Reflections on Forty Years of U.S. Energy Policy

Statement of

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before the

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Mr. Chairman,

Thank you for the invitation to testify today about my reflections on the last forty years of energy policy and my assessment of the implications of that history for future policy. It's a large question and I want to focus my comments on one important part of it – technological change.

From the time of the first OPEC oil embargo nearly 40 years ago, the United States has looked to technology for solutions to its energy problems. Indeed, the first government reports to recommend an energy research and development agenda appeared within weeks of that 1973 event. In 1975, President Ford established the Energy Research and Development Administration, pulling together energy research programs scattered across the federal landscape. In late 1977, ERDA became part of the new Department of Energy. And today, energy R&D remains a major element of DOE's mission, and of the Administration's energy policy.

But despite the evergreen promise of technology solutions, the history of federal energy R&D has been full of twists and turns in both program goals and management philosophy. President Nixon opted for energy independence. President Carter created the first National Energy Plan and with it, the Synthetic Fuels Corporation. Presidents Reagan and Bush preferred a more modest effort focused on precompetitive research and avoided large demonstration programs altogether. President Clinton favored efficiency and renewable energy programs, while reducing the nuclear budget at DOE to near zero. The second President Bush attempted to reverse some of the Clinton priorities, and laid management emphasis on achieving tangible results from federal R&D. At the National Academies' Summit on America's Energy Future in 2008, Senator Jeff Bingaman summarized in the attached image these stops and starts of energy technology policy over this period.

Although this record leaves a lot be to desired, I believe it has taught us several valuable lessons. Today I'd like to focus on the lessons that seem to me to be most important, and then on what they can tell us about how the federal government might approach energy technology policy in the future. In doing so, I will rely on several National Research Council reports in which I've participated over the last dozen years. While these reports are exceedingly valuable sources, I should stress that the views I will express are my own.

LESSONS LEARNED

First, energy security and a clean environment are the overarching goals for energy policy, and hence for energy R&D. There are other desirable attributes of the energy system, such as reliability and affordability, but the private sector has substantial regulatory and economic incentives to provide them. But energy security and environmental goals dominate energy policy in two crucial ways. First, they are public goods, hard for the private sector to provide and so appropriate subjects for public policy. And second, unlike the more modest goals like affordability, meeting these overarching goals may well require a total overhaul of the energy system. Energy security and a stable climate share another important characteristic. It's easy to see what needs to be done to meet them, but hard to decide how much to do. Thus, energy technology enhances energy security largely reducing the economy's dependence on oil the economy from all sources. Similarly, limiting future climate change requires greatly reducing the emission of carbon dioxide from the energy system. These strategies are clear and their costs are real. On the other hand, it's very hard to calculate the benefits of greater energy security or a more stable climate. As a result, policy makers face a difficult choice in balancing fairly certain costs against uncertain risks in deciding how to much oil or carbon dioxide to carve out of the system.

I dwell on this policy dilemma because it's easy to fall into the trap of doing nothing while waiting for science to provide some kind of optimal level of action. Waiting is not a strateby, and as I'll mention next, we've been doing a lot of waiting around when it comes to energy policy.

Second, today's energy system is cleaner and more efficient, but not fundamentally different, from the one we had forty years ago. The Clean Air Act has driven a significant improvement in air quality associated with energy system emissions. For example, EPA reports¹ that between 1980 and 2008 national average atmospheric concentrations of sulfur dioxide has decreased by 71 percent, of nitrogen dioxide by 46 percent, and of ozone by 25 percent. Concentrations of particulate matter (PM10) declined 31 percent between 1990 and 2008, while concentrations of the smaller PM2.5 particles dropped 19 percent between 2000 and 2008. These reductions were achieved despite an economy that more than doubled in size.²

The story on energy efficiency is similarly positive. EIA reports that the energy intensity of the U.S. economy³ declined by 51 percent between 1973 and 2008, a substantial fraction of which can be attributed to improvements in energy efficiency (the balance is attributable to s structural economic shift from a manufacturing base of activities to a services base). The improvement was most dramatic in the consumption of petroleum and natural gas, where the intensity of these fuels dropped by 60 percent. Oil use alone fell by the same amount, arguably enhancing energy security by reducing national dependence on oil. The intensity of fuels connected with electricity use (coal, nuclear, renewables) fell less – by nearly 23 percent between 1973 and 2008, and by 31 percent from its peak in 1983.

But if the energy system has become cleaner and more efficient over the past forty years, it is not much different. Importantly, the system still depends almost entirely on fossil fuels. In 1973, fossil fuels accounted for almost 93 percent of energy use in the U.S.⁴ By 2008, this fraction had dropped to 84

¹ At <u>http://www.epa.gov/airtrends/sulfur.html</u>

² Despite this considerable progress, more remains to be done. A 2009 NRC report, *The Hidden Costs of Energy*, evaluates the damages from air pollution in the electric and transportation sectors caused by remaining pollution.

³ Measured as quadrillion Btu of energy used per 2005 dollars of GDP; see <u>http://www.eia.doe.gov/emeu/mer/pdf/pages/sec1_16.pdf</u>

⁴ See <u>http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_9.pdf</u>

percent. However, the growth of nuclear power accounts for the entire decline. During this same period, the near monopoly of petroleum fuel in the transportation sector changed hardly at all, from 96 percent in 1973 to 94.5 percent in 2008.⁵

An important corollary to this continuing reliance on fossil fuels is that the basic technology of energy production and use has not changed much in forty years. The internal combustion engine and the fossil fuel powerplant still dominate the system. That these technologies produce considerably fewer air pollutants is a tribute to increased efficiency and post-combustion clean-up devices, not to the deployment of a fundamentally cleaner way of making energy.

Third, federal energy R&D has made a positive but modest contribution to changing the energy system. Since the consolidation of energy research into a single agency during the Ford Administration DOE has been responsible for most of the government energy R&D program. Between 1978 and 2009, DOE budgets added up to well over \$100 billion on energy R&D (2000\$). And since government polices – from R&D cost-sharing to environmental regulation to tax incentives – strongly influence the allocation of private investment in energy R&D, the federal government has probably been the single largest force in U.S energy R&D expenditures since 1978. This despite the fact that, adjusted for inflation, the total level of DOE-sponsored energy R&D sponsored in 2010 is half of what it was in 1980.

But what has this expenditure achieved? In 2001 the National Research Council published one of the few independent evaluations of the results produced by some of these R&D programs.⁶ The review was limited to DOE's energy efficiency and fossil energy programs, and looked back at the benefits and costs of those programs over the first 25 years of DOE's existence. The net result of this evaluation indicated that DOE had made positive contributions to the changes in the energy system. In particular, the aggregate economic and environmental benefits attributable to these DOE programs exceeded the government's total costs by a factor of more than two.

But this broad conclusion obscures a more complex dynamic. To paraphrase the study's conclusions:

 Almost all the benefits came from four programs – three that introduced new energy efficiency technology to large consumer markets (more efficient fluorescent light ballasts, more efficient windows, and more efficient refrigerators), and one that resulted in a major reduction in damages from NOx emissions through the use of low NOx burners and selective catalytic reduction. It is worth noting that the total federal cost of the three efficiency programs was only \$12 million, although they produced \$30 *billion* in economic benefits.

⁵ See <u>http://www.eia.doe.gov/emeu/aer/pdf/pages/sec2_10.pdf</u>

⁶ National Research Council, *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000, 2001.* The summary benefit cost assessment on which this section is based is found at p. 6 of the report.

- The large realized benefits accrued in areas where significant market barriers existed. For example, the building market is fragmented and not conducive to innovation in energy efficiency. And the NOx reduction produces an environmental benefit that private markets cannot easily capture. Public funding would be expected to have considerable leverage in removing these barriers.
- Other programs produced important but smaller benefits. In all such cases, however, the report observed that DOE participation took advantage of private sector activity to realize an additional public benefit. In other words, getting the public benefit depended on the existence of a private market for the underlying technology. (In the case of NOx controls, that market was established by the Clean Air Act and subsequent federal requirements for NOx controls on all new power plants.)
- In contrast, government attempts to force introduction of new technologies for which there is no private market have rarely been successful. In this connection, the NRC study pointed especially to the large synthetic fuels demonstration programs that the government undertook in the 1970s and early 1980s, but which produced no tangible benefit.

A number of technological advances in the energy system did in fact take place between 1978 and 2000, but the private sector was the principal source of technological innovation. The NRC study selected 23 of the most important innovations in fossil energy and energy efficiency during this period and determined the level of DOE contribution to their development. In only three cases was DOE research the dominant factor, while in 13 cases DOE's influence was absent or minimal. In the remaining 7 cases, DOE made an influential but not dominant contribution.

Finally, innovation is more than RDD&D. From the beginning, it was understood that government energy R&D had to develop products that would meet public policy goals by succeeding in the marketplace. This imperative thus raised the issue of how to design a government program that would lead to private sector commercialization of new technology that had a public benefit. To resolve that issue, we needed a model of the commercialization process we wanted to influence.

At the outset, we picked the wrong model (I say "we" because I helped get it wrong). We borrowed from the Defense Department and NASA the standard model for government product development – Research, Development, and Demonstration – and added a third "D" – Deployment. Unfortunately, the linear RDD&D model has had staying power, and indeed still sometimes appears in DOE's program designs. But it's not the right model.

A more useful model is the innovation process that routinely takes place in the private sector, because that is the process that DOE research needs to influence. Studies of this model⁷ show that the innovation process is not neatly

⁷For a summary of this research see, for example, Robert W. Fri, *The Role of Knowledge: Technological Innovation in the Energy System*, The Energy Journal, Vol.24:4...

linear but messy; it is incremental, integrative, and cumulative. Innovators tend to take small, incremental steps to minimize the already considerable risk they are assuming in trying to develop a new product. They integrate ideas from a variety of sources, assembling them into an innovative product. And over time, these incremental steps cumulate into major – even disruptive – changes in technology. An excellent example of how this process has worked in the energy system is the introduction of the aeroderivative turbine for electricity generation. The basic technology was developed for defense programs to power aircraft, then borrowed from the aerospace industry, and ultimately adapted to electric generation applications to become a very energy efficient powerplant. The improved technology was so successful that for a time it dominated investments in new powerplants. And although this final result may have seemed like breakthrough technology, it was really a borrowed idea integrated into the energy system and improved incrementally over time.

It is also useful to see this innovation step as a part of a broader process of technological change. Rubin⁸ describes the change process in four steps – invention, innovation, adoption, and diffusion. Invention involves the generation of the new scientific and technological ideas that set the table for innovation. The adoption step carries an innovative product into the marketplace. Diffusion happens as the product expands its markets, importantly due to learning than reduces costs and improves performance. Finally, it's important to note that both the innovation step and the whole change process are intensely recursive. Feedback loops and trial-and-error abound in this world until the innovator finally "gets it right" or loses his shirt.

LOOKING AHEAD

Against this background, what can we say about the future of the federal energy R&D programs? Addressing this key issue posed by this subcommittee – requires answering four questions.

Should the energy system change in a fundamental way? As noted earlier, the existing energy system is cleaner and more efficient, but not really different, from the one that existed in 1973. Looking forward, however, taking energy security and climate change seriously would mean decarbonizing the energy system and drastically cutting the nation's dependence on oil. And that, of course, would require a wholesale change in the existing energy system.

As noted in the first lesson discussed above, the benefits of limiting climate impacts and enhancing energy security are real, but hard to pin down. The costs of a wholesale change in the energy system are real and potentially large. While economists have tried to quantify these values, unfortunately, science can't provide a clear balancing of the benefits and costs. Deciding how much climate change and how much oil use is acceptable are thus both crucial judgment calls.

⁸ E.S. Rubin, "The Government Role in Technology Innovation: Lessons for the Climate Change Policy Agenda," *Proceedings of the 10th Biennial Conference on Transportation Energy and Environmental Policy*, Institute of Transportation Studies, University of California, Davis, Davis CA

My own view is that the benefits are real and potentially much larger than the costs of change. If I'm right, we should be planning for a major change in the energy system. If not, continuing the incremental improvements that have characterized the last 40 years is probably good enough and we will simply accept and adapt to whatever future climate change and oil price shocks may occur..

What will the future energy system look like? Unless the nation responds aggressively to the challenges of energy security and climate change, the energy system of the future will look very much like the one of today. It will be cleaner as environmental regulations continue to tighten, and increasingly efficient as old capital stock turns over. But electricity will continue to be produced mostly by burning fossil fuels, and most light duty vehicles will continue to rely on gasoline. Renewable sources of electricity, alternative transportation fuels, and electric vehicles – pure or hybrid – will slowly gain market share. However, using fossil fuels will continue to be convenient and relatively cheap, so a fundamental change in the energy system is unlikely for a long time to come.

But more of the same is not destiny, for technology is capable of a fundamental change if we decide we want one. A recent NRC study, *America's Energy Future* (AEF), assessed the potential⁹ of available (or nearly available) technology to change the energy system. Its key conclusions were:

- Efficiency measures can reduce energy consumption by 15 percent by 2020 and by another 15 percent by 2030. These reductions would more than offset the projected increase in energy consumption in the EIA 2007 reference case.
- Renewable energy sources, coal or natural gas-fired powerplants with carbon capture and storage, and new nuclear power could completely replace the existing electric power production system by 2035.
- Substantial opportunities to reduce fuel use in transportation exist, but liquid fuels made from biomass or coal have a limited potential to displace oil before 2035. Further reduction of oil use will require a new generation of vehicles, probably powered with electricity or hydrogen.

While this technical potential is impressive, optimism about actually realizing it should be guarded. A multitude of market imperfections, regulatory obstacles, and behavioral barriers stand in the way of reaching anything like the full potential. In addition, while AEF judged that carbon capture and storage and new nuclear technologies could be deployed in large quantity after 2020, it also noted that both technologies need first to be proved in the U.S. at commercial scale before attracting significant private investment – and we are only beginning to take the steps necessary for this purpose.

⁹ National Research Council, *America's Energy Future: Technology and* Transformation, 2009. In the AEF study, potential is defined as the maximum deployment of a technology with an aggressive (but not crash) program, and in the absence of any barriers to deployment.

Finally, even if the technical potential reported in AEF were to be reached, the energy system would still depend largely on old technology, especially for electricity production. Moreover, AEF concludes that the cost of electricity would rise with any of the new production technologies. And new technology to reduce oil consumption in the transportation sector would be required, as noted earlier. For all these reasons, it seems likely that technologies that are yet to be invented must enter the energy system by 2035, and certainly beyond, if we are to have truly clean, efficient, and affordable energy system.

What can government do to accelerate technological change in the energy system? As discussed earlier, the experience of the last forty years has provided a clearer picture of how government policy can accelerate technological change in the private sector. Building on this experience, four strategies seem to me to be especially important in crafting this policy.

<u>Align private incentives with public goals.</u> Innovation is a complex function of the private sector and as such innovation works best when it's economically rewarded in private markets. Indeed, experience strongly suggests that rewarding private sector activity that also produces a public good is the most powerful strategy for technological change. I seriously doubt that an overhaul of the energy system will take place without such a reward.

Both price signals and regulation can provide the necessary incentive. A price signal is usually more directly linked to the desired outcome (increasing the price of carbon directly affects CO2 production, for example) and, if applied economy-wide, engages the maximum range of innovative activity. Regulation can also have a potent effect, as has been the case with refrigerator efficiency and light duty vehicles, but runs the danger of unintended side effects. Arguably, efficiency standards for light duty vehicles both substantially reduced fuel consumption for the target vehicles, but also helped to induce a vast market for unregulated trucks posing as sports utility vehicles.

<u>Fund purpose-driven basic research.</u> Virtually all authorities agree that funding basic research is an appropriate function of government, and it is an essential one for changing the energy system for two reasons. As noted above, we need wholly new technologies create an energy system that is affordable and effective, particularly in reducing oil consumption. In addition, because innovation is an integrative process, it needs a robust menu of scientific and technological research on which to draw. Basic research thus sets the table for innovation in ways that cannot be predicted.

But this research needs to be plausibly connected to desired outcomes for the energy system. Broadly speaking, this connection can be made in two ways. One is to focus research on problems which, if solved, would create fundamental changes in our energy options. For example, artificial photosynthesis could revolutionize the capture and storage of solar energy. Similarly, basic advances in catalysis could greatly increase the attractiveness of carbon capture, especially if it promoted the retrofit of existing power plants. The second general approach is to encourage the application of diverse disciplines to energy problems. Both genomic engineering and nanotechnology could make important contributions to energy, although neither was developed with energy in mind.

<u>Focus applied research to overcoming well-defined market barriers.</u> Unlike basic research, DOE's applied research (its fossil, efficiency, renewable, and nuclear programs) focuses on fairly well-defined technologies. In some cases, such technologies have a reasonable chance of market success if they meet attainable technical and commercial goals.

If a technology has a reasonable chance of market adoption, <u>and</u> if its adoption would also help achieve a public policy goal, then the government has in interest in its success. Energy efficiency technologies often combine these attributes, for example. The NRC retrospective study noted earlier provides persuasive evidence that government support of such technologies can be very effective if it is directed toward removing a well-defined barrier standing between the technology and the marketplace. The barrier may be a technical problem that an innovator is unable to solve, or it may be a problem of market structure. Many barriers to efficiency technologies are of the latter type.

In short, while designing programs of applied research is as much art as science, government policy should observe two prerequisites. First, there must be a reasonable chance of adoption in an existing market. And second, the government intervention should focus sharply on removing well-defined barriers in the way of getting to that market.

Invest with great care in technologies that do not yet have markets. In the past, government energy research programs have invested heavily in such technologies – the synthetic fuels program of the late 1970s, for example. The rationale for these investments is usually that, although not competitive now, the technology in question will be needed in the future to meet public policy goals. Unfortunately, such programs usually don't work out very well. The market turns out not to materialize, or if it does, it addresses the problem in ways that government programs did not foresee.. Thus, the crash of oil prices in the 1980s – and not the synthetic fuels program – solved the looming oil crisis of the late 1970s. Similarly, reductions in SOx emissions required by the Clean Air Act amendments of 1990 were achieved initially by transporting low sulfur coal to eastern power plants, not by flue gas desulfurization technology that almost all policy analysts assumed.

This is not to say, of course, that government should never invest in insurance policies, only that it should do so with its eyes open. In particular, the record of success is poor, and so the risk of loss is high. A current example will illustrate the nature of the risk. Both carbon capture and storage and evolutionary nuclear technology need demonstration at commercial scale before attracting significant private sector investment. But the market for both depends in a major way on government policy that aggressively promotes decarbonization of electricity production. So the policy question is: in the absence of government policy to control carbon, should government invest in demonstrating CCS and evolutionary nuclear technology?

I advocate an aggressive government demonstration program, fully understanding that the result may be money wasted. But because I think that the nation is likely to have an aggressive carbon policy in the next few years, then CCS and nuclear could have a major market and play an important role in meeting climate objectives. However, both are large and expensive technologies at commercial scale, and their demonstration will take several years to produce the commercial experience that would give confidence to investors. As a result, waiting to conduct the demonstration until our climate policy is decided would only delay getting started on the challenge of reducing domestic carbon dioxide emissions. On balance, therefore, it seems prudent to me to move urgently to demonstrate these technologies in the hope that one or both proves to be a winner in a world of carbon dioxide control. That world may not happen, and commercial experience with one or both technologies may prove to be disappointing, but in this case the risk seems worth it.

What are the main new challenges for research? I'm confident that the scientists and technologists can craft a research agenda that expands basic research and that focuses applied research on specific market barriers. Indeed, Secretary Chu and his team have already introduced organizational innovations that seem to me to be very much in the right direction. So in concluding my testimony, I'd like to raise two issues from the social sciences that strike me as crucial to the success of technology change going forward.

First, we need to know more about household energy use and consumer behavior. Household decisions directly determine 40 percent of total energy use and another 30 percent indirectly. But household decisions are not always made on the sole basis of economic rationality. Energy efficiency programs famously fall short of the level of adoption that so-called rational behavior suggests should be the case. Therefore, it seems to me that behavioral science research may be as important as technology R&D in promoting the use of energy efficiency.

Second, it's clear that any program to change in a fundamental way the composition of the national energy system requires a sustained effort over a long period of time. The history of government energy R&D, however, is one of twists and turns in goals and philosophy. Designing an energy R&D portfolio that maintains a reasonable degree of continuity over several decades is an extraordinary governance challenge, but one that needs to be addressed if the nation is to see real results from its substantial investment.

Starts and Stops in Energy Technology Policy

VEHICLE TECHNOLOGY

- Virtually pollution-free car (Nixon 1970)
- Reinventing the Car (Carter 1977-1980)
- Partnership for a New Generation of Vehicles (Clinton 1993-2000)
- FreedomCar (Bush 2003)

NUCLEAR TECHNOLOGY

- Clinch River Breeder Reactor (1970-1983)
- Advanced Liquid Metal Reactor Program (1989-1994)
- Global Nuclear Energy Partnership (2006)

COAL UTILIZATION

- Synthetic Fuels Corporation (1979-1985)
- Clean Coal Technology Program (1987)
- Clean Coal Power Initiative (2001)
- Future Gen (2003)

BIOFUELS

- Alcohol fuels (Energy Security Act 1980)
- Oxygenated fuels (Clean Air Act Amendments 1990)
- Biofuels (EPAct 2005; EISA 2007)