and the European Union. Eliminating such barriers will help to cut project costs and improve the rate of technology deployment.

Export Promotion

The potential market for the global clean energy industry over the next two decades has been estimated at more than $30 trillion. Realizing the promise of this market requires the coordination among U.S. government agency programs and the strong support of policy makers. U.S. government export promotion activities will support business decisions to expand U.S. investments in cleaner energy technology production, creating U.S. jobs, a cleaner and more efficient array of energy options for our own domestic energy future, and an opportunity to expand and retain workforce in this critical industry.

A substantial, focused U.S. government effort to promote exports of cleaner and renewable energy goods and services is required. We applaud efforts made by the Departments of Commerce, Energy and State in this area thus far, and urge that they be expanded and coordinated. The cleaner energy export programs established in the Energy Independence and Security Act of 2007 should be a core piece of the overall strategy. These include the International Clean and Efficient Energy Technologies and Investment in Global Energy Markets and International Clean Energy programs.[4] These programs are critical to position U.S. companies to provide services and manufactured goods and deserved to be fully funded.

CONCLUSION

Meeting global energy needs in a carbon constrained world is a challenge that can only be met by a combination of technology provided by industry and sound public policies that promote the deployment of cleaner energy technologies around the world. The United States is in a position to lead by example through the establishment and continuation of domestic policies to promote technology development and deployment, such as the renewable energy production tax credit. The United States also must take a leadership role in the creation and implementation of multilateral mechanisms, including investment funds, to address the barriers that today prevent the widespread use of existing cleaner energy technology. This effort should include assistance to emerging economies in fashioning appropriate public policies to support the introduction of new technologies, including incentives, reduction of trade barriers, and protection of intellectual property rights, and funding for U.S. government clean energy export promotion programs.

[4] See http://thomas.loc.gov/cgi-bin/bdquery/z?d110:h.r.00006:

The CHAIRMAN. Thank you very much. Let me just ask one question of you and then Senator Sessions can ask any questions he has and then we'll go to the other two witnesses.

Mr. BHATIA. Thank you.

The CHAIRMAN. General Electric recently put out a report, as I understand it, quantifying the potential gains or net gains to the economy that you see from the production tax credit, and could you give us a little bit of a description of what you conclude in that report?

Mr. BHATIA. Yes, Mr. Chairman. You are making reference to a study we put out last week by our GE Energy Financial Services Branch which had done a careful examination of what the cost to the U.S. Treasury would be from an extension of the production tax credit and estimated—the conclusion was that the effects, the total effect would be a net present value, a positive net present value to the U.S. Treasury of $250 million through the renewal of the production tax credit. This is particularly with reference to wind energy.

I think it's a particularly relevant important study, given the debate that has been going on about whether the extension of the production tax credit would be a net positive or net negative.

The conclusion is, and it's, in fact, probably a relatively conservative estimate, but when you look at the incremental income generated, the taxes generated and so forth, it would be a plus of 250 million to the United States Treasury.

The CHAIRMAN. OK. Senator Barrasso, Mr. Bhatia needs to leave for another appointment, so we were going to have any questions that people wanted to pose to him posed at this time. Did you have any questions?

Senator BARRASSO. I do, Mr. Chairman.

The CHAIRMAN. Go ahead.

Senator BARRASSO. Thank you very much, Mr. Chairman. Mr. Bhatia, if I could ask you about public/private partnerships. General Electric has made a significant commitment in Wyoming to work with our University of Wyoming School of Energy Resources, with our legislature, and I think that is a good way to go in developing technologies. We're working there on clean coal technologies, coal to liquids, coal to gas, and I was wondering if you'd like to make any comments about that.

Mr. BHATIA. Senator, first of all, we greatly appreciate the support that you've offered, that the State of Wyoming has offered. We, simply said, see this as being an enormous global challenge and it's one that's not going to have any solutions that any single company or government acting alone is going to be able to derive. It's going to necessarily involve substantial partnerships.

We've been pleased with the cooperation thus far. We look forward to continuing it and again we see this not just in a single sector of the energy area but in fact something that's going to need to be replicated throughout. So we're delighted by it.

Senator SESSIONS. Thank you very much. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Sessions.

Senator SESSIONS. Thank you. I noticed that you did say, Mr. Bhatia, that you felt that mandatory transfers of technology to developing world, I guess free, requiring companies who've invested to develop it is not a good policy.

I would just add that I think we have to go to the next step. The American taxpayers can't give the money to buy it from GE either. We're in a competitive marketplace. We're competing with low-wage countries who are putting Americans out of work and I think that we cannot transfer our wealth around the globe to meet these goals when we're actually hurting our own economy.

Let me ask you about GE's view on nuclear power. Do you believe, from your commitment and your company's commitment, that nuclear power can be competitive costwise in the next 50 years in producing electricity with the lowest no CO_2 emissions, no global warming gases, and no pollutants into the atmosphere?

Mr. BHATIA. Senator, we are very much present in the nuclear energy industry. We are a significant player in that industry. We believe that it is an important part of what will be the solution, a solution here. It's something that we believe can, with the appropriate policy structures in place, be an important and cost-competitive part of the equation.

But as I——

Senator SESSIONS. Let's talk about costs. Are you concerned that the regulations and some of the practical shortages that now exist may be driving up costs more than is necessary and some of that could be avoided?

Mr. BHATIA. To be honest with you, Senator, I don't know that we have looked at, you know, precisely what the implications are for specific policy engagements would be on that front. I'm happy to continue a conversation with you on that, but at this point, I think all I would say is that we're confident that nuclear is going to be part of the equation.

The CHAIRMAN. Thank you very much. We will include your full statement in the record.

Mr. BHATIA. Thank you very much.

The CHAIRMAN. Why don't you go ahead to your appointment? Dr. Wilson, we're anxious to hear your testimony and then Dr. Kopp.

Mr. BHATIA. Thank you.

STATEMENT OF TOM WILSON, SENIOR PROGRAM MANAGER, GLOBAL CLIMATE CHANGE RESEARCH, ELECTRIC POWER RESEARCH INSTITUTE (EPRI), PALO ALTO, CA

Mr. WILSON. Thank you, Chairman Bingaman, Ranking Member Domenici, and members of the committee.

I'm Tom Wilson, Senior Program Manager for Global Climate Research at the Electric Power Research Institute.

EPRI conducts research and development on technology, operations, and environment in the global electric industry, and we really appreciate the opportunity to be here today to provide testimony on the challenges to meet future energy needs while addressing global climate change.

In my written testimony, I describe several EPRI analyses of climate technology needs that complement the work that IEA has produced earlier this morning. I compare in that written testimony the findings and contrasts of our results as well.

I'd like to summarize my results here from those studies and a few key points. First, while the geographic scope and the analytical methodologies are different, the key findings of the EPRI and IEA analyses are strikingly similar.

Significant reductions in future CO_2 emissions are possible, but they require fundamental technology change. Technology change is slow and requires immediate investment in RD&D in order to deal with it as well as commitment to deal with a variety of other issues, including regulatory, siting, liability, public perception, and deployment issues, especially at those early plants.

Second, I have a chart in front of you, over here to the left, that provides a high-level summary of EPRI's analysis, a technical assessment of how CO_2 emissions from the electric sector could be reduced.

Using the Energy Information Administration's Annual Energy Outlook 2008 as a starting point, we made more aggressive assumptions regarding energy efficiency, renewables, nuclear generation, advanced coal generation, carbon capture and storage, plug-in electric hybrid vehicles and distributed energy resources.

Our analysis shows that by deploying advanced technologies, it's technically feasible to slow, stop and reduce CO_2 emissions from the electric power sector in the United States Given our aggressive assumptions, we show that the United States electric power sector emissions could be reduced to 1990 levels by 2030 and decreased sharply thereafter. However, in order to achieve these large reductions in future CO_2 emissions, we'll need all of these technology options, even those which are not currently available.

Significant additional public and private RD&D funding is needed over a sustained period to show that these technologies work, to demonstrate their reliability, to reduce their costs, and to gain public acceptance.

Third, in addition to the advanced generation targets highlighted in the IEA study, grid modernization is a necessary enabling step to significant emission reductions. This includes smart grids and communications infrastructures to enable end use efficiency and demand response, enable distributed generation, and to enable PHEV, Plug-In Electric Hybrid Vehicle, Integration, along with an electric grid infrastructure with the capacity energy storage technologies and robustness to operate reliably with up to 30 percent intermittent renewable resources in some regions of the country.

Now RD&D requires the commitment of real money, so I think it's critical to point out that expanded RD&D is not only necessary to produce these technologies but is a good investment for the U.S. economy.

Our economic analysis estimates for a scenario in which emissions in 2050 for the economy are approximately half of what they are today in an effectively managed RD&D investment on the order of tens of billions of dollars over the next 25 years could lower the cost of emission reductions in the United States on the order of $1 trillion between now and 2050.

The fundamental implication of our work, and I must say that of the IEA, that of RFF, that of MIT, that of the United States Climate Change Science Program, and virtually every study that's been done on this issue over the last decade, is that we must move from analysis to action if we want to have—deploy this whole technology of low-cost, low- carbon technologies in a timely and efficient manner.

EPRI's planning several additional activities that I'd like to tell you about. First, we're moving forward aggressively to demonstrate the advanced electric technologies in the chart before you. One project came online in February of this year. EPRI, Alstom and We Energies started operation of a 1.7 megawatt electric post- combustion capture and CO_2 capture process using a chilled ammonia solvent.

In April, EPRI's Board of Directors approved six larger-scale technology demonstration projects to examine hyper-efficient electric end use technologies, smart grid demonstrations, compressed air energy storage, two demonstrations of pulverized coal with partial carbon capture and storage, an IGCC plant with partial carbon capture and storage, and lower-cost oxygen production.

EPRI's currently launching these initiatives with public and private sector partners as a vital first step to meeting growing demand for electricity while reducing greenhouse gas emissions.

Second, recognizing this is a global problem, we're extending our analyses that we've done here in the United States to work with other countries to understand how their electric sectors in particular could help decarbonizes.

Mr. Chairman, this concludes my remarks. I look forward to your questions and those of your colleagues.

Thank you.

[The prepared statement of Mr. Wilson follows:]

PREPARED STATEMENT OF TOM WILSON, SENIOR PROGRAM MANAGER, GLOBAL CLIMATE CHANGE RESEARCH, ELECTRIC POWER RESEARCH INSTITUTE (EPRI), PALO ALTO, CA

Thank you, Chairman Bingaman, Ranking Member Domenici, and Members of the Committee. I am Tom Wilson, Senior Program Manager for Global Climate Change Research at the Electric Power Research Institute (EPRI). EPRI conducts research and development on technology, operations and the environment for the global electric power industry. As an independent, non-profit Institute, EPRI brings together its members, scientists and engineers, along with experts from academia, industry and other centers of research to:

- collaborate in solving challenges in electricity generation, delivery and use;
- provide technological, policy and economic analyses to drive long-range research and development planning; and
- support multi-discipline research in emerging technologies and issues.

EPRI's members represent more than 90 percent of the electricity generated in the United States, and international participation extends to 40 countries. EPRI has major offices and laboratories in Palo Alto, California; Charlotte, North Carolina; and Knoxville, Tennessee.

EPRI appreciates the opportunity to provide testimony on the challenges to meeting future energy needs and to developing the technologies for meeting increased global energy demand in the context of the need to address global climate change. In my testimony, I will describe several EPRI analyses of technology needs that complement the work in the recent International Energy Agency's (IEA) report, "Energy Technology Perspectives 2008", and compare and contrast our findings.

We are in considerable agreement with the IEA study on the need for immediate investment in research, development and deployment of new technologies to achieve significant to substantial greenhouse gas emission reductions. The IEA study adds further detail and specificity to a rapidly growing set of assessments reaching similar conclusions in the U.S., in the OECD and around the world. With the global population expected to increase by 40% by 2050, and with global aspirations for economic growth (by 2050, the IEA projects global GDP to grow to 4 times its current level), the challenge of providing dramatically expanded energy services while simultaneously reducing greenhouse gas emissions is formidable.

In addition to elaborating on the points of agreement, I will also highlight a few insights that EPRI analysis has identified that are mentioned in the IEA report, but that are not highlighted there. In particular, technologies to modernize the electricity transmission and distribution grid and energy storage technologies appear to us as critical to enabling the widespread deployment of renewable generation and to opening new approaches to demand-side efficiency improvements. I will also provide you a brief update on EPRI's efforts in 2008 to move from "analysis to action", promoting early deployment of the needed technologies.

EPRI analysis

EPRI has conducted national and international research that has highlighted the role of technology in addressing climate change since the early 1990s. In 2007, EPRI released its own analysis, The Power to Reduce CO_2 Emissions—The Full Portfolio[1], which addressed the technical feasibility for the U.S. electricity sector to achieve significant future CO_2 emissions reductions. The analysis examined the technology development pathways and associated research, development and demonstration (RD&D) funding needed to achieve this potential, as well as the economic impact of realizing emissions reduction targets under two different technology scenarios. This analysis is attached as Appendix A of my testimony. The first element of EPRI's analysis—called the "Prism" analysis because of its multi-colored illustration of the results—examined the impact of enhanced performance and expanded deployment of a group of advanced technologies on potential CO_2 emissions reductions for the U.S. electricity sector. Key technologies included:

- end-use energy efficiency
- renewable energy
- advanced light water nuclear reactors
- advanced coal power plants
- CO_2 capture and storage
- plug-in hybrid electric vehicles
- distributed energy resources

The analysis revealed that if "aggressive, but technically feasible" advanced technology performance and deployment levels could be achieved, annual CO_2 emissions from the U.S. electric sector could be reduced to approximately 30% below 2005 levels in 2030. The analysis also highlighted the critical role that enabling technologies—energy storage and a modernized transmission and distribution system—would play.

To understand the potential cost of making significant future CO_2 emission reductions, EPRI subsequently completed an economic assessment of the entire U.S. economy using the MERGE model[2] MERGE was used to estimate the least-cost combination of technologies that meets a representative CO_2 emissions constraint. The MERGE analysis explored two technology scenarios for achieving this constraint: 1) "Limited Portfolio"; and 2) "Full Portfolio". The Limited Portfolio focused on the currently-available technologies, while the Full Portfolio incorporated significant improvements in a full-range of technologies, including wind, solar, end-use efficiency, nuclear, advanced coal plants, carbon capture & sequestration and plug-in hybrid electric vehicles. The results from analyzing the two scenarios reveal that the Full Portfolio provides a significant economic benefit, reducing the policy cost of compliance by 50-66% (on the order of $1 trillion) while still meeting the specified emissions constraint.

Four major conclusions emerged from this analysis:

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[1] This EPRI report was released in August 2007. It is attached and is publically available at: http://mydocs.epri.com/docs/public/DiscussionPaper2007.pdf. The Prism analysis has subsequently been updated to reflect the baseline assumptions in the Energy Information Administration's Annual Energy Outlook 2008, Report DOE/EIA-0383 (March 2008).

[2] MERGE is a general equilibrium model of the global economy originally developed by Dr. Alan Manne (Stanford University) and Dr. Richard Richels (EPRI) to assess a wide range of energy and environmental issues. MERGE has been used for more than a decade to analyze the cost of CO_2 emissions mitigation as a function of technology cost, availability, and performance. MERGE models long time horizons to capture economic effects of potential climate change and encompasses all major greenhouse gases and all emitting sectors of the economy. Using technology descriptions and policy constraints as inputs, the model outputs not only energy production by technology, but also prices for wholesale electricity and carbon emissions. While the model is global in scale, the current analysis focuses on the U.S.

- A technology-based strategy for the electric sector has the potential to lead to sustainable and dramatic reductions in future U.S. CO_2 emissions. Further, this strategy also creates opportunities to de-carbonize beyond the electricity sector and outside the US.
- A diverse portfolio of advanced technologies will be required. No single technological "silver bullet" will suffice. Removing any one of the advanced technologies from the portfolio significantly increases the cost of achieving any greenhouse gas emission reduction constraint.
- Significant additional public and private sector research, development and demonstration (RD&D) funding is needed over a sustained period to achieve these technological outcomes. In the near-term early demonstration of new technologies—e.g., carbon capture and storage, new nuclear, advanced transmission and distribution system—is critical to rapidly move them to commercial status. Longer-term research to enable full scale deployment of key technologies is equally critical. Given that the lead time for moving technology from the drawing board to full commercial status is measured in decades, the time for starting is now.
- A technology-based strategy reduces the economic costs of achieving a greenhouse gas emissions constraint. An investment in RD&D investment (public and private) will lower the cost of emissions reductions in the U.S. on the order of $1 trillion between now and 2050.

IEA analysis

The IEA also examined two scenarios in its analysis: 1) technologies needed to reduce global CO_2 emissions to 2005 levels by 2050 (the ACT scenario); and 2) technologies needed to reduce CO_2 emissions by 50% below 2005 levels in 2050 (the "Blue" scenario). Similar to EPRI's analysis, the IEA Blue scenario concludes that a full portfolio of both improved and fundamentally new technologies will be needed to meet the 50% reduction target. The IEA report delineates 17 technologies that must be deployed in order to achieve the goals of the second scenario. IEA also urges immediate RD&D investment to develop the necessary technologies, including CO_2 capture and storage (CCS), renewable energy, and nuclear power. Finally, IEA perceives tremendous opportunity to de-carbonize other sectors through electrification.

Major conclusions from the IEA analysis include:

- Deep global emissions cuts are technically achievable. Implementation of RD&D roadmaps for 17 technologies identified by the IEA are expected to make the largest contributions.
- All technologies will be needed, including new and emerging technologies, such as coal with carbon capture and storage, renewable energy, and nuclear power.
- A major acceleration in RD&D is needed both to bring forward new technologies and to reduce the costs of those already available.
- Energy efficiency represents a tremendous opportunity and a cost-effective near-term option. However, if we are to reduce CO_2 emissions by 50% over 2005 levels in 2050, new technologies still under development must also be deployed that can achieve de-carbonized power generation.

Differences between EPRI and IEA Analyses

The key findings of the EPRI and IEA analyses—as you have seen—are strikingly similar. Significant reductions in emissions are possible, but they require fundamental technological change. Technology change is slow and requires immediate investment in RD&D as well as the commitment to deal with regulatory, siting, and public perception issues.

The methodologies that led to these similar conclusions are quite different:

- Geographic Scope. EPRI's Prism and MERGE analyses in 2007-8 focused on the United States. Prism specifically focused even more narrowly on the electric sector. In contrast, the IEA study provides a global picture with significant detail for 10 countries.
- Modeling Approach.
  - —The IEA approach uses a bottoms-up, partial equilibrium approach (ETP-MARKAL) , and calculates the amount of emissions and technology development/deployment costs associated based on specific assumptions about CO_2 emissions costs and technology deployment levels. In this sense, the IEA analysis assumes that certain deployment goals will be met and reflects the consequences of these assumptions.

—EPRI's Prism analysis took a similar approach to the IEA analysis. We made technology deployment assumptions and calculated resulting emissions.

—In contrast, the EPRI MERGE model uses a general equilibrium approach and calculates the lowest cost combination of technology deployments which achieve a specified emissions constraint. CO_2 emission costs, wholesale electricity production costs, and the economic impact of a CO_2 constraint on U.S. GDP are also calculated.

- The emission reduction scenarios are different. The IEA Blue scenario, which reaches 50% below 2005 levels in 2050, is most directly comparable to the EPRI MERGE Full Portfolio scenario.
- For the IEA Blue and EPRI Full Portfolio scenarios,

—Electricity production costs in the IEA study for the different technologies look reasonably comparable to those used in the MERGE analysis.

—For the electricity sector results in the Blue scenario, the IEA global generation shares (in percentage terms) for each technology in 2050 are comparable, although somewhat different, to results EPRI has obtained for the U.S. based on MERGE analysis:

• The nuclear, coal+CCS generation shares are a little lower in the IEA Blue scenario.

• The gas + CCS, tidal, solar, biomass and biomass + CCS generation shares are higher in the IEA Blue scenario.

- The IEA study examines the possibility of CCS retrofits. This is particularly important for rapidly developing countries, which have many relatively new, high-emitting coal plants. Recent EPRI analyses are exploring the economics and technical feasibility of CCS retrofits in the US.

Given these methodological differences, we find the results to be both complementary and reinforcing.

Conclusions and Next Steps—Analysis to Action

One fundamental implication of our work and of the IEA study is very clear—we must move from analysis to action if we are to deploy this full portfolio of technologies in a timely and effective manner. EPRI is planning additional action in two areas:

EPRI Demonstration Projects. EPRI has identified a number of technology demonstration projects that target critical gaps that must be filled to achieve this "Full Portfolio" of technologies. One project came on-line in February of this year. EPRI, Alstom and We Energies are testing a 1.7 MWe post-combustion CO2 capture process using a chilled ammonia solvent.

In April, EPRI's Board of Directors approved six larger-scale technology demonstration projects with the intention of accelerating progress towards a low-carbon future: hyper-efficient electric end-use technologies; smart grids; compressed air energy storage; pulverized coal (PC) with partial CCS (two alternate capture technologies); integrated gasification combined cycle (IGCC) with partial CCS, and lower-cost O2 production. EPRI is currently launching these initiatives with public and private sector partners as a vital first step to meet the growing demand for electricity while reducing greenhouse gas emissions.

Global Prism and MERGE analyses. The IEA effort breaks new ground on examining the technology options for reducing emissions in the so-called 'G8+5' (the Group of Eight developed nations and the five largest emerging economies of the developing world: China, India, Brazil, South Africa, and Mexico). EPRI is carrying out a complementary effort to illustrate the global value of advanced electricity technologies and to add additional technological detail to the MERGE global model so that we can provide an integrated, but detailed view of the possible implications of global climate policies. If we are successful at developing and globally deploying the "Full Portfolio" of low-cost, low-carbon electricity options, we will likely achieve more benefit for the global climate than would be accomplished through years of protracted negotiations. Mr. Chairman, this concludes my prepared remarks, and I look forward to your questions and those of your colleagues. Thank you.

The CHAIRMAN. Thank you for your testimony. Dr. Kopp.

STATEMENT OF RAYMOND J. KOPP, SENIOR FELLOW AND DIRECTOR, CLIMATE POLICY PROGRAM, RESOURCES FOR THE FUTURE

Mr. KOPP. Thank you, Mr. Chairman, members of the committee.

I'm a Senior Fellow and Director of the Climate and Technology Policy Program at Resources For The Future, which is a 50+ year-old resource institution headquartered here in Washington that focuses on energy, environmental and natural resource issues.

Resources For The Future is both independent and non-partisan. We neither lobby nor take positions on specific legislative or regulatory proposals. However, individual researchers are encouraged to express their individual opinions and I emphasize the views I'm going to express today are my own.

IEA's recent report provides an excellent engineering perspective on the suite of technologies and scale of deployment needed to achieve global greenhouse gas concentration targets. The report is certainly sobering in terms of investment scale.

At the same time, it is reassuring insofar that it identifies a feasible technology and investment path consistent with carbon dioxide concentration stabilization. While reaching that target represents an enormous technical, economic and political challenge, the IEA report does demonstrate this is not an impossible task.

The most important aspect of the report, in my estimation, is the focus on the global technology and investment building blocks that will be similar to attain deep reductions in emissions.

A similar analysis, focused at a country level, would be quite valuable and I would encourage the committee to pursue such an assessment for the United States. The analysis should, however, go beyond IEA's assessment and address the specific within-country challenges to the deployment, development and deployment of non-carbon technology and the public policies required to overcome those hurdles.

The example of what I mean, let's consider carbon capture and sequestration. Capturing and sequestering carbon dioxide emissions from coal-fired power plants is a foundational technology component of any deep emissions reduction plan.

A carbon price, as well as increased funding on related research, will be crucial components to successful deployment. However, by themselves, policies to price carbon and accelerate R&D are unlikely to be sufficient. Regulations for the storage of carbon dioxide must be written. Storage sites must be selected. Almost assured local opposition to storage must be overcome. A vast carbon dioxide transport infrastructure has got to be sited, financed and constructed.

These are country-level policy concerns and therefore not addressed by the IEA, but are nonetheless substantial barriers to deployment of this technology. A thorough United States assessment of carbon capture and sequestration deployment would address these barriers and provide policy solutions.

The same is true for nuclear power. The IEA report suggests that 30 percent of global energy needs could be met with nuclear power, but such a large expansion of nuclear power would require more than a carbon price and R&D directed at reactor design.

Regulatory reactor safety concerns continue to limit public support for nuclear power. Long-term waste storage hangs over the head of the industry. Concerns about proliferation are very real and would be exacerbated by greatly increased growth in spent fuel reprocessing, and a worldwide lack of skilled engineers is still a drag on the technology.

These are all barriers that must be addressed by public policies, in addition to carbon pricing and funding for research and development.

The same is true for the deployment of biofuels and I talk about that in my written testimony. Land use issues are substantial, both domestically and internationally, and these must be overcome by policies, in addition to carbon pricing and additional financing for research and development, and the same holds true for renewables. Solar, wind, other source renewable technology require great enhancements to our existing grid. These are policies that are going to extend beyond carbon pricing and funding for research and development.

If we choose to undertake U.S. studies as suggested, I strongly encourage that the analysts, as has already been suggested by members of the committee here, include a careful examination of the barriers to technology deployment and point out where public policy is needed to overcome those barriers, and if I might, one last point, Mr. Chairman.

Achieving the IEA concentration targets requires a lengthy investment process. Any delay means greater atmospheric concentrations in the coming years. Unfortunately, we do not have a magic wand and will not will this process to commence. Rather, we must follow a slow and arduous path to develop and implement the many public policies, domestic and international, that will remove barriers and enable investment.

This all suggests that we must buy some badly needed time. Fortunately, I think we have a very good option. The IEA report addresses only energy-related carbon dioxide emissions, those coming from the combustion of fossil fuels. Notably absent is the 15 to 20 percent of global carbon dioxide emissions that come from land use, most notably deforestation in tropical countries.

While it is widely known that China and the United States are now the two largest carbon dioxide emitters in the world, it is less known that the countries ranking third and fourth are Brazil and Indonesia, primarily due to their carbon dioxide emissions from deforestation.

Energy-related carbon dioxide emissions can be reduced with the deployment of non-carbon energy technologies as IEA has pointed out. These reductions require large-scale investments and will take a good deal of time.

In contrast, reducing carbon dioxide emissions by reducing the rates of deforestation can be accomplished with targeted domestic policies that alter the economics of land use to make a standing forest more valuable than alternative uses of the land.

Using the growing international carbon market and the United States market that might be established under Federal legislation to monetize the carbon contained in these standing forests will provide the economic incentives needed to alter land use decisions.

In principle, such land use decisions could be changed very quickly, giving rise to rapid reductions in carbon dioxide emissions. These large-scale reductions in forest-related CO_2 are surely to become ever more valuable in light of the hard work ahead to achieve the needed energy-related reductions requiring much longer lead times.

Thank you, Mr. Chairman.

[The prepared statement of mr. Kopp follows:]

PREPARED STATEMENT OF RAYMOND J. KOPP, SENIOR FELLOW AND DIRECTOR, CLIMATE POLICY PROGRAM, RESOURCES FOR THE FUTURE

Thank you, Mr. Chairman, for the opportunity to offer testimony before the committee about the challenges of meeting future energy needs in the context of global climate change. I am a senior fellow and director of the Climate Policy Program at Resources for the Future (RFF), a 56-year-old research institution, headquartered here in Washington, DC, that focuses on energy, environmental, and natural resource issues.

RFF is both independent and nonpartisan, and shares the results of its economic and policy analyses with members of both parties, environmental and business advocates, academics, members of the press, and interested citizens. RFF neither lobbies nor takes positions on specific legislative or regulatory proposals, although individual researchers are encouraged to express their individual opinions, which may differ from those of other RFF scholars, officers, and directors. I emphasize that the views I present today are mine alone.

The International Energy Agency's (IEA) recent report, Energy Technology Perspectives 2008: Scenarios and Strategies to 2050, prepared in support of the G8 Plan of Action, provides an excellent engineering perspective on the suite of technologies and scale of deployment needed to achieve a concentration target of 450 ppm for carbon dioxide (CO_2). Importantly, the IEA augments the technology information with economic estimates of cost and required investment.

The report is certainly sobering in terms of investment scale, particularly with respect to investments in research, development, and demonstration (RD&D) and physical capital. At the same time, it is reassuring insofar as it identifies a feasible technology and investment path consistent with CO2-concentration stabilization at 450 ppm. While reaching this target represents an enormous technical and economic challenge, the IEA report demonstrates it is not impossible.

The report reflects a good deal of our collective understanding of the challenges posed by climate change:

- Most importantly, there is no silver bullet. In addition to conservation, virtually all of the low-carbon technologies commercially available and those to become available over the next few decades must be deployed.
- Carbon pricing is crucial to providing incentives for both conservation and technology development and deployment.
- Governments will be required to greatly enhance spending on RD&D, and to ensure the efficiency and efficacy of that spending.

Additionally, the IEA focuses attention on the global technology and investment building blocks that will be necessary to attain deep reductions in emissions. A similar analysis focused on the regional and country level would be quite valuable and I would encourage the committee to pursue such an assessment for the United States. That analysis should go beyond the IEA assessment, however, and address the specific within-country challenges to the development and deployment of non-carbon technologies and the public policies required to overcome those hurdles.

If the technologies addressed in the IEA report are to be deployed at the scale suggested, removal of barriers to deployment will require a public policy response. While cost and technical feasibility will be important limiting factors, it would be unwise to overlook the suite of complementary public policies that must be developed to address technology-specific barriers. A U.S.-based analysis of technology roadmaps akin to the IEA report should address specifically these complementary policies, some of which I've highlighted below. Such policies will be required for the successful implementation of all the major technologies needed to reach a 450 ppm target and extend beyond the establishment of a carbon price and the provision of additional R&D funding.

Carbon capture and sequestration (CCS). Capturing and sequestering CO_2 emissions from coal-fired power plants and eventually all fossil combustion is a foundational technology component of any emissions reduction plan targeting 450 ppm CO_2. A carbon price, as well as greatly increased funding of related research, development, and deployment, will be crucial components to implementation. However, by themselves, policies to price carbon and accelerate R&D are unlikely to be sufficient. Regulations for the storage of CO_2 must be written, storage sites selected, almost assured local opposition to storage to overcome, and a vast CO_2-transport infrastructure sited, financed, and constructed. These are country-level policy concerns and therefore not addressed by the IEA report, but are nonetheless substantial barriers to the deployment of this technology. A thorough U.S. assessment of CCS would address these barriers and provide solutions.

Nuclear power. The IEA report suggests that 30 percent of global energy needs could be met by nuclear power, and in the IEA BLUE scenario, global nuclear power generation triples. But such a large expansion of nuclear power will require more than a carbon price and R&D directed to new reactor design, and the issues to be resolved are substantial. Reactor safety concerns continue to limit public support for nuclear power. Long-term waste storage hangs over the head of the industry. Concerns of proliferation are very real and would be exacerbated by greatly increased growth in spent-fuel reprocessing, and a worldwide lack of skilled engineers is a drag on the expansion of the technology. These are all barriers that must be addressed by public policies in addition to carbon pricing and R&D.

Bioenergy. Both for purposes of electricity generation and the production of liquid fuels for transport, bioenergy is essential in the IEA scenarios and is the largest renewable energy source. Carbon pricing is crucial to the development and deployment of bioenergy technology and technical innovation has a large role to play, but several barriers to deployment will remain. Bioenergy will compete worldwide for land used to produce food and fiber, raising the cost of all three. Accelerated bioenergy production in the United States can drive local land-use decisions and have direct impacts—both good and bad—on local rural development. Expanding the production of crops for bioenergy can affect U.S. environmental quality, including adverse impacts to biodiversity and water quality, as well as create international challenges to ecosystems and biodiversity through increased deforestation. Public policies to address the land-use issues raised by increased bioenergy production in the United States are just as important to the expansion of this technology as carbon pricing and R&D.

Wind and solar power. One of the great renewable energy successes is wind-generated electricity. While it has proven to be an increasingly economical renewable energy source, it can still benefit from a carbon charge and additional RD&D. However, wind is generated where the wind blows, not necessarily where you find the electricity load centers. Transmission thus becomes crucial. The current U.S. grid is not designed to take full advantage of western or offshore wind resources. Therefore carefully planned grid expansion will be required for a large-scale increase in wind-generated electricity. This is likely true for solar as well. A greatly expanded and improved electricity transmissions grid has been a U.S. priority for at least two decades; however, given the manner in which we regulate and finance transmission, very little progress has been made. In addition, intermittency will always be a problem with wind, meaning the electricity system must be designed to accommodate intermittency with sufficient reserve capacity, storage, and interconnected systems.

TWO FINAL POINTS

Global demand for energy continues to rise, and over time, the bulk of that increase will come from non-OECD developing countries. Not surprisingly, the majority of the investment in energy-producing and -consuming technologies tracked by the IEA scenarios must take place in the same non-OECD countries. It is likely that new low-and no-carbon energy sources (coal with CCS, nuclear, and renewables, for example) will be more costly than conventional fossil sources. In OECD countries, we may be willing to bear carbon prices in the range that the IEA predicts in order to level the playing field between fossil and non-carbon technologies. However, non-OECD countries that are hard-pressed to afford current fossil technology will be less willing to bear the same carbon prices or devote scarce resources to subsidizing low- and no-carbon energy sources—certainly not in the immediate term. The obvious question unanswered by the IEA report concerns the elements of U.S. foreign policy (pursued jointly with the other OECD countries) that would lead to the necessary global deployment of the technology suite.

The last point concerns time. Achieving the IEA scenarios requires the process of investment in RD&D, conservation, and physical, energy-related capital to begin immediately. Any delay means greater atmospheric concentrations in the coming years. Unfortunately, we cannot wave a magic wand and will this process to commence; rather, we must follow a slow and arduous path to develop and implement the many public policies, domestic and international, that will remove barriers and enable investment.

We must buy some badly needed time and, fortunately, we have a very good option. The IEA report addresses only energy-related CO_2 emissions—that is, CO_2 released from the combustion of fossil fuels. Notably absent is the 15 to 20 percent of global CO_2 emissions that come from land use, most importantly deforestation in tropical countries. While it is now widely known that China and the United States are the two largest CO_2 emitters, it is less well-known that the countries ranking third and fourth are Brazil and Indonesia, due to widespread deforestation in these countries.

Fossil-based CO_2 emissions can be reduced with the deployment of non-carbon technologies, but as noted by the IEA, these reductions require large-scale investment and will take a good deal of time. In contrast, reducing CO_2 emissions by reducing rates of deforestation can be accomplished with targeted domestic policies that alter the economics of land use to make a standing forest more valuable than alternative uses of the land. Using the growing international carbon market and the U.S. market that might come into being to monetize the carbon contained in standing forests will provide the economic incentives needed to alter land-use decisions. In principle, such land-use decisions could be changed very quickly, giving rise to rapid reductions in CO_2 emissions. These large-scale reductions in forest-related CO_2 are sure to become ever more valuable in light of the hard work ahead to achieve the needed fossil-based reductions requiring much longer lead times.

The CHAIRMAN. OK. Thank you both very much for your testimony.

Let me ask you each a question. Dr. Wilson, EPRI came out with a study on plug-in hybrids that has been cited pretty broadly. Could you just give us the short version of what you concluded as to the barriers that might need to be overcome for us to get widespread use of plug-in hybrids? I know you contemplate that in your chart here.

Mr. WILSON. Yes, sir. We view the plug-in hybrids—I'll talk about the opportunity briefly. The opportunity is, No. 1, you can fill up your gas tank for less than a dollar a gallon at current electricity rates.

No. 2. The study you're speaking to refers—was done jointly with NRDC, the Natural Resources Defense Council, and it, I think, is the most detailed demonstration of the fact that greenhouse gas emissions will be reduced by going to plug-in hybrid electric vehicles.

No. 3. Reduced oil reliance on foreign oil imports.

Now what are the challenges? The challenges, Number one, are batteries, trying to get wide-scale deployment and manufacturing and get the costs down of lithium ion batteries is the first key challenge. Toyota is introducing a nickel metal hydride version of their Prius in the near future as a plug-in hybrid, but that is not the battery of the future. It's looking toward additional more future batteries and those are contemplated maybe to be on the market by 2010. So batteries are one key area.

A second area is the charging and recharging infrastructure. Now if a plug-in hybrid——

The CHAIRMAN. Let me just ask on that. You say Toyota's going to put on the market a nickel metal hydride plug-in hybrid?

Mr. WILSON. They're working on the Prius now. They're testing it.

The CHAIRMAN. I see. We were in Japan and went to their test site and they are testing it, but they indicated they weren't going to market it, that they're not going to market a plug-in hybrid until they can do it with a lithium ion battery. Is that different from your information?

Mr. WILSON. I'm not entirely sure.

The CHAIRMAN. OK. Yes. Why don't you check that and let me know if you find out something different because we were advised that even though they are testing a nickel metal hydride plug-in hybrid, they do not intend to market that? They're going to market a lithium ion battery hybrid, plug-in hybrid.

Mr. WILSON. Thank you.

The CHAIRMAN. So go ahead. I'm sorry to interrupt you there.

Mr. WILSON. So getting to the lithium ion is a key challenge.

The second challenge is recharging and for plug-in hybrids, it's different than electric vehicles which you needed to fully charge in order to use them. You can just partially charge them at a low rate. In fact, I think having that load in the grid is sort of like having a—is comparable to a dishwasher in terms of the drain as on the grid. So it's a very small drain. It's one which we need to integrate for a couple reasons.

One is so that we can make efficient use of resources, charging off peak, providing off-peak rates. The second is that we might be able to use that storage at some point in the future to help the grid out, to help use that as a source of electricity in times of need, so that's a second major issue.

The CHAIRMAN. All right. Thank you. Dr. Kopp, let me ask you on your point about deforestation. The emissions trading scheme that they have in Europe, in that scheme, they do not recognize carbon credits for avoided deforestation and other land use practices, and I believe they explain that by saying that they just think it's too hard to monitor.

How would you suggest that we solve that problem? Do you think that their concerned about monitoring it is overblown, or what do you suggest?

Mr. KOPP. Mr. Chairman, their concern is not overblown. There are several concerns with developing a deforestation-based carbon asset. Monitoring is one of them. Leakage is another particular issue. Permanence is another issue. Of course, you have this fear that since there is so much carbon dioxide that comes from deforestation, that if you allowed that into a carbon market, you might "flood" the market with these carbon-based assets and in some sense cause destabilization.

There's a large body of researchers right now that are working on particularly those issues. As you know, a lot of the Bali process and the Bali roadmap, there is a well-defined goal to define mechanisms and procedures that would allow for deforestation credits to be admitted into the global carbon market. That process is ongoing right now.

I think I personally have a lot of confidence that we're going to overcome all those particular issues, but those are very real issues right now, and at this point in time, the European Union's trading system did not see fit to include deforestation as a viable offset, but I believe over the next 18 to 24 months, you're going to see a tremendous amount of research that suggests this is going to be a very viable asset, carbon-originating asset, and one that I think does buy us the needed time while we try to go through all these other processes of engaging other countries to reduce their carbon emissions, develop the technologies and deal with these other particular barriers to technology deployment.

The CHAIRMAN. All right. Thank you very much. Senator Sessions.

Senator SESSIONS. With regard to the forests, Dr. Kopp, fundamentally, trees that become mature and start dying give back carbon dioxide and as they die they give back what's in their cellulose, I guess, but a healthy growing forest sucks out of the atmosphere CO_2. That's what it breathes.

Do you think there's a possibility that we could learn how to manage our forests and thin our forests to maintain a growing vigorous forest, utilize that cellulose and the energy from the sun, solar and wind sense, to create a sizable portion, a noticeable portion of our energy needs?

Mr. KOPP. Senator Sessions, I think there's no doubt that enhanced management of existing forest stands, both within countries like the United States and elsewhere, is going to be a component of managing carbon dioxide portfolios going forward and there's a lot of work already underway to think about how we should properly manage those forests, both those privately held and those in the public domain.

Senator SESSIONS. I couldn't agree more. I do think some of the public forests could be thinned. Fire breaks could be cut. Other things could be done and that wood, instead of just being thrown away that may not be legitimate for timber, could be ground, chipped, and chipped wood is right now, I believe, valuable for energy. Chipped wood today delivered as far as 50 miles can produced an energy source that's cost effective and in our State where you clear cut a tract of land, you replant the tops and limbs that are left there, they rot, they emit CO_2, where if they could be converted to energy and it's easier to replant for the landowner and then you have a vibrant growing forest, it's really a drawing in CO_2. So I think there's great potential here, I really do, and maybe we can work on it.

I'm very interested also in the plug-in hybrids. I think a lot of people think that—I mean, this is a solution that goes to carbon fuel profits. It goes to oil-exporting nations. If we could create a little better battery—I'd like you to talk to me a little bit more about that—you could charge that battery at night and I talked to someone who makes a device that could time when you charge a battery. It wasn't that expensive, and you said for a dollar, you could have the equivalent of a tank of gasoline? A dollar's worth of electricity could produce a tank of gasoline.

Mr. WILSON. That's the calculation our people have made.

Senator Sessions. Then, of course, you're looking at if it were nuclear-powered electric generation, you'd have zero emissions of CO_2 or any global warming gases and we would therefore be able to reduce significantly our imports of foreign oil, reduce the wealth transfer that's now occurring, and serve environmental needs, also. Am I off base on that?

Mr. WILSON. Yes, I think you made the points I was trying to make earlier better than I did. I21Senator Sessions. The thing is pretty dramatic to me because it seems to me in terms of a major breakthrough. Would this be perhaps the closest thing we've got to a breakthrough, a plug-in hybrid?

Mr. WILSON. This one contributor, if you look at our—unfortunately, you're in a position, we can't see our slices up there, it's one thing out of the many that would reduce emissions, but it's an important contributor for the reasons you've outlined.

SenatorSESSIONS. Now if you were going to commute—if the battery would take you 30 miles or 40 miles without having to turn on your hybrid engine, just the charged battery, the electric car battery, and you commuted to work less than that, you'd use not a drop of oil. You could come back at night and recharge your battery and if you don't go more than 30-40-50 miles, you may not use any oil at all.

Mr. WILSON. Yes. One estimate is about 78 percent of people commute less than 40 miles round trip a day.

Senator SESSIONS. Just think in terms of CO_2, even if you're utilizing a mix of power sources and not totally nuclear, is it your statement that studies have shown that still is an improvement on CO_2 emissions to utilize hybrid technology?

Mr. WILSON Yes. The EPRI/NRDC study that was released last July says that the emissions from a plug-in electric hybrid vehicle, taking electricity solely from an old coal plant, is comparable to a regular hybrid vehicle today. So if you take electricity from old coal, new coal, coal renewables, nuclear, hydro and the other—natural gas and the other resources, then it's lower.

Senator SESSIONS. If you have a cleaner coal technology as we go forward and an increase in nuclear power, that would be less, and then is it not true that nuclear power is a 24-hour-a-day, seven-day-a-week source of electricity and so you do have times in which it is particularly valuable at the off-peak hours, 11 p.m. to 5 a.m. hours?

Mr. WILSON. Yes.

Senator SESSIONS. So if you were drawing on the grid, you would be drawing as a percentage more nuclear clean energy than if you were solely drawing it from a coal, old coal plant?

Mr. WILSON. That's correct.

Senator SESSIONS. Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much. Let me thank both of you for coming and testifying. I think it's useful testimony. We'll include your full statement in the record and that will conclude our hearing.

[Whereupon, at 12:02 p.m., the hearing was adjourned.]

APPENDIX

Responses to Additional Questions

Responses of Karan Bhatia to Questions From Senator Bingaman

Question 1. You have spoken at length about the need for international collaboration and assistance for clean energy development. How do you suggest that we support tech transfer between developed and developing countries without placing a large burden on US companies and US taxpayers?

Answer. Left unaddressed, climate change threatens to impose substantial, long-term cost burdens on businesses and taxpayers in the United States and elsewhere. While potentially imposing some near-term costs, the policies recommended in my testimony to encourage utilization of cleaner energy options in the developing world would likely be very cost-effective over the long run. Moreover some of those policies would carry little cost burden even in the near term. For example, ensuring that the United States pursues sound domestic policies on renewables (including extending the renewable energy production tax credit), and advising developing countries on sound energy policies, would not impose substantial costs, and removal of trade barriers would actually reduce costs, to American businesses or taxpayers.

Similarly, adequate protection of intellectual property rights (IPRs) is an essential and cost effective means to promote innovation and transfer of advanced cleaner energy technologies. Companies in technology-intensive industries will continue to be reluctant to deploy proprietary technology in countries where the risk of losing control of the technology is not mitigated by strong IPR regimes. By giving innovators assurance that their technologies will not be illegally expropriated, strong IPR systems can increase market-based cross-border technology transfers, to the benefit of both U.S. and foreign innovators.

Additionally, funding mechanisms such as the proposed Clean Technology Fund should emphasize deployment of new technologies in ways that will bring down costs so that the cost differential between advanced clean technologies and the traditional technologies in use today will be reduced significantly, and with it the need for such taxpayer supported programs. In this regard, as stated in the written testimony, it is essential that mechanisms such as the CTF work effectively with private sector and export credit agency financing. While GE commends the creation of the CTF, we are concerned about the practical usability of its financial products especially for private sector driven projects. We welcome a detailed discussion on this issue.

Question 2. What policies will incentivize companies such as GE Energy to locate their production facilities in the U.S.?

Answer. The market for cleaner energy technologies is global. GE currently has and will continue to have a global supply chain, with manufacturing in the United States as well as other countries. Policies that support a robust U.S. market for cleaner energy technologies—particularly the renewable energy production tax credit—support the decision to locate production facilities in the U.S.

Our wind business offers a case in point. The policy-driven growth of wind in the U.S. has helped GE expand its wind business revenues from less than $1 billion in 2004 to more than $6 billion this year. Since entering the wind industry in 2002, GE has invested over $700 million in technology, increased its wind turbine production six-fold, and tripled its U.S. wind turbine assembly sites. Renewable-energy related jobs at GE have grown to more than 2,500. These include manufacturing jobs in Pensacola, FL; Greenville, SC; Salem, VA; Erie, PA and Tehachapi, CA, as well as non-manufacturing professional jobs at our headquarters in Schenectady, NY. Last October we announced plans to add 500 more jobs in Schenectady, NY in Wind Engineering, Project Management, and Services.

GE has also tripled the number of its suppliers, who now account for 2,000 US jobs and cover 15 states. We have made many long-term agreements with critical suppliers in states from coast to coast, giving them line-of-sight to our anticipated production volume, so that they have the confidence to expand with us. Last November, we celebrated with our suppliers the opening of two new blade supplier manufacturing facilities for our 1.5-megawatt turbine in South Dakota and Iowa, which will create approximately 1,250 jobs. These suppliers provide wind components and subcomponents such as blades, towers, bedplates, nacelles, gearboxes, generators, pitch and yaw bearings, hub castings, and cables.

GE's presence in the US wind segment gives us insight into its future growth, and we see significant job creation potential over the next five years. We estimate that sustaining a 30% growth rate over the next five years would triple the size of the U.S. wind industry and associated jobs.

Today, wind turbine manufacturers are struggling with the same global challenge: obtaining sufficient components from their suppliers to manufacture and assemble wind turbines. Current bottlenecks in the wind turbine production chain result from the long lead times associated with mechanical components such as gearboxes and large bearings.

More investment in the supply chain is needed. The ability to make this investment—particularly the investment needed from our suppliers themselves—is directly affected by Federal tax policy. When the wind production tax credit has been allowed to expire, new installed capacity has dropped dramatically in the following year, as component suppliers slashed their investments in long term plant and equipment, scaled back their workforces and reduced their inventories in anticipation of reduced demand. Then, when Congress renewed the credit (retroactively in some cases), the key components required to produce wind turbines were in limited supply. As a result, industry's ability to add new generating capacity has not been able to keep pace with demand.

This on-and-off policy scheme has made it difficult for suppliers to make long-term commitments. Conversely, a more stable long term incentive for wind power would generate the confidence for suppliers to make the long-term investments in manufacturing capability that are needed to assure the availability of critical components.

Failure to extend the renewable tax incentives would also cause the U.S. to forgo long-term export opportunities. The connection between a stable domestic policy and a vibrant export sector for renewables is exemplified by Germany, whose incentive system has created the world's leading installed base in a country with a moderate wind resource. Wind power technology is Germany's second-leading export industry after automobiles. The adoption of policies that ensure the predictability of incentives for solar and wind energy could support a similarly vibrant export base here in the United States.

Other forms of national and state policies also can sustain the growth of the U.S. cleaner energy industry. GE has been supportive of a federal Renewable Portfolio Standard, and has endorsed the establishment of a cap-and-trade system to control emissions of greenhouse gases.

Question 3. If a CO_2 cap and trade program is implemented in the U.S. how do we keep production facilities here?

Answer. The energy industry is and will continue to be a global industry serving a global market and with global manufacturing. A U.S. cap and trade program would provide another policy incentive to support the growth of a domestic market for cleaner energy technologies, which, as in the case of the renewable energy PTC, will support decisions to locate production facilities in the U.S. Particularly in the case of large or bulky components there are advantages to locating production close to the markets where the technology is to be deployed.

RESPONSES OF KARAN BHATIA TO QUESTIONS FROM SENATOR DOMENICI

We all recognize that renewable energy must be part of the solution to meet ever increasing global energy demands while also addressing CO_2 emissions. However, setting goals and targets is quite a different thing than actually accomplishing them. I understand that there is a significant backlog of renewable energy projects that are unable to transmit their energy to the grid. The fact is that with only a 6.8% growth in total transmission line miles since 1996, our nation's infrastructure development is simply not keeping pace with system demands.

Question 1. Do you agree that one of the major obstacles to the development of renewable energy is the lack of available transmission capacity to bring alternative energy resources online? In EPAct 2005, Congress sought to address transmission siting in general through the use of National Interest Electric Transmission Corridors in areas of severe congestion. Is additional federal authority needed to ensure the necessary transmission infrastructure?

Answer. GE agrees that the lack of transmission to bring electricity generated by renewable resources to locations where it is needed is a major impediment to greater use of the nation's abundant renewable resources. Many of the nation's most promising wind resources are located in relatively remote areas where there is little or no transmission access. In other areas, congestion on the existing grid also may limit opportunities to deliver wind-generated electricity to the areas where electricity is consumed.

For renewable energy to reach its full potential, transmission issues must be solved so that location-constrained resources may be brought online. In some areas this may require expansion of the grid. In other areas, this may require regulatory policies to assure that wind resources have access to the grid.

Further investment in transmission lines is essential for large-scale wind installations to be built. Congress is to be commended for providing important incentives for transmission investment in the Energy Policy Act of 2005. Going forward, it will be important to implement fully the many EPAct 2005 transmission-related authorities, including: authority for the Department of Energy to coordinate transmission planning by Federal agencies; the requirements for the designation of energy corridors on Federal lands; and the identification of National Interest Electric Transmission Corridors where new transmission is needed.

Consistent with the focus of EPAct 2005 on advanced transmission technologies and with the smart grid provisions of the Energy Independence and Security Act of 2007, GE is working to develop and deploy innovative technologies to increase the capacity and efficiency of the existing transmission grid. GE also is working to enhance the ability of wind energy to contribute to the stability of the power grid. GE's wind turbines support both grid voltage and grid frequency stability during normal operations, and even contribute to grid voltage regulation if no wind is present ("WindFree Var" technology). Recent grid integration technologies have focused on making wind power plants more robust during grid failures. Similar to conventional power generation equipment, modern wind plants stay connected to the utility grid and help the grid recover from short-term disturbances in a controlled manner ("Low/Zero Voltage Ride Through" technology).

Question 2. We often hear the costs of carbon reduction expressed as a fraction of GDP. In the Energy Technology Perspectives report, for example, the cost of carbon reduction is projected to be between 0.4% and 1.1% of global GDP.

How uniformly do you think these costs will be distributed across the global economy? Will some economic segments bear disproportionate costs and how can we manage these disparities?

Answer. All economies will be challenged by the costs of cutting carbon emissions. Without knowing what policy framework will be in place and the scale of the carbon reductions that will be required, it is difficult to estimate the distribution of the costs of advanced cleaner energy technologies. The concern that developing countries will be unable or unwilling to bear the cost burden for deploying advanced cleaner energy technologies underlies proposals for multilateral technology deployment funds. These funds or other incentive mechanisms offer one way to manage the disparities in economic impacts of carbon reduction policies.

Question 3. In the U.S. we have implemented a number of incentives and risk mitigation vehicles for clean energy sources including renewable and nuclear energy. In the Energy Policy Act of 2005 we provided tax incentives and loan guarantees. Earlier this year I also introduced the Clean Energy Investment Bank Act of 2008.

How important do you think these strategies are for fostering the development of low emission technologies domestically and do they provide a model that can be adopted internationally?

Answer. Policies to stimulate the growth of domestic markets for cleaner energy technologies are very important to spur technology investment and innovation. The initiatives included in the Energy Policy Act of 2005—extension and expansion of the renewable energy production tax credit, solar investment tax credits, investment tax credits for integrated gasification combined cycle and other advanced coal projects; loan guarantees for innovative technologies; and risk insurance for the first new nuclear power plants—all are important contributors to the development of a strong domestic market for cleaner energy technologies. The U.S. industry is responding to these policy initiatives with investment in research, development, demonstration and technology deployment.

Successful U.S. policy initiatives such as the renewable energy production tax credit provide an important model that can be adopted internationally. The PTC has worked well in the U.S., and at a cost that has not placed an undue burden on U.S. consumers.

Not all types of incentives work equally well, however, and the type of incentive needs to be tailored to the maturity of the technology. A production-based incentive that appropriately rewards advancements in technology and capability, such as the

PTC, is appropriate for a more mature technology such as wind. But for other technologies, such as solar, where substantial research and development is needed, tax incentives may more appropriately be investment-based rather than production-based. Also, financial incentives must be coupled with government-sponsored research and development programs until solar and other emerging clean energy technologies reach sufficient maturity to be near price competitive with traditional technologies.

RESPONSES OF NEIL HIRST TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. CCS: Overall, this was a very thought-provoking report, particularly in the scope and scale of both the problem of reducing CO2 emissions and the solution for rapid deployment of clean energy technologies. The scale is fairly daunting. In particular, the report calls for significant investments in the area of demonstrating and deploying carbon capture and sequestration technologies for substantial CO_2 emission reductions. The ACT scenario calls for 20 large-scale demonstration projects by 2020, with a CO_2 price of at least $50/ton to make CCS economically competitive. We have been working, here in the US, to develop and demonstrate CCS technologies at scale, but it is difficult to overcome financial, regulatory, and liability-related issues. These remain as significant obstacles in the path of rapid deployment. I would consider the US to be a world leader in this area of technology development despite those hurdles. As it is difficult to deploy on our own soil, the prospect of developing the technology abroad is quite daunting. I have particular concerns with China and India adopting this technology when they currently struggle to afford higher efficiency coal plants. How do you see CCS moving forward given these hurdles, and what can be done to diffuse the technology into the developing world?

Who should be coordinating the global development and deployment of CCS technologies? Should it be the US or the EU? If not, who? Additionally, the economic costs for deployment are quite high according to your report. Who will pay the lion's share of these costs? Should the American taxpayer be expected to foot the bill for a technology that needs to be deployed in non-OECD nations? And finally, if we find that CCS is not feasible due to costs, safety, or any other reason—what are our options? CCS is a significant portion of your clean energy technology solution—should it not become a commercially deployable technology, then what?

Answer. Given the importance of CCS, the deployment of CCS technologies should be through a multi-country effort in order to minimise costs and delays. The EU and the United States have a major role to play, with perhaps 10-15 of the 20 demonstration projects we think necessary being potentially being led by these two. Demonstration in the +5 countries is also necessary, probably with technology support from G8 countries. There should be a co-ordination amongst the countries involved in the CCS deployment, which could be through an international group, working with the IEA that would build on the momentum created by the IEAGHG and the CSLF.

The issue of burden sharing in terms of costs was not covered in the ETP 2008 analysis for CCS demonstration and hence we are not able to give you an opinion on your question about who will bear the lions share of the costs and what role American taxpayers will have in that process. It should be noted though, that not all arrangements would lead to CCS costs being borne by the taxpayer once deployment begins. A number of schemes, such as the European Emissions Trading Scheme, have been proposed where the CO_2 price would provide the incentive to deploy CCS. For non-OECD nations, including CCS within the CDM is a priority. Early developers of this technology would be well placed to sell into the very large global market for CCS that we see in the BLUE scenario.

Under our "BLUE no CCS" scenario emissions halving by 2050 would not be achieved if we left the CO_2 reduction incentive at USD 200/t CO_2. Emissions would fall to only 20.4Gt vs. 14Gt under the BLUE Map scenario. The share of renewables in power generation would need to increase from 45% to 63% and nuclear would rise from 23% to 25%. Alternatively, we estimated that trying to reach the BLUE Maps 50% reduction would require a near doubling of the marginal cost of CO_2 saved. CCS therefore seems to be a particularly important option for deep emissions cut scenarios.

Question 2. Given the recent increases in oil and other fossil fuel prices can you speak on how some of the assumptions and timelines in the report may have changed? For example, in this country, with gasoline topping $4/gallon we have seen a significant and rapid shift in consumer behavior towards hybrid and fuel efficient vehicles.

Answer. We have not done this analysis, but see two possible effects based on the evolution of our projections over the last three years as prices have increased. First, is that more efficiency does occur, but this is modest and is likely to be more than outweighed at the global level by the second effect, which is a shift to coal in industry and electricity generation, as well as more CO_2 intensive liquid fuels (tar sands, coal to liquids etc).

Question 3. Looking at the 17 key energy technologies profiled, I am surprised that you have not listed geothermal, specifically enhanced geothermal energy. MIT put out a report on geothermal energy that concluded that it would be affordable to generate 100 GW or more by 2050 in the United States alone, for a maximum investment of 1 billion US dollars in research and development over 15 years. Why do you not project greater growth in the geothermal energy development sector?

Answer. We believe that geothermal is an important technology. In terms of electricity generation, it increases 20-fold in the BLUE scenario from 2005 to 2050, but from a very low level (Page 85). At a global level in the scenarios, it is competing with CCS, nuclear, wind, solar etc to decarbonize electricity generation. The 17 technologies were chosen based on those that contributed the most to CO_2 reductions. Although geothermal is an important technology our analysis showed that it had a smaller contribution globally than the other technologies listed.

Question 4. In your report, you state there are some challenges to future deployment of geothermal energy—but the fact of the matter is that this is an off the shelf technology that has been commercially available in some capacity for at least a decade. With that in mind, why did the authors feel that other technologies were more viable, such as fuel cell technology, that are really still in the R&D stage? It seems that there should be more emphasis on the potential for broad deployment of geothermal technology.

Answer. Conventional geothermal in areas of geothermal activity is tried and tested, but enhanced geothermal which is applicable much more widely needs more development and current cost estimates are higher than for other alternatives in many cases. Geothermal is mainly for electricity generation, while fuel cells are predominately for use in transport, so the two technologies do not compete directly. The difficulty of decarbonising the transport sector means that this sector potentially needs technologies that are not yet commercially available.

Question 5. Efficiency plays a large role in this report in reducing emissions, and several other reports have also discuss the large gains that can be made at negative costs with efficiency measures. However, we have not been very successful in deploying efficiency technologies and measures in this country. Could you talk a bit on what programs and policies have been successfully in other countries?

Answer. We would have to say that no one country sets a perfect example across all energy efficiency areas. However, many countries or regions target particular areas of energy efficiency very well. To generalize, the most energy efficient economies usually have a history of a blend of rigorously applied energy efficiency policies, relatively high energy prices (but not bills) and core technical competences in the delivery of energy efficient services. While no single economy has yet applied all available best practice energy-efficiency policies, the most efficient economies typically include many of the following policies:

- Stringent mandatory performance requirements and labelling for appliances commercial and industrial equipment as well as building energy codes for new buildings and major refurbishments. Including, investment in regulatory compliance infrastructure to ensure mandatory provisions are respected.
- Ambitious fuel economy performance requirements and labeling for light and heavy road vehicles
- Capacity building measures in energy efficiency delivery.
- Ambitious utility energy efficiency resource standards or similar delivery mechanisms.
- Effective fiscal and financial incentives and funding mechanisms to encourage energy efficiency in all usage sectors.
- Large-scale and significant energy-management incentives and requirements, as well as awareness raising activities.
- Targeted measures to address economic split-incentive barriers to energy efficiency such as the "landlord-tenant problem".
- Incentives for the development and operation of pubic transport networks that enable travel-mode shifting away from private vehicles and facilitate higher urban densities.

Collectively the appropriate blend of policies can be set out through the development of detailed national and regional energy efficiency action plans and effective implementation ensured via in-depth monitoring and evaluation efforts. Some examples of the above policies are discussed in Energy Policies of IEA Countries—2006 Review.

Question 6. What are the most promising new energy efficiency technologies for buildings -both in the G-8 and in developing countries?

Answer. The buildings sector is interesting in that it relies the most on existing technologies. They are "new" in that they are not widely deployed today, either because they are costly, or due to a number of barriers to uptake that affect so many energy efficiency options. The most important technologies are those to improve the building envelope to very low energy consumption "passive house" levels (double glazing with inert gases, greater insulation, "tighter" and smarter building design etc), as well as energy efficiency in appliances (including air conditioners), highly efficient heat pumps for space and water heating, solar thermal hot-water heating, more efficient lighting (including LEDs), solar photovoltaics and the use of sustainable bioenergy for heating and cooking. (See Chapter 17 and Annex D of ETP 2008 for a more extensive list of Buildings sector technologies and also "Promoting Energy Efficiency investments: Case Studies in the Residential Sector", IEA 2008).

Question 7. What are the barriers to further acceptance of these technologies and how can we meet them?

Answer. Barriers to the uptake of low-carbon and energy efficiency options are many. A variety of market barriers inhibit energy efficiency improvements. They take many forms, ranging from higher initial costs, inadequate access to capital, isolation from price signals, information asymmetry, and split-incentives. The Energy Technology Perspectives 2008 deals mainly with technology policy recommendations. Helping overcome these barriers requires deployment programmes and an incentive to reduce CO_2 emissions. The IEA undertakes extensive policy analysis of the barriers to energy efficiency, recent reports include "Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency" and "Promoting Energy Efficiency Investments". It is a complicated topic, but getting it right is essential to achieving low-cost CO_2 emission reductions.

Question 8. One thing that comes to mind looking at the annual infrastructure growth numbers in the both the ACT and BLUE scenarios is how are we going to support this level of growth in terms of production capacity, commodities and skilled labor supply?

Answer. The annual infrastructure capacity additions presented for electricity generation are annual averages for the period 2010 to 2050. These, in the case of the emerging options and nuclear, start out low and then increase over time. This is an attractive opportunity for industry and they are likely to be able to have the time to ramp up capacity in manufacturing and labor skills to meet the growth of these markets. However, to have the confidence to make these investments and avoid bottlenecks, industry will need a clear signal that there is a long-term market for their products. A policy framework that provides a long-term incentive to reduce CO_2 emissions is therefore important.

Access to a skilled labor force is becoming a significant concern for all sectors as the skilled workforce ages and birth rates in some countries have stagnated. Additionally, the growth of skilled engineers and scientists appears to be strongest in developing nations such as China and India. (See also "PISA 2006 Science Competencies for Tomorrow's World", OECD 2007).

Question 9. Does the IEA have any plans to do a regional or country level analysis of energy technology pathways? In your opinion, what technologies hold the most promise for the United States?

Answer. Energy Technology Perspectives 2008 provides a first attempt at looking in detail at the transition required to meet the ACT and BLUE scenarios. We hope to expand upon this analysis of technology roadmaps in the future if our member countries are interested in us pursuing this analysis. We have not undertaken any country level analysis of the technology roadmaps. However, having said that, all 17 roadmaps included in Energy Technology Perspectives 2008 are likely to be relevant to the United States given your size, geographical diversity, manufacturing and industrial base, and current energy system. (See also "Energy Policies of the United States: 2007 Review", IEA 2007)

Question 10. As I mentioned in my opening statement, it is the 20th anniversary this week of James Hansen's ground-breaking testimony on global warming. This week he made the statement that it is inevitable that CO_2 from oil is going to get into the atmosphere because we're not going to be able to tell Saudi Arabia and Russia not to sell their oil. The best that we can do is to phase out all coal use by 2030 except at those plants fitted with CCS. Have you considered the difficulties in phasing out oil use in those countries which produce so much?

Answer. No. Our scenario analysis is based on meeting the goal of a 50% reduction in CO_2 emissions below today's level in 2050 at least cost. Currently, the world is dependant on liquid fuels from oil for transport. Our analysis suggests that to reduce the global use of oil below today's level is very challenging and potentially expensive. In our 50% reduction case global oil demand is 25% below current levels, but this means that oil is still one of the main sources of energy supply.

Question 11. In your report, you do not really address non-technology driven carbon sequestration, such as smart agricultural and forestry management practices—has your agency given any consideration to these as viable options for CO_2 emissions reductions?

Answer. Our analysis is restricted to CO_2 and methane emissions from the energy sector, around 60% of GHG emissions (depending on the data). Agriculture and forestry issues are outside our area of expertise and so we have left this analysis to others who are more competent. What is clear is that these will also have to be addressed if the goal of stabilizing CO_2 concentrations in the atmosphere is to be achieved. (See also "Environmental Performance of Agriculture in OECD Countries since 1990", OECD 2008).

Question 12. In the report, heat pump technologies are presented in one of your roadmap scenarios—are you referring primarily to geothermal heat pumps, air-source or water-source heat pumps? What is your breakdown in the percentage of each of these down the road? In other words, is there one type of heat pump technology that is more readily deployable for broad application? If these are geothermal heat pumps, that would put a greater emphasis on geothermal energy technologies.

Answer. We believe a mix of heat pump technologies will be used. Ground-source or geothermal heat pumps are significantly more expensive than air-to-air heat pumps due to the need to install a ground loop. Given the recent improvement in the operating parameters of air-to-air heat pumps we believe that these will take the lion's share of the global market. However, in cold-climate countries, geothermal heat pumps are likely to maintain significant market share, as their improved efficiency when operating in low temperature environments will mean they are more economic (depending on the relative prices of heating fuels and electricity).

RESPONSES OF NEIL HIRST TO QUESTIONS FROM SENATOR DOMENICI

The Energy Technology Perspectives report describes a number of CO_2 emission reduction scenarios based on modelling of the global economy.

Question 1. How well do you think these models reflect the particular realities of the U.S. economy? Are there certain technological options that the U.S. might not benefit from or, alternatively, might receive greater benefit from?

Answer. The IEA model is a 15 region global model, supplemented by individual country models in some cases. The United States is not currently separated out in the model. However, we worked with individual country MARKAL modellers from the IEA's implementing agreement "Energy Technology Systems Analysis Programme" to gain insights into individual country results under the ACT and BLUE scenarios. From the United States, we worked with Brookhaven National Laboratory's MARKAL team. As previously mentioned, all 17 technologies for which we made roadmaps are likely to be relevant to the United States.

Question 2. As I mentioned in my opening statement, under the most aggressive scenarios to reduce CO_2 emissions by 50% in the Energy Technology Perspectives report, you predict that global oil consumption will still be at 60-70 million barrels a day even in 2050. That is less than current consumption but you know that OPEC supply is roughly the same as today and that supply from other sources is reduced.

Can you explain the features of your modelling that results in OPEC production being at the same levels in 2050 as they are today?

Answer. OPEC countries are projected to continue to be the least-cost oil producers into the conceivable future. From an economic perspective, they are likely to be the most competitive oil producers and therefore likely to supply the majority of oil in the future, as the lower-cost conventional oil reserves outside OPEC are depleted.

Question 3. You testified that in order to meet global energy demand while also addressing global climate change issues, we must maintain annual hydropower capacity additions at today's level.

What is today's level of annual hydro capacity additions? According to the Department of Energy, there are 5,677 sites in the U.S. with undeveloped capacity of about 30,000 MW. Shouldn't we be trying to develop as much as this capacity as possible? Some environmental groups have long sought the removal of hydropower dams. Wouldn't such actions be counterproductive to addressing global climate change?

Answer. At a global level, around 12 GW (12 000 MW) of new hydro capacity has been added annually in recent years, including increases in capacity in existing hydro systems. Many of the low-cost options for additional capacity will come from increasing the capacity of existing hydro systems. As with many renewables, there is an environmental trade-off between existing eco-systems and the development of new hydro dams. This is very much a national issue and a transparent process for assessment of the costs and benefits, both national and potentially global when we consider the CO_2 savings, is important to the acceptability of permitting any new electricity generation plant.

RESPONSES OF NEIL HIRST TO QUESTIONS FROM SENATOR MURKOWSKI

Question 1. In this country there is considerable desire by environmental groups, not to meet the minimum recommendations of the IPCC for 50% carbon emission reductions by 2050, but to require considerably higher reductions of at least 70% and preferably above 80% by that date. From your research do you have any estimates what it would cost the global economy or the U.S. specifically to reduce emissions by 80% by 2050 and do you believe that such a level of reduction is achievable given current and pending technology?

Answer. We have not done any scenario analysis around a more stringent target than the 50% global reduction in the BLUE scenario. For more ambitious goals, the costs and uncertainty would be higher than in BLUE. A 50% global reduction would imply a considerably greater reduction in the US, bearing in mind the rapid growth rates of major developing countries.

Question 2. From the IEA's research, do you have an opinion on whether a carbon tax or a carbon "cap and trade" emissions system would be more economically advantageous to produce emission reductions? Is there a discernible consensus in foreign nations and to what approach is most acceptable to reducing carbon worldwide?

Answer. In theory, with perfect information, both a carbon tax and emissions trading ought to have the same impact, for an identical price of carbon. However, in the real world where uncertainty is the norm, the two approaches have different qualities. A carbon tax provides certainty on price, but not the quantity of emissions saved, while emissions trading provides certainty about the emissions saving, but not the price to achieve it. As there is less certainty on the quantity saved with a carbon tax, the preference of the majority of IEA countries has been for "quantity-based" approaches, i.e. emission reduction goals and emissions trading, due to the nature of the risks of missing emissions targets. This provides the certainty that policy-makers in the IEA region are demanding on climate change. All countries that are members of the IEA have either implemented, or are beginning the process of implementing emissions trading—at the local level if not the national level as in the US.

In practice, not all sectors are amenable to emission caps because of administrative and transaction cost, so another form of price signal may be appropriate in those cases. A tax on carbon emissions would help for some of these end-uses. Where market failures exist at the end-use, e.g., in rental apartments where landlords and tenants have objectives, the IEA has demonstrated that other regulatory measures are effective and lowest cost policy approach in these special circumstances.

With respect to non-IEA member countries, in particular the rapidly emerging industrialized economies like China and India, we would note that they are the most active participants in the CDM market as sellers. While they clearly have concerns about assuming binding obligations that may inhibit their economic development, their enthusiasm for CDM is consistent with a growing comfort with market based approaches to climate protection.

RESPONSES OF NEIL HIRST TO QUESTIONS FROM SENATOR BUNNING

Question 1. In your testimony you said worldwide government R&D spending on energy technology has been cut in half in the last 25 years. Of the $10 billion governments did spend last year, $8 billion came from the United States and Japan. Many of my colleagues insist that the United States be a leader in addressing climate change. Would you agree that our leadership in federal support for energy technologies in the last 25 years has not been followed? Do you believe these countries who have failed to follow our lead in spending, would voluntary harm their own economies to follow our lead with climate change legislation?

Answer. In real terms (real USD 2006), United States government spending on energy related R&D peaked in 1979 at around USD 8.5 billion, before declining to USD 2.4 billion in 1997. This trend is broadly replicated in all IEA countries. However, in recent years the trend has been slightly upward in the United States and other IEA countries. Our scenarios show that this investment in public sector R&D needs to grow significantly if the goals in the ACT and BLUE scenarios are to be met. Only time will tell what agreement is reached at an international level on post-

Kyoto goals, but countries will no doubt take into account the costs and benefits of taking action to address climate change.

Question 2. Mr. Hirst, in your first diagram you outline a plan to cut carbon emissions in half. Nearly 30% of that reduction comes from carbon capture and sequestration and improved efficiencies at power plants. When such a large chunk of emissions reduction could come from helping coal adopt new technologies, would you agree with me that comprehensive government incentives for coal are necessary?

Answer. CCS which allows coal to be used in a CO_2 constrained world, is certainly a key technology that needs support. Energy Technology Perspectives 2008 outlines a hybrid policy approach to meeting the goals of the BLUE scenario. Firstly, a stable long-term incentive system to reduce CO_2 emissions needs to be put in place to put a value on saving CO_2. CCS will never be widely adopted without this. Secondly, due to the long-term nature of the problems and the goals, significant deployment programmes need to be in place to help bring down the costs of promising technologies, including CCS, and ensure the uptake of energy efficiency options. To get this process started, investment in R&D and demonstration is also required. We have called for a commitment to 20 CCS demonstration plants around the world by 2010. National governments will need to ensure that this happens. Depending on the approach taken, the financing of these demonstration plants will be a matter for negotiation between government's and the potential builders and owners of these plants.

Question 3. Mr. Hirst, you also discuss how important it is to extend the production tax credit for wind energy. If in 30 years of government support wind energy still needs a generous tax credit for companies to make money, what can America hope to achieve by throwing billions of dollars more at this technology? Does it make sense to continue to provide generous incentives to one technology while providing only modest support for the others—like advanced clean coal and nuclear energy—that are substantial parts of your emissions reduction plan?

Answer. As already discussed, we believe a hybrid policy approach that covers R&D and demonstration, deployment and an overall CO_2reduction incentive is necessary to achieve the ACT and BLUE goals. This approach will be required to varying degrees for most of the 17 key technologies we have identified. National policies will have to take into account local resource availability, technical expertise, current energy system etc. For example, wind is now economical in many parts of the world in excellent wind sites and depending on local fuel prices. However, additional deployment policies, particularly for offshore wind, are important at a global level. Deployment policies help to lower costs through "learning by doing", large-scale deployment should come once the costs have come down sufficiently not to make the overall programme costs too onerous.

RESPONSES OF TOM WILSON TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Given the recent increases in oil and other fossil fuel prices can you speak on how some of the assumptions and timelines in your analyses may have changed? For example, in this country, with gasoline topping $4/gallon we have seen a significant and rapid shift in consumer behavior towards hybrid and fuel efficient vehicles.

Answer. The EPRI Prism analysis which was submitted as part of our written testimony assesses the technical potential of a wide range of technologies to reduce CO_2 emissions. In particular, we estimated the annual CO_2 reductions if plug-in hybrids comprised 10% of new light duty vehicle sales by 2017 and 33% by 2030. We did not analyze the economics of this market penetration in our submission. However, we do believe that the cost-effectiveness of the plug-in hybrid will improve as the gasoline price rises, and greater CO_2 reductions will likely result.

Question 2. The IEA report cites public/private partnerships and industry leadership as key to technology demonstration and deployment. It also cites international collaboration as being key. EPRI has been an excellent example of industry driven leadership on energy R&D within the U.S. Could a similar organization be set up or expanded from EPRI that is a global consortium?

Answer. We agree with the IEA that public/private partnerships and industry leadership are critical to technology demonstration and deployment. The international dimension of this RD&D challenge is critical. Although EPRI was initially funded by US companies, EPRI now has members in 40 countries, with non-US members providing 20% of our research budget. Our nuclear programs are truly global, while non-US funding of our fossil generation research has grown dramatically in the last three years. Our current plans call for one of our initial demonstration projects of CO_2 capture and storage to be located in Europe.

Question 3. The IEA ETP 2008 report sites decarbonizing the transportation sector as one of the most difficult and expensive options for CO_2 reduction. Do you agree with this assessment? Do you have rough timelines for plug-in hybrid and EV penetration into the U.S. and global markets?

Answer. Yes. We agree that decarbonizing the transportation sector will be difficult. Expanded use of plug-in hybrid electric vehicles—fueled by increasingly lowcarbon electricity sources—provides another option for decarbonizing the transportation sector. At present, plug-in hybrid technology has tremendous momentum, with GM, Ford, Toyota and others vying to be either first to market or "best to market". The forces driving this interest—pressures to reduce petroleum dependency and the high cost of fuel and to address climate change—all point in the direction of PHEV technology deployments in the years ahead.

Question 4. Dr. Wilson, you stated during the hearing that Toyota plans to market its plug-in hybrid electric vehicles soon. Will these first vehicles marketed use a NiMH battery pack or Li-ion?

Answer. To the best of our knowledge, all of the major automotive manufacturers in the U.S. market that are developing plug-in hybrid or electric vehicle technology are likely to use energy storage systems based on lithium ion battery technology.

The nickel metal hydride battery has been the enabling technology of today's highly successful hybrid electric vehicles from Toyota, Ford, GM, Honda, and others. However, lithium ion batteries can store much more energy in a smaller, lighter package and this is critical to automotive designers, especially for plug-in hybrids. Furthermore, the potential for improvement in lithium ion battery systems is far greater—it is essentially a family of battery chemistries containing a wide variety of different designs suited for different purposes.

Over the next several years, it is highly likely that lithium ion battery systems will occupy a much greater share of the market in all electric-drive vehicles: hybrid, plug-in hybrid, and battery electric vehicles.

Responses of Tom Wilson to Questions From Senator Domenici

We all recognize that renewable energy must be part of the solution to meet ever increasing global energy demands while also addressing CO2 emissions. However, setting goals and targets is quite a different thing than actually accomplishing them. I understand that there is a significant backlog of renewable energy projects that are unable to transmit their energy to the grid. The fact is that with only a 6.8% growth in total transmission line miles since 1996, our nation's infrastructure development is simply not keeping pace with system demands.

Question 1. Do you agree that one of the major obstacles to the development of renewable energy is the lack of available transmission capacity to bring alternative energy resources online? In EPAct 2005, Congress sought to address transmission siting in general through the use of National Interest Electric Transmission Corridors in areas of severe congestion. Is additional federal authority needed to ensure the necessary transmission infrastructure?

Answer. The lack of available transmission capacity is a major obstacle to the deployment of renewable energy. We currently have unprecedented demand for new transmission related to wind. There are big problems building needed transmission across the country. Examples include crossing Arizona, getting into New York City, into California from the northwest, Idaho to Chicago, into Michigan from the south, etc. These and other examples are documented in the National Transmission Grid Study, 2002. It is important to note that the 2002 study was produced before today's huge amount of wind coming into the queue in several regions of the country. In addition to new transmission, we need to also look into technologies that will allow us to much more effectively use existing and new transmission corridors, such as, higher voltage transmission lines, HVDC lines, advanced conductors, compact line design, and other technologies and practices.

Question 2. In the Energy Technology Perspectives report electric vehicles are only seen as a significant contributor to CO2 reductions under the most aggressive reduction scenarios.

What role do you see electric vehicles playing in domestic U.S. emission reduction efforts? What is the current status of electric vehicle technology and infrastructure development?

Answer. Last year, EPRI completed a comprehensive nationwide air quality and greenhouse gas assessment in cooperation with the Natural Resources Defense Council. We used the most sophisticated modeling tools available in order to understand, as closely as possible, what the electricity system's response to PHEVs will be in terms of which plants will be dispatched to generate the charging energy, what the net changes to emissions will be in the electricity and transportation sectors, and how the emissions will react chemically in the atmosphere to affect air quality and greenhouse gas emissions. Under nearly any foreseeable scenario, electricity is a low-carbon fuel, compared with gasoline and diesel. A PHEV charged by the most carbon-intensive generating plants is essentially equal to a conventional hybrid in terms of total greenhouse gas emissions. When you actually look at utilities' responses with respect to new generation, the increased regional requirements for renewables, and expected responses to future carbon constraints, the GHG reductions are considerable.

Electric vehicle technology is improving rapidly, although large scale commercialization of electric-drive vehicles is still difficult. Most of the fundamental technologies required for electric vehicles (EVs) and PHEVs, like motors and electric accessories, have been developed and commercially deployed in hybrid electric vehicles from a number of automotive manufacturers. However, powerful electric motors are still expensive, and the large 'energy' batteries required for EVs and PHEVs have not been produced in commercial quantities and the ability of these batteries to satisfy warrantee durability requirements has not been established. Automakers, EPRI, the DOE, and other organizations are performing the research to demonstrate the durability of the battery technology, but the work is still ongoing.

The infrastructure to support PHEVs is in place for initial vehicle deployments. PHEVs were designed with the lessons learned from difficulties in the attempt at EV commercialization in the mid-90's, so the amount of electrical energy on board was limited so that a PHEV could be charged overnight from a standard 120V wall plug. This means that a PHEV is equivalent to about 3 large-screen TVs, or a wall-mount air conditioner. As the number of PHEVs increases and as EVs are introduced into the market, infrastructure improvements will be required to: allow higher charge rates for a number of vehicles in a neighborhood, automate measurement of energy for reduced night-time rates, and allow public charging away from home and for people without garages.

Question 3. I was interested to learn that EPRI is moving forward with a large-scale technology smart grid demonstration program. I believe we must modernize our nation's electricity transmission and distribution system and to that end, Congress included a Smart Grid title in the 2007 Energy Independence and Security Act.

Why isn't EPRI working with the Energy Department as part of its Smart Grid Advisory Committee? Is EPRI working with the federal government in any capacity on Smart Grid issues?

Answer. EPRI is working closely with the Department of Energy, Environmental Protection Agency, Federal Energy Regulatory Commission, and the NationalInstitute of Science and Technology on Smart Grid issues. We meet regularly with each of these organizations to discuss interoperability standards, common information protocols, and the overall requirements for the Smart Grid. Recently, EPRI was invited by DOE to present "Smart Grid Characteristics, Values and Metrics" at its Smart Grid Implementation Workshop in Washington. We have also been invited to present at the July 23 FERC-NARUC Smart Grid Collaborative meeting. EPRI staff attended the first Electricity Advisory Committee meeting and the Institute would be most pleased to contribute technical information at any time. In addition, EPRI is developing a five-year Smart Grid Demonstration Initiative that is expected to have ten or more substantial demonstrations focusing on the integration of widely distributed resources. We anticipate broad stakeholder participation and close coordination with DOE.

RESPONSES OF TOM WILSON FROM SENATOR SESSIONS

Question 1. How do carbon emissions of plug-in hybrid vehicles compare to conventional gasoline-, diesel-, and hybrid-powered vehicles when taking the current national electricity mix into account?

Answer. EPRI recently examined this question in the most comprehensive environmental assessment of electric transportation to date. Conducted with the Natural Resources Defense Council (NRDC), the assessment focuses on the likely environmental impacts of bringing a large number of PHEVs onto American roads over the next half century.

The first part of the study used a scenario based modeling analysis to determine how PHEVs would change U.S. greenhouse gas (GHG) emissions between 2010 and 2050 under various circumstances. This inclusive "well to wheels" analysis tracked emissions from the generation of electricity to the charging of PHEV batteries and from the production of motor fuels to their consumption in internal combustion vehicles. Researchers used detailed models of the U.S. electricity and transportation sectors to create a range of potential scenarios and changes in both sectors. The three scenarios for the electricity sector represented high, medium, and low levels of carbon dioxide (CO_2) and total greenhouse gas emissions, as determined by the projected mix of generation technologies and other factors. For the transportation sector, the three scenarios represented high, medium, and low market penetration of PHEVs from 2010 to 2050. Results were unambiguous: GHG emissions were reduced significantly over the nine scenario combinations.

The cumulative GHG emissions reduction by 2050 was at least 3.4 billion metric tons (Gt), assuming a persistently high level of CO_2 intensity in the electricity sector and a low level of PHEV fleet penetration. Assuming low CO_2 intensity and a high level of fleet penetration, the cumulative GHG reduction was 10.3 Gt. Reductions were realized for each region of the country.

RESPONSES OF RAYMOND L. ORBACH TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. The TEA report lists Hydrogen Fuel Cell Vehicles as on [sic] of its 17 key technologies. In your testimony you list hydrogen as a fuel as an attractive, breakthrough technology, but one that is a longer-term possibility. Should it be considered as a technology that will be able to achieve significant market penetration by 2030? Will it be commercially viable before 2030? Before 2050?

Answer. The Department of Energy's (DOE) Hydrogen Program is working to overcome barriers to the commercialization of hydrogen and fuel cell technologies—including fuel cell vehicles (FCVs) as well as fuel cells for stationary and portable power applications. The Program is led by the Office of Energy Efficiency and Renewable Energy (EERE), and integrates EERE's efforts with the R&D efforts of the offices of Nuclear Energy, Fossil Energy, and Science, and coordinates with the Department of Transportation. The Program's primary strategic document, the Hydrogen Posture Plan, identifies a number of technology development targets in the 2015 timeframe that will enable automobile and energy companies to opt for commercialization of fuel cell vehicles (FCVs) and hydrogen fuel infrastructure by 2020. The Posture Plan is currently being updated by DOE.

Analysis conducted by Oak Ridge National Laboratory[1] suggests that if the Hydrogen Program's 2015 targets are met and effective transition policies are in place to overcome initial economic barriers, the market share of fuel cell vehicles could grow to 50 percent by 2030 and more than 90 percent by 2050. However, the exact timeline of market penetration and commercialization will depend on a variety of factors, including the pace of scientific and technological progress, the market's acceptance of a new technology, and the time it takes the private sector to make the necessary investments in infrastructure.

In 2004, the National Research Council conducted a comprehensive analysis of the path toward a hydrogen economy.[2] In its "optimistic scenario," hydrogen fuel cell vehicles would comprise 40 percent of new vehicle sales (not the fleet stock) in 2030.

Question 2. It is clear from the IEA report that the sooner we can implement technologies still in the basic and applied research stage, the more options we will have to reduce emissions. How can [sic] structure our R&D system to speed up the transfer of knowledge being generated from basic research to its implementation in the applied areas of technology development?

Answer. Department-wide research and development (R&D) integration activities seek to align the science programs and the technology programs to accelerate the seamless transfer of basic discovery science to the applied research and technology development stages. Science pursues high-risk, game-changing knowledge that has the potential to create transformational technologies. Science also seeks solutions to the longer-term scientific issues that challenge multiple technology platforms (such as materials in extreme environments, basic biological processes in plants and microbes that form the basis of renewable biomass, control of energy, and charge transduction in solar energy conversion). Technology programs focus on improving the performance and reliability of existing technology platforms towards specific near-to-mid-term goals. By housing science programs and technology programs in a single agency, DOE brings the strengths of both types of programs to bear in solving our Nation's energy security challenges.

The basic research programs in the Office of Science and the DOE applied technology programs also facilitate the bridging of basic and applied research by holding

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[1] Analysis of the Transition to Hydrogen Fuel Cell Vehicles and the Potential Hydrogen Energy Infrastructure Requirements (ORNL/TM-2008/30). March 2008. D. Greene et al & P. Leiby (ORNL); B. James & J. Perez (Directed Technologies, Inc.); M. Melendez & A. Milbrandt (NREL); S. Unnasch, D Rutherford & M. Hooks (TIAX)

[2] National Research Council. 2004. The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs. National Academies Press. www.nap.edu.

joint arantee and contractor meetings. These meetings promote communication between researchers and technology developers, stimulate the sharing of ideas, and promote collaboration to bridge and minimize gaps in the research continuum. The Hydrogen Fuel Initiative, for example, which funds both basic and applied research, promotes links between the two communities through joint meetings among all of the grantees to directly foster interactions and transfer knowledge. The Department's Small Business Innovation Research (SBIR) program also provides a mechanism for the research community to bridge basic and applied research for the development of new technologies.

There have been many cases of knowledge transfer between basic and applied research programs with successful industrial impact. One example concerns battery research. A basic research project initiated by the Office of Science at the Massachusetts Institute of Technology more than a decade ago led to the discovery of a new nanostructured cathode material for battery applications. Based on the knowledge gained, a new battery technology was developed by A123Systems of Watertown, Massachusetts. The development was further supported by a DOE SBIR grant starting in 2002 and support by the Office of Energy Efficiency and Renewable Energy. Within the last three years these new batteries have reached the commercial marketplace in power tools produced by North America's largest toolmaker, Black and Decker, and they currently are being implemented in hybrid and plug-in hybrid electric vehicles, amongst other applications. In early August 2007, Al23Systems and General Motors (GM) announced the co-development of Al23Systems' nanophosphate battery for use in GM's electric drive E-Flex system. This joint effort is expected to expedite the development of batteries for both electric plug-in hybrid vehicles and ftiel cell-based vehicles. This successful effort testifies to the importance of long-term, broad-based fundamental research: it also serves as a model for the Department's successful transfer of basic discovery research to breakthrough technology applications which underpin globally competitive U.S. industries.

Question 3. The IEA report emphasizes the need for RD&D partnerships in developing critical energy technologies. What current partnerships is the DOE office of Science involved in? What nations should we be pursuing closer research partnerships with?

Answer. The Office of Science has international research partnerships in a number of areas. The best examples of such partnerships are U.S. participation in the Large Hadron Collider, an important high energy physics experiment, and in ITER, an international partnership to build the first sustained burning plasma fusion experimental reactor. The common feature of these two experiments is their scale—their size would make it prohibitive for any one nation to attempt to build them.

The question of large-scale scientific facilities was one of the featured discussions at the G-8 Science Ministerial in Okinawa, Japan in June, 2008. The U.S. delegation raised the topic of the need for continued international cooperation on these large-scale science facilities; and Ministers generally understand the importance of cooperation not only to fund such large-scale projects, but also to gain the widest scientific, engineering and project management expertise possible. The G-8 Science Ministers will continue to discuss this issue at coming meetings, with the hope of creating a template for future international cooperation.

Secretary Bodman participated in the G-8 Energy Ministerial meetings in June where ministers and other high-level government officials from G8 countries, China. India, and Korea (G8+3) discussed ways to enhance global energy security, while simultaneously combating global climate change. During the meeting the G8 countries stressed the critical role of carbon capture and storage (CCS) in tackling the global challenges of climate change and energy security. The countries agreed to launch 20 carbon capture and storage demonstration projects by 2010. Under its restructured FutureGen program, the U.S. will provide funding for the addition of CCS technology to multiple commercial-scale Integrated Gasification Combined Cycle (IGCC) or other advanced clean-coal technology power plants. Additionally, the U.S. is funding nine large-scale field tests of geologic storage of carbon dioxide (injecting at least 500,000 tons/year of carbon dioxide), using carbon dioxide from a variety of conventional sources.

Secretary Bodman and his G8+3 colleagues agreed to the establishment of the International Partnership for Energy Efficiency Cooperation (IPEEC). The IPEEC will serve as a high-level forum for facilitating a broad range of actions that yield high efficiency gains. The partnership will support on-going work of the participating countries and relevant organizations, exchanging, information of best practices policies and measures and developing public-partnership in key energy consuming sectors as well as on a cross-sectoral basis.

Question 4. Undersecretary Orbach, you oversee the Department's science and technology portfolio and you have often stated it is your job to manage this portfolio in an integrated fashion. Can you please explain the programs you have or are proposing for FY2009 that integrate the Office of Science activities with those of the applied energy programs?

Answer. The Office of Science (SC) provides basic research in broad areas relevant to the Department's applied programs, as well as to applied research programs in universities, research institutions, and industry. This support is provided primarily through our Basic Energy Sciences, Biological and Environmental Research, Advanced Scientific Computing Research, and Nuclear Physics programs, although other SC programs have also provided discoveries that have application in applied research.

The Department's July 2006 report, "DOE Strategic Research Portfolio Analysis and Coordination Plan," identified 21 additional areas of opportunity for coordination that have great potential to increase mission success. SC supports basic research and coordination efforts that underpin nearly all 21 areas, and six areas are highlighted in the FY 2009 SC budget request for increased R&D coordination: Advanced Mathematics for Optimization of Complex Systems, Control Theory, and Risk Assessment; Electrical Energy Storage; Carbon Dioxide Capture and Storage; Characterization of Radioactive Waste; Predicting High Level Waste System Performance over Extreme Time Horizons; and High Energy Density Laboratory Plasmas. The Office of Science request for FY 2009 R&D coordination is $114.9 million. These areas are in addition to the research areas the Office of Science has coordinated with the Department's applied programs over the past several years, including hydrogen production, storage, and use; solar energy utilization; biofuels derived from biomass; advanced nuclear fuel cycle technologies; and building technologies and efficient industrial process.

SC also proposes in our FY 2009 budget to initiate new models of research management. Following on the success of the Bioenergy Research Centers, which recently began operations. the request provides competitive funding for Energy Frontier Research Centers. These centers, which we expect will be built around collaborations among universities, laboratories, and private entities, will allow SC to harness even more of the Nation's inventive genius in pursuit of energy and national security, as well as economic competitiveness. We expect these basic research effiwts will have significant benefits for applied energy research.

Question 5. Undersecretary Orbach, you have often stated that while it is important for the Office of Science to integrate in with the activities of the applied energy programs—they should not drive the Office of Science—you often call this a reverse osmosis effect—can you please explain what you mean by that?

Answer. Reverse osmosis is, perhaps, not the best analogy. The issue has to do with the extent to which basic research should he independent of direction by the technology needs of the Department, While basic research should collaborate with the applied programs, it should never be directed by them. Such direction, even if well-intentioned, could serve to down-select basic research solely to those areas of greatest perceived promise and thus diminish the potential for basic research discoveries and breakthroughs to bring to light new technology solutions that may have broader. unexpected impacts. The R&D community and the science mission agencies have long recognized that the results of basic research often cannot be foretold. A single basic research discovery can have hundreds, if not thousands of applications, which may evolve only gradually over time. That is the unique benefit of basic research—to the Department's technology programs and to the Nation. At the same time, however, the basic research community should be informed of the needs of the applied research community and the technological barriers they face and should develop basic research directions ("use-inspired" research) that attempt to answer questions and acquire the fundamental knowledge needed to overcome the technological barriers. Such communication has been facilitated by the technical workshops the Office of Science has lead over the past six years.

I would also like to point out that attempts in the past to place an applied technology "filter" on basic research programs in the mission agencies have not been successful. The well intentioned attempt of the Mansfield Amendments of 1973, for example, to tightly couple basic research to applications failed to achieve the desired results and had adverse impacts on basic research that have reverberated throughout the research enterprise. The Mansfield Amendments also famously separated the basic academic research community from the defense R&D establishment and negatively affected the NASA and AEC realms as well. Such attempts to "direct" basic research drive federal agencies to place greater focus on short-term R&D at the expense of longer-term basic research. Private sector R&D is also increasingly focused on short-term R&D with demonstrated value to company stockholders. As a result, basic research funding in the U.S. has been relatively flat in recent years. If this trend continues, the U.S. will find it increasingly difficult to develop the truly transformational energy technologies we need to maintain our global leadership and economic competitiveness.

Question 6. Undersecretary Orbach, in my visits to the national laboratories it is becoming apparent to me that facilities like the Combustion Research Facility at Sandia Livermore are becoming the de facto interface between basic and applied programs. Does the Department realize that this gap exists in translating basic energy research into applied research and what is it doing to solve this problem?

Answer. The Department of Energy (DOE) has long recognized the challenge of translating basic energy research into applied programs and ultimately into transformative energy technologies. The ongoing efforts to identify and address priority research needs that help bridge the gap between basic and applied research include the DOE scientific and technical workshops and the basic and applied R&D coordination working group efforts, and Federal and DOE laboratory working groups.

The example you cite, the Combustion Research Facility (CRF) at Sandia National Laboratories, Livermore, is one of many examples of a successful interface between basic and applied energy programs at the DOE laboratories. The CRF was originally implemented 28 years ago as an Office of Science user facility and, as with all SC user facilities, has served both basic and applied researchers in the area of combustion science by providing unique experimental and computational resources. Over the years, the CRF has evolved into a laboratory with a significant internal portfolio of basic research, supported by the Office of Science, and applied research, supported by DOE technology programs. At the same time, the CRF has maintained a leading presence in the combustion science community as a center for collaborative research that has included strong connections with th U.S. automotive and engine manufacturing industries.

There are numerous other examples beyond CRF and vehicle technologies where the co-siting and co-funding of basic and applied researchers have led to effective knowledge transfer and significant technological progress. Examples of such successes include multi-junction solar cell research at the National Renewable Energy Laboratory that set the world record in photovoltaic efficiency; development of intermetallic alloys at Oak Ridge National Laboratory that achieved savings of millions of dollars at U.S. steel plants; and ultrananocrystallince diamond research at Argonne National Laboratory that enabled world-wide commercialization of abrasion-resistant coatings.

Furthermore, knowledge transfer is best accomplished by people—and SC supports the training of large numbers of students and researchers by funding their experiments and their use of major SC facilities such as light sources, neutron sources, Nanoscale Science Research Centers, electron micro-characterization facilities, and supercomputers. The Department will continue these and other efforts to enhance the integration of basic and applied research at scientific user facilities, DOE national laboratories, U.S. universities, and industries and to better address the critical need to translate basic scientific discovery into transformative energy technology.

Question 7. Undersecretary Orbach—along these lines of inquiry—why hasn't the Department been able to initiate a focused basic research program to support the applied programs in solid state lighting, it seems a natural area for your nanosciencc areas but for more than four years no such program has emerged?

Answer. The Office of Science (SC) supports a forefront Fundamental research program that builds a solid foundation of new knowledge to increase our understanding of how nature works, helping create transformational technologies for long-term energy security. Specifically, SC-supported nanoscience research focuses on understanding and controlling matter at the quantum, atomic, and molecular levels, where energy is generated, stored, transferred, and utilized. Such knowledge will impact a broad range of current and future generation energy technologies, including lighting applications.

In the spring of 2006, SC held a workshop on basic research needs for solid state lighting, which further highlighted the impact of nanoscience on energy applications. Had the FY 2008 appropriation supported the requested level, we would have been able to initiate a focused solid state lighting research program during FY 2008; however, it did not. The FY 2009 budget request proposes Energy Frontier Research Centers that will bring together teams of investigators to address the grand challenges in basic research, as identified in several workshops, and could include solid state lighting research.

Question 8. Undersecretary Orbach,—Table 5.3 in the ETP 2008 report seems to me to be the critical underpinning of implementing technologies in a carbon constrained world, I ask that the Department please evaluate this table and give the committee its opinion on current cost, learning rate and cost to target to reach commercialization?

Answer. While I cannot comment on the specific economic assumptions and predictions contained in the table, I can state that each of these forms of energy generation may require additional basic and applied research to make it a desirable alternative.

RESPONSES OF RAYMOND L. ORBACH TO QUESTIONS FROM SENATOR DOMENICI

The Energy Technology Perspectives report emphasizes the importance of funding for basic science education and technology research and development, particularly in energy. The IEA analysis says that funding in these areas is half what it was 25 years ago.

Question 1. Although the U.S. science and technology R&D funding is significantly greater than that of other countries, do you believe there is a need to reprioritize funding to better support energy technology development?

Answer. The Office of Science (SC) is constantly assessing the priorities of our research efforts to ensure the best return on investment to the U.S. taxpayer and support the Department's mission. In setting priorities we consider existing and developing mission needs and areas of greatest promise for basic research, as informed by a series of rigorous assessments. These assessments include National Academy of Sciences studies, SC research planning workshops, and SC Advisory Committees' reports, as well as coordination across the Administration and consultation with the Congress. Congressional Committees of Jurisdiction receive information on SC priorities primarily through the budget process but SC also provides the Committees and interested Members with information from the various expert professional assessments it commissions.

Further, SC is proposing to initiate a new model of research management and prioritization. Following on the success of the Bioenergy Research Centers, which recently began operation, the Office of Science will provide competitive funding for Energy Frontier Research Centers. These centers will allow the Office to harness even more of the Nation's inventive genius in pursuit of our goals of energy and national security, as well as economic competitiveness.

Question 2. The Energy Technology Perspectives report considers technology implementation over the next 40 years. Even with this horizon the TEA argues that it is necessary to make technology selections today given the long economic life typical of energy generation and industrial facilities.

Of the transformational technologies you discussed in your testimony, which do you believe have the best prospects for impacting the implementation of low carbon technology on that time scale?

Answer. The transformational technologies I mentioned will result from basic research investments we make today. I expect many of the technologies will be available within 40 years, but it is difficult to predict precisely. In the area of biological innovation, where the investment is quite large in terms of facilities, researchers, and research facilities we may see transformational changes in years, rather than decades. But fusion energy, for example, which holds tremendous long-term potential, is still decades away, and will likely be nearing commercialization towards the end of 40 years.

It is important to maintain a balanced research portfolio to assure that we have the ability to continue to build our energy supply through currently existing low carbon methods such as nuclear energy, coal with sequestration, and renewables, while continuing to pursue breakthroughs in transformational energy research areas.

Question 3. The Energy Technology Perspectives report describes a number of CO_2 emission reduction scenarios based on modeling of the global economy. How well do you think these models reflect the particular realities of the U.S. economy? Are there certain technological options that the U.S. might not benefit from or, alternatively, might receive greater benefit from?

Answer. Energy Technology Perspectives 2008 (ETP'08) contains an assessment of clean energy technologies, roadmaps to commercialize these technologies and emission reduction scenarios ("Baseline", "ACT" and "Blue" scenarios). ETP'08 does not provide country-level data so a direct comparison with U.S. energy-technology models is not possible. Nonetheless, the technology strategies identified in the U.S. Climate Change Technology Program Strategic Plan (September 2006, DOE/PI-0005) are consistent with those outlined in ETP'08. All important energy technologies identified in ETP'08 are part of DOE's technology portfolio and supported in the President's FY 2009 budget request.

RESPONSES OF RAYMOND L. ORBACH TO QUESTIONS FROM SENATOR BUNNING

Question 1. Mr. Orbach, you suggest that much of our needs could be met by nuclear power, but you also mention that many hurdles stand in the way. While I understand some of these obstacles like the Yucca Mountain program that has been stalled by some of my colleagues, would you please offer this committee any policy suggestions that we can hopefully pass today to make new nuclear facilities a real source of power?

Answer. While it is too early to declare victory, I remain guardedly optimistic that we will see new nuclear capacity during the next decade. Over the last 5 years, there has been significant progress in revitalizing commercial nuclear power within the United States, stemming from federal energy policy, market conditions and forecasts, and concerns over carbon emissions. The nuclear industry has indicated interest in submitting applications to construct up to 34 new reactors domestically; applications that cover 18 units have already been received by the Nuclear Regulatory Commission.

Equally important to bringing new reactors online is maintaining the current fleet of 104 operating reactors. Operating these reactors for periods longer than their present certification requires better understanding of plant components and systems. I believe the best strategy to achieve the required level of understanding is through development and application of science-based tools that can systematically evaluate the components and systems of these reactors, which I believe is necessary to ensure their continued contribution to our energy portfolio for as long as reasonably possible.

And finally, we need to fully implement the Advanced Fuel Cycle Initiative/Global Nuclear Energy Partnership, which will help reduce proliferation risks and address longer-term waste concerns. We want to work with emerging nuclear power nations as they take their first steps to help ensure that increases in global demand for nuclear energy are met with proliferation-resistant solutions.

Question 2. I want to be clear—I support efforts to expand wind and solar energy where it makes economic and logistical sense. However, I am not naive—the wind does not always blow and the sun does not always shine. And in times like these, I believe it is critical that our nation's electric grid have a backstop to ensure generation does not cease due to weather conditions. Dr. Orbach, would you agree that until renewable energy can be stored at a level that meets all the demands of our utility grid, our nation would be wise to also invest in other advanced energy infrastructure—like new coal plants and nuclear plants—that meet future demand no matter the forecast?

Answer. Yes. While the Administration promotes all forms of clean energy through the Department of Energy's research and development programs, there are currently no proven technologies other than coal and nuclear power that can provide large quantities of "always on" electricity needed to power America's businesses and industry. The Department is focusing its research and development efforts on advanced energy technologies that could transform the way we produce and use energy. Basic and applied research that could improve technology to capture and store electricity is key to deploying some renewable energy technologies at a greater scale. Investing in a portfolio of energy technologies, including nuclear and coal, is the best approach to meeting the Nation's near-term and long-term projected energy demands.

Question 3. Dr. Orbach, you mentioned that scientific breakthroughs in bioenergy can change the whole equation. While I hope you to be right. I would also like to look at what can be done today to diversify our nation's fuel source outside of our agriculture industry. That is why I introduced coal-to-liquid legislation. This clean burning diesel and jet fuel allows our nation to kick its dependence on middle east oil and keeps energy dollars here at home. Would you agree that if given similar incentives to that of bioenergy, CTL could increase our energy supply and bring relief to domestic air carriers, along with other forms of American transportation?

Answer. Depending on the economics of production and the price of transportation fuels, coal-to-liquids technology could increase our diesel and jet fuel supply. The U.S. Government—directly and through industrial partnerships and international cooperation—has previously supported research and development on coal-to-liquids technology. These government programs resulted in improved processes, catalysts and reactors. In part as a result of these past efforts, technology is commercially available for producing liquid fuels from coal that are clean, refined products requiring little if any additional refinery processing. These fuels can use the existing fuels distribution and end-use infrastructure. The greatest market barriers for commercial introduction of the technology in the U.S. are the uncertainty of world oil prices, the high cost of coal to liquids production coupled with high initial capital cost, the long decision-to-production lead times, and the challenge of incorporating carbon management into producing coal-to-liquid products.

Question 4. Dr. Orbach, I often hear that the United States must do more as a leader of clean technologies. Yet, some of the folks who make this argument object to policy that would give clean coal technology the same incentives given to wind and solar energy, even as China builds roughly 50 coal plants a year. You said that there are obstacles when addressing carbon sequestration and clean coal technology, but do you believe that if given the same incentives as other clean technologies, United States clean coal can change the way the world approaches coal generation?

Answer. Clean coal technology is an important component of the Administrations vision for a cleaner, more secure energy future. Advancements in this technology can address concerns about CO_2 emissions and global climate change while maintaining coal's important role in our economic and energy security. Proper incentives and policy can support the development of technologies for affordable CO_2 capture and Carbon Capture and Storage (CCS) demonstration projects that will help accelerate their deployment in the energy market. In addition, the Department is working through the Office of Fossil Energy's Carbon Sequestration Program to develop low-cost novel technologies to capture CO_2 and to validate the safety and effectiveness of CO_2 geologic sequestration. However, technology development takes significant time and resources. Scaling from laboratory experiments to a commercial operation may require years of effort and investment both by the Federal Government and industry.

[Responses to the following questions were not received at the time the hearing went to press:]

QUESTIONS FOR RAYMOND J. KOPP FROM SENATOR BINGAMAN

Question 1. In your testimony you make the important point that only with complementary policies will an energy technology deployment scheme be workable. Can you speak to the effectiveness of the EU ETS in encouraging the development and deployment of clean energy technologies?

Question 2. In regards to carbon pricing and carbon allowance allocation, the IEA report makes the statement that given the distinct sector emission reduction pricing ranges and option characteristics, a single generic price or cap across the whole energy system may not be the best approach to incentivizing CO_2 reductions. In such circumstances, industries with cheaper options could benefit from large windfall profits. Do you have any thoughts on a workable allocation or pricing scheme that would avoid such a situation?

QUESTIONS FOR RAYMOND J. KOPP FROM SENATOR DOMENICI

In your testimony you refer to the impact that public perceptions have on the adoption of low carbon emitting technology. Perceived risks and "not in my back yard" concerns have certainly had an impact on needed expansions to the electrical grid and adoption of clean nuclear and renewable technologies.

Question 1. Can you suggest ways in which we might educate the public on the fundamental issues associated with energy technology and greenhouse gas emissions so that they can make better informed cost benefit decisions?

Question 2. We all recognize that renewable energy must be part of the solutions to meet ever increasing global energy demands while also addressing CO_2 emissions. However, setting goals and targets is quite a different thing than actually accomplishing them. I understand that there is a significant backlog of renewable energy projects that are unable to transmit their energy to the grid. The fact is that with only a 6.8% growth in total transmission line miles since 1996, our nation's infrastructure development is simply not keeping pace with system demands.

Do you agree that one of the major obstacles to the development of renewable energy is the lack of available transmission capacity to bring alternative energy resources online? In EPAct 2005, Congress sought to address transmission siting in general through the use of National Interest Electric Transmission Corridors in areas of severe congestion. In addition federal authority needed to ensure the necessary transmission infrastructure?

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