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ELECTRICITY GENERATION

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED EIGHTH CONGRESS

SECOND SESSION

ON

SUSTAINABLE, LOW EMISSION ELECTRICITY GENERATION

APRIL 27, 2004

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ELECTRICITY GENERATION

TUESDAY, APRIL 27, 2004

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

The committee met, pursuant to notice, at 10:03 a.m. in room SD–366, Dirksen Senate Office Building, Hon. Pete V. Domenici, chairman, presiding.

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

The CHAIRMAN. The hearing will please come to order. This hearing of the Energy and Natural Resources Committee on sustainable low-emissions electricity generation shall come to order. This committee has heard testimony in several previous hearings about our growing dependence on imports of oil and now we are beginning to see how we are going to become more and more dependent, if things do not change, on natural gas from overseas or a substitute for it.

We have all heard serious questions about the availability of these precious resources. Past hearings have noted alarming statistics. Oil imports now fulfill about 55 percent of the total U.S. petroleum demand, with projection that imports will reach 70 percent of the U.S. needs by 2025. Natural gas imports are similarly expected, believe it or not, to be 23 percent of the total demand by 2025.

These trends are disturbing enough in the near term, but in the longer term we face far greater challenges if we want to maintain our standard of living, our strong economy that runs on energy. Natural gas and crude oil are finite resources. Experts debate when supplies will dwindle to the point that it will no longer make economic sense to use them in electricity generation and transportation. Few people will argue that these resources are sufficient to maintain our thirst for energy throughout the next century.

In this hearing, we look beyond the next few decades to the days when natural gas and oil simply cannot be used to provide economic electricity generation or transportation fuels. Today we want to ask what we should be doing today to prepare for that future. Only three sources of energy in use today have the potential to expand substantially to take up the slack when we are forced to shift from oil and gas. Those are renewable sources of energy, nuclear energy, and clean coal. Only these three sources clearly have the potential to protect the environment and meet our energy needs beyond this century.

Some may argue that only one of these sources can meet our needs if only we expand our conservation efforts. I do not believe that. Conservation is vital, but it is not the whole answer to our future needs. Diversity of energy sources is equally vital. Our Nation will need all the energy resources it can produce, or maybe there I should say the new sources we can produce.

I hope our witnesses today will share their perspective on the energy demands and the challenges of the future. In addition, I would like to hear their views on the research and development efforts that must be undertaken now to prepare for that future.

Testifying today before us are Dr. Richard Smalley, a winner of the Nobel Prize for pioneering work in nanotechnology and director of the Carbon Nanotechnology Laboratory at Rice University. We are very, very appreciative that you joined us today and we are very pleased to know that we have an American of such accomplishments as you. Thank you so much.

Dr. SMALLEY. Thank you.

The CHAIRMAN. We have the Honorable David K. Garman, Acting Under Secretary for Energy Sciences and Environment and Assistant Secretary of Energy Efficiency and Renewable Energy in the Department; Dr. Ernest J. Moniz, professor of physics at MIT and Under Secretary of the Department of Energy in the Clinton administration. That is where I first met him and it was a pleasure working with him there then because he knew a lot and it was good to have somebody in the Department that knew a lot.

Dr. Francis—I do not know what I am saying.

Dr. MONIZ. I appreciate it.

The CHAIRMAN. I will just stop there.

Dr. Francis P. Burke, vice president for research and development at CONSOL Energy, Inc. We look forward to your testimony today.

Senator Bingaman, do you care to make an opening statement?

Senator BINGAMAN. Well, very briefly, Mr. Chairman. Thanks for having the hearing. I think this is a very important issue. Obviously it is an important issue because of the problems that we can foresee related to price and availability of oil and gas in the future, but also of course with regard to emissions and how we position ourselves to deal with the need to reduce emissions, CO_2 emissions in particular, as we move forward.

The information I have been given here is that in 2002 electricity generation represented 39 percent of the Nation's carbon dioxide emissions. In 2025, according to the EIA the estimate is that electricity production will account for about 40 percent of our total carbon dioxide emissions.

The CHAIRMAN. What is the 2002 one?

Senator BINGAMAN. 39 percent. So clearly it is a major issue. The question of which technologies we can use to generate electricity is a major factor in determining whether we come to grips with this emissions problem as well. You have an excellent group of witnesses here and I look forward to hearing from them.

Thank you.

The CHAIRMAN. Thank you very much.

Senator Bunning.

STATEMENT OF HON. JIM BUNNING, U.S. SENATOR FROM KENTUCKY

Senator BUNNING. Thank you, Mr. Chairman. I am pleased that we are having this hearing today and I want to thank you for holding it.

The CHAIRMAN. You are welcome.

Senator BUNNING. I think it is important that we remain focused on our needs to increase our domestic energy production and lessen our dependency on foreign nations such as those in the Middle East. While we appear to be trying to move away from combat in Iraq, there is still a lot of uncertainty in the Middle East. The need to increase our own production of energy has never been more important than now.

This hearing is especially important because of the high price of oil and natural gas and gasoline. We need to have alternative forms of energy to keep the cost of energy in our country down.

I am proud to be from a coal State. Generations of Kentuckians have made their living in coal fields and coal mines. For the last decade, coal in Kentucky has been on the downturn because of Federal legislation and regulation policies which forced electric generation to invest in natural gas-fired facilities instead of coal. Now I am glad to see that we have turned things around and are taking steps to make sure that coal continues to play a vital role in meeting our future energy needs.

This focus on clean coal is good for the environment. It is certainly good for the economy and for putting people back to work. It is also a good way to decrease our reliance on foreign sources of energy. Clean coal technology will result in a significant reduction in emissions and a sharp increase in energy efficiency of turning coal into electricity. I hope that we can continue to work to bring new clean coal technology quickly into the commercial sector.

I thank our witnesses for appearing before us today to discuss this important topic. I look forward to hearing their testimony.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you very much, Senator.

The Senator from Hawaii.

STATEMENT OF HON. DANIEL K. AKAKA, U.S. SENATOR FROM HAWAII

Senator AKAKA. Thank you Mr. Chairman, for convening today's hearing on this extremely important topic. I would like to add my welcome to our distinguished witnesses today, Dr. Richard Smalley, Dr. Ernie Moniz, and Dr. Francis Burke. I would like to offer a special aloha to Dave Garman whom I have known for many years when he worked for the Senate, and I want to send my aloha to the family, too, Dave, and welcome you to this hearing.

Mr. Chairman, the quality of the air Americans breathe has improved significantly over the last 20 years, but many challenges remain in protecting public health and the environment. One of the most significant challenges is to reduce airborne pollutants released from the Nation's powerplants, especially those fueled by coal. I want to say to my friend the Senator from Kentucky that I am not against coal. I am just pointing out a fact here. Carbon dioxide emissions are not regulated under the Clean Air Act, but there is a growing interest in requiring reporting and reductions in carbon dioxide emissions.

More than one-half of electricity generated in the United States today comes from coal. While coal is the Nation's major fuel for electric power, natural gas is the fastest growing fuel. Natural gas is more plentiful than oil in the United States, but as demand increases domestic producers must turn to deeper and more expensive gas reservoirs. As demand and costs for natural gas rise, alternative electricity sources such as clean coal, nuclear, and biomass will play an increasingly important role as potential sources of energy.

Hawaii's overall energy prices are the second highest in the Nation, behind the District of Columbia. Our prices of electricity rank among the highest in the Nation, which is a dubious honor because our gasoline prices are also consistently the highest in the Nation. Most of Hawaii's electricity is generated by petroleum-fired plants, and data indicate that over the last decade, while sulfur dioxide emissions from utility plants in the State were falling, emissions of nitrogen oxides and carbon dioxide were increasing.

The State of Hawaii has moved ahead in providing guidelines for requiring renewable sources of electricity for its residents. Currently, 8.4 percent of our electricity in the State is from renewables, while nationally just 2 percent of electricity is from renewable sources. Electricity generated from solar, wind, biomass, geothermal, municipal solid waste, and hydro sources all play a role in Hawaii's renewable portfolio.

As you know, I have long been a supporter of sustainable energy sources. I am confident that American scientific ingenuity, through basic R&D can help make low-emission and sustainable electricity competitive in the markets of the future.

Mr. Chairman, you have convened an outstanding panel of forward-looking witnesses today to help us understand the future of low emission and sustainable electricity generation. With Hawaii's unique situation, I look forward to hearing various perspectives on how we will be able to move from petroleum dependency to more sustainable and healthier electricity generation.

Thank you very much, Mr. Chairman.

The CHAIRMAN. Senator Murkowski.

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

Senator MURKOWSKI. Mr. Chairman, thank you for calling this hearing on sustainable low emissions electricity generation. Promoting technologies to generate electricity in an environmentally friendly and cost-effective way is one of my top priorities. About 70 percent of our Nation's electricity is generated by the combustion of fossil fuels, 50 percent from coal, 18 percent from natural gas, 2 percent from oil. Despite sustained high natural gas prices, almost all new generating capacity in America built over the last few years is designed to run solely on natural gas. By 2025, EIA predicts natural gas will account for about 23 percent of all electricity generation. It is clear that Congress must act to increase our domestic supplies of natural gas.

On April 2 I sent a letter to each of my colleagues outlining the importance of an Alaskan natural gas pipeline to our economic recovery and job creation. As this committee looks for ways to generate electricity in an environmentally responsible manner, I encourage my colleagues who are opposing the energy bill to reconsider their position. The energy bill takes some important first steps towards increased use of sustainable low emission electricity generation. It also includes the necessary fiscal and regulatory provisions to lesson the cost of financing the construction of an Alaska natural gas pipeline. It streamlines the permitting process and expedites judicial review of the project. In passing the energy bill, we can unlock 35 trillion cubic feet of proven reserves of natural gas stranded on Alaska's North Slope.

While natural gas is increasingly important as part of our electricity generation mix and will become even more so in the future, coal still remains the backbone of our electricity portfolio. There are several emerging technologies that are being developed to find new ways to use our abundant coal resources in an environmentally responsible way. Again, I would like to remind my colleagues that this is an area where the energy bill, which is currently stalled in the Senate, can help.

The coal title of the energy bill authorizes $2 billion to fund the Clean Coal Power Initiative. The development of clean coal technology will help our Nation use its abundant coal resources in an environmentally responsible manner. In Alaska we are working to find new ways to use our reserves while mitigating the impact on the environment.

In Healy, Alaska, we have a small experimental clean coal powerplant which is sitting dormant because it just barely missed its emissions requirements. The Healy clean coal plant is illustrative of why the Federal Government must take the lead in investing in emerging technologies. Once the kinks can be worked out, new processes that will greatly benefit the environment and that may not have been developed without Federal support can become economically viable and eventually commercial.

Once the Healy clean coal plant and other clean coal technologies demonstrate better ways for us to generate electricity from coal, we can utilize our Nation's vast coal resources in an environmentally responsible manner. As we work together to promote the construction of the Alaska natural gas pipeline and look for cleaner ways to utilize our coal resources, we must also consider other low-emission electricity generation, such as nuclear and renewables.

The renewable energy production incentive program which is reauthorized in the energy bill is vital for the development of renewable energy technologies, such as wind and geothermal. This incentive program is particularly important for small rural electric cooperatives, like those in Alaska, which are seeking new ways to generate electricity in sustainable and cost-effective ways while protecting the environment at the same time.

Part of this hearing and the testimony is going to focus on the need to have a work force educated in the physical sciences to work on these emerging technologies. I agree that as we promote new technologies we must always remember that our trained work force is vital if these technologies are going to become a commercial reality.

Mr. Chairman, I appreciate the opportunity to listen to the panel of witnesses that you have brought before us today. I am looking forward to their comments, and again I thank you for the highlight on this very important issue.

The CHAIRMAN. Thank you very much, Senator. I do want to say we are all aware now that the energy bill is at least in two parts: the part that is the tax provisions, which principally if completed in their totality would be production tax credits for solar, wind, bio, and then also the same for nuclear and a very similar one for clean coal; we will then, hopefully before the year is out, move to the rest of the bill. It will have a lot of amendments on it, just because there are many who do not share our interest in getting it done, and there are some with legitimate amendments.

I am going to move now to Dr. Smalley. I just mentioned who you were and what you were and that little tiny bit was enough to distinguish you. I want to call to everyone's attention a statement, just a little tiny statement in his statement. It says at a point in your statement: "However, I am an American scientist, brought up in the Midwest during the Sputnik era, and, like so many of my colleagues in the United States and worldwide"—most important five words—"I am a technology optimist."

With that, I would ask for your testimony.

STATEMENT OF RICHARD E. SMALLEY, Ph.D., DIRECTOR, CARBON NANOTECHNOLOGY LABORATORY, RICE UNIVERSITY

Dr. SMALLEY. Thank you, chairman.

Energy is the single most important challenge facing humanity today. As we peak in oil production and worry about how long natural gas will last, life must go on. Somehow we must find the basis for energy prosperity for ourselves and the rest of humanity for the 21st century. By the middle of this century, we will need to at least double world energy production from its current level, with most of this coming from some clean, sustainable, CO_2-free source. For worldwide peace and prosperity, it must be cheap.

We simply cannot do this with current technology. We need revolutionary breakthroughs to even get close. As the chairman said, let me repeat, I am an American scientist, brought up in the Middle West in the Sputnik era, and I am a technology optimist. I think we can do it. We can find the new oil, the new technology that provides massive clean, low-cost energy, the energy necessary for an advanced civilization of what may very well be ten billion human beings on this planet before this century is done.

Electricity I am quite convinced, electricity is the key. Consider for example a vast interconnected electrical energy grid for the North American continent from above the Arctic Circle down to below the Panama Canal. By 2050 this grid will interconnect several hundred million local sites. There are two key aspects of this future grid that will make a huge difference: one, massive long-distance electrical power transmission; and two, electrical storage, storage of electrical power on local sites with real-time pricing.

Storage of electrical power is critical for stability and robustness of the electrical power grid and it is absolutely essential if we are ever to use solar and wind as our dominant primary energy source. The best place to provide the storage is locally, near the point of use. Imagine by the middle of the century that every house, every business, every building, has its own electrical energy storage device, equivalent to an uninterruptible power supply capable of handling the entire needs of that site for 24 hours.

Since the devices are small and relatively inexpensive, the owners can replace them with new models every 5 years or so as worldwide technological innovation and free enterprise continuously and rapidly develop improvements in this most critical of all aspects of the electrical energy grid.

Today, using lead-acid storage batteries such a unit for a typical house storing 100 kilowatt-hours of energy would take up a small room and cost over $10,000. But through the revolutionary advances in nanotechnology, it may very well be possible to shrink the size of that unit down to the size of a washing machine and drop the cost below $1,000. With intense research and entrepreneurial effort, many schemes are likely to be developed over the years to supply this local storage technology, a market that very well may expand to several billion units worldwide. Think of the automobile industry, but in your home.

With these advances, the electrical grid can become exceedingly robust. Its local storage protects the customers from power fluctuations and outages. With real-time pricing, the local customers have incentive to take power from the grid when it is cheapest. This in turn permits the primary electrical providers to deliver their power to the grid when it is most efficient for them to do so, and it vastly reduces the requirements for reserve capacity to follow peaks in demand. Most importantly, it permits a large portion or even all of the primary electrical power in the grid to come from solar and wind.

The other critical innovation needed is massive electrical power transmission over continental distances, permitting, for example, hundreds of gigawatts of electrical power to be transported from solar farms in New Mexico to markets in New England. Then all primary power producers can compete with little concern for the actual distance to market.

Clean coal plants in Wyoming or Kentucky, stranded gas in Alaska, wind farms in North Dakota, hydroelectric from northern British Columbia, biomass from Mississippi, nuclear power from Hanford, Washington, solar power from the vast deserts, all of these remote powerplants from all over the continent can now contribute power to consumers thousands of miles away on the grid. Everybody plans.

Nanotechnology in the form of single-walled carbon nanotubes forming what we call the Armchair Quantum Wire may play a big role in this new electrical transmission system. Such innovations in power transmission, power storage, and the massive primary power generation technologies themselves can only come from miraculous discoveries in science together with free enterprise and open competition for huge worldwide markets.

America, this land if technological optimists, this land of Thomas Edison, should take the lead. We should launch a bold new energy research program. Just a nickel for every gallon of gasoline, diesel oil, and fuel oil would generate $10 billion a year. That would be enough to transform the physical sciences in this country and to inspire a new Sputnik generation of American scientists and engineers.

At minimum, it will create a cornucopia of new technologies that will drive wealth and job creation for this next generation in our country. At best, it will solve the energy problem within this generation, solve it for ourselves and, by example, solve it for the rest of humanity as well.

It sounds corny, but I think it is a good line: Give a nickel, save the world.

Thank you.

[The prepared statement of Dr. Smalley follows:]

PREPARED STATEMENT OF RICHARD E. SMALLEY, PH.D., DIRECTOR, CARBON NANOTECHNOLOGY LABORATORY, RICE UNIVERSITY

I appreciate the opportunity today to testify to your committee on this most important of issues.

We are heading into a new energy world. With economic recovery in the countries of the OECD and rapid development of China and soon India, huge new demands will be placed on the world oil and gas industry. Yet oil production will probably peak worldwide sometime within this decade, and the future capacity of natural gas production is unclear. Coal will be able to pick up some of the slack, but with current technology this will amplify the threat of massive climate change.

Energy is at the core of virtually every problem facing humanity. We cannot afford to get this wrong. We should be skeptical of optimism that the existing energy industry will be able to work this out on its own.

Somehow we must find the basis for energy prosperity for ourselves and the rest of humanity for the 21st century. By the middle of this century we should assume we will need to at least double world energy production from its current level, with most of this coming from some clean, sustainable, CO2-free source. For worldwide peace and prosperity it needs to be cheap.

We simply cannot do this with current technology. We will need revolutionary breakthroughs to even get close.

Oil was the principal driver of our economic prosperity in the 20th century. It is possible that Mother Nature has played a great trick on us, and we will never find another energy source that is as cheap and wonderful as oil. If so, this new century is certain to be very unpleasant.

However, I am an American scientist brought up in the Midwest during the Sputnik era, and like so many of my colleagues in the US and worldwide, I am a technological optimist. I think we can do it. We can find "the New Oil", the new technology that provides the massive clean energy necessary for advanced civilization of the 10 billion souls we expect to be living on this planet by 2050. With luck we'll find this soon enough to avoid the terrorism, war, and human misery that will otherwise ensue.

Electricity is the key. As we leave oil as our dominant energy technology, we will not only evolve away from a wonderful primary energy source, but we will also leave behind our principal means of transporting energy over vast distances. By 2050 we will do best if we do this transportation of energy not as oil, or coal, or natural gas, or even hydrogen. We should not be transmitting energy as mass at all. Instead we should transport energy as pure energy itself.

Consider, for example, a vast interconnected electrical energy grid for the North American Continent from above the Artic Circle to below the Panama Canal. By 2050 this grid will interconnect several hundred million local sites. There are two key aspects of this future grid that will make a huge difference: (1) massive long distance electrical power transmission, and (2) local storage of electrical power with real time pricing.

Storage of electrical power is critical for stability and robustness of the electrical power grid, and it is absolutely essential if we are ever to use solar and wind as our dominant primary power source. The best place to provide this storage is locally, near the point of use. Imagine by 2050 that every house, every business, every building has its own local electrical energy storage device, an uninterruptible power supply capable of handling the entire needs of the owner for 24 hours. Since the devices are small, and relatively inexpensive, the owners can replace them with new models every 5 years or so as worldwide technological innovation and free enterprise continuously and rapidly develop improvements in this most critical of all aspects of the electrical energy grid. Today using lead-acid storage batteries, such a unit for a typical house to store 100 kilowatt hours of electrical energy would take up a small room and cost over $10,000. Through revolutionary advances in nanotechnology, it may be possible to shrink an equivalent unit to the size of a washing machine, and drop the cost to less than $1,000. Since the amount of energy stored is relatively small, there are many technologies that are being considered. One is a flow battery with a liquid electrolyte based on salts of vanadium. Another features a reversible hydrogen fuel cell which electrolyzes water to make hydrogen when it stores energy, then uses this hydrogen to make electricity as it is needed. Another uses advanced flywheels. With intense research and entrepreneural effort, many schemes are likely to be developed over the years to supply this local energy storage market that may expand to several billion units worldwide.

With these advances the electrical grid can become exceedingly robust, since local storage protects customers from power fluxuations and outages. With real-time pricing, the local customers have incentive to take power from the grid when it is cheapest. This in turn permits the primary electrical energy providers to deliver their power to the grid when it is most efficient for them to do so, and vastly reduce the requirements for reserve capacity to follow peaks in demand. Most importantly, it permits a large portion—or even all—of the primary electrical power on the grid to come from solar and wind.

The other critical innovation needed is massive electrical power transmission over continental distances, permitting, for example, hundreds of gigawatts of electrical power to be transported from solar farms in New Mexico to markets in New England. Now all primary power producers can compete with little concern for the actual distance to market. Clean coal plants in Wyoming, stranded gas in Alaska, wind farms in North Dakota, hydroelectric power from northern British Columbia, biomass energy from Mississippi, nuclear power from Hanford Washington, and solar power from the vast western deserts, etc., remote power plants from all over the continent contribute power to consumers thousands of miles away on the grid. Everybody plays. Nanotechnology in the form of single-walled carbon nanotubes (a.k.a. "buckytubes") forming what we call the Armchair Quantum Wire may play a big role in this new electrical transmission system.

Such innovations in power transmission, power storage, and the massive primary power generation technologies themselves, will come from miraculous discoveries in science together with free enterprise in open competition for huge worldwide markets.

It would be useful to have these discoveries now.

America, the land of technological optimists, the land of Thomas Edison, should take the lead. We should launch a bold New Energy Research Program. Just a nickel from every gallon of gasoline, diesel, fuel oil, and jet fuel would generate $10 billion a year. That would be enough to transform the physical sciences and engineering in this country. After five years we should increase the funding to a dime per gallon. Sustained year after year, this New Energy Research Program will inspire a new Sputnik Generation of American scientists and engineers. At minimum it will generate a cornucopia of new technologies that will drive wealth and job creation in our country. At best we will solve the energy problem within this next generation; solve it for ourselves and, by example, solve it for the rest of humanity on this planet.

Give a nickel. Save the world.

The CHAIRMAN. Terrific. Thank you.

I wanted to tell you that the bill that we are trying to get passed has some very, very pronounced and live sections on nanotechnology. We do not have the nickel, but if we think enough about it we will pay for it, because I would submit to you we paid for National Institutes of Health at a much higher rate than you have just suggested because we got excited about health. If we can get excited about what you are talking about, we certainly should be able to take the National Science Foundation and the Department of Energy and work toward doubling their spending in a 10-year period. There are a number of us that are going to introduce such legislation. The time has come to double that because you cannot add that much more to National Institutes of Health unless you just want to give every university in the United States carte blanche to fund every kind of research that anybody has to offer, which I do not want to do. I am the only one so far who spoke up against the funding, and NIH thought I was nuts when I did it, but I did it because I do not know how much more it can grow.

The Senator from the great State of Kentucky, I want to suggest something to you and then we will go on to the next witness. There is a new invention that is currently in the market that is called Horizon Sensor. It is a little company in Ratone, New Mexico, where an engineer has invented a machine that is so simple with reference to coal that everybody forgot about it other than him. It cuts a swath of coal, in your coal and any other major coal veins. The physical evidence is that over 95 percent of the dirty stuff is in the top and bottom six inches. So the swath comes along and leaves the six inches and takes the rest out. When the coal comes out the other side to be mined, it is almost clear of the major pollutants, the mercury and the bad stuff.

Currently the Department is considering submitting to the EPA that it be mandatory that it be used on mines that are producing coal that has the structure that I have just described. I thought it would be good maybe if we brought that person down to have a showing perhaps in your State at your leisure. I think it would be something very exciting.

Now we are going to go to you, Dr. Moniz, because that is the way I have it in my list. So if you would proceed. I do not think I will go through your bio except to tell everybody that he was second in charge of the Department of Energy, his expertise was nuclear. When he left there he joined up with another very involved person, Dr. Deutche. They have since that time published a great manuscript on nuclear.

I am going to suggest to you, Dr. Moniz, that I was just telling Senator Bingaman after all these years I am about 3 weeks away from a book on nuclear power, the future of the world, and it will be ready.

Mr. Smalley, I want to suggest that you probably know, that at Sandia National Laboratories there is the largest facility for nanoresearch in the world and it is about two-thirds finished. So I do not think we are short of money. I think we may be a little short of what we want to do with it, which people like you could be very helpful on.

Your statement will be made part of the record, doctor. Let us proceed.

STATEMENT OF ERNEST J. MONIZ, Ph.D., PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. MONIZ. May I just note before starting, Senator, that I am looking very much forward to your book and recall your very interesting and important talk at the Kennedy School some years ago which put together nuclear power with nonproliferation issues in a way that I thought was extremely important. Also, I will mention for the gentleman from Kentucky that with John Deutsch our new study is on coal.

But if I may go to my statement, Mr. Chairman, Senator Bingaman, and members: Thank you for the opportunity to discuss the results of our MIT study on the future of nuclear power. The study was framed by the global warming challenge of increasing energy use, especially electricity use, very substantially by mid-century to meet global human need while at the same time cutting emissions of greenhouse gases. We believe the United States will join others in this effort and stress the importance of enabling the technological solutions early on, really in the next decade to 2, if we have any chance of being on the glide path to addressing this problem by mid-century.

This is a very stiff challenge and we believe that all options represented here on this panel must be on the table, including nuclear power. The United States must certainly be a leader if this kind of global growth is to be realized on a scale big enough to seriously impact greenhouse gas emissions by mid-century, probably a tripling or so of American deployment by mid-century, again if this global scenario is to be realized.

This is obviously very challenging for a technology that has, bluntly, not seen a new plant ordered in a quarter century because it is facing economic, safety, waste, proliferation, and public acceptance issues. The principal utility criteria for moving ahead with new plants in the United States includes operational confidence, licensability, and economics. This growth will be met for several decades by evolutionary versions of currently deployed technologies, so-called thermal reactors, principally light water reactors, with some possibility of heavy water reactors, and then in a couple of decades gas-cooled reactors in the mix.

But the advanced reactors and fuel cycles much discussed these days in the research community are many decades from deployment and thus are not relevant to the challenge that I have laid out, getting on the trajectory to meet greenhouse gas challenges in this first half century.

Within this context, we offer several recommendations which I will summarize briefly: Economics. The economics of new nuclear plants are challenging in a restructured electric sector. A merchant plant model of costs shows that if nuclear power is to be competitive with coal and natural gas industry must demonstrate reactor capital cost reductions that are plausible, about 25 percent, but as yet unproved, and the social costs of greenhouse gas emissions need to be internalized. Enough plants need to be built on budget and schedule to remove the financing risk premium.

For the United States, overcoming this first mover problem is really the key to determining the role of nuclear power. Based upon the public good of determining the competitiveness of evolutionary reactor designs in the evolved regulatory context, we recommend electricity production tax credits for first movers modeled after those in place for wind, with a total credit scaled to first mover costs. This has the advantages of technology neutrality in addressing carbon emissions and of still requiring substantial private sector equity investments and therefore keeping risk where it belongs.

First mover demonstration of the economics and safety of new plants must occur within the next decade or so if nuclear power is to make a significant contribution to mitigating climate change in the first half of this century. We note that the 2003 energy bill conference report included such a mechanism, production tax credits, although with somewhat higher total credit and smaller first mover capacity relative to the MIT report.

Waste management. In the growth scenario, long-term storage of spent fuel prior to geological emplacement, specifically including international spent fuel storage, we believe should be systematically incorporated into waste management strategies. The scope of waste management R&D should be expanded significantly as a very high priority. An extensive program on deep borehole disposal was one example that we put forward.

Proliferation. The current international safeguards regime should be strengthened to meet the nonproliferation challenges of globally expanded nuclear power. The IAEA additional protocol needs to be implemented and the accounting and inspection regime should be supplemented with strong surveillance and containment systems for new fuel cycle facilities.

The Nonproliferation Treaty implementation framework should evolve to a risk-based framework, keyed to fuel cycle activity. Central to this is having growth in global nuclear power realized by having fuel cycle services, especially fresh fuel supply and spent fuel removal, provided by a relatively small number of suppliers under international oversight. Such an approach needs to be established over the next decade prior to a possible acceleration in nuclear power deployment and American leadership is essential.

R&D. The government nuclear energy R&D program is substantially underfunded. The MIT study group priorities for the next 5 to 10 years encompass waste management, thermal reactor development, safeguards, uranium resource assessment, and advanced fuel cycles. Specifically, a major international effort, the nuclear system modeling project, as we called it, should be launched to develop the analytical tools and to collect essential scientific and engineering data for integrated assessment of fuel cycles. Large demonstration projects are not justified in our view in the absence of this advanced analysis and simulation capability.

Any international program, however, must be pursued with proliferation resistance as a key criterion, both in terms of fuel cycles explored and in terms of facilities required while pursuing the program. We recommend joint management of such programs by the Nuclear Energy and Nonproliferation Offices of the Department of Energy.

Finally, we observe that public acceptance is critical to expansion of nuclear power in many countries. In the United States, the public does not yet see nuclear power as a way to address global warming. Environmental organizations, power providers, and the government need to engage in a much more open discussion of the benefits and problems associated with nuclear power and climate change.

Thank you again for the opportunity. I will be most happy to address the committee's questions.

[The prepared statement of Dr. Moniz follows:]

PREPARED STATEMENT OF ERNEST J. MONIZ, PH.D., PROFESSOR OF PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INTRODUCTION AND SUMMARY

Mr. Chairman, Senator Bingaman, and members of the Energy and Natural Resources Committee, I thank you for the opportunity to discuss the results of an interdisciplinary study on The Future of Nuclear Power [1] carried out at MIT and published in Summer 2003. It produced a set of recommendations aimed at preserving the option for nuclear power to contribute significantly towards meeting the greenhouse gas (GHG) emissions challenge. That challenge is to maintain or reduce the level of anthropogenic global GHG emissions over the next several decades even as energy demand increases substantially, especially in the developing economies of the world. As a reference point, about 6.5 Gigatonnes of carbon are emitted annually, principally from energy production and use, and a risky doubling of pre-industrial carbon dioxide concentrations in the atmosphere is expected in the second half of this century in a "business-as-usual" (BAU) scenario. Policy options and recommended actions for the next decade are offered in the MIT study with an eye towards possible Terawatt-scale global deployment of nuclear power by mid-century. That represents nearly a tripling of today's global capacity, which most likely would modestly increase nuclear power's market share of global electricity production. The Terawatt scale (which is about a third of total primary energy use per year in the United States) is that at which nuclear power (or other "carbon-free" technologies) displaces carbon emissions from fossil fuel plants at the Gigatonne scale.

A possible tripling of nuclear power capacity to mid-century is a major challenge for a technology that is projected by EIA to continue at more or less constant deployed capacity for the next two decades in a BAU scenario. Of course, international commitment to major reductions of energy sector carbon intensity would be far from BAU, and that provides the context for the MIT study. We believe that such a commitment will eventually be forthcoming, that the United States will join with others to do so, and that an early commitment will greatly improve the odds of holding GHG atmospheric concentrations at acceptable levels. Success will likely require Terawatt-scale or greater contributions from all technology pathways the "negawatts" of accelerated efficiency gains, renewables, nuclear power, and clean coal with carbon dioxide capture and sequestration.

We shall discuss only the nuclear power pathway. To realize growth on the indicated scale, economic, safety, waste, and proliferation challenges must be met to the public's satisfaction. Some key observations and recommendations, elaborated in the rest of the testimony, include:

- A mid-century growth scenario on a scale that substantially impacts greenhouse gas emissions would be realized with thermal reactors operated principally in a once-through mode. This best meets the principal utility criteria for moving ahead with new nuclear plants in the United States [2]:
  - Operational confidence based on familiarity with the system designs and standardization of both design and operation
  - Licenseability, for which the extensive regulatory history with light water reactors is very important
  - Economics, requiring large reductions in overnight capital costs compared to past experience.
- The economics of new nuclear plants are challenging in a restructured electricity sector. A merchant plant model of costs shows that, if nuclear power is to be competitive with coal and natural gas, industry must demonstrate reactor capital cost reductions that are plausible but as yet unproved, and the social costs of greenhouse gas emission need to be internalized [1]. For the United States, overcoming the "first mover" problem is key to determining the role of nuclear power. Based upon the public good of determining the competitiveness of evolutionary reactor designs in an evolving regulatory context, we recommend electricity production tax credits for "first movers", modeled after those in place for wind, with a total credit scaled to first mover costs. This has the advantages of "technology neutrality" in addressing carbon emissions and of still requiring substantial equity investments (and therefore keeping risk with the private sector). First mover demonstration of the economics and safety of new nuclear plants must occur within the next decade or so if nuclear power is to make a significant contribution to mitigating climate change in the first half of this century. We note that the 2003 energy bill conference report included such a mechanism, although with somewhat higher total credit and smaller first mover capacity relative to the MIT report.

- Long-term storage of spent fuel prior to geological emplacement, specifically including international spent fuel storage, should be systematically incorporated into waste management strategies. The scope of waste management R&D should be expanded significantly; an extensive program on deep borehole disposal is an example. Successful operation of geological disposal facilities and public acceptance of the soundness of this approach are essential for large-scale new nuclear power deployment.
- The current international safeguards regime should be strengthened to meet the nonproliferation challenges of globally expanded nuclear power. The International Atomic Energy Agency (IAEA) Additional Protocol [3] needs to be implemented, and the accounting and inspection regime should be supplemented with strong surveillance and containment systems for new fuel cycle facilities. The Nonproliferation Treaty implementation framework should evolve to a risk-based framework keyed to fuel cycle activity; central to this is having growth in global nuclear power deployment realized by having fuel cycle services, in particular fresh fuel supply and spent fuel removal, provided by a relatively small number of suppliers under international oversight. Such an approach needs to be established over the next decade, prior to a possible acceleration in nuclear power deployment. American leadership is essential.
- Widespread deployment of nuclear power in the second half of this century and beyond, as might be necessary in a GHG-constrained world, may call for advanced fuel cycles and reactors requiring a sustained R&D effort. Gas-cooled reactors have potential advantages with respect to safety, proliferation resistance, modularity, and efficiency and could, given accumulated experience, contribute earlier, perhaps in two decades. A major international effort, the Nuclear System Modeling Project, should be launched to develop the analytical tools and to collect essential scientific and engineering data for integrated assessment of fuel cycles (advanced fuels, reactors, irradiated fuel reprocessing, waste management). Large demonstration projects are not justified in the absence of advanced analysis and simulation capability. Any international program should be pursued with proliferation resistance as a key criterion, both in terms of the fuel cycles explored and in terms of capabilities required while pursuing the program. Joint management of such programs by the nuclear energy and nonproliferation offices of the Department of Energy is called for.
- The government nuclear energy-related R&D program is substantially underfunded. The MIT study group recommended priorities for the next five to ten years encompass waste management (engineered barriers, waste form characterization, deep borehole disposal), thermal reactor development (cost reduction, high burn-up fuels, gas cooled reactor development), safeguards (MPC&A tracking systems, containment and surveillance systems),uranium resource assessment, and advanced fuel cycles (modeling, simulation and analysis project, new separations approaches).
- Public acceptance is critical to expansion of nuclear power in many countries. In the United States, the public does not yet see nuclear power as a way to address global warming. Environmental organizations, power providers, and the government need to engage in a more open discussion of the balance of risks associated with nuclear power and climate change.

GLOBAL GROWTH SCENARIO

The MIT study group constructed a scenario for global growth of electricity demand to mid-century and for nuclear power's share of that growth. The scenario for electricity demand was based on U.N. world population and urbanization projections and an assumption of national per capita electricity consumption rising towards a world standard. The resulting projection for global electricity production is consistent with EIA projections over the next two decades (slightly below the EIA reference case) and yields an increase of nearly a factor of three by mid-century. The nuclear power market share, assuming a strong impetus to deploy nuclear power (presumably because of greenhouse gas emission "caps" and of satisfactory resolution of the challenges noted above), is based upon national capabilities and infrastructure. The resulting scenario is shown in Table 1.

Table 1.—GLOBAL GROWTH SCENARIO

Region	Projected 2050 GWe capacity	Nuclear electricity market share	
		2000	2050
Total world	**1,000**	**17%**	**19%**
Developed world	625	23%	29%
U.S.	300		
Europe & Canada	200		
Developed East Asia	115		
FSU	50	16%	23%
Developing world	325	2%	11%
China, India, Pakistan	200		
Indonesia, Brazil, Mexico	75		
Other developing countries	50		

Projected capacity comes from the global electricity demand scenario in Appendix 2, which entails growth in global electricity consumption from 13.6 to 38.7 trillion kWhrs from 2000 to 2050 (2.1% annual growth). The market share in 2050 is predicated on 85% capacity factor for nuclear power reactors. Note that China, India, and Pakistan are nuclear weapons capable states. Other developing countries includes as leading contributors Iran, South Africa, Egypt, Thailand, Philippines, and Vietnam.

Several features of the scenario deserve note. The total deployment of 1000 GWe globally is nearly a tripling of today's deployment. This corresponds to an approximately level world market share and would displace about 1.8 Gigatonnes of carbon (equivalent) emissions annually from coal plants of equivalent capacity [4]. Such a displacement might represent about 25% of incremental greenhouse gas emissions from energy use in a business-as-usual scenario, a significant amount. Indeed, one may question whether difficult public policy steps are worthwhile from a climate change perspective unless one envisions nuclear power contributing to the "solution" at this level.

To reach such a level, the developed world will need to increase its nuclear market share substantially, up to about 30%. In particular, the United States must play a lead role, because of the combination of high per capita demand and projected population increase of about 100 million people. The reality that no new nuclear plants have been ordered in the United States for a quarter century is one indicator of the difficulty in realizing this global scenario. In contrast to the U.S. situation, projected stable (e.g., France) or declining (e.g., Japan) populations in countries seen today as more favorably disposed to nuclear power serve to limit demand growth.

A substantial part of the growth also occurs in the developing economies, but in a relatively small number of countries. This has important implications for addressing proliferation concerns, particularly since China, India and Pakistan already have nuclear weapons capabilities and thus are not major concerns for fuel cycle-associated proliferation (since they are likely to continue with dedicated weapons programs). An incentive structure that has the relatively small number of remaining countries engaged in nuclear reactor construction and operation but not in enrichment or reprocessing has major nonproliferation benefits; we return to this below.

ECONOMICS

The economic comparison of new nuclear plants with baseload coal and natural gas plants and the economics of closing the fuel cycle underpin many of the recommendations. The baseline costs for new plants were compared within a framework of

- merchant plants (i.e., a competitive generation market in which investors bear the primary risk)
- experience, rather than engineering analyses lifetime levelized costs.

Table 2 shows that, with gas prices of about $4.50/MCF, both pulverized coal and natural gas combined cycle plants have a substantial cost advantage relative to the nuclear plant baseline in the absence of a carbon "tax" (detailed discussions of the methodology and of the input parameters can be found in the MIT report). An independent analysis performed by Deutsche Bank [5] is in quite close agreement. This comparison may be altered significantly by two factors.

Table 2.—COMPARATIVE POWER COSTS

Case (year 2002 $)	Real levelized cost cents/ kWe-hr
Nuclear (LWR)	6.7
+ Reduce construction cost 25%	5.5
+ Reduce construction time 5 to 4 years	5.3
+ Further reduce O&M to 13 mills/kWe-hr	5.1
+ reduce cost of capital to gas/coal	4.2
Pulverized coal	4.2
CCGT [1] (low gas prices, $3.77/MCF)	3.8
CCGT (moderate gas prices, $4.42/MCF)	4.1
CCGT (high gas prices, $6.72/MCF)	5.6

[1] Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

- First, as shown in Table 2, plausible reductions in new nuclear plant costs can bring them in line with coal and gas. Reducing capital costs by 25% to $1500/kWe, a target that has not yet been met but appears plausible with new systems approaches and enough experience, has a large financial impact. A similar impact would arise from eliminating the risk premium (higher equity requirements and higher return on equity) for financing nuclear plants. Presumably, this reduction in the cost of financing would be achieved only by building and operating several plants successfully.
- The second major factor is the uncertainty surrounding internalization of carbon emission costs. Table 3 shows the impact of a carbon "tax" on the levelized costs for coal and gas. Clearly, the competitiveness of nuclear power would be enhanced significantly if carbon emission costs are internalized at $50 to $100 per tonne, which is considerably less than the cost of carbon dioxide capture and sequestration using today's technologies for either pulverized coal or natural gas, close to $200/tonne [6]. Also, $50/tonne is about the bid price today in the nascent European carbon trading market.

Table 3.—POWER COSTS WITH CARBON TAXES

	Carbon tax cases levelized electricity cost		
Cents/kWe-hr	$50/tonne C	$100/tonne C	$200/tonne C
Coal	5.4	6.6	9.0
Gas (low)	4.3	4.8	5.9
Gas (moderate)	4.7	5.2	6.2
Gas (high)	6.1	6.7	7.7

If nuclear power is to be deployed at mid-century on the scale being discussed, substantial construction of new plants must be underway within ten to fifteen years. Both the economics and new regulatory procedures need to be demonstrated. We recommend, for the United States, that production tax credits be offered to first mover nuclear plants at a rate set by that for wind. This is currently 1.8 cents/kWh, which can be thought of as about $75/tonne [4] of avoided carbon from a coal plant (and with the public benefit of carbon avoidance for decades following expiration of the credit). A production tax credit has the advantages of fundamentally keeping the risk with the private sector and of being applicable to any carbon-free option. Because of the very different natures of nuclear power and wind with respect to base-load characteristics, we recommended limiting the credit to 10 GWe of first mover capacity and to a total of about $200/kW. This recommendation is reflected in the 2003 energy bill conference report, although with less eligible capacity and a potentially much higher credit per installed kilowatt. The public good argument for such a mechanism rests with the importance of having government, industry, and financial markets understand in a timely way whether new nuclear power will be competitive with fossil fuels and thus a serious option for simultaneously meeting electricity demand and addressing climate change.

The "first mover" reactors are overwhelmingly likely to be evolutionary advances of operating reactors, with passive safety features replacing some of the active systems in today's plants. This addresses the first two principal criteria noted in the introduction [2], while the tax credit provides the incentive to determine the economics. Clearly other criteria will also need to be met to make a business decision [2]: reliable demand for baseload electricity; cost of alternatives, especially natural gas prices; continued successful operations of existing nuclear plants and a path to resolve plant security and spent fuel disposal issues; regulatory predictability through the Combined Operating License process; possible risk sharing through a "first mover consortium;" and recognition of the environmental benefits.

If the industry is not confident in meeting cost targets with a substantial production tax credit available for several plants (allowing cost reduction through experience and by spreading one-time costs), then the credit will go unused with the obvious implications for nuclear power's role in meeting greenhouse gas challenges. The experience of successfully building and operating several plants is needed to work down the substantial risk premium for private sector financing of new nuclear plants.

The MIT study also looks at the economics of plutonium recycling in the PUREX/MOX fuel cycle, which creates a significant proliferation risk by separating weapons-usable plutonium during normal operation. Not surprisingly, the once-through fuel cycle costs less. This is reflected indirectly in the difficulty of funding military plutonium disposition programs, where MOX fabrication costs alone are seen to equal the entire once-through fuel costs, and in the indefensible accumulation in several countries of about 200 tonnes of separated plutonium from power reactors. The arguments given in the past for pursuing PUREX/MOX have been inadequacy of uranium resources, which is no longer a credible argument, and the energy value in the plutonium, which is basically answered by the unfavorable economics. The current reason offered is the benefit to long-term waste management, to which we now turn.

NUCLEAR WASTE MANAGEMENT

The management and disposition of irradiated nuclear fuel has not yet been dealt with anywhere in the world. This is a major impediment to the growth of nuclear power. The Yucca Mountain repository is moving towards a licensing decision and, if it proceeds to successful implementation, a major milestone will have been achieved. Nevertheless, the MIT study's growth scenario calls for a dramatically expanded capacity for waste management in any fuel cycle.

Partitioning of the spent fuel to remove plutonium and possibly other actinides unquestionably reduces long-term radioactivity and toxicity of the waste. Nevertheless, the MIT study group did not find the benefits of partitioning and transmutation to be compelling on the basis of waste management. There are several reasons. First, although successful implementation has not yet been demonstrated, the scientific basis for long-term geological isolation appears sound. Partitioning leads to a large volume and mass reduction, but these are not terribly important criteria for repository design. Heat and radioactivity, which are far more important criteria, are only marginally reduced on the century time scale, since the fission products remain with the waste. In addition, the trade-off of benefits possibly of small consequence to human health—in the millennium time scale against near-term increases in waste streams, occupational exposure, and safety concerns is not clear. There is certainly little evidence that the public is more concerned with the millennium rather than the generational time scale. Finally, other approaches may yield even greater confidence in long-term isolation and may do so more economically and simply. This would include advanced engineered barriers and other disposal approaches, such as deep boreholes. These are modest diameter holes drilled 4 to 5 kilometers deep into stable crystalline rock. The approach looks promising and economical because of drilling advances, because the geochemical environment (highly reducing) is favorable, and because the emplacement is not subject to surface vagaries. This is not to say that deep boreholes will prove to be the best approach, since major uncertainties exist. The point is that important alternatives to partitioning exist for adding even greater confidence to long-term waste isolation and these should be explored vigorously through new R&D programs.

An important role for advanced fuel cycles well into the future cannot be excluded, although significant economic and technical barriers must be overcome. The MIT study recommends a program of analysis, simulation tool development, and basic science and engineering of advanced concepts, and eventually appropriate project demonstrations. Such a program carries some risk of itself aiding possible proliferants by providing technology know-how with respect to actinide separation and metallurgy, as well as associated research facilities. However, the U.S. approach of rejecting plutonium recycle and cutting off research and international cooperation on fuel cycles demonstrably proved ineffective, since other countries have moved forward anyway. Rejection of the civilian MOX option should continue. Our recommendation is one of U.S. engagement to shape international advanced fuel cycle R&D properly, with an open mind to its eventual outcome, even while pursuing and advocating the open fuel cycle with thermal reactors as the basis for growth over the next decades. We also recommend that the U.S. government offices responsible for nonproliferation have an explicit management role, along with the nuclear energy office, in defining the scope, scale and location of such international R&D programs.

NONPROLIFERATION

Global expansion of nuclear power into numerous new countries raises concerns about proliferation. This is not new, since a similar concern formed the backdrop for President Eisenhower's "Atoms for Peace" speech fifty years ago. However, the nonproliferation regime rooted in the Nuclear Nonproliferation Treaty (NPT) framework faces new circumstances: the end of the Cold War has changed security threats and relationships; the dramatic spread of manufacturing capability and technology lowers the barriers for translating nuclear know-how into nuclear weapons; and the post-9/11 world is more aware of the capabilities of terrorist groups and their interest in nuclear materials. These realities have refocused attention on the control and elimination of weapons-usable fissionable material (HEU and plutonium) and on the uncomfortable recognition that countries can move to the threshold of a nuclear weapons capability within the NPT regime.

Strengthening the nonproliferation regime in the face of a possible global nuclear power growth scenario calls for many coordinated actions. One fundamental change to the NPT implementation regime, discussed in the MIT report, would focus on a risk-based framework rooted in the technology, as opposed to political views. The key issue is that power reactors are not themselves the major proliferation threat, as opposed to enrichment and reprocessing plants, in the fuel cycle. Thus, states that deploy only reactors, with international assistance as desired, would have internationally secured fresh fuel supply and spent fuel removal. This would involve either "fuel cycle states" or internationally operated fuel cycle centers. The advantages of a country taking a "reactor-only" path would be avoidance of significant nuclear fuel cycle infrastructure development and maintenance costs, of intrusive safeguards regimes (since spent fuel and refueling operations for light water reactors are relatively easily monitored), and, most important, of nuclear waste challenges. The relatively inexpensive fresh fuel services (in particular enrichment) might even be offered at cost or below through international agreement and support. An insistence on developing a full fuel cycle infrastructure, given the option of internationally guaranteed, economically attractive fuel cycle services and avoidance of significant challenges (especially waste management), would greatly heighten suspicions about proliferation intent, presumably leading to toughened international control mechanisms with regard to such countries. The major obstacle is acceptance of the spent fuel in a multiplicity of countries. So far, only Russia has expressed interest in receiving such fuel. This willingness of Russia to accept return of spent fuel may yet facilitate a resolution of the concerns about Iran's nuclear infrastructure development, a resolution much along the lines being suggested here for broader application. Clearly, establishing the validity of long-term secure spent fuel and/or high-level waste geological isolation is a critical step for responsible growth of nuclear power in response to electricity supply and climate change imperatives.

PUBLIC ATTITUDES

The MIT study carried out a poll of well over 1000 Americans on their attitudes and understanding of energy-related issues. By and large, the public has a good understanding of relative costs and environmental impacts of different technologies; the cost of renewables was a notable exception, in that these were widely thought to be inexpensive. Nevertheless, it was interesting that perceptions of technology, rather than "external" factors such as politics or demographics, were at the core of their attitudes. A majority of respondents did not believe that nuclear waste can be stored safely for many years, and the typical respondent believed that a serious reactor accident is somewhat likely in the next ten years. The poll also showed that, in the United States, the public does not connect concern about global warming with carbon-"free" nuclear power. There is no difference in support for building more nuclear power plants between those who are very concerned about global warming and those who are not. This may prove to be either an opportunity for nuclear power advocates to better educate the public or a major obstacle to motivating the growth scenario. A more open discussion is needed among interested constituencies about the balance of risks in dealing with nuclear power expansion and climate change.

CONCLUDING REMARKS

The MIT study sought to define actions needed to enable nuclear power as an option for significantly mitigating greenhouse gas emissions while satisfying increasing global demand for electricity. If expansion of nuclear power is to contribute in a meaningful way up to mid-century, a robust growth period must commence within ten to fifteen years. This in turn means that very soon costs of new plants must be understood, including those costs driven by the licensing process and possible litigation, and issues surrounding waste management must be resolved. Addressing the financial risks associated with first mover plants, perhaps through first mover production tax credits, is an important step. However, resolving the economics is a necessary but not sufficient condition for the robust growth scenario. In addition, difficult international nonproliferation measures must be adopted and nuclear spent fuel management programs must demonstrate successful implementation and earn widespread public acceptance. These challenges are linked in ways that are complicated by the very different nuclear policies of the United States and some of its allies. Only if these challenges are met can nuclear power responsibly expand to the Terawatt scale needed for seriously contributing to climate change mitigation at mid-century.

REFERENCES AND NOTES

[1] The Future of Nuclear Power, ISBN 0-615-12420-8 (July 2003), available online at http://web.mit.edu/nuclearpower/; this workshop paper is largely drawn from this report. The study was funded principally by the Sloan Foundation. Study group members were Professors S. Ansolabehere, J. Deutch (co-chair), M. Driscoll, P. Gray, J. Holdren, P. Joskow, R. Lester, E. Moniz (co-chair), and N. Todreas.

[2] Long-Term Strategy for Nuclear Power, Marilyn C. Kray, Exelon Corporation, presented to the Pew Center for Global Climate Change/National Commission on Energy Policy 10-50 Workshop (March 2004)

[3] The Additional Protocol permits the IAEA to inspect undeclared facilities suspected of use in a nuclear weapons development program.

[4] For the reference coal plant, we take a capacity factor of 85%, a heat rate of 9,300 BTU, and a carbon intensity of 25.8 kg-C/mmBTU.

[5] Adam Siemenski, Deutsche Bank, presentation at the 2002 EIA NEMS conference

[6] David, J. and H. Herzog, "The Cost of Carbon Capture", Fifth International Conference on Greenhouse Gas Control Technologies (Australia, 2000); available at http://sequestration.mit.edu

The CHAIRMAN. Thank you very much.

Now, David, you are next. I am just going to say that you worked for us here and we were very proud of you then. I was personally proud to recommend you. It seems, however, that with the passage of each month you get another job. I do not know how many more you can handle. But when they cannot get somebody, they fill another niche with you. You have done a great job in Renewables and I am sure you will as Under Secretary.

Dr. Smalley, I made a misstatement. The biggest facility at Los Alamos—excuse me—at Sandia is not a nanocenter. It is a microengineering center. There is a nanocenter, but it is equal to four others. So I am sorry that I misstated.

David, would you proceed.

STATEMENT OF DAVID GARMAN, ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. GARMAN. Thank you, Mr. Chairman. Since my written statement is part of the record, I will be brief, and I will focus on renewable energy as I was asked to by the committee.

Over the past 3 years we have invested about a billion dollars in renewable energy technologies, plus another nearly $3 billion to promote efficient use of energy from all resources. Let me make my pitch for energy efficiency here. There are environmental consequences to any kind of power generation and energy use—coal, wind, nuclear, hydro, solar. The environmental consequences may vary, but there still are consequences. Therefore, the cleanest, most sustainable, environmentally benign form of energy is in essence the energy we do not need, the energy we manage to save, the so-called negawatt.

So any discussion of sustainability should recognize the value of energy efficiency at the start, and I need not dwell on that point because the members of this committee all understand the importance of smart energy use and have been leaders in the effort to promote energy efficiency.

So with that said, let me turn to a discussion of renewable energy research and development, because even with solid efforts toward energy efficiency we are still going to need much more energy supply. As a consequence of the renewable energy R&D undertaken by the Department of Energy and our partners, the cost of wind-generated electricity has fallen from roughly 80 cents per kilowatt hour in 1980 to as little as 4 cents today. The cost of solar photovoltaic electricity has fallen from over $2.00 per kilowatt hour in 1980 to less than 25 cents today. The cost of geothermal electricity has fallen from 15 cents per kilowatt hour in 1985 to between 5 and 8 cents today.

Continued research and development will and it must yield further progress. We believe we can achieve onshore wind generation at 3 cents per kilowatt hour by 2012 in all areas of the Nation with average annual wind speeds of 13 miles per hour or greater, the so-called class 4 areas and above. We believe we can achieve solar photovoltaic power generation at a cost of 6 cents a kilowatt hour by 2020. We also hope to move geothermal power down to the 5 to 8 cent range by 2010.

If we continue to succeed in bringing down the cost of these technologies, we think their market share will continue to increase and any policy measures that a future administration or Congress might wish to employ to accelerate renewable energy deployment will be less expensive for taxpayers and ratepayers alike.

Even with business as usual policies, the analyses that we perform as part of our budget formulation process suggest that the R&D we are currently engaged in can increase our production of renewable energy from today's roughly 6.8 quadrillion Btu's to some 27 quadrillion Btu's in 2050. Now, that is not a prediction of the future. I know I am not clever enough to design or predict a particular energy future. But instead, Mr. Chairman, we see ourselves as being in the options business. We are working to provide a rich set of technology options. We do so because we know we ultimately face limits in the amount of carbon dioxide or criteria pollutants we can safely emit or limits in the amount of petroleum we can affordably extract or other limiting factors we cannot yet fully appreciate.

Recognizing that there is no silver bullet, we invest in a diverse technology portfolio that includes renewables, nuclear, clean coal with carbon sequestration, as well as associated technologies such as hydrogen, superconductivity, and fuel cells that can help us to move or store or utilize that energy more efficiently.

With that, Mr. Chairman, I will look forward to questions and discussion. Thank you.

[The prepared statement of Mr. Garman follows:]

PREPARED STATEMENT OF DAVID GARMAN, ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY, DEPARTMENT OF ENERGY

Mr. Chairman, Members of the Committee, I appreciate the opportunity to discuss the Administration's views on the role that renewable energy technologies can play in sustainable electricity generation.

As stated in the President's National Energy Policy, the Administration believes that renewable sources of energy can help provide for our future energy needs by harnessing abundant, naturally occurring sources of energy with less impact on the environment than conventional sources. We are committed to a research, development, demonstration and deployment program that supports that role. The Department of Energy (DOE) FY 2005 budget request for renewable technologies totals $374.8 million, a $17.3 million increase over the FY 2004 appropriation. This year's budget proposes increases in our programs for wind, hydropower, geothermal, hydrogen, and (when the impact of Congressional earmarks is taken into account), solar and biomass as well. Over the past three years we have invested nearly a billion dollars in renewable energy technologies, not including substantial cost-sharing from our private sector partners.

Advances in technology over the past 25 years have brought us great strides in lower costs, improved performance and competitiveness of renewable energy technologies. Today, electricity is being produced from the wind, the sun, the earth's heat and biomass in a variety of applications across the Nation.

The current contribution of non hydropower renewable energy resources to America's total electricity supply is relatively small (about 2.3 percent), and we expect it to remain relatively small for years to come. Nevertheless, the promise is great. For example, since 2000, nationwide installed wind turbine capacity in the United States has more than doubled. We believe that renewable power technologies are still at the stage where significant advances are likely to result from strong R&D programs. Such advances coupled with lowered manufacturing costs, increased user confidence that results from increased deployment, and appropriate market-based incentives proposed in the President's FY 2005 Budget can lead to a significant role for these technologies in serving future electricity demands.

My testimony today will discuss those renewable energy technologies in DOE's Renewable Energy Portfolio.

WIND TECHNOLOGIES

Wind energy is a virtually emissions free electricity generation technology that eliminates environmental concerns associated with conventional fuel cycles, such as mining or other extraction, combustion and other emissions, and waste disposal. Wind energy is also one of the most widely used and fastest growing renewable energies in the world. According to the American Wind Energy Association, worldwide installed capacity increased by 26 percent in 2003. Globally the total amount of installed wind power has grown 500 percent since 1997, from 7,636 megawatts (MW) to 39,294 MW in 2003.

Wind resources are widespread and substantial in many areas of the nation, particularly in the Midwest and West. The Department estimates that in 2003 nearly $2 billion was invested in new wind power facilities. Installed wind power capacity reached 6,374 MW by the end of 2003 with utility-scale turbines now installed in 30 states.

Improvements driven by DOE sponsored research have dramatically reduced costs. A recent study by the National Renewable Energy Laboratory showed that wind energy systems are currently capable of producing electricity for less than $0.05 per kilowatt hour (kWh) in locations with Class 4 [1] wind speeds. At higher speed Class 6 [2] wind speed sites, the cost of electricity is less than $0.04/kWh without subsidies.

While significant potential remains to tap in to high quality wind resources with today's technology, these resources are generally not in the areas where people live or where transmission is available. The Department is now focused on developing technology that can cost-competitively harvest more widely available, lower speed

[1] Class 4 sites are locations with average annual wind speeds of 13 miles per hour, measured at a height of ten meter.

[2] Class 6 sites are higher wind speed sites, with average annual speeds of 15 miles per hour.

wind resources that are generally closer to populations and load centers. This so-called "low wind speed" technology will expand the land area where wind can be developed by a factor of 20, while reducing the average distance between the wind resources and where power is needed by a factor of five.

We are also looking at off-shore wind energy resources off the coasts and in the Great Lakes of the United States. These areas offer immense, economically viable wind energy resources that are close to major urban areas with growing demand and increasingly limited energy production and delivery options. Wind turbines located in shallow waters offshore could produce electricity for $0.07-0.08/kWh in Class 4 sites with current technology, with the potential for future cost reductions with further research.

DOE's Wind Energy program has a long term goal of $0.03/kWh for onshore systems in Class 4 sites in 2012. DOE projects that the development of technology for onshore Class 4 wind sites will result in an installed capacity level in 2025 of an estimated 59,000 MW, the largest portion of which will be represented by turbines designed specifically for use in moderate wind areas.

GEOTHERMAL TECHNOLOGY

Geothermal energy uses steam and hot water from the Earth to create energy. Geothermal power plants have a proven track record of performance as baseload facilities, with capacity factors and availabilities often exceeding 95 percent. Today, domestic geothermal energy production is a $1 billion a year industry that accounts for about 15 percent of all non-hydropower renewable electricity production, and about 0.35 percent of total U.S. electricity production. Geothermal's net summer capability in the U.S. has grown from about 500 MW in 1973 to over 2,200 MW today in the states of California, Nevada, Hawaii, and Utah. Other states with significant near-term potential include Alaska, Arizona, Colorado, Idaho, New Mexico, Oregon, and Washington. Recent estimates by industry of hydrothermal potential ranges from 5,000 MW with current technology to over 18,000 MW with advanced technology.

The U.S. Geological Survey estimates that already-identified hydrothermal reservoirs hotter than 150° C have a potential generating capacity of about 22,000 MWe and could produce electricity for 30 years. We further estimate that additional undiscovered hydrothermal systems may have a capacity of 72,000-127,000 MWe. At depths accessible with current drilling technology, virtually the entire country possesses some geothermal resources. The best areas are in the western United States where bodies of magma rise closest to the surface.

The Energy Information Administration projects geothermal installations totaling 6,800 MWe by 2025, based on the assumption that natural gas prices will remain relatively stable. Geothermal output is projected to increase from 13 billion kWh in 2002 to 47 billion in 2025. The EIA projection does not forecast new geothermal capacity occurring from the undiscovered hydrothermal resource base or the potential of non-hydrothermal resources, such as the heat energy that underlies much of the country, which may be recoverable by use of enhanced geothermal systems (EGS) technology being developed through our research and development program.

EGS technology has the potential to make a sizeable addition to the inventory of geothermal resources available for production. When that broader resource base is considered, 40,000 MW of resources could be made economic in the 2020-2040 timeframe. Of course, these projections also depend heavily on the ability to reduce the cost of energy using EGS technology to competitive levels.

SOLAR ENERGY TECHNOLOGY

Fifty years ago scientists at Bell Laboratories developed the first silicon solar cell. With efficiencies of less than six percent, these solar cells offered, for the first time, the ability to power a wide range of electrical equipment. Photovoltaic (PV) arrays convert sunlight to electricity without moving parts and without fuel wastes, air pollution, or greenhouse gasses. PV systems can be installed as either grid supply technologies or as residential or commercial scale customer-sited alternatives to retail electricity.

Today solar energy accounts for one percent of non-hydroelectric renewable electricity generation and 0.02 percent of total U.S. electricity supply. But PV technology has progressed remarkably in terms of both performance and cost in recent decades. The cost of PV-generated electricity has dropped 15 to 20 fold over the past 25 years and such systems are highly reliable. Thousands of systems are successfully operating today, serving applications that range from water pumping to residential power to remote utility power applications.

Crystalline silicon wafer technology dominates today's PV market. Direct manufacturing costs (labor and materials) for crystalline silicon module power in the United States are around $1.95/watt. This corresponds to an installed system vendor price for grid-tied PV energy of about $0.22 per kWh over a 25-year lifetime. Crystalline silicon module reliability has greatly improved to the point where modules are now warranted for 25 years, and many will probably have a functional lifetime much longer than this.

DOE's photovoltaic program is focused on the next-generation technologies such as thin-film photovoltaic cells, leap-frog technologies such as polymers and nanostructures, and technologies to improve interconnections with the electric grid. Our research and development seeks primarily to reduce the manufacturing cost of highly reliable photovoltaic modules. DOE's research goal is to achieve grid-tied systems with lifetime energy costs around $0.06/kWh and 30 years lifetime by 2020.

Even though some thin-film modules are now commercially available, their real impact is expected to become significant during the next decade. Thin films using amorphous silicon, a growing segment of the U.S. market, have several potential advantages over crystalline silicon. They can be manufactured at lower cost, are more responsive to indoor light, and can be manufactured on flexible or low-cost substrates. Other thin film materials are expected to become increasingly important in the future.

In addition to improvements in crystalline silicon technology, other notable technical accomplishments achieved over the past decade through our research and development programs include:

- The price of inverters (for changing direct current of the PV modules into alternating current suitable for the commercial power grid) is decreasing, and their reliability is steadily increasing. DOE seeks at least ten year warranted reliability.
- Production of thin film modules is expected to increase sharply in CY 2004 and 2005. The environmental issues of safely retiring these modules have been successfully resolved by DOE researchers at Brookhaven National Laboratories.
- The development of super-high efficiency cells, with efficiencies now nearing 38 percent under concentrated sunlight, has progressed faster than expected ten years ago, in part due to the major investment in this technology by the space PV industry in collaboration with NREL researchers.
- DOE made extensive contributions to Article 690 of the National Electric Code which deals with PV safety issues. This is a major development because it helps to remove a serious impediment to wide-scale PV grid-tied deployment—the reluctance of commercial power companies to allow PV systems to be interfaced to their power lines.

In the longer term, DOE expects wide-scale deployment of very inexpensive systems made from novel specially engineered materials, e.g., quantum dot and organic material technologies. Such systems will allow not only utility scale power, but also inexpensive production of fuels such as hydrogen, or complex carbon-based fuels through synthesis using atmospheric carbon dioxide.

Concentrating solar power may also offer significant potential. DOE recently contracted for an independent study by Sargent and Lundy, a draft of which was reviewed by the National Academy of Sciences (NAS). The report found that concentrating solar power troughs could reach costs of 4.3-.6.2 cents per kWh and solar power towers could reach 3.5 to 5.5 cents per kWh by 2020. (These cost estimates are predicated on significant R&D investments and market incentives not included in the President's FY 2005 Budget).

BIOMASS

Biomass represents an abundant, domestic and renewable source of energy that has significant potential to increase domestic energy supplies. Biomass is used to generate electricity through the direct combustion of wood, municipal solid waste, and other organic materials, cofiring with coal in high efficiency boilers, or combustion of biomass that has been converted chemically into fuel oil.

Biomass power is a proven electricity generating option that today accounts for about 70 percent of nonhydroelectric renewable electricity generation and 1.6 percent of total U.S. energy supply, or about 9,733 MW in 2002 of installed capacity. This includes about 5,886 MW of forest product and agricultural residues, 3,308 MW of generating capacity from municipal solid waste, and 539 MW of other capacity such as landfill gas. The majority of electricity production from biomass is used as base load power in the existing electrical distribution system. EIA projects that electricity output from biomass combustion will increase from 37 billion kWh in 2002 (1.0 percent of generation) to 81 billion kWh in 2025 (1.3 percent of generation).

More than 200 companies outside the wood products and food industries generate power in the United States from biomass. Where power producers have access to very low cost biomass supplies, the choice to use biomass in the fuel mix enhances their competitiveness in the marketplace. This is particularly true in the near term for power companies choosing to co-fire biomass with coal to save fuel costs and earn emissions credits. An increasing number of power marketers are starting to offer environmentally friendly electricity in response to consumer demand and regulatory requirements.

The Department estimates that the total available domestic biomass, beyond current uses for food, feed, and forest products, is between 500-600 million dry tons per year. Within the continental U.S., we can literally grow and put to use hundreds of millions of tons of additional plant matter per year on a sustainable basis. These biomass resources represent about 3-5 quadrillion Btus (quads) of delivered energy or as much as 5-6 percent of total U.S. energy consumption. In terms of fuels and power, that translates into 60 billion gallons of fuel ethanol or 160 gigawatts of electricity. This is enough energy to meet 30 percent of U.S. demand for gasoline or service 16 million households with power.

The current focus of our biomass program is the simultaneous production of liquid fuels, products, and power in a so-called "biorefinery." Simultaneous production of products, fuels, and electricity enables the selection of the highest value outputs while providing synergies that can lower production costs. Successful development of these technologies could provide important jobs and income for rural America through the sustainable production of biomass feedstocks for biorefineries that produce power, fuels, chemicals and other valuable products.

THE EERE PORTFOLIO OF TECHNOLOGIES

The overall EERE portfolio provides a combination of multiple renewable energy technologies-solar, wind, biomass, geothermal, and others—together with research and development of energy efficiency technologies. Such a diverse portfolio offers benefits that extend beyond those of the individual technologies described above, and we believe it is important that EERE's research, development, demonstration, and deployment activities continue as a balanced portfolio.

A diverse and balanced portfolio offers several benefits:

- near, mid, and long term research activities and associated deployment opportunities are included, ranging from low-wind speed turbines to quantum-dot photovoltaics.
- degrees of risk are balanced within technology areas—such as research on several types of thin-film photovoltaics technologies along with high-risk work on advanced concepts—as well as across technologies.
- synergies are identified and built between technologies. For example, geothermal, biomass, hydropower, wind, and solar offer power in different regions of the country according to the available resources, at different times of the day and year, and in ways that can complement each other, filling in where another resource is not available. Further, the natural gas saved by producing power using wind turbines, for example, will be available for conversion to hydrogen.

The current portfolio will take us far toward a clean energy future, as we continue to fund innovative ideas. For example, our Future Generation photovolatics solicitation in 1998 funded 18 competitively awarded projects out of 72 proposals from 1999 to 2002. In addition to contributing to our program goals, these activities helped to build our national capacity for innovation, as each project was with a different university.

CONCLUSION

Renewable energy technologies hold tremendous promise in moving the Nation toward sustained, low-emission electricity supply. Government-sponsored research and development efforts over recent decades have been very successful in helping to lower the costs and improve the reliability of renewable energy technologies, and more can be achieved with robust research and development in the future.

The Administration believes that, in the context of a comprehensive energy strategy, more is needed for renewables to gain market share and contribute to our energy independence and environmental objectives. That is why the President's FY 2005 Budget includes energy tax proposals devoted to increasing efficiency and renewable energy, such as extending and modifying the tax credit for producing electricity from biomass and wind, providing tax credits for energy produced from landfill gas, residential solar energy systems, and investment in combined heat and power; and extending the ethanol tax exemption.

Another important factor is that these renewable sources of generation must be able to integrate into our existing distribution system. The tools that form the necessary interface between distributed energy systems and the grid need to be less expensive, faster, more reliable and more compact. And as pointed out in the National Energy Policy, renewables don't fit into traditional regulatory categories and are often subjected to competing regulatory requirements. The lack of uniform interconnection protocols and regulatory treatment is another area where developers of small renewable energy projects have to negotiate interconnection agreements on a site-by-site basis.

That completes my statement, Mr. Chairman. I would be happy to respond to questions the Members of the Committee may have.

The CHAIRMAN. Thank you very much.

Dr. Burke.

STATEMENT OF DR. FRANK P. BURKE, VICE PRESIDENT, RESEARCH AND DEVELOPMENT, CONSOL ENERGY, INC., ON BEHALF OF THE NATIONAL MINING ASSOCIATION

Mr. BURKE. Thank you, Mr. Chairman. I am vice president of research and development for CONSOL Energy, which is the largest Eastern U.S. coal producer, with production in Kentucky, Ohio, Pennsylvania, West Virginia, and Virginia. I am testifying on behalf of CONSOL and the National Mining Association to discuss technology to enable coal to continue to provide low emission electricity to our Nation that we will need to meet our energy demand in the future.

Mr. Chairman, we agree with the statement in your letter of invitation that action should be taken today to prepare the Nation for a future time when oil and gas prices and availability limit their uses to areas other than electricity generation.

In 2003, the United States mined a billion tons of coal, primarily to generate electricity. 52 percent of U.S. electricity comes from coal. We are self-sufficient in coal. In fact, coal is the Nation's only net energy export. The Department of Energy forecasts that U.S. coal use will grow to 1.4 billion tons in 2020. This will require the construction of 120 gigawatts of new coal-fired powerplants while maintaining most of our existing 300 gigawatts of existing capacity.

The United States is not unique in its dependence on coal and it is vital to our national interest to promote the increased use of coal, not only domestically but worldwide. The most compelling evidence of this is China. The Chinese, who already use 50 percent more coal than the United States, expect to double their coal-fueled electric generating capacity by 2020 and to nearly triple it by 2040.

Therefore, throughout the world economic growth and political stability are tied to electricity and electricity throughout the world is tied to coal. The desire and in fact the necessity of the world to utilize its abundant coal resources will not be denied. Energy availability and energy quality are key to meeting all three aspects of sustainable development: economic, societal, and environmental. The question is not whether we will use coal for human development, but how we will use it.

We can reconcile our need for coal with our environmental and economic needs through technology. Clean coal technology can preserve our existing coal-based electricity capacity and can replace and expand as needed in the future, all while continuing to reduce emissions. Many of the technical challenges and opportunities for future coal generation technology are embodied in a clean coal technology road map that has been developed by industry and the Department of Energy. This is discussed in more detail in my written testimony.

The road map sets power cost, efficiency, and environmental performance objectives for technologies that will allow existing plants to meet anticipated future environmental restrictions, such as expected mercury regulations. The road map also lays out the R&D pathway for the next generation of coal-based plants. Furthermore, the road map allows us to determine the costs for the necessary R&D and demonstration work. We estimate this to be $10 to $14 billion in public and private funds between now and 2020.

Unfortunately, the Federal funding in the administration's fiscal year 2005 budget for both the core R&D program and the clean coal power initiative demonstration is low, barely half of what is needed to follow the road map. Without adequate support from the public sector, it will not be possible to meet the road map's schedule.

A new aspect of DOE's program is the FutureGen project. FutureGen would minimize pollutant emissions to near-zero levels. This facility would be based around a coal gasification system with the capability to make hydrogen and to sequester a million tons of carbon dioxide per year. We believe that a program like FutureGen that defines the cost and feasibility of advanced coal use options is a prudent strategic investment. Furthermore, FutureGen would serve as an important research platform capable of testing advanced powerplant components as they emerge from the R&D program.

My company is one of a consortium of ten coal and electricity companies offering to provide the public sector resources to conduct the FutureGen project. As discussions about FutureGen proceed, it is important to understand that it is not a substitute for either the core R&D program or the CCPI demonstration program. We need the core research to bring new technologies to the status that they can be tested at FutureGen and elsewhere and we need to continue R&D and demonstration projects on technologies that are not part of the FutureGen design.

Furthermore, it will be critical for government to commit to fully funding its share of the project before major costs are incurred.

Beyond R&D, we need to plan for the commercial deployment of these new technologies. The coal-related provisions of Chairman Domenici's pending energy legislation are critical in this regard. First, the bill authorizes $2 billion to 2012 for the Clean Coal Power Initiative, which will help ensure that we can bring products out of the R&D program to commercial readiness. Second, the energy bill contains over $2 billion in vital tax incentives that are necessary to the deployment of clean coal technologies. We strongly urge the Senate to act on energy legislation and we applaud Chairman Domenici for his steadfast leadership.

In conclusion, Mr. Chairman, we need to continue to define, follow, and fund a technology road map that focuses on the costs, efficiency, and environmental performance of coal-based electricity generating technologies in order to preserve our existing infrastructure and build new coal-based powerplants.

Thank you.

[The prepared statement of Mr. Burke follows:]

PREPARED STATEMENT OF DR. FRANCIS P. BURKE, VICE PRESIDENT, RESEARCH AND DEVELOPMENT, CONSOL ENERGY, INC., ON BEHALF OF THE NATIONAL MINING ASSOCIATION

Mr. Chairman, my name is Frank Burke. I am Vice President of Research and Development for CONSOL Energy Inc. (CONSOL). I am appearing here on behalf of CONSOL and the National Mining Association (NMA) to testify on how technology can permit coal to provide the fuel to generate low emission electricity that our nation will need to meet our energy demands of the future.

I would like to commend you, Mr. Chairman, for holding these important hearings. Mr. Chairman, we agree with the statement in your letter of invitation to testify that "actions should be taken today to prepare the nation for a future time when oil and gas prices and availability limit their uses to areas other than electricity generation." As emphasized in the Energy Information Administration's (EIA) latest Annual Energy Outlook published in January of this year, the demand for electricity is expected to increase by nearly 50% by 2025 and we can only assume that this growth will continue beyond that time. Affordable and clean electric energy must be available to allow our nation to reach its full economic potential. Clean electric energy means economic growth and it means jobs. Coal, which is over 90% of our nation's domestic energy resource on a Btu basis, and now provides over 50% of the electricity we use, is - and must continue to be - the source for much of this electricity. Advanced clean coal technologies that are being developed under long-standing federal/private partnerships will assure that coal can continue to be used in a manner consistent with environmental needs.

CONSOL Energy Inc., founded in 1864, is the largest producer of high-Btu bituminous coal in the United States, is the largest producer of coal by underground mining methods, and is the largest exporter of U.S. coal. CONSOL has 19 bituminous coal mining complexes in seven states. We have a substantial technology research program focused on energy extraction technologies and techniques, coal utilization, emission management and byproduct utilization. CONSOL has been an active partner with DOE in the advancement of many technologies and in basic research. CONSOL is a publicly held company (NYSE:CNX) with over 6,000 employees.

The NMA represents producers of over 80 percent of the coal produced in the United States, the reliable, affordable, domestic fuel used to generate over 50 percent of the electricity that we use today. NMA's members also produce another form of fuel uranium that is the source of just over 20 percent of our electricity supply. NMA also represents companies that produce metals and non-metals, companies that are amongst the nation's largest energy consumers. Additionally, NMA members include manufacturers of mining and processing equipment, machinery and mining supplies, and transporters, engineering, consulting and financial institutions serving the mining industry.

THE DEMAND FOR ENERGY WILL INCREASE DURING THE NEXT TWO DECADES AND BEYOND

Energy, whether it is from coal, oil, natural gas, uranium, or renewable sources, is the common denominator that is imperative to sustain economic growth, improve standards of living and simultaneously support an expanding population. The significant economic expansion that has occurred in the United States over the past two decades, and the global competitiveness of U.S. industry, was in no small measure due to reliable and affordable energy.

Our demand for energy will continue to increase. The 2004 Annual Energy Outlook issued by EIA in January of this year forecasts that total energy use in the United States will grow by 40% percent between 2002 and 2025. All sources of energy will be required to meet this increase in use. Over this period, continuing a trend that began over two decades ago, the nation will become even more dependent on electricity to meet final energy demands. The same EIA report predicts that electricity demand will increase by nearly 50% by 2025. Unlike the forecast of a year ago, EIA is now predicting that much of this increase will come from coal-fired power generation. The demand for coal for electricity is expected to grow from today's nearly 1 billion tons to 1.5 billion tons annually by 2025 when coal will produce approximately 52% of the electricity used by U. S. consumers.

New coal fired capacity will be needed to meet this growing demand for electricity. For first time in several years, EIA has increased its estimate of new coal fired capacity that will be built within their forecast timeframe. EIA is now forecasting that 112 GW of the 356 GW of capacity that will be built between now and 2025 will be coal fired, a forecast that is over 50% greater than a year ago. At the same time, we cannot overlook the importance of the existing coal fired generating fleet which will remain the source for 75% of future coal fired power. Very little of the 305 GW of coal-fired capacity that is in operation today will be retired over the next 20 years. The existing units will have to be operated at a higher capacity and with lower emissions. Considerable additional investment will be required to maintain these plants and to install pollution control equipment needed to meet new SO_2, NO_x and mercury requirements.

The reason that coal demand is expected to grow more quickly than previously forecast is the expectation that the natural gas supply will be limited and much higher in price. Indeed we have seen a substitution of coal for natural gas in the past year as natural gas prices have hit, and remained at, near record highs. In 2003, generation from coal increased by more (29,856 million kWh) than the total increase in demand for electricity (12,491 million kWh). Conversely, generation from natural gas dropped by more than 8% (or by 58,377 million kWh) to the lowest level since 2000. Use of coal-fired capacity has increased while use of natural gas capacity has declined despite the large number of new natural gas-fired units built over the last decade. Again, the reason is price. The use of natural gas for electricity generation increased by 75% between 1990 and 2002, while use of gas by industry declined by 2%, and total gas use increased by 20%. This resulted in concerns about supply and caused prices to escalate.

Clearly, the trends of the past are unsustainable in the future. Higher prices for natural gas mean higher prices for electricity and higher raw material costs for industries using gas as a feedstock. Considerable job losses have already occurred due to the higher gas prices brought about by over-reliance on gas for power generation. Both of these factors impair our overall economic growth and employment levels. Fuel diversity is a requirement for stability. We cannot - as we have done over the past decade - put all our eggs in the natural gas basket. Coal generation will have to increase at existing plants and new coal power plants must be brought on line. The challenge for coal is to build these plants with low emission technologies. This will require support from Congress in terms of public policy.

The fact that coal generation can increase while emissions decline has been demonstrated by history. In 2004, sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions will be 40% less than in 1980 while electricity from coal will be approximately 70% greater. Existing air pollution controls already have reduced mercury emissions by 40%, and emissions will continue to decrease as a result of current and future regulations and legislation. This history is a good indication of the trends that can be expected in the future lower emissions as more coal is used for generation of electricity.

The United States is not unique in its dependence on coal, and it is vital to our national interest to promote the increased use of coal not only domestically, but worldwide as a key component of our energy and economic security. The most compelling evidence of this is China. This year, the Chinese will mine and consume 1.5 billion tons of coal. In 15 years, they will consume 2.5 billion tons; China's increase alone will equal our current consumption. They expect to double their coal-fueled electricity generating capacity to 600 GW by 2020. By 2040, the Chinese expect to use 4 billion tons of coal annually.

Throughout the world, economic growth and political stability are tied to electrification, and electricity is tied to coal. Therefore, the desire and, in fact, the necessity of the world to utilize its abundant coal resources will not be denied. Energy availability and energy quality are key to meeting all three aspects of sustainable development: economic, societal and environmental. The question is not whether we need or will use coal for human development, but how we will use it.

THE NEED FOR CLEAN COAL TECHNOLOGIES

One of the principal reasons for developing new coal-fired generating technologies is to ensure that electricity generation from coal does not compromise environmental quality. Because of its chemical composition, coal poses more environmental concerns than other fossil fuels. On average, coal contains more sulfur and nitrogen, and more mineral matter, than oil or natural gas. Fortunately, the means are available to control the emission of these substances into the environment to levels that meet current regulatory limits with the wide range of technologies already deployed on many coal-fired power stations. These include particulate collection devices, such as electrostatic precipitators and fabric filters that control emissions of coal ash, flue gas desulfurization scrubbers of various designs that control emissions of sulfur dioxide (SO_2) and a variety of methods and devices for reducing nitrogen oxide (NO_x) emissions. Many of these were developed under the DOE-industry partnerships of the Clean Coal Program. There are no technologies in widespread commercial use today to control emissions of mercury or carbon dioxide from coal-fired power plants, but as I will discuss, these are the subjects of active research programs.

Like others throughout the world, the United States faces the challenge of meeting our need for low cost energy while reducing the environmental impact of energy production and use. The EPA recently proposed new environmental regulations that will reduce SO_2, NO_x, and mercury emissions from existing power plants to levels well below current regulatory limits. This will require the widespread deployment of improved technology that further reduces SO_2 and NO_x emissions below current regulatory levels at an acceptable cost. Mercury will be substantially reduced as a co-benefit of increased SO_x and NO_x control, but, in the long run, it probably will be necessary to develop and deploy technology specific to mercury emissions. In addition, there are opportunities to improve the efficiency of existing generating units. Increasing efficiency can reduce emissions, because less fuel is required for each unit of electricity generated, and efficiency improvement is the only method currently available to reduce CO_2 emissions from power production.

These Clean Coal systems will need to be designed and integrated in a way that achieves the expected benefits of each, without creating any unintended consequences. For example, the use of combustion modifications to reduce NO_x emissions can result in increased carbon in coal fly ash, making fly ash less valuable as a byproduct. Selective Catalytic Reduction, which is an effective means for NO_x control, can cause deposition that impairs efficiency in the boiler system. On the other hand, the intelligent integration of technologies can have synergistic benefits. As noted earlier, emission control devices installed for other pollutants can remove a limited amount of mercury from some coals from the flue gas coming out of the plant's stack at no additional cost. As another example, the solid byproducts from coal combustion can be converted into salable materials such as wallboard gypsum and road aggregates. Research is underway to learn how to take full advantage of co-benefits such as these, and to incorporate them into the design of existing and new power plants.

In the future, we will need new coal-fired power plants to meet electricity demand growth and to replace existing facilities as they reach the end of their economic lives. Notable among these new technologies are supercritical pulverized coal combustion, advanced combustion, integrated gasification combined cycle (IGCC), and various hybrid power systems. These technologies hold the promise of high-energy efficiency and minimal environmental impact if they are developed and successfully deployed at an acceptable cost. For example, IGCC technology is currently being demonstrated at several sites, but it must still be considered pre-commercial technology because of its relatively high capital cost. Nevertheless, IGCC systems can produce some of the cleanest power available from coal; emissions from these systems approach the levels generated by modern natural gas-fired power plants, and research is underway to reduce the capital cost through design improvements. As with all technologies, the full benefits of potential design optimization will not be gained until a sufficient number of full-scale commercial units have been built and operated.

THE CLEAN COAL TECHNOLOGY ROADMAP

The term "Clean Coal Technology" (CCT) is used to describe systems for the generation of electricity, and in some cases, fuels and chemicals from coal, while minimizing environmental emissions. This is accomplished through increased efficiency (i.e., electricity produced per unit of fuel [energy] input), equipment for reducing or capturing potential emissions, or a combination of the two. Various CCTs are commercially available, or have been demonstrated at full commercial scale, but need further commercial use for economic optimization. Other CCTs are in the research and development stage.

Currently available CCTs include the efficient pulverized-coal-fired boiler (supercritical type) equipped with a full complement of fully-developed, state-of-the-art pollution control technologies. An example of this would be a supercritical boiler equipped with selective catalytic reduction for NO_x, high efficiency flue gas desulfurization for SO_2, and a particulate collection device. It is important to realize that many coal-fired generating units are currently equipped with these CCT systems, some of which were brought to the state of commercial readiness since 1986 in the Department of Energy's previous Clean Coal Technology program.

Clean Coal Technology also refers to high-performance technologies that are well along the development path, but not yet fully demonstrated to be commercially available because of either technical or economic risks. Examples of these are integrated gasification combined cycle (IGCC) and advanced combustion power plant technologies.

"Advanced" Clean Coal Technology refers to technology concepts that are in development for future use, such as advanced IGCC or ultrasupercritical boiler technology. In this context, the term "advanced" refers to improvements in costs, efficiency, and performance that are expected at some future date, assuming successful development.

Moving advanced clean coal technologies to full commercial operation will take a continuing commitment to research, development, demonstration and a strategy to ensure that the technologies, once developed, will be deployed commercially. To provide a means of planning future research needs, and to chart progress toward meeting them, the industry, largely through the efforts of the Coal Utilization Research Council, the EPRI, and the Department of Energy, has devised a Clean Coal Technology roadmap that sets cost and performance targets and a timeline (See Tables, below) for new coal technology.

It must be clearly understood that these are merely research targets and are not intended to serve as a basis for regulatory requirements. Moreover, as noted later, progress along the roadmap will depend upon adequate funding. If the roadmap were followed, technology would be available in the near term to allow operators of existing coal-fueled power plants to meet increasingly stringent environmental regulations, such as those of the Clear Skies Act. Again, were the roadmap followed, it would be possible in 2015 to design a high efficiency power plant, capable of carbon capture, with near-zero emissions; by 2020, the first commercial plants of this design would be built.

DOE/CURC/EPRI CCT Roadmap I

Roadmap performance targets	Reference plant*	2010	2020
SO_x, % removal	98%	99%	>99%
NO_x, lb/MMBtu	0.15	0.05	<0.01
Particulate matter, lb/MMBtu	0.01	0.005	0.002
Mercury	"Co-benefits"	90%	95%
By-product utilization	30%	50%	~100%

*Reference plant has performance typical of today's technology. Improved performance achievable with cost/efficiency tradeoffs.

DOE/CURC/EPRI CCT Roadmap II

Roadmap performance targets	Reference plant*	2010	2020
Plant efficiency (%, HHV)	40	45-50	50-60
Availability, %	>80	>85	~90
Capital cost, $/kW	1000-1300	900-1000	800-900
Cost of electricity, $/MWh	35	30-32	<30

*Reference plant has performance typical of today's technology. Improved performance achievable with cost/efficiency tradeoffs. W/o carbon capture and sequestration.

The roadmap contains considerable detail on the specific technological advances that are necessary to meet the roadmap coal. Some of these "critical technologies" are listed below.

Improvements for Existing Plants

- Mercury control
- Low-NO_x combustion at reduced costs
- Fine particle control
- By-product utilization

Advanced Combustion

- Ultra-supercritical steam
- Oxygen combustion
- Advanced concepts (e.g., oxygen "carriers")

Gasification Systems

- Gasifier advances and new designs (e.g., transport gasifier)
- Oxygen separation membrane
- Syngas purification (cleaning) and separation (e.g., hydrogen, CO_2)

Energy Conversion Advanced gas turbine technology using H2-rich syngas

- Fuel cell systems using syngas
- Fuels and chemicals

Carbon Management

- CO_2 capture and sequestration
- <10% increase in cost of electricity for >90% removal of CO_2 (including sequestration)
- "Hydrogen economy"

Systems Integration

- Integrated power plant modeling and virtual simulation
- Sensors and smart-plant process control

Finally, the roadmap makes it possible to estimate the cost of the research, development and demonstration programs necessary to achieve the performance targets, as shown in the table below. These values represent the total cost of the research programs, including both federal funds and private sector cost shares.

Coal technology platforms	RD&D spending through 2020
IGCC/gasification	$3.5 billion
Advanced combustion systems	$1.7
Innovations for existing plants	$1.4
Carbon capture/sequestration	$2.8 (?)
Coal derived fuels and liquids	$1.2
Total	$10.6

The cost for carbon capture and sequestration research is shown with a question mark, to denote the relatively greater uncertainty in the estimate of the cost of research in this unprecedented area. It could be substantially higher, particularly because a number of large scale, long-term demonstrations will be needed to understand the technical, economic and environmental feasibility of carbon sequestration technology. This was one conclusion of a recent National Coal Council report, entitled "Coal-Related Greenhouse Gas Management Issues," which provides a detailed discussion of the opportunities and impediments to developing, demonstrating and implementing greenhouse gas management options related to coal production and use.

THE ROLE OF THE FEDERAL GOVERNMENT IN TECHNOLOGY DEVELOPMENT

The DOE Office of Fossil Energy, through its Coal and Environmental Systems program, expended about $198 million in 2004 to co-fund coal-related R&D, in addition to providing $170 million for the Clean Coal Power Initiative demonstration program. The DOE is supporting the development of new technology for mercury reduction and carbon management. The DOE coal program seeks to develop advanced, highly efficient, low-emitting energy complexes, for the production of electricity, fuels and chemicals. The federal government has had a significant role in the development of clean coal technology. The original Clean Coal Technology (CCT) program and the current Clean Coal Power Initiative support the first-of-a-kind demonstrations of new coal use technologies. These demonstrations encompass a wide range of technologies, including environmental controls, new power generating facilities and fuel processing. Forty projects were conducted in the original CCT program, with a total value of $5.4 billion, consisting of $1.8 billion in federal funds and $3.4 billion in non-federal funds (a 2/1 leverage on federal dollars).

In 2002, the Energy Department announced the selection of eight projects to receive $316 million in funding under Round 1 of the Clean Coal Power Initiative program, the first in a series of competitions to be run by the Energy Department to implement President Bush's 10-year, $2 billion commitment to clean coal technology. Private sector participants for these projects have offered to contribute over $1 billion, well in excess of the department's requirement for 50 percent private sector cost-sharing.

Three of the projects are directed at new ways to comply with the President's Clear Skies Initiative that calls for dramatic reductions in air pollutants from power plants over the next decade-and-a-half.

Three other projects are expected to contribute to President Bush's voluntary Climate Change initiative to reduce greenhouse gases. Two of the projects will reduce carbon dioxide by boosting the fuel use efficiency of power plants. The third project will demonstrate a potential alternative to conventional Portland cement manufacturing, a large emitter of carbon dioxide.

The remaining two projects will reduce air pollution through coal gasification and multi-pollutant control systems.

CONSOL has been an active participant in coal-use research since the 1940s. Our goals are closely aligned with those of the DOE coal program, and much of our research has been done in partnership with the DOE. We were a member of the project teams for two of the CCT projects, and we made both financial and technical contributions to these projects. We also were selected for award under the recent Power Plant Improvement Initiative program to demonstrate a multi-pollutant control technology, targeted at the smaller power plants that generate about one-fourth of our coal-based electricity.

Much of our research is directed at helping our utility customers deal with the consequences of environmental regulations. For example, we developed a new technology for the beneficial use of the solid byproduct of flue gas desulfurization, by converting it into aggregates for use in road and masonry construction. This technology, which we piloted in partnership with DOE, reduces the cost and the land-use consequences of solid waste disposal. It can provide a valuable source of construction materials in areas without good indigenous sources, such as Florida, and areas of high growth, such as the southwestern states. Projects like this, which are a win for the economy and a win for the environment, justify CONSOL's commitment to work in partnership with the DOE to develop technology that makes sense from both perspectives.

In some cases, research and demonstration projects, such as those conducted under the DOE Coal and CCT programs, have been sufficient to bring important technologies directly to the marketplace. For example, over $1 billion in Low-$NO_x$ burners have been installed at U.S. power plants since being demonstrated in the CCT program. However, other CCT program technologies, such as Integrated Gasification Combined Cycle systems, have not been widely commercialized at their current stage of development because of the technical and economic risks that remains despite these one-of-a-kind demonstrations. Nevertheless, large scale demonstrations are essential to understand the technical and economic performance of these new technologies and to provide potential owners and inventors with sufficient confidence to be able to attract financing.

The DOE has issued a second CCPI solicitation. We believe that these large-scale demonstration projects are essential to reduce the technical and economic risks of new advanced clean coal technology.

The government has a critical role to play in providing resources to follow the Clean Coal Technology roadmap, but unfortunately, current funding levels are not sufficient to meet the roadmap goals. The table below compares the funding levels required to follow the roadmap to the level in the Administration's FY 2005 budget.

Technology program (all figures in $millions)	Administration FY 2005 request	CURC roadmap annual R&D budget [1]
IGCC/Gasification	34.5	106
Advanced combustion	0.0	18
Advanced turbines	12	17 (sungas from coal)
Existing plants	18.1	43
Carbon sequestration	49	79
Advanced research		
Advanced materials only	4.65	4.0
Coal derived fuels & liquids	16.0 (H_2 only)	13 (Fuels only)
Total R&D	**160**	**280**
Clean coal power initiative	50	240.0
FutureGen	227	([2])

[1] This number is 80% of the total R&D amount required and represents the federal contribution.

[2] The CURC roadmap does not explicitly include the FutureGen initiative.

Although it varies by program area, the overall R&D funding level is little more than half of that called for in the CURC roadmap. Unfortunately, this continues a pattern of past years of under funded clean coal research. Unless research and demonstration funds are increased, it is unlikely that technology will be developed on the roadmap schedule, if at all.

Similarly, the funding level for the CCPI falls well below the roadmap requirements. Furthermore, the progress of the CCPI program is hampered by the requirement for annual, as opposed to advance appropriations. Because of the size and cost of demonstration projects, it is necessary for the DOE to use money from both FY04 and FY05 appropriations to be able to fund the current solicitation. Future CCPI solicitations are likely to be delayed or limited in scope for the same reason. It is even possible that some necessary demonstrations will not be done because the available appropriations are insufficient. Given this situation, it may be appropriate for the Department to consider targeted solicitations focused on the roadmap objectives, or to utilize other approaches to match demonstration priorities with budgetary limitations.

Because it was proposed after much of the work on the Roadmap was completed, the FutureGen initiative is not explicitly included in the Roadmap or in the CURC funding recommendations. However, the goals of the FutureGen project are consistent with the Roadmap, and properly coordinated with the core R&D and demonstration programs, FutureGen can be an important element in meeting its objectives, as discussed below.

THE FUTUREGEN PROJECT

In February of last year, the Department of Energy announced plans to build a prototype of a coal-based power plant of the future. Dubbed "FutureGen," this facility would be based around a 275MW IGCC system, but it would have the capability to convert synthesis gas into hydrogen and to capture and sequester up to one million tons per year of carbon dioxide. FutureGen would be designed to minimize emissions of criteria pollutants and mercury to "near zero" levels. Furthermore, the FutureGen facility would be designed to serve as a "research platform" capable of testing advanced components, such as air separation membranes or fuel cells, during the ten year duration of the project, and perhaps beyond. The Department issued a "Request For Information" soliciting responses last June from parties willing to undertake the FutureGen project. My company, CONSOL Energy Inc., is a member of a ten-company group of major U.S. coal producers and users, which submitted a response to the DOE RFI, offering to enter into negotiations to conduct the FutureGen project. In part, our submittal says that the FutureGen mission should have four key elements:

1. develop commercially competitive and affordable coal-based electricity and hydrogen production systems that have near-zero emissions;
2. develop large-scale CO_2 sequestration technologies that are technically and economically viable and publicly acceptable;
3. provide a large-scale research platform for the development and commercialization of advanced technology; and,
4. provide opportunity for stakeholder involvement and education.

The vision of FutureGen as a research platform is particularly significant because it means that the FutureGen facility can be used as a test site to bring promising technologies out of the core R&D program and to accelerate their testing at scales up to full commercial implementation without the need for separate stand-alone test facilities.

However, it is important to understand that FutureGen should not be viewed as a substitute for either the core R&D program or the CCPI demonstration program for at least two reasons: First, the FutureGen facility will not be operating for at least five years. During that time we need to continue the research needed to bring new technologies to the state that they can be tested at FutureGen. Second, we need to continue R&D on technologies, such as combustion-based systems, that are not part of the FutureGen design. That said, as the FutureGen concept is further defined, industry and government should look for opportunities for efficiencies in the coordination of the R&D program, the CCPI, and FutureGen to produce the greatest benefits at the lowest possible cost. This coordination should be an integral part of the ongoing technology road-mapping process.

Finally, although the exact cost is not known, DOE originally estimated the project cost as $1 billion, with 80% provided by the federal government, and 20%, or $200 million, provided by the industrial alliance and its partners. Both an acceptable cost share ratio and the ability of the Government to commit its full cost share to the project before major costs are incurred are critical to the project's success.

INCENTIVES FOR CLEAN COAL TECHNOLOGY DEPLOYMENT

The foregoing discussion in this statement deals with the need for research, development and demonstration of advanced clean coal technology, and discusses technical and economic criteria that these new technologies will need to meet to achieve acceptance in the commercial marketplace. However, while the Clean Coal Power Initiative and the enhanced core Fossil Energy authorization that are included in the pending conference report of the energy bill, H.R. 6, are necessary for the continued development of coal technologies, they are not by themselves sufficient to ensure that these technologies will find their way into widespread commercial use. When they are initially introduced, they will need to be built with substantial engineering contingencies to assure their operability and reliability, which will increase capital and operating costs. Over time, as operating experience is gained, these costs will come down. Therefore, there is a need for financial incentives to offset the increased technical and financial risk inherent in the initial deployment of advanced clean coal technologies. These critical incentives are included in the conference report to H.R. 6, in the tax package that is part of the new "leaner" energy bill, S. 2095 and in the energy tax provisions that have been incorporated in S. 1637, the FSC/ETI bill. We strongly urge the Senate to act on these energy provisions on an expedited basis so that comprehensive energy legislation can be enacted this year.

CONCLUSIONS

Mr. Chairman, there is little doubt that coal will continue to be widely used in the United States and abroad as a principal fuel for electricity generation, and coal's use will grow over time. We appreciate your strong recognition of that fact. The interests of the economy, society, and the environment in coal can be reconciled if we invest now in the development and deployment of advanced clean coal technology which will allow coal to be truly a low emission form of electricity. By working with industry to develop a coal technology development roadmap, the Department of Energy has and continues to align its program with a logical path forward to support the development of advanced clean coal technology. The coal industry remains committed to do our part to see that coal remains an abundant, affordable fuel for power generation, and to help to advance the technologies needed to meet the goals of societal, economic and environmental betterment.

Senator BUNNING [presiding]. Thank you, Mr. Burke.

I am going to pinch-hit for the chairman since he has been called away. I will get my questions or some of them out of the way, then I will proceed with Senator Bingaman and Senator Akaka.

Mr. Garman, in the past the Government pushed the use of natural gas. Today that singlemindedness is causing serious problems for Americans because of the current high price of natural gas. The presidential fiscal year 2005 budget, as Mr. Burke mentioned, request is for $237 million for FutureGen and only $50 million for Clean Coal Power Initiative.

The President's clean coal plan has pledged to commit over $2 billion over 10 years for advanced clean coal technology. Funding only $50 million will not meet that pledge. While the prospect of FutureGen seems promising, why does it seem that DOE is pushing one program over another by focusing more on FutureGen rather than the Clean Coal Power Initiative.

What do the other witnesses think about this and what do you think about it?

Mr. GARMAN. I thank you for that question. One of the reasons that we are going after FutureGen is because it is analogous to the long bomb. It is a daunting R&D effort. It is something that is worthy of Federal participation. If we are successful in FutureGen, if we are successful in being able to design and deploy and demonstrate a coal plant with virtually zero emissions, no emissions of carbon dioxide, then we will have made a tremendous stride toward stabilizing greenhouse gas concentrations in the atmosphere. We would have developed U.S. leadership in a new technology that could be applicable in India, China, and all of the other high coal-burning countries of the world.

It is a high-risk, high-reward proposition. Yes, it is true that we have in our budget submissions taken some money from nearer term incremental improvements in the performance of clean coal technology and shifted it to that longer-term higher-risk effort. But we think there is an argument for doing that.

Senator BUNNING. Well, let me ask you. It is my understanding that DOD has not yet announced projects for FutureGen, but it has projects already under way for Clean Coal Power Initiatives. How does the DOE plan to spend $237 million for FutureGen if no projects have been announced?

Mr. GARMAN. We sent a plan to the Congress on FutureGen outlining our future plans, I believe, on March 4 of this year. We described a FutureGen program where we envision about a——

Senator BUNNING. But you do have Clean Coal Projects——

Mr. GARMAN. Yes, we do, and we will continue that work in that area. But I will tell you it is my understanding that we will be using some of that budget authority in the context of FutureGen in the future.

Senator BUNNING. Well, it seems disproportionate when you have $50 million on one side and $237 million on the other, and you are throwing the long bomb with $237 million and you are developing clean coal technologies at a—well, at a much lesser rate, and you actually have programs in clean coal technology right now.

Mr. GARMAN. Correct.

Senator BUNNING. So why the disparity?

Mr. GARMAN. Because FutureGen is also a clean coal program.

Senator BUNNING. Well, I understand that, but it is a maybe program.

Mr. GARMAN. It has risk, yes, it does.

Senator BUNNING. Big time.

Mr. GARMAN. Yes, sir.

Senator BUNNING. Well, it is my opinion—and maybe some of the other panelists can weigh in; I would like for them to.

Mr. BURKE. Could I address that?

Senator BUNNING. Yes, please do.

Mr. BURKE. My company is one of ten companies that last year responded to DOE's request for information and offered, contingent upon our ability to negotiate an appropriate agreement, to do the private sector portion of the FutureGen project. We view FutureGen as being a very important strategic element in the overall clean coal technology area. It is a longer term strategic issue compared to some of the nearer term issues that are being funded out of the core R&D program and out of the Clean Coal Power Initiative program right now.

FutureGen is one technology, the FutureGen project will be one technology. We think that, in addition to FutureGen, it is necessary to continue to develop other parallel clean coal technologies.

[Buzzer sounds.]

Mr. BURKE. I am sorry.

Senator BUNNING. Do not bother about that.

Mr. BURKE. I am sorry, I did not know if I was supposed to do something.

Senator BUNNING. No, we are, but you do not have to.

Mr. BURKE. I apologize.

So FutureGen is important from the strategic point of view. Probably the most important thing about FutureGen is it will be a full-scale demonstration of carbon sequestration, which is a very important element in the overall clean coal technology program. But it is only one demonstration of carbon sequestration. We need demonstrations of carbon sequestration at a number of sites. We need the development of a variety of clean coal technologies that stress not only new facilities, not only gasification-based systems, but combustion-based systems and technologies that address existing plants.

So I think in that context the FutureGen project is an important strategic objective, but the CCPI and the core R&D programs are essential to continue to develop a range of clean coal technologies that we need to use now and in the near term, as well as to provide technologies which will ultimately be tested at facilities like FutureGen.

Senator BUNNING. Dr. Moniz.

Dr. MONIZ. Thank you Senator Bunning. First let me just repeat, as I said earlier to the chairman, that at MIT John Deutsch and I have a new major study going on on coal, so I would be especially happy to answer your questions in approximately a year. However, a few comments may be at least framing some of the questions. I do share some of your concern.

FutureGen I believe has extremely important objectives. Having said that—and I am fully supportive of going forward with research and development in gasification technologies and others, other of the technologies that are part of FutureGen. I think some of the questions that legitimately can be raised, however, involve questions about when is the right time for a major integrated demonstration project. Let us face it, we have had in the history, in our history, a number of large initiatives that proved to be premature in terms of their demonstration of commercial technologies.

I do not know the answer, but I think that that is a legitimate question. I believe that one needs clarity on the goals. For example, any project, FutureGen or any other, that is, let us say, focused on trying to demonstrate commercial viability versus providing a flexible research platform for looking at different technologies typically have a hard time coexisting. I have to be honest, I do not have complete clarity as to which of these is the leading effort.

The integration is a little bit of concern in the sense that I believe, as David said, and I completely agree with him, and Francis as well, that there are several risky technologies here being integrated and a strategy of trying to separate some of those for research may or may not prove more effective for getting to the goal I think we all share.

From that point of view, what I believe is missing—and not only in this part of the research portfolio, but the entire energy R&D budget I believe remains underfunded. In that context, we do not have the kind of overall portfolio balance between shorter term projects, longer term home runs that I think we need in the Federal R&D portfolio.

Senator BUNNING. Thank you.

Dr. Smalley, you have something to add?

Dr. SMALLEY. No.

Senator BUNNING. Okay. Senator Bingaman.

Senator BINGAMAN. Thank you very much.

Let me just frame the issue the way I hear it being discussed here. Senator Bunning made a very good point by referring to the effort of, his characterization as I took it, of the FutureGen project as throwing a long bomb. It strikes me that on the one hand we have got the administration trying in various ways in this R&D area to throw the long bomb.

We are committed to a new hydrogen economy and we have this hydrogen posture plan which we have been given by the Department of Energy. When you get over here to figure 6 on page 10 and look at when all of this is going to start happening, not a whole lot starts happening in the marketplace until you get past 2020. This is a long bomb as I see it.

FutureGen is the same way. It is a proposed project to develop hydrogen from coal production and also sequester emissions. It sort of feeds into the hydrogen economy that we are aiming for, which is this long bomb.

Now, what you have talked about, Dr. Smalley, in your testimony is very different than that, at least the way I understood it. You suggested that we launch a bold new energy research program, as you were putting it. As I understand, you particularly put emphasis on the need for advances in storage technology and advances in technology, much of the work which you are credited with related to transmission of electricity over long distances with great efficiency.

What I understood you to be talking about is a very multifaceted, robust energy research effort that would move us ahead in a lot of different areas to make what progress could be made as quickly as it can be made in each of these areas, rather than throwing the long bomb. My concern, frankly, is when I look at the budget of the administration DOE-wide, the request for hydrogen this next year is up 43 percent for R&D related to hydrogen. The request for other energy R&D activities in the DOE over the next 5 years all shows a decline. Renewables are proposed for a 21 percent decline, fossil energy production 22 percent decline, conservation R&D—which, David, you referred to the importance of conservation—is scheduled for a 26 percent decline over the next 5 years.

It seems to me we are putting all of our eggs in one basket. We are saying, look, let us go for the long bomb, it will solve all our problems and it will happen after 2015 or 2020, and in the mean time we can afford to cut back on funding of research in these other areas.

Dr. Smalley, maybe you would have a comment as to whether I have correctly characterized what you have proposed and whether there is any validity to that characterization of what we are talking about.

Dr. SMALLEY. Yes, Senator, I think that is a fair summary. I believe the path that we are on right now is not going to get us there.

We are not going to be in a situation where we will have energy security. The economic basis for strength of this country and, for that matter, the world is going to be eroded. It is hard to fully internalize what it means when we do in fact peak in worldwide oil and as natural gas prices continue to go up. We have never been in this circumstance before in the history of this country.

Oil and gas are so wonderful. What we need to do is find something to replace them. I am a great believer that we should try to do what we possibly can with coal. We should push it. I believe we should push it even stronger than what is being talked about now. But the big answer is probably someplace else.

The status of basic research and even the development enterprise in the physical science and engineering in this country is in decay. What you mentioned as the budget projections for DOE is only going to enhance this decay. We are just not going to get there on this path. That is why I am calling for a major program.

As Senator Domenici pointed out, we still would be talking about something tiny compared—well, not tiny, but about half of what is currently the NIH budget. The NIH budget is what we do when we are serious about something. I believe it is time to get very serious about not only our energy problem here in this country—energy is a worldwide business. We compete worldwide for the energy that is produced.

There will be a new energy technology that will come out. There will be a new oil. We will get to it some time. Maybe it will be 50 or 100 years from now. It will be there. When we are there, it will transform the largest enterprise of humankind, energy. I do not believe the United States can afford to be out of that business. We need to be the leaders in it, to take the opportunity to develop our science and engineering capability and to get the new startup companies and the major divisions of existing large companies involved in this.

So I am a great fan of clean coal and nuclear, both fission and fusion, biomass and so forth. I do not think we can afford to take anything out of the equation. We are going to need all the energy we can possibly get. But even doing that is not going to get us there. This is a bigger problem than we are giving it credit for.

Senator BINGAMAN. I think my time is up. I guess, David, go ahead.

Do you mind if he responds? Go ahead.

Mr. GARMAN. Sure. Thanks for the chance to maybe give a slightly different characterization of our resource portfolio than you provided. We believe that our research portfolio is balanced several different ways, with a variety of technologies, against a spectrum of risks, both high risks and lower risks. Yes, it is true that we are engaged in some very high-risk long-term propositions, such as FutureGen and the President's hydrogen initiative.

But it is also true that we are engaged in much shorter-term types of R&D activities such as making more efficient building insulation or window material for a building. Our technology spectrum is arrayed to deliver results in the mid and the short and the long term, not to mention technology deployment activities that can be as simple as the President's commitment to low-income weatherization, which is not included in the figures that you portrayed. It is $291 million that we want to use today to upgrade the energy efficiency for those low-income Americans that can least afford higher energy prices. That is taking technology and putting it to work right now.

So in that sense we think our portfolio is balanced and, just as in the case of an individual stock investor if—I had money and could invest in something, I would invest in a wide variety of things, some high risk, maybe some more speculative equities, but I would also have something in T-bills. And we do that. The weatherization program is in essence our T-bill. But we have some high-risk propositions as well, looking for high rewards down the road.

Senator BINGAMAN. Mr. Chairman, I will wait for my next round. I will come back to the issue because I think Dr. Moniz and Mr. Burke both pointed out—I think Dr. Moniz said that the R&D budget for nuclear is woefully underfunded. Mr. Burke said that the funding for this road map toward clean coal is barely half of what, the projected funding is barely half of what the road map requires.

So I think we have a serious problem as to whether we are putting the resources behind these things to actually make any major progress.

Go ahead.

Senator BUNNING. Thank you, Jeff.

I would be remiss as a U.S. Senator from Kentucky, since you are here, David, if I did not get into this a little bit. As the new Under Secretary, you have the responsibility for the Energy Employee Compensation Program. As of late March, the Department of Energy had completed only 4.5 percent of over 2,700 Kentucky workers' requests for assistance. 88 percent of those completed cases were found ineligible cases or were withdrawn. Zero Kentuckians have received any payment for their claims.

After almost 4 years and $10 million spent on the program, when will the thousands of workers at Paducah who need ongoing medical benefits from workers compensation get the help they so desperately need?

Mr. GARMAN. Thank you, Senator, and this was one of the first briefings I received. I have been on the job precisely 1 week and 1 day, but am already trying to get as immersed in this issue as I can be.

I think my predecessor sat in this chair and said that he had not been satisfied with the way that the Department of Energy got out in front of this issue, and clearly we did not get a quick start, no doubt about it. Similarly, I read very carefully the transcript of the hearing that was held on this issue recently, and I sense something else is going on here beyond simply the slow pace of the Department of Energy's progress in going through the EEOICA Part D provisions. That is, even when we are successful—and we have moved a number of cases to the physician review panel and cases have emerged from the physician review panel; about 476 actually have come out of the process on the other end. But I am hearing that Senators are not satisfied with what came out of the other end—a piece of paper from a physician that gives them perhaps a leg up when they go before State compensation boards and try to get compensated for the exposures they had.

We pledge to work with you, I think as my predecessor did, to try to grapple with some of these very difficult issues, willing payer issues among them, and how to speed this process along. I am going to be very careful not to overpromise to you, Senator, because I think there has been a lot——

Senator BUNNING. It would not do any good, promising after almost 4 years.

Mr. GARMAN [continuing]. Of overpromising that has been done in relation to this program, and I do not want to make it worse. But I think we need to envision a two-track approach. Track one is to speed up the process—and we have committed to that. We are now running through 100 cases a week. We want to ramp that up to 300 cases a week.

But we also want to explore with you alternative aspects, different ways of dealing with this problem.

Senator BUNNING. I have a bill to do just that.

Mr. GARMAN. I know you do, and I am preparing to engage with you and the Deputy Secretary and the Secretary as well on that. So we do want to work with you.

Senator BUNNING. Do you have an Assistant Secretary, by the way?

Mr. GARMAN. No, sir, we do not.

Senator BUNNING. You do not?

Mr. GARMAN. No, sir.

Senator BUNNING. Okay. Well, the whole point I am trying to make is that the DOE has not lived up to their commitment to get it done. They have kind of thought that it would go away, and it is not going away. It is getting worse.

My suggestion is to get as many of those people with their certificates so they can at least try to find a willing payer. If we have a willing payer in Kentucky or any other areas—New Mexico, Colorado, or wherever it might be—they ought to be able to get some kind of compensation out of workers comp.

My suggestion is to take a look at our new bill and see if that is not going to be an alternative to what has been a very frustrating 3½ years for the workers.

Mr. GARMAN. Yes, sir.

Senator BUNNING. Thank you.

The Chairman.

Mr. CHAIRMAN [presiding]. Thank you very much, Senator.

Senator Bingaman.

Senator BINGAMAN. I already had one round, Mr. Chairman, if you want to go ahead.

The CHAIRMAN. Thank you very much. I have about three and that is it. I will submit a few in writing.

Dr. Moniz, I strongly concur with most of the key points that you made. Expansion of nuclear is needed in the country. Production of tax credits is a good way to encourage the construction. I am glad you have come out that way. Interim storage of spent fuel is essential in the near term, and international safeguards through the IAEA should be strengthened, and significant research should be accomplished on multiple fronts to determine our best path forward.

I would put a little different emphasis on a few areas overall, but overall I think we are thinking alike. Your thoughtful testimony is appreciated. In your testimony you emphasize that the Department's nuclear energy program is substantially underfunded. I previously expressed my amazement that the current budget proposal calls for a 26 percent cut in nuclear R&D after Congress worked to restore that funding from zero in 1997.

What level of R&D funding would you recommend for 2005 for nuclear energy compared to the administration's proposed level of $96 million and $130 million in the current year?

Dr. MONIZ. Mr. Chairman, first if I may again say that I think the first context is the entire energy R&D budget I think is too low. We are literally back in 1965 levels in terms of real dollars, before we had our first energy crisis.

With regard to nuclear energy, let me first note that the budget recommendations we made for R&D in the current organization of the Department of Energy would not be only in the Nuclear Energy Office. It would be nuclear energy, it would be in waste, etcetera. But we recommended going up to, ramping up to approximately $450 million per year in this area.

This would fund, the discussion we were having a few minutes ago, we believe an appropriate portfolio of activities that would have relatively short-term impacts, for example, the very important issue of high burn-up fuels in thermal reactors, to the much longer term focused issues like literally we believe a $50 to $100 million a year analytical simulation project to understand how one should design fuel cycles and acquire the bench-scale scientific and engineering data required to inform those analyses.

These are, unfortunately, not there.

The CHAIRMAN. Right. Well, you know, I understand how bad things look, but I have been here when we had no nuclear activity to speak of and when we had a Department that was embarrassed to have any indication that they were doing anything in the nuclear field. You came along at the end of that era and I am very appreciative that at least you broke that, but you surely did not get it broken—you did not break it and cause a great surge of research even in your day.

Dr. MONIZ. May I add a comment, Mr. Chairman?

The CHAIRMAN. Sure.

Dr. MONIZ. In fact, one of those initiatives is an example of what I think is very unfortunate, is in a bipartisan way the administration and the Congress—I testified with Senator Bingaman on this a couple of years ago—we did start this NERI program, the Nuclear Energy Research Initiative, specifically focused on new concepts developed especially in the university and university-laboratory partnership settings.

That is now—I believe 2 years ago I noted that it was really time to get beyond paper and raise that level. Well, actually it has gone now to zero, which is not a very good approximately to $100 million.

The CHAIRMAN. Well, as far as I am concerned as the appropriator, I have not been sitting by. I am the one started all of those. They were zero a few years ago, whoever was President. I do not even remember who was. But I am the one that got them up, with your help and others.

Dr. MONIZ. Yes.

The CHAIRMAN. And this year it is back down, you know, which is to me kind of goofy. I mean, you get started in the right way and all of a sudden because you have got a tight budget you do away with something that is terrifically important.

Dr. MONIZ. And in particular, if I may say, things like the NERI go exactly along the lines of what Dr. Smalley was saying about we have to be building our young people up and investing in longer term university-based research as well.

The CHAIRMAN. Well, I want to just talk about another one with you. You know, you talk a little bit in your remarks about how important it is that the environmentalists, whatever that is, that somehow they come to an understanding how well nuclear power addresses some of their major issues, not all of them, but clearly the dirty air, it is a model. That does not mean we know yet how to satisfy everybody on where to put the waste, but if we did it like France we know how to do that in a nickel. That is nothing, temporary, but it is pretty much everybody knows how to do it. We could do it with a big team of existing engineers.

But can you suggest how a wider appreciation of the environmental benefits of nuclear power might be achieved?

Dr. MONIZ. Well, if I may bring up and recall an editorial in Science magazine written by Richard Meserve earlier this year, former Chairman of the NRC. He wrote an editorial that was interesting. It picked up from the poll done in our study that said that the public did not certainly connect particularly global warming issues with nuclear power.

What he noted really was that, not his words, but there is almost a conspiracy of silence in making the connection. Many in the environmental community have not been willing to readdress the question of nuclear power in this role. However, he points out as well that in the utility industry this point is not being made either, often because the same utility that may be promoting a nuclear plant is also promoting coal plants and they do not want to get into that discussion. And frankly, the administration has not been very forthcoming in making especially this link between nuclear power and global warming.

I do not know what to say other than the obvious, that we need to have I think much more open and frank discussions. I want to make it clear, I am an advocate not of nuclear power; I am an advocate of energy supply, of clean environment, and of energy security. I am not pushing any particular technology.

But nuclear power simply has to be discussed openly, its plusses and its minusses, in terms of the challenges that we face for energy supply and clean energy supply.

The CHAIRMAN. Well, I disagree with you that the energy, electricity companies are not attempting to promote nuclear. I have been amazed at what they have been doing and how they have been putting themselves out front. The consortium they just put together to see if the statute we drew will work is pretty exciting.

Dr. MONIZ. Yes.

The CHAIRMAN. But I do agree that if you are looking for promotion and that kind of activities, there seems to be something running into each other where you cannot get that done.

Dr. MONIZ. We actually do not disagree on the point that you just mentioned, Senator. Clearly, these consortia going forward to test combined construction and operating licenses, etcetera, are an important movement. I was referring more specifically to the role of nuclear power in global warming, which is not a link that is being made by the companies. Frankly, I believe in the end, certainly for me, that is uniquely the principal driver for having to address the question of nuclear power's future on a relatively short time scale.

The CHAIRMAN. My last question is directed at Dr. Smalley and Mr. Garman. I realize that if wind and solar renewable sources are accompanied by energy storage we can compensate for their intermittent production of electricity. Dr. Smalley discussed the vision for such storage in his testimony, and I will be brief. It was very emphatic in his testimony and he emphasized the importance of it.

I would be interested in the perspectives from both of you on current studies of energy storage and whether you think we need to expand that research or cause something to change so it will happen with more effectiveness. In addition, I wonder if you have made estimates of the additional costs incurred by renewables if storage is required.

Do you want to start, David?

Mr. GARMAN. There is substantial work going on in energy storage technologies today. Compressed air energy storage systems for utility-scale work have been demonstrated. Flow batteries are showing some promise as storage media; reversible fuel cells, something we are working on in the context of the hydrogen so that when you have excess electricity generation you can make hydrogen; when you do not have it you let the hydrogen flow back into electricity.

These are all things that are being worked. Of course, we can always discuss the scale of the activity and whether more can be done. In all of these activities that the panel has raised, I think we all agree that more can be done. I am also mindful of what you said in our Appropriations Committee hearing: The money is limited. So we have this tension built into the system where we are trying to make sure the portfolio is optimized as best we can.

The CHAIRMAN. All right.

Dr. Smalley.

Dr. SMALLEY. It has been over 150 years since the lead-acid battery was discovered. We still have not really beat it. It is not for lack of trying. There has been a tremendous effort for pretty much this entire time to get the lead out of the batteries.

As you commented, I am a technological optimist. I assume that mother nature really has provided a way for us to do this. We just really have not found it yet. It may very well turn out that that new battery that is transformingly better than the lead-acid battery just cannot be made with the materials we have today. It might take a few little miracles.

Now, you may have heard me say this before, but let me say it again. The good news is that miracles do happen. I have been involved in the physical sciences for over 30 years and I have seen quite a number of them during my time period. They come out of this thing we call the garden of physical sciences and engineering. I think of it as a garden. And I think the real issue in front of us is just how should we handle that garden, how big should it be, how should we nurture it, how should we cultivate it, weed it, how do we learn how to direct resources in a way that actually treats it as a serious enterprise of humanity and we get technologies out.

We have a huge problem to solve here that is connected to essentially every other problem facing humanity. We have to solve it. Electricity I think is going to be at the core of this. Storing that energy in vast amounts cheaply will be transforming. That is the major reason I made my testimony about this. You do not need me to tell you that it would be wonderful to have photocells at the cost of paint, of course. But I think this is one area that deserves more attention in our research portfolio. It is something else for us to work on that actually connects to so much else, nanoelectronics, the whole push for new nanomaterials. This is something that could have a huge impact on energy while following these paths that we are taking really for other reasons.

The CHAIRMAN. Well, I would say, at least from my standpoint, just so you know how mundane we are still working at what level of activity in terms of electricity transmission, for the first time we got Republicans to agree to a bill that essentially says if you have got a bottleneck that we can solve it by eminent domain. It is not that simple. A lot of things have to be tried. But essentially the bottom line is in the bill that is pending you go through all those hoops and we have agreed that at the end of them, if they do not work, that the law will establish the fact that somebody will do it.

Now, you have told us that that is an essential thing, but it is also such a baby step that one wonders why we are still here today talking about it. But that is the kind of problem that we have in this field.

Superconductivity, we know how important that is and we have been pumping money into it and we have been told by our scientists we are right there or almost there, and frankly I am not sure we are very much further than when Ronald Reagan announced I do not know how many centers, but he put one of them in our State after we complained up at Los Alamos. But there have not been great strides; some, but not great.

Senator Bingaman.

Senator BINGAMAN. Thank you.

I wanted to just ask Mr. Burke. Some of the statements you make in your testimony I think need to be focused on here. You say over on page 6, talking about this clean coal technology road map, “Were the road map followed, it would be possible by 2015 to design a high efficiency powerplant capable of carbon capture with near-zero emissions, and by 2020 the first commercial plants of this design would be built.” So, that is possible?

Then, on page 10 you say: “Unfortunately, current funding levels are not sufficient to reach the road map goals.” Then you go on to say: “This continues the pattern of underfunding clean coal research and unless research and demonstration funds are increased it is unlikely that technology will be developed on the road map schedule, if at all.”

Mr. BURKE. Right.

Senator BINGAMAN. So, you are basically saying this whole notion that we are going to have emission-free use of coal may never happen.

Mr. BURKE. We do not have the technology to do it now, Senator, and the road map envisions that technology and attempts to define the time in the future when it would be available if research, development, demonstration, and commercial deployment follows a particular path. Then the people that put the road map together, people in industry and people in the Department of Energy—this road map is a combined effort of industry and the Department of Energy. The people that put the road map together then attempted to determine what the specific pieces of research were that were needed from laboratory scale up to demonstration scale and what those would cost and put together an estimate for the cost to follow the road map within that time frame.

That is the comparison I am making, between the cost as estimated to achieve that vision of the future and the funding levels that have been and are now in the DOE budget.

Senator BINGAMAN. So basically what you are saying is, if we keep funding clean coal R&D at the levels we have been funding it and at the levels that are proposed for next year, we will not develop the technology needed to have emission-free power production from coal any time in the foreseeable future?

Mr. BURKE. Well, I think the road map sets out goals, quantitative goals in terms of emissions levels and costs and efficiencies, performance and cost and efficiency goals. The work that is being done today, that is being done now, will help to move toward those goals. There will be improvements. So I do not think that the fact that the funding levels are below what we think are necessary obviates any value in doing that research. There is still a high degree of value in doing that research.

Some of it is directed at much more near-term objectives, like mercury control for example, which we will need to implement in the next decade, and that technology will be developed. We need more funding for that, but nevertheless those technologies, those near-term technologies, we developed.

I think that the road map also addresses this longer term strategic issue and, as I said, sets performance goals. The likelihood I believe is not that we will not make progress toward those goals, but that we will not achieve those specific goals within that time frame, particularly the cost goals. There is a lot we can do if we are willing to spend money. We can build a power plant now that can capture and sequester CO_2, but we would not want to pay what that is going to cost.

So the road map constrains this technology development in terms of the cost of electricity. We think that is what coal delivers, is low-cost electricity that really helps to vitalize our economy, and that is what we want to protect.

Senator BINGAMAN. Yes. David, go ahead.

Mr. GARMAN. I would just make an observation, having been through several roadmapping exercises in technology development. Road maps, as Mr. Burke said, are developed with a consortia of folks from the Department of Energy, from the national labs, from civil society, and from industry. It is an aspirational product, really. We say: We want to achieve this technological result in this time frame. And most technology road maps are underfunded because there is not enough money to go around to fully fund all of them.

So what we do is, instead of pursuing five paths to a particular technology, we will pursue three. Instead of achieving this goal in the time frame of 2015, well, if the money is not there we will let it slip to 2020. So the roadmapping exercise is still extremely valuable because it does present a consensus view on how we can overcome technological obstacles to get to a shared vision.

However, there is rarely enough money to do precisely what everybody wants to do in their various road maps. I would argue that is probably true of just about every road map that is developed in the Department of Energy and in industry as well.

Senator BINGAMAN. Mr. Chairman, let me just make a comment to summarize the point I made earlier when you were not here.

The CHAIRMAN. Sure.

Senator BINGAMAN. It seemed to me that the portfolio, as I think various people have referred to it, portfolio of activities that we are pursuing in the R&D area related to energy, I think we need to do a real analysis as to whether or not it is balanced. I know David's view is that it is balanced, that this is the proper allocation.

My own sense is that we are putting so much money into this new hydrogen economy idea and some of the long distance goals that are involved in that that. You can say maybe that does not come out of the rest of the R&D activities, but it seems to me there are a lot of R&D-related activities that could be pursued as part of the energy budget that are being neglected while we put very substantial amounts into some of these other things. That is a concern to me. I just wanted to make that point again.

Thank you again for the hearing.

The CHAIRMAN. Thank you.

Well, let me thank you for your observations and thoughtfulness. Let me close by my own observation, and in particular I want to address this at you, Dr. Smalley. Maybe it will prompt an answer, maybe it will not.

I am a technology optimist, but I never have called myself that. In the book I am writing I call myself something else, but I think if you were reading it you would say, well, there it is; that is his way of saying it. I just think there are no humankind problems that are not solveable. That is my theory. I thought it was based upon faith, but you believe it and I do not think you believe it on faith. You believe it because you have seen things happen, and your vision is pretty big. I have not seen that many happen where I am party to it, but I look at it and I have seen it happen.

But I actually believe that our future depends on a regularity of breakthroughs that are big enough to make us make our economy continue to be more powerful and able to cope in a competitive world. I think we cannot make it without that.

So looking back at what happened, well, I guess the first thing I would say, the computer chip and computerization was the recent one. It took us from an era to another era and we did not even know it was happening, and then as it evolved further it made us more and more capable of doing things the rest of the world could not keep up with us on. But lo and behold, they are almost there.

You are looking around, I assume, for what is next. I am. And I wonder if you have an idea, based upon what you know, some aspect of nanotechnology, microengineering. Do you have an idea what might be next?

Dr. SMALLEY. Those of you who know me will know that I am going to say carbon nanotubes. I believe that they may very well offer a path to this long distance power transmission that we have been looking for.

But let me not talk so much about my research, just the more broad issue. I have wondered often in my life why I live in Houston, Texas. It is not the hottest place for scientific research. It is not MIT, although we will get there. The one thing I have learned in Houston, Texas, from people I have talked to is how huge the energy business is, and Houston is the capital of the oil and gas business worldwide.

Over this past couple of years I have every day realized just how massive and wonderful oil and gas were. You know, in 1900 people got crazy rich as this magnificent energy source came self-propelled out of the ground. If you read this wonderful book by Daniel Yergin, "The Prize," it is the history of oil for the past 100 years. It is pretty much the history of the entire world. It is how we got rich.

We have grown up, lived in a world where it seemed like that was going to go on forever. Well, some time over this next 20 or 30 years we have got to go invent something completely new. We have never been in this position before.

Yes, I believe in miracles coming out of the garden and I have seen a lot of them—lasers, microelectronics for example, these stop lights that we see these days that actually came from Sandia, the strained layer super-lattice—just stunning miracles. If you told me before that you were going to have diodes in your street lights that you could see even though the sun is shining, I would have said you are crazy. These things do happen.

But if you look over the past 50 years at the rate at which these major inventions happened and you look at what is going to be necessary to make the fuel cells work in our automobiles, for example, we need more miracles quicker than we have had in history. The challenge is how do we, with the resources of this country, nurture that enterprise to make miracles happen. You cannot predict them. It is a tremendous challenge, but it is in fact the one that is in front of us today.

The CHAIRMAN. Well, I was going to say—first of all, I thank you very much for your thoughts. I assume that the members of the panel are just as impressed as I am with what he has said. Every one of us, whether we are well read or not, have read enough recently to know that these miracles occur because of people. They are well trained or they are full of ideas or they are just innovative people.

I was reading just the other day on how jet engines that we now take for granted, somebody in England literally developed that and right off the bat it worked. It was not like he took 20 experiments. He just had an idea that if he pushed that hot air out there was a way to push it so that it would push whatever it was pushing against through air. And he was a little short man nobody thought much of, and there he came up with that thing.

That was one of the pieces, that was one of those miracles. It may not be the one, but it is a pretty big one. And whoever came up with the computer chip has a big one. I think we have got to come up with a couple more, not just because we need it to stay big in the world, which is probably true, and to stay alive and stay healthy. But I think we need it because the world needs it, whether it is a breakthrough in energy, which you have just told us today that is where it has got to be, I think. You have said the world runs on energy and I assume if it is going to run out we had better start running to catch it right.

So anyway, I thank you very much. Good to be with you.

[Whereupon, at 11:45 a.m., the hearing was adjourned.]

APPENDIX

Responses to Additional Questions

CONSOL Energy Inc.,
Research & Development,
May 13, 2004, South Park, PA.

Senator Pete V. Domenici,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

Dear Chairman Domenici: Attached are responses for the record to the questions concerning my testimony of April 27, 2004 and posed in your letter of April 29. I am grateful for the opportunity to testify before your committee on the need for Clean Coal Technology, and my optimism that, with the proper dedication of private and public resources, coal will deliver its full value as America's most abundant energy resource.

Sincerely,

F.P. Burke.

Responses of Dr. Frank Burke

Question 1. Dr. Burke, the Administration has proposed reducing Mercury emissions from power plants by 70 percent by 2018. Would you please provide the Committee with an assessment of the present state of technology associated with Mercury emissions reduction in currently operating plants and in the new coal-fired power generation technologies?

Answer. At present, there is no mercury-specific control technology in use on power plants in the U.S. To some extent, devices installed to control SO_2, NO_x and particulate emissions remove mercury, but the amount removed is highly variable, depending on a number of factors including the type of control device (e.g., wet scrubber, dry scrubber, fabric filter, electrostatic precipitator), boiler type and operating conditions, and coal composition. Although the mercury removed as a "co-benefit" of existing control technology may for some units be sufficient to achieve the 2018 goal, it is clear to me that new technology will be needed to avoid severely disrupting the reliability of the U.S. coal supply and coal-based electricity.

With respect to the 70% mercury reduction requirement posed in the question, it is important to realize that 70% is the average mercury reduction required for all coals and sources. However, coals vary widely in mercury content. For coals that contain more mercury than the average, a greater percentage of mercury reduction may be required, depending on the form and implementation of the final rule. For example, if a hypothetical rule required the emissions from bituminous coal units be reduced to a level corresponding to a 70% reduction from the average coal, half of the coal would require more than 70% reduction, 20% would require more than 80% reduction, and 10% would require more than 90% reduction. Therefore, a great deal of the U.S. coal supply could be jeopardized by a rule based on the hypothetical performance of a developing technology applied to an "average" coal. To some extent, this would be mitigated under a cap-and-trade program, for which the average performance of the fleet of boilers is a more meaningful concept. Nevertheless, even a cap-and-trade program would not guarantee the ability of many coals to be used at a 70% overall reduction level. In that context, EPA's discussion of developing and existing removal technologies in the Supplemental Notice to the mercury rule is instructive. EPA explains that technologies for 50-70% mercury removal may be commercially achievable after 2010.[1]

"Although pursuit is continuing on some mercury emission control technologies at the bench and pilot scale, much work has already been completed at these smaller

[1] Supplemental Notice to the Proposed Rule, 69 Fed. Reg. 12,403 (March 16, 2004).

scales. However, some technologies, like sorbent injection, have entered the large-scale field testing stage, and we have initiated a full-scale demonstration project for sorbent injection technology. It appears that these technologies, with at least 50-70% mercury emission reduction, will be ready for broader full-scale demonstration. on bituminous coal in 2005, and on subbituminous coal and lignite in 2007. If these demonstrations are successful, commercial deployment could occur on a large scale after 2010, or perhaps later."

In general, I concur with EPA's opinion as it pertains to the installation of technology on new units. Therefore, to reliably meet a 70% average mercury reduction requirement without eliminating much of the existing coal supply from the market will require the development and commercial deployment of new technology with performance beyond that expected to be achieved in 2010. With respect to existing units, the situation is further complicated by the diversity of sources in operation and the problems that are likely to be encountered in retrofitting first-of-a-kind technology at full scale. Therefore, the performance of new technology with an "average" coal in a new-plant installation, may overstate its performance with a higher mercury coal in a retrofit application.

Question 2. Dr. Burke, I know that there are many different types of coal used in the U.S. to generate electricity. What kind of problems arise in developing new, clean technologies when you are confronted with such a wealth of diverse energy sources?

Answer. The principal challenges are the lack of a sound, fundamental understanding of mercury chemistry, the diversity of sources and their coals that must be controlled, the difficulty in designing mercury control tests that can be extrapolated to a wide range of sources, and the cost of and time needed to do long-term performance tests that will be necessary to convince potential users of the efficacy of candidate technology.

As explained in my response to the first question, coals are highly variable in mercury content, mercury chemistry in the boiler environment is poorly understood, and the efficacy of various control technologies with the wide range of U.S. coals is largely unknown. Fundamental research on mercury is needed to better understand the results of previous and current mercury control technology tests and to identify and develop new approaches. Intensive long-term measurements of mercury emissions are essential to provide underlying information for applying the research to practical applications. Short-term episodic measurements of mercury emissions, like those done in EPA's 1999 Information Collection Request program, while valuable, are wholly inadequate to provide the basis for intelligent rule-making, particularly if the rule anticipates the availability of as yet to be developed technology, as explained above. To illustrate the point, the EPA data used in the mercury rule-making consists of the results of three one-hour tests at only of 80 of the over 1100 coal-fueled electricity generating units in the country. Thus the mercury sampling time used to obtain the data bears the same relationship to the total annual operating time of the 1100 units as 3 seconds does to a day.

One of the fundamental problems with mercury technology development is that mercury is present in very low concentrations in coal and therefore in flue gas. The analogy has been made that the concentration of mercury in flue is equivalent to 30 ping-pong balls dispersed in the Astrodome. As a result it is difficult to measure mercury concentrations accurately (the standard measurement method has an uncertainty of 20% or more) and mercury concentrations, even from a single mine, are much more variable (by a factor of 2-to-3) than other coal constituents of concern, such as sulfur. This creates problems with designing and executing well-controlled experiments. In addition, mercury control can be greatly affected by unrelated factors, such as coal chemistry (primarily chlorine and sulfur), carbon burn-out in the boiler, flue gas temperature profile, boiler load, and others. This makes it problematic to extrapolate or generalize the results of even a well-designed and controlled experiment to predict the performance of a technology in all circumstances for all coals.

Another challenge to the development and deployment of mercury control technology is cost. To be confident in the application of a technology it must be subject to long term testing at full scale. The operation of most coal-fired boiler units changes frequently, such as when the unit is cycled daily and seasonally to follow load demand, shuts down for a planned or unplanned maintenance outage, or performs operational procedures such as soot-blowing. Long-term testing and performance monitoring are expensive (~-$2-3 million per test), and as a result relatively little has been done. The Department of Energy's budget over the last several year, combined with private-sector cost sharing, has only been sufficient to initiate eight long-term tests which are just getting under way.

Question 3. Dr. Burke, you mention in your prepared remarks that China's use of coal to generate electricity will grow by a billion tons from 1.5 billion annually to 2.5 billion tons by about 2020. I assume that India and other developing nations in the Far East will experience similar growth in the use of coal. Do you think our efforts to develop new clean coal power technologies will be available and affordable to these nations to help them reduce their emissions of sulfur and nitrogen oxides, mercury and carbon?

Answer. I believe that the developing economies will utilize their indigenous coal resources. Helping them to do so contributes to global economic and political stability. If we pursue our current research and deployment agenda in a timely manner, U.S.-developed technologies can have a major impact in helping coal-using countries throughout the world to meet economic and environmental objectives.

The United States is leading the world in the development of power generation and emission control technologies for coal-fueled power plants. The principal drivers behind the technology development program in the U.S. are defined in a technology "roadmap" jointly developed by the Department of Energy and the coal and electric utility industries, and described more fully in my written testimony. The roadmap lays out cost and performance targets designed to do two things: First, to develop suitable technologies so that coal can be used in a manner that meets our environmental objectives. Second, to ensure that the capital and operating costs of these technologies are low enough to allow coal to be used in a way that meets our economic need for affordable energy. These needs and aspirations are not unique to the United States. We should look for opportunities for international collaboration where they exist, such as in the DOE Carbon Sequestration Leadership Forum, which is fostering international cooperation to address greenhouse gas emissions. However, we need to set and follow our own research, development and deployment agenda to ensure the continued availability of our domestic coal resources.

Question 4. You also discuss the difficulties associated with controlling carbon dioxide emissions in your prepared statement. Can you please elaborate on the challenges associated with controlling carbon emissions?

Answer. All fossil fuels (coal, oil and natural gas) consist mostly of carbon (75-85% by weight). Carbon dioxide is the thermodynamically stable end product of fossil fuel combustion. In a sense, the purpose of fossil fuel technologies, whether used in cars, furnaces or power plants, is to turn carbon into carbon dioxide and utilize the energy produced by that chemical transformation. Therefore, there is no practical way to avoid the production of carbon dioxide in fuel use, although its production can be minimized through efficiency improvements. Beyond that, "carbon management" implies that carbon dioxide be "captured" from the source and "sequestered" to prevent its emission into the atmosphere.

Because of thermodynamic limitations, fuels are converted to useful energy (such as electricity) with some unavoidable loss of the original energy value of the fuel. Conventional power plants operate at 30-40% efficiency (the U.S. average is about 33%). Increasing efficiency reduces the amount coal needed to generate a unit of electricity and reduces carbon dioxide emissions accordingly. For example, replacing a 33% efficient technology with one 40% efficient would reduce carbon dioxide emissions by about 20%. Advanced systems under research now have the potential to increase power plant efficiency to about 60%. The employment of these systems provides the benefit of lower fuel usage and, thus cost, so efficiency gain can be pursued based on its economic advantage alone. The principal challenge is to gain the efficiency improvement, while maintaining an acceptably low capital cost. I believe that power production efficiency improvement should be pursued as the first and most expedient approach to reducing carbon dioxide emissions.

The first challenge to controlling carbon dioxide emissions is to develop energy efficient and cost effective technologies for the capture of carbon dioxide from the variety of sources that produce it. Technologies to capture carbon dioxide from sources such as flue gas exist, in the sense that commercial technologies developed for other uses, like amine scrubbing of natural gas, could be applied. However these technologies exact a large energy penalty, and are prohibitively expensive for application to large combustion sources like coal-fueled power plants. Some sources, such as coal gasification systems, may offer advantages in terms of ease of carbon dioxide capture, but these have not been proven in practice. In any event, the vast majority of coal-fueled power plants in the U.S. and elsewhere are combustion-based, and it is likely that most plants built for the next several decades will be combustion-based. Relatively little research has been done on the important issue of carbon dioxide capture, particularly from combustion sources, but some promising approaches have been identified, and there is reason for optimism.

Once captured, the carbon dioxide must be stored or "sequestered" for geologically long times to avoid its emission to the atmosphere. A number of opportunities for "terrestrial" sequestration (i.e., biomass accumulation) exist. However, in all likelihood, large-scale carbon management would require injection into suitable geologic formations. There are some relevant examples of this, such as the injection of carbon dioxide into oil-bearing formations to stimulate production, and a project in the North Sea in which carbon dioxide recovered from a natural gas production facility was injected into a saline aquifer. These examples are encouraging, but the sheer volume of carbon dioxide that would need to be sequestered worldwide to eliminate global emissions is staggering, about 25 billion tons per year. Therefore, there is an urgent need for large, long-term tests to assess the economic and technical feasibility of carbon dioxide sequestration in variety of geologic and geographic sinks. Projects like the U.S. FutureGen initiative, which would involve sequestration of about 1 million tons of carbon dioxide per year, are a step in the right direction. However, considerably more needs to be done in both fundamental, research and practical application testing before carbon sequestration can have an assured place in energy and environmental policy decisions.

I call your attention to a report prepared by the National Coal Council in May 2003 entitled "Coal-Related Greenhouse Gas Management Issues." The report is available on the NCC web-site at: (http://www.nationalcoalcouncil.org/Documents/fpb.pdf). This report describes in more detail the principal approaches to carbon dioxide management described briefly above, discusses current research and public policy actions addressing the issue, and makes recommendations to the Department of Energy in the three areas of implementing, developing and demonstrating greenhouse gas management technologies.

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