Testimony of
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U.S. House of Representatives
Committee on Energy and Commerce
Subcommittee on Energy and Environment

Hearing on
The American Clean Energy Security Act of 2009

Panel on Low Carbon Electricity, Carbon Capture and Storage, Renewables and Grid Modernization

April 23, 2009

My testimony is based on research described in 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. Lester B. Lave and Sompop Pattanariyankool are colleagues in this research.

Chairman Markey, Ranking Member Upton, and members of this subcommittee including my Representative, Mr. Doyle, thank you for giving me the opportunity to testify.

At Carnegie Mellon University, I am a faculty member in the Engineering College and the Tepper School of Business. I am also executive director of the Carnegie Mellon Electricity Industry Center. The opinions here are mine and do not necessarily reflect the views of my coauthors, Carnegie Mellon University, or any other institution.

I commend you for searching for ways to reach the goals of reducing greenhouse gas emissions and pollution, enhancing energy security, maintaining electric supply reliability, and controlling costs. Renewable energy sources are a key part of the nation's future, but I caution that a singular emphasis on renewable energy sources is not the best way to achieve these goals. One goal is paramount as the greatest challenge of the century: reducing air emissions and the atmospheric concentration of carbon dioxide.

I have two recommendations that I hope you will consider:

1. 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 energy security, and improving sustainability, ensuring that energy prices are not so high that they derail the economy.
2. Ensure that efficiency gains, in generating electricity, as well as transmitting and distributing it, and in using it, can count in any low-carbon legislative mandate, such as Sec. 231 of the discussion draft.

If estimates of the amount of recoverable fossil fuels are correct, without carbon dioxide controls we will run out of atmosphere long before we run out of fossil fuels. Burning any appreciable fraction of the estimated 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.

All fossil fuel sectors contribute emissions and need to be addressed, but my testimony focuses only on the electricity sector. The United States is increasing its reliance on electric power and will have to generate 40% more electricity by 2030 if demand keeps growing as it has the past 35 years. We face the additional challenge of quickly reducing carbon dioxide. At the same time, the price of power has risen 25% nationally in four years, and has risen much faster in cities such as Baltimore. We spend about 3% of GDP annually on electricity.

Removing 80% of the CO_2 we emit today from electric power generation with the most cost-effective technologies we know about will cost us about 2/3 of one percent of GDP annually. That's about what we spent on the Clean Air Act. That amount is affordable. But if we try to specify which technologies – like renewables – are the only ones that need apply and don't allow the least expensive clean technologies to compete, these costs can grow to unaffordable levels.

It is important to develop competing low carbon technologies to keep costs low, rather than trying to select technologies based on attributes that have little to do with controlling CO_2.

A national RPS is an expensive way to reduce greenhouse gas emissions because "renewable" and "low greenhouse gas" are not synonyms; there are several other practical and often less expensive ways to generate electricity with low carbon dioxide emissions. In addition, renewable energy is concentrated in only certain states. A national RPS would force other states to transfer wealth to windy or sunny states, instead of using it to develop low carbon technologies that are appropriate to their locales.

Mandating technologies can be much more expensive than mandating performance, by capping emissions at a level that declines over time or by requiring that no more than a given amount of CO_2 be emitted for every kilowatt-hour produced. Renewables portfolio standards unnecessarily increase costs (and often leave out efficiency and demand-side response) in an attempt to eliminate the use of uranium, coal, natural gas, and large hydroelectric power. What is needed instead is a direct performance standard that lowers the limits on emissions of CO_2 in a predictable fashion over the next few decades to very low levels.

For renewables, 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. Legislation should give each region the greatest flexibility to achieve the goals at least cost, including renewables, efficiency, conservation, fossil fuels with carbon capture and sequestration (CCS), and nuclear.

Many people like wind turbines in the abstract but don’t want them as neighbors, for example, the proposed wind farm off Cape Cod. In my state of Pennsylvania, we now have 200 wind turbines. About 10,000 would be required to meet a 25% RPS and the resulting land use issues can't be ignored. A handful of states require wind farm operators to pay into a fund for decommissioning the turbines at their end of life. A quick YouTube search for "wind turbine failure" is all that is required to see why this is very good idea.

Achieving a large national RPS requires building large amounts of transmission from areas with good wind resources to population centers. More people oppose transmission lines than wind turbines. There are likely to be delays of ten years or more in siting transmission.

Even in good areas, the wind doesn't blow all the time. Looking at all the wind power plants in Texas in 2008, we find that in a quarter of the hours during the year Texas wind production was less than 10% of its rated capacity. That means that when a wind farm is built, some other power source of the same size must be built to provide power during those calm hours. Our research shows that natural gas turbines, that are often used to provide this fill-in power, produce more CO_2 and much more nitrous oxide (as they quickly spin up and then slow down to counter the variability of wind than) than they do when they are run steadily.

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 spending money on always-available generation capacity, nor do we get all the air emissions benefits we once expected. For new generators, the capital cost is the vast majority of new costs and so the savings by having free fuel from the wind or sun are small.

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 Arizona Desert. A very large solar generator there had a duty cycle, what we call the capacity factor, of 19%, out of the possible 100%, if it had generated full power every hour of the two years we studied it. Wind turbines have higher potential in good wind sites but, for example, the average capacity factor for the wind turbines in Texas was only 29% in 2008.

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 Atlanta, Washington, or New York 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 variable power challenges the grid to provide reliable, high quality power when wind and solar are contributing more than a few percent 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 hydroelectric 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. The discussion draft does not appear to contain significant incentives for large-scale electricity storage.

Wind farms can affect climate downwind, reducing precipitation. Massive reliance on wind energy would take energy out of the wind, changing the Earth's climate. All power generation options have feet of clay. There is no generation utopia. But just because there is no free lunch doesn't mean we can't eat: we just have to acknowledge the issues honestly so that we are not faced with a public backlash later on.

There are other renewable sources that are also low-carbon. 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. Run of the river hydro could provide small amounts of power. Geothermal provides power in California and more is planned for the Southwest. Where there are good geothermal resources, this resource can be attractive. However, the good areas are limited to the West. Biomass could provide significant amounts of power at competitive costs, but there is a limited amount of land and water, and the biomass may be better used for transportation fuels. Ocean currents and waves can provide power, but corrosion and withstanding storms make the power expensive, in addition to other problems.

Where they can compete for our low-carbon dollar, renewables should be applauded. In good sites, wind power is competitive with new fossil generation with carbon capture and sequestration. At good sites, solar thermal power is almost competitive with new fossil generation. However, even at the best sites, solar photovoltaic generation is several times the cost of other low-carbon power per kilowatt-hour. We should not pick technologies with legislation – rather we should pick the low carbon goal and allow the cost-effective winners to emerge.

Federal support of R&D in this industry is essential to achieving low carbon electricity at affordable cost. While solar photovoltaic power is too expensive for massive deployment, I urge funding solar photovoltaics research, since this technology will ultimately provide most of our energy. I also recommend R&D funding for bulk electricity storage, such as compressed air. 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.

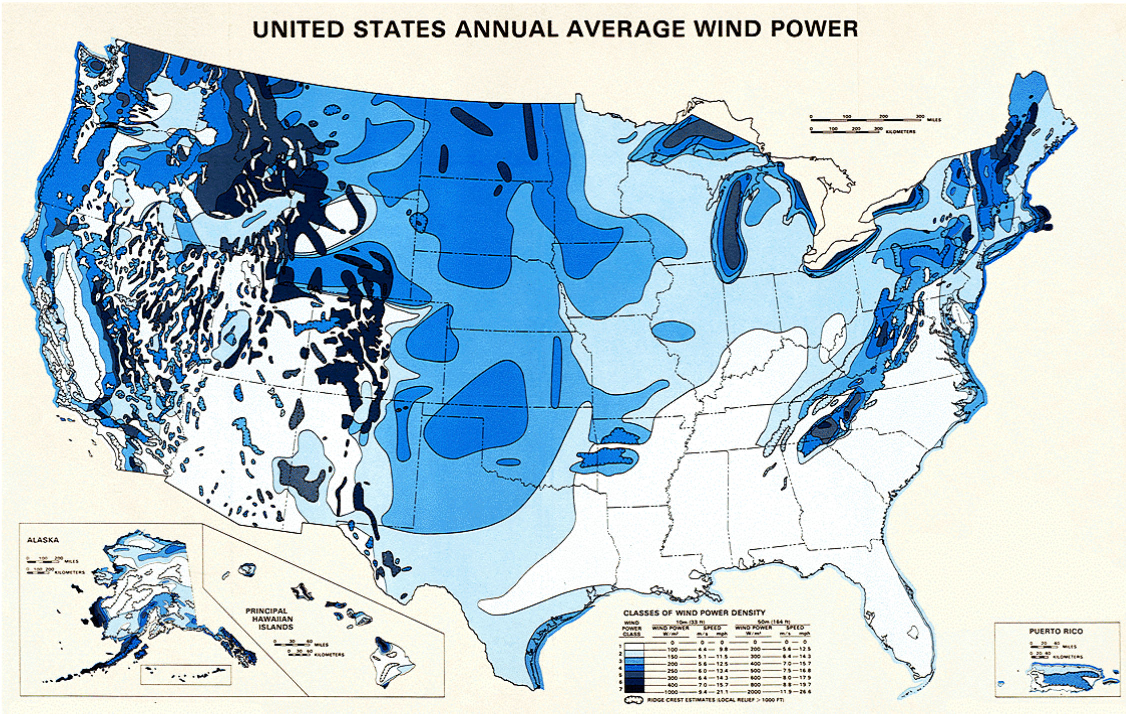
It is essential that demonstration coal plants with carbon capture be built to improve the technology and that we show that massive underground injection of carbon-dioxide in a range of geological strata can sequester the carbon dioxide without leakage. The Section 114 incentives are at the low end of what is required to demonstrate the commercial viability of sequestration.

It is also essential that we build half a dozen nuclear plants using new technology to assess their costs and performance.

I commend the Committee and Congress for moving this most important topic forward. I hope that you will keep two principles in mind:

1. 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 energy security, and improving sustainability, ensuring that energy prices are not so high that they derail the economy.
2. Ensure that efficiency gains, in generating electricity, as well as transmitting and distributing it, and in using it, can count in any low-carbon legislative mandate, such as Sec. 231 of the discussion draft.

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


UNITED STATES ANNUAL AVERAGE WIND POWER
ALASKA
PRINCIPAL HAWAIIAN ISLANDS
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CLASSES OF WIND POWER DENSITY
WIND POWER CLASS
10m (33 ft)
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1 2 3 4 5 6 7
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100 4.4 9.8 200 5.6 12.5
150 5.1 11.5 300 6.4 14.3
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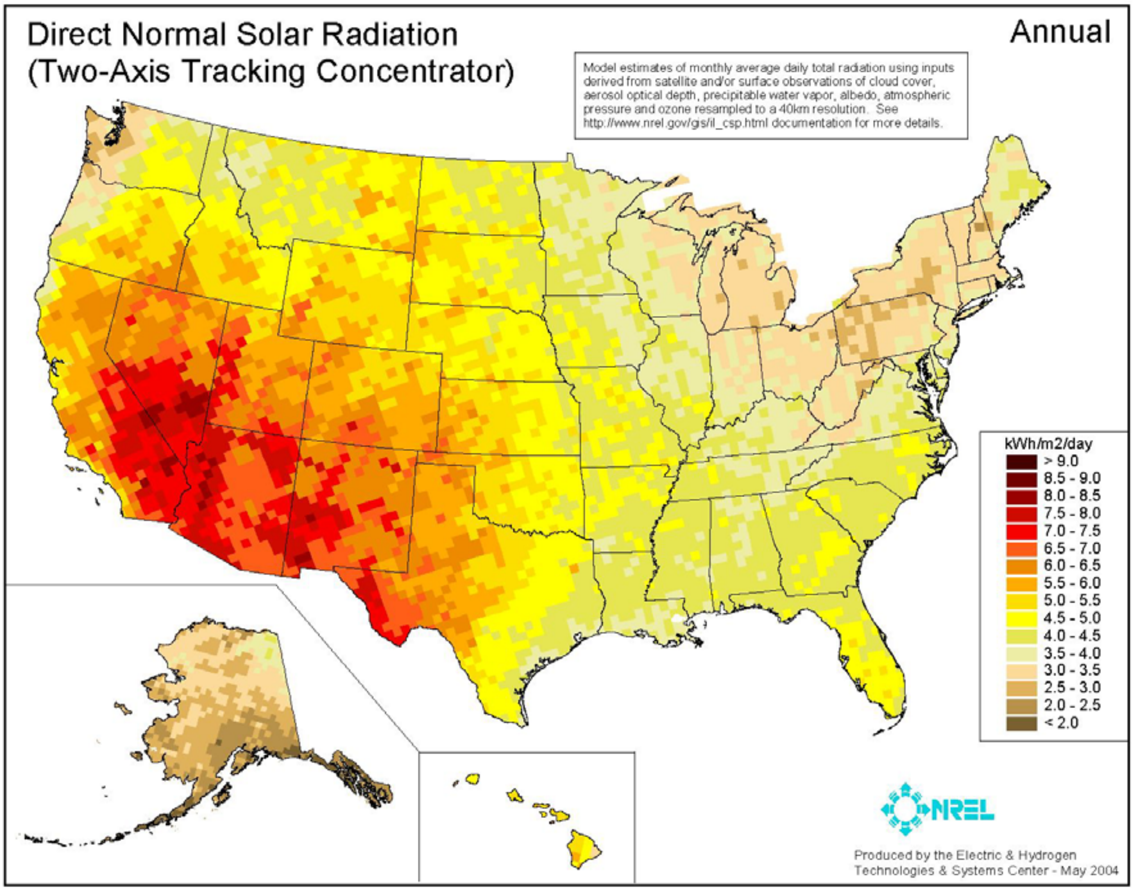
RIDGE CREST ESTIMATES (LOCAL RELIEF > 1000 FT)


Direct Normal Solar Radiation
(Two-Axis Tracking Concentrator)
Annual
Model estimates of monthly average daily total radiation using inputs derived from satellite and/or surface observations of cloud cover, aerosol optical depth, precipitable water vapor, albedo, atmospheric pressure and ozone resampled to a 40km resolution. See http://www.nrel.gov/gis/il_csp.html documentation for more details.
kWh/m2/day
> 9.0
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3.5 - 4.0
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NREL
Produced by the Electric & Hydrogen Technologies & Systems Center - May 2004

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He is the author of more than fifty peer reviewed scientific publications, and author of several books and book sections. He has received research support from a wide range of federal and state agencies, as well as foundations, nongovernmental organizations, and companies.

The publications of the Carnegie Mellon Electricity Industry Center are available at www.cmu.edu/electricity .

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A National Renewable Portfolio Standard? Not Practical

Legislation that mandates specified electricity production from renewable sources paves a path to costly mistakes because it excludes other sources that can meet the country's goals.

A discussion of renewable energy seems to addle the brains of many sensible people, leading them to propose policies that are bad engineering and science or have a foundation in yearning for utopia. For example, Michael Bloomberg, self-made billionaire and mayor of New York City, proposed putting wind turbines on the tops of skyscrapers and bridges. No need to ask the engineers whether the structures could bear the strain or whether there were good wind resources. Disagreeing with the mayor, the Alliance for Clean Energy New York said, "New York is really a solar city." Like Mayor Bloomberg and the Alliance, 25 governors, and more than 100 members of Congress, we love renewable energy. However, even this wonderful idea requires a hard look to see what is sensible now and why some current and proposed policies are likely to be costly, anger many people, and undermine the reliability of our electricity system. Congress needs to understand some facts before voting for a national renewable portfolio standard (RPS).

We share the goals of reducing pollution and greenhouse gas emissions, enhancing energy security, maintaining electric supply reliability, and controlling costs. The mistake is to think that a blinkered emphasis on renewable energy sources is the best way to achieve these goals. Unfortunately, this mistake has swept through 25 state legislatures.

These states have indicated their dissatisfaction with the current electricity-generation system by enacting binding RPSs, which require that wind, solar, geothermal, biomass, waste, or other renewable resources be used to generate up to 30% of the electricity sold by 2025. At the federal level, H.R. 969 was introduced in the 110th Congress to require that 20% of the nation's electric power be generated by renewable energy sources. Organizations ranging from MoveOn.org and the Union of Concerned Scientists to the American Wind Energy Association urged its passage as a way to fight global warming, promote energy independence, increase wind-lease payments to farmers, and move the country toward a clean energy economy based on solar and wind power. H.R. 969 was not enacted, but a national RPS will certainly be recon-

Renewable energy sources are a key part of the nation's future, but wishful thinking does not provide an adequate foundation for public policy.

sidered after the election.

A national RPS is a bad idea for three reasons. First, "renewable" and "low greenhouse gas emissions" are not synonyms; there are several other practical and often less expensive ways to generate electricity with low CO_2 emissions. Second, renewable sources such as wind, geothermal, and solar are located far from where most people live. This means that huge numbers of unpopular and expensive transmission lines would have to be built to get the power to where it could be used. Third, since we doubt that all the needed transmission lines would be built, a national RPS without sufficient transmission would force a city such as Atlanta to buy renewable credits, essentially bribing rural states such as North Dakota to use their wind power locally. However, the abundant renewable resources and low population in these areas mean that supply could exceed local demand. Although the grid can handle 20% of its power coming from an intermittent source such as wind, it is well beyond the state of the art to handle 50% or more in one area. At that percentage, supply disruptions become much more likely, and the highly interconnected electricity grid is subject to cascading blackouts when there is a disturbance, even in a remote area.

Renewable energy sources are a key part of the nation's future, but wishful thinking does not provide an adequate foundation for public policy. The national RPS that gathered 159 cosponsors in the last Congress would be expensive and difficult to attain; it could cause a backlash that might doom renewable energy even in the areas where it is abundant and economical.

Consider the numbers. Past mandates and subsidies have increased wind's share of generated electric energy to 0.8% of total U.S. generation and geothermal's share to 0.4%. Generation from photovoltaic cells and ocean waves and currents totals less than 0.02%. Wood and municipal waste provide 1.3%, and conventional hydroelectric 6% (but large hydroelectric power is generally excluded from RPS calculations). The near-term potential for acquiring significant additional generation from any of the renewable sources except wind is small. Thus, a renewable portfolio standard requiring 15 to 30% of electricity from renewable sources requires that wind generation be expanded at least 15-fold and perhaps more than 30-fold.

The timeframes for reaching these production goals are very short. Eighteen states require that by 2015 at least 10% of their electricity must come from renewable sources. California and New York require 25%. Satisfying the state mandates would require the production and siting of hundreds of thousands of wind turbines. Because there is little wind power near large population centers, tens of thousands of miles of new transmission lines would have to be built within the next few years. Not only can transmission costs double the cost of delivered power, but the median time to obtain permission and build long-distance transmission lines has been 7 years—when they can be built at all. A Wall Street executive responsible for financing transmission lines stated that of 35 lines he has been involved with at an advanced stage, 80% were never built.

As Massachusetts has already discovered, implementing an RPS is far more difficult than passing popular legislation. The proposed wind farm off Cape Cod is stalled, and Massachusetts is badly behind in meeting its RPS. Even beyond siting the wind farms, states and the federal government would have to expedite permitting and obtaining the land and permission to build transmission lines, as well as provide the resources to review interconnection applications quickly. Although the public supports renewable energy in the abstract, many groups object vociferously to wind farms in particular places and to transmission lines nearly everywhere.

Producing sufficient wind turbines would require a major increase in manufacturing capacity. Demand (driven by state RPSs and the federal renewable production tax credit) has already stretched supplies thin, creating an 18-month delivery delay for wind machines. It has also emboldened manufactures to reduce wind turbine warranties from five years to two.

Many current laws mandate the use of a specific technology, apparently assuming that legislators can predict the success of future R&D. An RPS is such a law. In our judgment, laws ought to specify requirements that generation technologies must meet, such as low pollution, affordability, power quality, and domestic power sources, and leave the means of realizing the goals to technologists and the market.

Technological realities

Wind and solar generation are qualitatively different from electricity generated by fossil fuels, nuclear energy, or hydropower. Wind and solar generation are variable, do not generate power most of the time, and generally do not generate electricity when demand is highest. The cost of renewable power includes ancillary expenses such as long-distance transmission, the need to operate fossil-fueled backup facilities, and storage. Each of the renewable sources has its particular liabilities.

Wind. For the next decade or two, wind is the most practical and cost-effective renewable option and has been deployed in 27 states. Wind and geothermal are, on a percentage basis, the nation's fastest-growing electric power sources. But even at the 2008 rate of growth (a historic high), wind will supply less than 2% of U.S. electric energy in 2020. If new policies aim to increase wind's share to 13% of 2020 electric energy, it would mean increasing annual wind installations from 5,400 megawatts (MW) (in 2008) to between 40,000 and 70,000 MW per year by 2020. Total land area for wind farms would be 30,000 to 50,000 square miles, about the area of Ohio.

Among the disadvantages of wind systems are that they produce power only when the wind is strong and that they are most productive at night and during spring and fall, when electricity demand is low. The capacity factor (the percent of maximum generation potential actually generated) of the best sites for wind turbines is about 40%, and the average capacity of all the wind turbines used to generate utility power in the United States was 25% in 2007.

Electricity can be generated by wind turbines for an unsubsidized cost of 8 cents per kilowatt-hour (kWh) (at sites with a capacity factor of 40%) to 12 cents/kWh (at sites with the 2007 average capacity factor of 25%). Transmitting the power to market could add 1 to 8 cents/kWh, depending on the distance and the cost of acquiring land and installing the lines. Because the best wind sites are remote, the cost of delivered wind power to the populous Northeast or Southeast would be 12 to 20 cents/kWh. A new coal gasification plant with CO_2 capture is estimated to produce power for 10 cents/kWh and could be located much closer to where the power is consumed. New nuclear plants might produce power for 12 cents/kWh. Energy-efficient appliances and buildings reduce energy consumption at a much lower cost.

Wind power does save fossil fuel, but not as much as it might seem. For example, if wind supplied 15% of the electricity, it would save less than 15% of fuel because other generators backing up the wind must often run at idle even when the wind is blowing and because their fuel economy suffers when they have to ramp up and slow down to compensate for variability in wind.

Variability also requires constant attention, lest it threaten the reliability of the electric system. On February 26, 2008, the power system in Texas narrowly avoided a breakdown. At 3 p.m., wind power was supplying a bit more than 5% of demand. But over the course of the next 3.5 hours, an unforecast lull caused wind power to fall from 2,000 MW to 350 MW, just as evening demand was peaking. Grid operators declared an emergency and blacked out 1,100 MW of load in a successful attempt to avoid a system collapse. According to the Electric Reliability Council of Texas, "This was not the first or even the worst such incident in ERCOT's area. Of 82 alerts in 2007, 27 were 'strongly correlated to the drop in wind.'"

At night the wind blows strongly and demand for power is low. On Hawaii's Big Island, wind supplies over a third of nighttime electric energy. Oil generators that are not required are shut down. On three nights during one week in June 2007 on the Big Island, the variability of the wind overwhelmed the ability of the single oil generator that remained running to compensate. While the system operators urgently tried to get a second unit warmed up, the frequency of grid power fell from its normal 60 hertz (Hz) to 58 Hz. Emergency procedures are implemented in most grids to prevent frequency from falling below 59.8 Hz to prevent damage to customers' electronic equipment.

The largest system with significant wind energy is Spain, where wind supplies 9.5% of electric energy every year. System operators there cope well, helped by large hydroelectric plants (18% of all generation capacity) that can react quickly to drops in the wind and store excess electricity when the wind blows strongly at times of low demand. Spain's large amount of excess capacity also helps to protect system reliability; it has 86 GW of generation, including 15 GW of wind, to serve a maximum load of 45 GW. In the U.S.'s largest wind area, Texas, there is 6 GW of wind capacity but only 0.5 GW of hydroelectric capacity (with no ability to store electricity). Instead of Spain's 90% excess generation capacity, Texas has 13%.

Can the United States do as well as Spain or, as mandated by 11 state RPSs, twice as well? Yes, but probably not without the $60 billion investment in new transmission lines recommended by the American Wind Energy Association. Such an interstate superhighway transmission system might allow remote generators or hydroelectric dams to pick up the slack when the wind dies down. A recent U.S. Department of Energy report relies on such a system to sketch a roadmap to 20% wind energy by 2030. Major investments in transmission lines, standby generators, and storage will be required to ensure that the lights don't flicker if 20% of the nation's electric energy comes from wind.

Finally, wind energy is a finite resource. At large scale, slowing down the wind by using its energy to turn turbines has environmental consequences. A group of researchers at Princeton University found that wind farms may change the mixing of air near the surface, drying the soil near the site. At planetary scales, David Keith (then at Carnegie Mellon) and coworkers found that if wind supplied 10% of expected global electricity demand in 2100, the resulting change in the atmosphere's energy might cause some regions of the world to experience temperature changes of approximately 1°C.

Solar. The amount of solar energy that reaches the United States each year is equivalent to an impressive 4,000 times the nation's electric power needs. Although using the Sun's energy has captured people's imagination, its practical near-term prospects for meeting an RPS are dim.

Electric power can be supplied by solar photovoltaic (PV) arrays and by solar thermal systems in which the Sun heats a fluid that generates steam to drive a steam turbine. PV has a nonsubsidized cost of 33 to 61 cents/kWh, almost 10 times the cost of the current electric power generation mix, and 3 to 5 times the cost of other low-carbon generators. The current cost of PV makes it more a subject for basic research than widespread deployment. Solar thermal is cheaper, but without subsidy is not competitive except in special applications.

One of the largest solar PV arrays in the United States is a 5-MW system operated by Tucson Electric Power in Arizona,. Over two years of operation, the capacity factor for that generator has averaged 19%. Even in Arizona, clouds cause rapid fluctuation in the array's power output. As with wind, large-scale solar power will require large transmission system investment to pair solar with steady power.

Solar thermal systems such as the new 64-MW Nevada Solar One installation should have smoother output power than PV systems because the thermal inertia of the oil used as a working fluid is expected to continue producing electricity despite the fluctuating thermal input. Molten-salt energy storage will be used to store energy for a few hours in order to generate power during the evening peak load. The facility is expected to have a capacity factor of 24%. The unsubsidized cost can be about 17 cents/kWh.

Solar subsidies in Japan and Germany, as well as solar set-asides in domestic state legislation, are based on legislators' assumption that the price for solar PV systems will decline to competitive levels as economies are achieved in manufacturing. At present, solar PV in states such as Pennsylvania (where the RPS requires 800 MW of solar PV) can produce wholesale power at 50 cents/kWh. Basic research might make solar PV competitive, but relying on large-scale orders to attain this goal with today's technology is fantasy.

Costs for a solar PV system (solar cells, electronics, packaging, and installation) would need to fall by a factor of 3 to 5 to produce power at rates competitive with other low-emissions sources, and that does not even include additional costs due to the variability of solar power. Cost reductions of this magnitude will not come quickly or easily. In fact, solar cell costs are now 10% higher than they were in 2004; the balance of the system components, representing half the total cost, have not become less expensive.

Geothermal. At a good site, geothermal power can generate electricity from hydrothermal sources at about 10 cents/kWh. At present, it supplies almost as much energy as does wind, and it has the advantage of providing a fairly steady supply. The median geothermal plant averaged a 63% capacity factor, comparable to that of coal-fired generators. However, the best locations are clustered in the Southwest, so long-distance transmission may be needed.

Today's geothermal power operates by pumping very hot subsurface water to the surface to produce steam to run a generator. Appropriate hydrothermal sources are limited, and large-scale geothermal power will require injecting surface water into very deep rock with techniques that are still in development and water that is scarce in the Southwest.

Run-of-the-river hydroelectric. Run-of-the-river hydro (a modern water wheel) can be attractive, but operates only when the river is flowing. To produce much energy, there would have to be a large, fast-flowing river. The potential power from this source is limited because many of the suitable rivers have already been dammed for hydroelectric power.

Biomass. At small scale, the use of waste biomass that would otherwise be left in fields is economically attractive. However, removing crop residue can make soil less productive and decrease its ability to store carbon. Biomass such as wood chips and switchgrass can be co-fired up to 10% with coal or can be burned in a specially designed furnace. The U.S. Department of Agriculture estimates that offering $60 per ton would produce 350 million tons of farm waste, tree

Rather than specifying a winning technology, Congress and state legislatures should specify the goals and provide incentives to reach them.

trimmings, municipal solid waste, and energy crops. Increasing the price to $90 per ton would pull in an additional 80 million tons. These prices are comparable to coal at $120 and $180 per ton, respectively. A generator burning biomass would raise the price of electricity by almost 4 to 7 cents/kWh, respectively. Transporting biomass is expensive, so it is likely to be used only near existing coal-fired power plants or in plants especially built for biomass. Thus, biomass might provide a few percent of generation.

Ocean. Systems to produce electricity from ocean tides, currents, waves, and thermal gradients are immature technologies whose costs and environmental effects are not fully known. The estimated global practical potential from tides and currents totals 70 GW, about 2% of current global electric power generation.

Storage. The variable nature of wind and solar generation requires demand response, other generation, or storage to fill the gaps when the wind calms or clouds obscure the Sun. At 38 sites in 18 states, water is pumped up into a reservoir by electric motors; when needed, the water flows back through the turbine to produce hydroelectric power. These pumped-storage facilities are expensive to build and have controversial environmental effects. The combined capacity of these pumped-storage facilities is 19,400 MW, or about 1.8% of the nation's generation capacity. Where they have available capacity, they are good choices for storing variable power.

In many areas of the country, electricity can be stored by using it to compress air, which is injected underground into depleted gas reservoirs, abandoned mines, or salt caverns. When electricity is needed (for example, when the wind is not blowing), the compressed air is released, heated, mixed with natural gas, and burned in a turbine to produce electricity. Many areas of the country have suitable geology. A 110-MW compressed-air energy storage facility of this type that has been operating since 1991 in Alabama can help provide power for 26 hours. At current natural gas prices, these storage facilities have capital and operating costs of approximately 8 cents/kWh of electricity produced.

Storage batteries are often used in small-scale, off-grid solar or wind systems. For large-scale application, sodium-sulfur batteries using a high-temperature chemical reaction have been deployed in several U.S. locations. These remain expensive. Plug-in electric hybrid vehicles that can be charged at night when the wind is blowing and demand is low may provide electricity storage in the future, but considerable technical and economic problems remain to be solved.

To sum up, we estimate that the states could accommodate 10% of the electricity coming from wind (or solar, if the costs were to come down) at any one time. With some attention and adjustment, we find that the electricity system could accommodate 15% or even 20%. To accomplish this, the system would require good prediction of wind speeds (or clouds for solar) several hours in advance, as well as a great deal of spinning reserve to substitute for the wind power when there are major changes in wind speed. Dealing with the minute-to-minute variability requires battery storage, fast-ramping generators, or customers who can react in minutes to raise or lower their use.

A national system must also deal with the fact that the best wind resources are in the Great Plains, about 1,000 miles from the Southeast where the electricity is likely to be needed. Policymakers must remain mindful of the difficulty of expanding transmission infrastructure. Community opposition will be widespread, the cost will be high, and the lines themselves will be vulnerable to disruption by storms or terrorists.

Thus, although a 20% national RPS might be physically possible with a very large transmission network and large amounts of spinning reserve, the logistical barriers will be high and the costs daunting. Embarking on this path without considering alternative strategies to reach the same ultimate goal would be short-sighted.

Energy efficiency

An RPS is essentially a narrowband solution to a broadband problem. By placing an inordinate focus on a limited number of renewable energy sources, legislators are neglecting numer-

Mandating rapid, massive deployment of these technologies will result in high cost, disputes over land use, and unreliable electricity, leading to a public backlash.

ous other options that can make significant contributions to the larger social goal of an adequate supply of clean, low-carbon, reliable, and affordable electricity. A prime example of a strategy that deserves more attention is energy efficiency.

In comparison with other developed nations, the United States is a profligate user of energy. For example, Americans use more than twice as much energy per capita and per dollar of gross domestic product as do Denmark and Japan. The comparison across nations or over time indicates a high potential for increased U.S. energy efficiency.

Experience in states such as California shows that aggressive policies can substantially reduce the growth of electricity demand. Aggressive efficiency standards for appliances and buildings, subsidizing efficient lighting, a five-tier electricity pricing structure with prices that start at 11.6 cents/kWh and go up to 34.9 cents/kWh for residential customers with high consumption, and incentive plans that reward utilities for lowering electricity use have led residential use per capita in California to grow only 4% from 1980 to 2005, while use in the rest of the United States grew 89%. The per capita demand in the commercial sector in California grew by 37% over that period, much less than the 228% growth in the rest of the country. California used 4% more electricity per dollar of gross state product in 2005 than in 1980, whereas the rest of the country used 40% more.

A new approach now in the early stages of implementation in California and elsewhere is changing from charging the same price for electricity at all times of the day to a system in which the price varies to reflect the actual cost of power at that time. On hot summer afternoons, inefficient and expensive generators are turned on to satisfy the additional demand; they may run for only a few dozen hours in a year, but the cost of building and maintaining them means that the cost of that peak electricity is very high. If customers were forced to pay the actual price at the time they use electricity, they would be motivated to shift some of their usage to lower-price hours, which would reduce the need for some expensive peaking capacity.

An economic model designed to predict consumer response to real-time pricing found that in the mid-Atlantic states, peak load would be reduced by 10 to 15%. But the model also found that total demand would increase by 1 to 2% as consumers took advantage of lower rates at off-peak hours. The shift to increased nighttime electric use would be a good match for wind's production profile but would not be a good fit for solar power. One potential downside of real-time pricing is that it may increase pollution emissions in certain regions of the country if customers switch their use from daytime, when natural gas is the predominant generation source for meeting peak demand, to the night, when coal dominates.

Policies to promote energy efficiency could clearly make a large contribution to reducing CO_2 emissions from electricity generation. However, the experience of California and other energy-conserving states indicates that implementing energy efficiency takes time and resources. An effective program requires actions that take years, such as replacing appliances and installing better insulation and windows. Although aggressive energy efficiency measures might lower electricity demand in states where the population is not growing, for most of the nation population is likely to grow faster than efficiency can be improved, so that total energy demand will continue to grow.

An inclusive strategy

Electricity is essential to modern life and commerce, from computers to natural gas furnaces to telecommunications to elevators and traffic signals. The critical importance of the electric system was made painfully clear by the 2003 Northeast blackout, which stopped all economic activity and endangered the lives and well-being of 50 million people.

The United States is increasing its reliance on electric power and will have to generate 40% more electricity by 2030 if demand keeps growing as it has during the past 35 years. The North America Electricity Reliability Council is warning that reserve generation capacity is becoming so low in the country (except for the Southeast) that unless generation is added or demand reduced, within a decade there will be brownouts or blackouts.

We face the additional challenge of quickly reducing CO_2 and other pollutants such as mercury and soot. At the same time, the price of power has risen 25% nationally since the last presidential election and has risen much faster in cities such as Baltimore.

The recent doubling of oil prices reduced imports appreciably. High oil, natural gas, and coal prices encourage energy efficiency, conservation, and a more sustainable fuel supply. Higher electricity prices, real-time pricing, and new efficiency standards can reduce growth in electricity demand. But even if the country can reduce the growth in electricity demand substantially, it will still need new generation capacity, much of it to replace old, inefficient plants.

Rather than specifying a winning technology, Congress and state legislatures should specify the goals—reduce pollution and greenhouse gas emissions, enhance energy security, maintain electric supply reliability, and control costs—and provide incentives to reach them. Since no current technology meets all goals, legislators must allow for tradeoffs. Specifying the goals rather than the technologies will lead to a technology race that will serve society.

Instead of enacting a national RPS, Congress should:

- Handle conventional pollution discharges through legislation and the Environmental Protection Agency.
- Handle greenhouse gas emissions through legislation such as a carbon tax or a cap-and-trade system that addresses such emissions explicitly.
- Handle energy security through energy efficiency programs such as equipment performance standards and consumer incentives and through maintenance of a high petroleum price.
- Maintain reliability through close monitoring of the new Electric Reliability Organization and of generating capacity and demand.
- Control costs through efficiency standards and encouraging a diverse portfolio of generating fuels, but avoid mandates to deploy expensive technologies. Rather, it should allow the market to determine the least-cost generation options.

Impatience to solve current problems has resulted in aggressive RPSs with strict deadlines. Although we agree that renewable technologies will help attain social goals, mandating rapid, massive deployment of these technologies will result in high cost, disputes over land use, and unreliable electricity, leading to a public backlash against these policies. The United States needs to focus on the goals, provide substantial incentives to meet them, and avoid polices that exclude economical ways to meet them.

Recommended reading

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