Testimony of
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My testimony is based on an article in the fall 2008 issue of Issues in Science and Technology, attached to this testimony, and in a longer working paper, and in several papers published in the research literature. Jay Apt and Sompop Pattanariyankool are colleagues in this research.

Chairman Bingaman, Ranking Member Murkowski, and members of this committee. Thank you for giving me the opportunity to testify on this important legislation.

At Carnegie Mellon University, I am a senior faculty member in the Business, Engineering, and H. John Heinz colleges. Granger Morgan and I direct the Electricity Industry Center and I am director of the Director Green Design Institute. I have the privilege of serving on two National Academy of Sciences committee studying energy issues. The opinions here are mine and do not necessarily reflect the views of my coauthors, Carnegie Mellon University, or any other institution.

I praise the draft legislation and recommend that you:

1. Tighten the definition of efficiency and eliminate the limit on its contribution. This will allow regions that don't have good wind and solar resources to meet the legislative goals at lower cost.
2. Focus on reducing carbon-dioxide emissions rather than singling out renewables as the answer. There are significant savings from letting all technologies compete in satisfying the goals of lowering greenhouse gas emissions, increasing environmental quality more generally, increasing energy security, and improving sustainability,

I commend you for Title VIII-Renewable Portfolio Standard. The basic approach is sound and well thought out. I share your goals of reducing greenhouse gas emissions, improving environmental quality more generally, making our energy supply more sustainable, enhancing energy security, and of ensuring that energy prices are not so high that they derail the economy or prevent Americans from living well. I praise your emphasis on efficiency, our cheapest energy "resource" and your support of distributed generation and combined heat and power. I agree that in the long term, renewable fuels will likely provide our energy. Finally, I commend you for generally trying to eschew picking the winning technologies. Let engineers and entrepreneurs find the best way of meeting the goals.

Unfortunately, there are significant difficulties and costs in implementing a federal RPS. While the industry struggles to meet your goal of a 20% RPS by 2039, 80% of generation could be emitting carbon-dioxide, polluting the air and water, and using imported oil and natural gas. My point is not that the RPS should be higher, but rather that the legislation should address the issues directly.

My greatest concern for electricity generation is abating carbon-dioxide emissions. Without controls, we will run out of atmosphere before we run out of fossil fuels. The world has 5,000 billion tons of fossil fuels, of which we have used only 6%. Burning any appreciable fraction of the coal, oil, and natural gas resources will send atmospheric carbon dioxide concentrations to far greater levels than humans have experienced and lead to major global climate change. Global climate change, not our stock of fossil fuels limits how much electricity we can generate from these fuels.

A carbon portfolio standard (CPS) would address this concern directly and more effectively. The available renewables technologies have quite different carbon emissions; giving equal credit to all doesn't make sense. Other technologies also have low carbon emissions and should receive attention.

The maps I have provided of wind and solar resources show vast differences among states. For example, the Southeast has neither good wind nor solar resources. It does have biomass, but that will be needed for producing liquid fuels. The legislation should give each region the greatest flexibility to achieve the goals at least cost, including focusing on renewables <u>or</u> conservation, fossil fuels with carbon capture and sequestration (CCS), and nuclear.

I emphasize efficiency since it has no emissions of air or water pollution, no greenhouse gas emissions, and does not harm the environment. After tightening the definition of efficiency in the draft legislation, I see no reason to limit efficiency's contribution to 25%. The efficiency definition should include distributed generation and combined heat and power, since their virtue stems from increased efficiency, not merely from having such a program. The energy efficiency accomplishments in states, such as California and New York, show a vast potential for efficiency, one greater than the likely contribution of renewables. Electricity use per capita in these two states is 40% less than the national average, twice the RPS goal for 2039. I recommend aggressive goals for energy efficiency, particularly in regions such as the Southeast that have poor wind and solar resources.

Achieving the increases mandated in the bill requires building large amounts of transmission from areas with good wind resources to population centers. Many people like wind turbines in the abstract but don't want them as neighbors, for example, the proposed wind farm off Cape Cod. More people oppose transmission lines. If the wind farms and transmission lines can be sited, there are likely to be delays of ten years or more, particularly for transmission.

Trading renewable credits will be limited by the combination of transmission constraints and the fact that the best wind resources are located far from population centers. If the excellent wind resources in the upper Midwest and Rocky Mountains cannot be exported, the local populations could use only a small proportion of the generation potential.

For large amounts of wind and solar to enter the grid, there must be inexpensive bulk storage of electricity. R&D into technologies such as compressed air is needed. Until bulk storage is possible, integrating more than 15% wind and solar power into the system will be costly and could compromise reliability.

I now summarize the difficulty of integrating large amount of wind and solar energy into the electricity grid.

As you know, wind and solar generation differ from the traditional ways of generating electricity because they are generally not available when we need power. Wind turbines and solar arrays generate electricity when the wind blows and the sun shines. One of the best solar sites in the USA is in the Sonora Desert in Arizona. A very large solar site there had a capacity factor of 19%, out of the possible 100%, if it had generated full power every hour of the year. Wind turbines have higher potential in good wind sites but, for example, the average capacity factor for the wind turbines in Texas was only 26% in 2006.

The solar map shows that the good sites are in the desert Southwest. Sites in the Southeast have lower potential because of cloud cover. The rest of the continental USA has much lower potential for generating solar power, particularly the most heavily populated areas. The capacity factor is important because almost all the costs are in manufacturing and installing the array. Thus, a solar array with a capacity factor of 20% would produce electricity at half the cost of an array with a capacity factor of 10%. Forcing solar installations into the areas where most Americans reside would consume a vast amount of resources per kilowatt-hour.

Nature is more generous in distributing good wind sites around the nation, but they are still distant from population centers. In particular, note that there are no good wind sites in the Southeast. As with solar, the cost of produced power is inversely related to the capacity factor since almost all the costs are building the wind farm. Thus a site with a capacity factor of 40% would have half the cost per kilowatt-hour as a site with a 20% capacity factor.

In general wind and solar power are not available when demand is highest. Wind tends to be strongest at night and lowest in the summer. Solar power is best in the summer, but the Arizona data show that the arrays have all but stopped producing electricity by 5 PM in the summer, just as demand is hitting its peak.

Another problem is that wind and solar generation are variable. Wind speed changes from moment to moment and clouds block the sun, even in the desert. This intermittent power challenges the grid to provide reliable, high quality power when wind and solar are contributing more than 5-10% of total generation.

One solution to both these problems is to store large amounts of electricity when these sources are generating so that it can smooth power output and have that output available when demand is high. Pumped hydro storage is the best way to store electricity, but few new sites are available. Compressed air storage looks promising, but is expensive and less efficient than pumped hydro.

Wind farms can affect climate just downwind, reducing precipitation. Massive reliance on wind energy would take energy out of the wind, changing the Earth Climate.

With present technology, the unreliability of generation from wind and solar means that reliable generation must backup every kilowatt-hour. A solar array or wind farm may not generate power for days because of a storm or lack of wind. Since we still want electricity, fossil fuel or hydro power must be available. A General Electric study for Texas found that even in windy April, there were hours when the wind farms were producing almost no power, requiring a rapid switch to natural gas turbines. Since this occurred during one of the windiest months, image the difficulties during the summer months when the demand for electricity peaks and wind resources are small.

The point is that wind and solar can lower the amount of fossil fuels used for generation, but they don't lessen the need for reliable generation capacity. For new coal generation with carbon capture and sequestration, and for new nuclear generators, the capital cost is the vast majority of new costs and so the savings are small.

I have focused my remarks on wind and solar, but there are other renewables. Hydroelectric dams generate six times as much power today as the other renewables, but there is little prospect for getting significantly more power. Dams are being torn down, not being built. Geothermal provides power in California and more is planned for the Southwest. Run of the river hydro could provide small amounts of power. Biomass could provide significant amounts of power at competitive costs, but there is a limited amount of land and the biomass is better used for transportation fuels. Where there are good geothermal resources, this resource can be attractive. However, the good areas are limited to the West. Ocean currents and waves can provide power, but corrosion and withstanding storms make the power expensive, in addition to other problems.

In good sites, wind power is competitive with new fossil generation with carbon capture and sequestration. Even at the best sites, solar photovoltaic generation is several times the cost of wind per kilowatt-hour. Japan engaged in a massive program of subsidizing solar; Germany is currently engaged in huge subsidies. While clever in many ways, the Japanese and Germans don't seem to understand that extracting power from sunlight, when there is relatively little sunlight, is expensive. The solar map shows that trying to generate solar power in most of the USA would be extremely expensive. At good sites, solar thermal power is almost competitive with new fossil generation.

This catalogue of difficulties should not be regarded as mean-spirited objections. Rather, my intent is to set out the problems that need to be solved. We agree that our energy supply must be made sustainable; we must reduce greenhouse gas emissions, enhance energy security, and produce energy at a cost that will not derail our economy.

America's largest fossil fuel resource is coal; we will rely on coal for much of our energy in the coming decades. In particular, coal will continue to provide most baseload electricity generation. It is essential that demonstration coal plants with carbon capture be built to improve the technology and that DOE shows that massive underground injection of carbon-dioxide in a range of geological strata can sequester the carbon without leakage. It is also essential that we build half a dozen nuclear plants using the new technology to assess their costs and performance.

While solar photovoltaic power is too expensive for massive deployment, I urge funding solar photovoltaics <u>research</u>, since this technology will ultimately provide most of our energy.   I also recommend R&D funding for bulk electricity storage, such as compressed air.

Chairman Bingaman, I commend you for this bill. I particularly commend you for not trying to identify the technology winners, such as through a solar mandate. I hope that you can make two changes:

1. Tighten the definition of efficiency and eliminate the limit on its contribution. This will allow regions that don't have good wind and solar resources to comply at lower cost.
2. Focus on reducing carbon-dioxide rather than singling out renewables as the answer. There are significant savings from letting all technologies compete in satisfying the goals of lowering greenhouse gas emissions, increasing environmental quality more generally, increasing energy security, and improving sustainability, ensuring that energy prices are not so high that they derail the economy.

Thank you for the opportunity to testify on this important legislation. I would be happy to answer any questions.

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He was elected to the Institute of Medicine of the National Academy of Sciences and is a past president of the Society for Risk Analysis. He has acted as a consultant to many government agencies and companies, including the Department of Energy, and Environmental Protection Agency. He has received research support from a wide range of federal and state agencies, as well as foundations, nongovernmental organizations, and companies.

He and Granger Morgan founded and direct the Carnegie Mellon electricity Industry Center, the largest engineering-business center focused on the electricity industry. The Carnegie Mellon Electricity Industry Center is supported by grants from the Sloan Foundation and Electric Power Research Institute, with contributions from a number of government agencies, organizations, and companies. He is the founder and director of Carnegie Mellon's Green Design Institute which has conducted research on sustainability, life cycle analysis, alternative automobile fuels, and related topics for 15 years.

He is chair of the Energy Efficiency/Conservation Panel of the National Academy of Sciences study on American's Energy Future and has served on many committees of the National Academy of Sciences, American Medical Association, American Association for the Advancement of Science and other professional organization.

He is the author of more than 500 peer reviewed scientific publications and author or editor of more than two dozen books.