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Carbon-Free, Nuclear-Free States

When it appeared a few years ago that the United States may put limits on carbon dioxide emissions from power plants, there was much talk of nuclear power being a major part of the answer to coal. But nuclear is costly, risky, and takes a long time to build. When it is part of the mix of new plants, it marginalizes all other investments. The CEO of General Electric called nuclear a "bet the company risk" in November 2007.

But there is good news. Analyses by IEER have shown that nuclear is not necessary and that electricity demand can be met with 100% renewable energy. Indeed, IEER first showed in 2007 that the entire energy sector can be made renewable at reasonable cost in three to five decades. After that we have focused our work at the state level, because federal action is stalled and because state-level policies are critical to the development of the electricity sector.

The two articles in this issue illustrate some of IEER's work to determine if it is feasible and affordable for states to transition to fully renewable and efficient electricity systems. The eUtah Roadmap and the Renewable Minnesota report were modeled after IEER's landmark 2007 study, *Carbon-Free and Nuclear-Free: A Roadmap for U.S. Energy Policy*.

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INSIDE

Renewable Energy Roadmap for Utah

BY ARJUN MAKHIJANI, PH.D.,

In early 2009, the Healthy Environment Alliance of Utah commissioned IEER to examine the feasibility and cost of replacing Utah's coal fired power plants with renewable sources like solar, wind, and geothermal. The result was the December 2010 report, *eUtah: A Renewable Energy Roadmap*. This article summarizes that report. References, sources, and other important details can be found in the full report.[1]

Methodology

The eUtah Roadmap examined options for reducing carbon dioxide (CO_2) emissions from the Utah electricity sector

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Photo courtesy Paul Torcellini and NREL

Installation of PV-integrated standing seam metal roof panels on the BigHorn Home Improvement Center retail complex in Silverthorne, Colorado.

A Plan for Minnesota's Renewable Electricity Future

BY CHRISTINA MILLS AND ARJUN MAKHIJANI, PH.D.,

In March 2012, IEER published the report, *Renewable Minnesota: A technical and economic analysis of a 100% renewable-energy based electricity system for Minnesota*. The study, which is summarized in this article, looked at how Minnesota might take advantage of its wind and solar resources to reduce its reliance on fossil fuels. The overall goal was to examine whether a fully renewable energy-based electricity system is technically and economically feasible at the state level. Full references can be found in the report.[1]

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by the year 2050 – specifically, reductions of 70 to 95 percent compared to 2010 levels. While benefiting the environment, our analysis is also important from an investment standpoint because a large uncertainty in electricity sector investments is related to effective carbon prices, whether via a tax, tradable permits, or regulations.

We developed five different scenarios, including a "business as usual" scenario which assumes continued reliance on coal, in order to yield insights into different approaches to reducing carbon emissions and managing investment risks. Then we compared their estimated costs. The five scenarios are described below.

The Scenarios

BAU: This is the reference scenario and assumes "Business As Usual" – the continued dominance of coal in the supply system. Existing plants are retired at 60 years, and replaced with the same type of facility. No new efficiency or Demand-Side-Management measures are assumed. In effect, this scenario assumes a zero carbon emissions cost. By allowing carbon emissions to rise in one scenario and be curbed in others, we can estimate what it will cost to reduce carbon emissions and infer a risk of a continued reliance on coal should there be a non-zero cost of CO_2 emissions in a coal-centered investment strategy.

Nuclear/CCS: This scenario provides an example of a conventional approach to CO_2 emissions reductions and assumes that the structure of the present electricity sector will continue but with carbon reductions as an added goal. Nuclear power and coal with carbon capture and storage are the main generation technologies in this scenario. Natural gas plays a supporting role, as it does at present in Utah. A medium level of efficiency improvements, typical of conventional utility planning, is assumed in this scenario. This scenario results in approximately 70 percent reductions in CO_2 emissions relative to 2010 and 80 percent relative to the emissions in 2050 in the BAU scenario.

Renewables/Natural Gas: In this scenario, a higher level of efficiency than in the Nuclear/CCS scenario is achieved, with slightly greater reductions in CO_2 emissions by using solar, wind, and geothermal generation, supplemented by natural gas combined cycle power plants. Since more than half the power is supplied by solar and wind, large-scale energy storage is needed. The reference technology for large-scale storage is compressed air energy storage.

Renewables/Natural Gas/CCS: This is the same as the Renewables/Natural Gas scenario, except that carbon capture and storage has been added to natural gas combined cycle power plants in order to achieve CO_2 emissions reductions of 93 percent relative to 2010. It is comparable in CO_2 reductions to the eUtah scenario.

eUtah: This scenario relies almost totally on wind, solar, and geothermal energy sources by 2050. The only non-renewable resource used is natural gas, which is used to reheat compressed air when it is withdrawn from the storage cavern. This scenario has CO_2 reductions of 97 percent relative to BAU in 2050 and about 95 percent relative to 2010.

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Renewable Energy Cooperatives

BY CHRISTINA MILLS

In June 2012 I had the privilege of joining Dr. Andreas Wieg and Michael Diestel, experts in German renewable energy and cooperatives, on a speaking tour in Iowa, Minnesota, and Wisconsin. Their visit was sponsored by the Heinrich Böll Foundation, with logistical assistance from IEER. Throughout the week we met with representatives of rural electric cooperatives, farmer associations, state legislators, representatives from state energy and agriculture departments, and members of the public to talk about the incredible potential for renewable energy development in the Midwest and what insight the German experience in promoting renewable energy can provide.

The cooperative business model is widespread across Germany, in housing, banking, and farming, among other industries. Traditional energy cooperatives, similar to U.S. rural electric cooperatives, have existed in Germany for many years, as well as some municipal utilities. However, in the last few years, a new concept of a renewable energy cooperative has taken hold. Since 2008, more than 500 new cooperatives have been formed in Germany with the sole purpose of developing renewable energy generation projects, from solar PV systems to wind turbines to district heating systems using local biomass supplies.

Photo credit: DGRV – Deutscher Genossenschafts und Raiffeisenverband e.V.

Spectators of the TSV Großbardorf football club are shaded by a solar PV rooftop. The solar rooftop is a project financed by a cooperative of local residents, who now get a return on their investment from the electricity sold as well as a season pass for home games.

Similar to the United States, Germany has only a handful of large energy companies controlling the vast majority of the energy market. While non-hydro renewable energy provided 17% of the German electricity supply in 2011, these companies are heavily invested in fossil fuels and nuclear power, and represented only 6.7% of the investment in renewable energy in 2010.

Realizing a fully renewable energy system is not solely a technical problem. As the Germans have discovered, it requires a new way of thinking about the business of energy. Will decentralized energy systems, such as solar and wind power, be able to function within today's centralized structure? Mr. Diestel and Dr. Wieg make a compelling argument that decentralized energy is best served by a decentralized energy business structure – in the case of Germany, this structure is the renewable energy cooperative.

Why does the business structure matter in renewable energy development? Certainly electrons do not care who is

SEE **COOPERATIVES** ON PAGE 4

UTAH FROM PAGE 2

We examined the electricity supply and demand of the Utah portion of PacifiCorp, the state's largest electricity provider, to establish a starting point for each of the scenarios. We have maintained the usual reliability criterion—12 percent reserve margin over demand—in all scenarios for every hour of the year.

In this study, we examined only central station generation options, even for renewable energy sources. That is because it is still very difficult to foresee the shape and cost of an intelligent electricity grid in which large numbers of distributed generation sources, storage types, and smart appliances would be managed as an integral part of grid operation. Yet the need for such an analysis emerges very clearly because a centralized approach to large-scale use of renewable energy is financially inefficient due to a large amount of spilled energy. That said, we find that solar and wind energy can be dispatched reliably, at all hours of the year, when there is storage.

Selected findings and recommendations from the eUtah Roadmap follow. For the full set of findings and recommendations, please read the full report.

Findings

1. A renewable electricity sector in Utah is technically feasible. Utah has enough solar, wind, and geothermal energy resources to meet the demand for electricity.[2] These technologies are commercially available today, though concentrating solar power and solar photovoltaics are at early stages of commercialization. While a centralized approach, as here, incurs significant added cost due to spilled energy, greater use of distributed technologies may reduce this cost.

2. Several approaches are possible for greatly reducing CO_2 emissions. Among them are solar and wind energy with storage, geothermal energy, nuclear power, coal with carbon capture and storage (CCS), and natural gas combined cycle power plants with CCS. The caveat with CCS approaches is that carbon storage technology has not yet been demonstrated sufficiently to show that it can support large-scale fossil fuel electricity generation with low overall emissions.

3. A 70 percent reduction in CO_2 emissions relative to 2010

in charge of their creation and transmission or who collects the electric bills. Yet, who owns the renewable energy projects and how involved local communities and residents are in developing them actually are important, and may be pivotal factors for realizing a carbon-free and nuclear-free future.

The two main goals of the German energy transition are to reduce greenhouse gas emissions by 80 to 95% by 2050 and to increase the amount of renewable energy to 60% by 2050. Yet renewable energy is facing similar opposition across Germany as it does in many rural communities in the U.S. The NIMBY ("Not In My BackYard") attitude is alive and well, but it tends to disappear when members of the community are part of the business and the profit of renewable energy development.

For instance, the costs of small and medium solar PV systems are significantly lower in Germany than in the United States (see Dear Arjun column on page 14). This is a product of clear, national policies, notably the feed-in tariff, which makes it easy for individuals to invest in their own solar panels or wind turbines, by providing a standardized process and a guaranteed price for the energy produced. Yet it doesn't explain why Germans are coming together and forming cooperatives solely for the purpose of renewable energy development.

Dr. Wieg recently compiled a survey of German renewable energy cooperatives and found that the ability to make money and the desire to spread renewable energy were important reasons that people invest in renewable energy. However, his survey revealed that the single most important reason was that it allowed them to do something together, within their own community, while building up the local economy.

There are a growing number of examples of how the renewable energy cooperative works in Germany, but one illuminating story is of one of Mr. Diestel's cooperative projects. The local soccer club in his town needed a roof over their seating area – a requirement of the German Football Association in order to compete in upper level divisions – but they didn't have the money to build one. Diestel and other members of the community decided to form a cooperative to raise money to build a solar panel roof. Members of the cooperative get a little bit of money each year, less than what they would earn if they put a smaller system on their own roofs for sure, but they also get season tickets to the soccer club and the pride of being part of the solution for their local soccer club.[1]

I believe that as we continue to promote a carbon-free, nuclear-free future at the state and local levels, the investment and involvement of members of the community will increasingly become a determining factor for renewable energy development – and maybe even more so than wind, solar, or biomass potential, or constraints on the transmission system. One can, if you look for them, find a growing number of similar projects in the U.S., for instance with community wind and solar projects in certain regions of the country.[2] The task ahead is to multiply these projects and increase both community solidarity and renewable energy all across the United States.

Endnotes

1. Read more case studies in "Energy Cooperatives: Citizens, communities and local economy in good company," by Dr. Andreas Wieg et al. (DGRV – Deutscher Genossenschafts und Raiffeisenverband e.V. and Agentur für Erneuerbare Energien e.V., 2011?). Available at www.dgrv.de/weben.nsf/

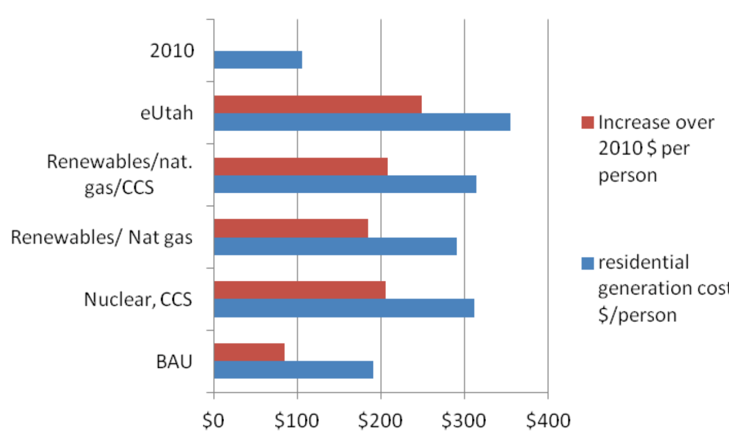
2. Examples include University Park Community Solar project in Maryland (http://www.universityparksolar.com/), Clean Energy Collective in Colorado (www.easycleanenergy.com), and Minwind projects in Minnesota (http://farmenergy.org/success-stories/wind-energy/minwind-iii-ix).

can be achieved at modest cost of electricity per unit GDP, especially when potential carbon costs are considered. Figure 1 shows the projected annual residential electricity generation costs per person in 2050 for each of the five scenarios, with the 2010 cost of $106 per person shown as a reference. It shows that costs would increase in all cases relative to the year 2010, but more in the low CO_2 emission cases.[3] Overall, the increases largely reflect growing use of electricity services with income. The higher relative costs reflect the costs of decreasing CO_2 emissions using central station technology without demand response technologies.

While the cost picture does not look rosy for reducing carbon when compared to present day electricity generation costs, it must be remembered that the increased cost is in the context of a growing economy and increasing use of the services that electricity provides. Hence, besides total cost, which is, of course, important, the fraction of gross domestic product (GDP) that goes into electricity is also relevant.

FIGURE 1

Residential sector generation cost per person per year in 2050 and increase relative to 2010



As shown in Figure 2, the fraction of GDP devoted to Utah electricity generation for all consuming sectors is very similar among the scenarios: all are below 2 percent. This picture shows that it would be affordable in a growing economy to transition to a mainly renewable electricity system (the Renewables/Natural Gas scenario) while keeping the expenditures on electricity generation at about 1.5 percent. In addition to being the lowest-cost carbon reduction scenario, the Renewables/Natural Gas scenario also has the least financial risk and is compatible with a variety of levels of CO_2 reduction, including more than 90 percent, either via the addition of CCS to combined cycle plants and/or incorporating a larger proportion of renewables instead of natural gas combined cycle plants in the long-term. The BAU scenario would reduce the percentage of GDP devoted to generation to about 1 percent, but it carries a high risk of carbon emissions cost.

When the cost of carbon emissions is factored in, the cost difference between the five scenarios becomes even smaller. As illustrated in Figure 3, adding $50 per metric ton – a plausible, conservative estimate for potential carbon costs – the difference in annual generation cost per person between the BAU scenario and the Renewables/Natural Gas scenario is only $67 in the year 2050. This is well within the variability of the fuel and capital cost parameters.

4. Carbon-emissions-related risks are high. Continued use of coal without CO_2 emissions controls (the BAU scenario) appears much lower in cost if one assumes there is zero cost for carbon emissions. But the risk of carbon-related costs is high. A carbon emissions cost of $45 per metric ton is the lowest non-zero value used by PacifiCorp in its Integrated Resource Plan. The risk of continued reliance on coal without carbon storage is reflected in current investment practices among many utilities (including PacifiCorp) which, for the most part, are focusing on natural gas combined cycle plants and wind energy rather than on coal. In the past year or so the preference for natural gas also reflects low

FIGURE 2

Percent of Utah GDP devoted to electricity generation in 2050, with the 2010 value shown for reference. Costs are for Utah electricity generation for all consuming sectors.

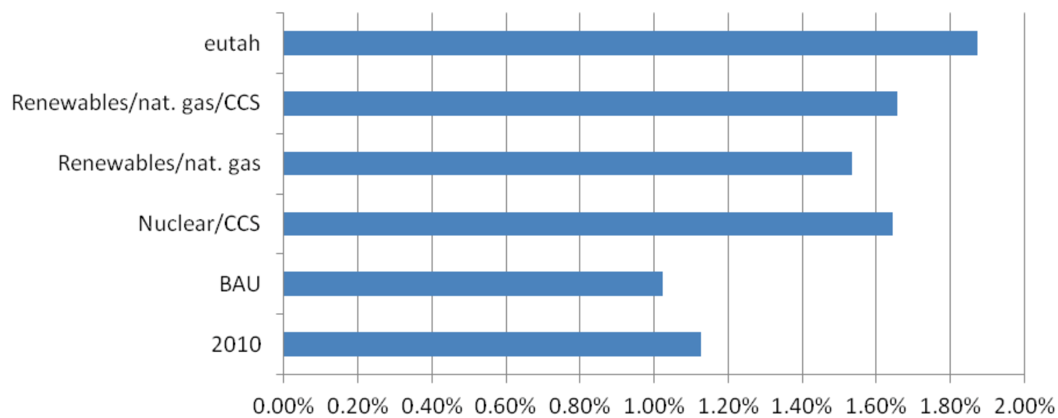
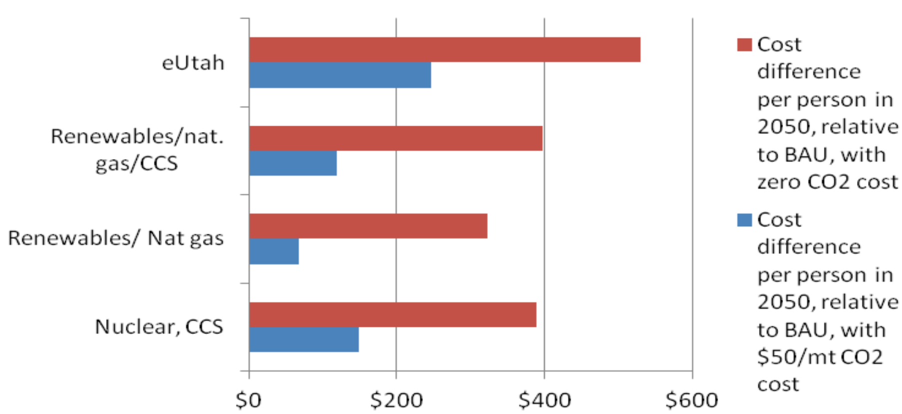


FIGURE 3

Cost differences per person in 2050 between Business-as-Usual (BAU) and other scenarios, with and without a price on carbon



natural gas costs.

5. Spilled energy greatly increases the cost of reducing carbon emissions in the renewable scenarios. There is a significant spilled energy cost embedded in all three renewable energy scenarios. Spilled energy is what we are calling solar and wind generated electricity that could have been utilized, but was not because there is a surplus of renewable electricity available relative to demand in periods when the storage capacity is also full. The highest spilled energy cost is in the eUtah scenario: estimated to be about $1.4 billion in 2050. The spilled energy cost in the Renewables/ Natural Gas scenario is estimated to be about $900 million in 2050. This means that considerable investments (up to maximums indicated by these amounts) can be made to reduce spilled energy, for instance by demand response, while lowering overall generation costs relative to the scenarios considered here.

6. Compressed air energy storage is the only commercial storage technology at present that could be used in Utah on a large scale. Many potential sites are available; one is currently being developed. Compressed air energy storage (CAES) has been used commercially for decades on a large scale with coal-fired power plants in Germany and Alabama. Compressed natural gas storage in caverns and aquifers is also a standard technology.

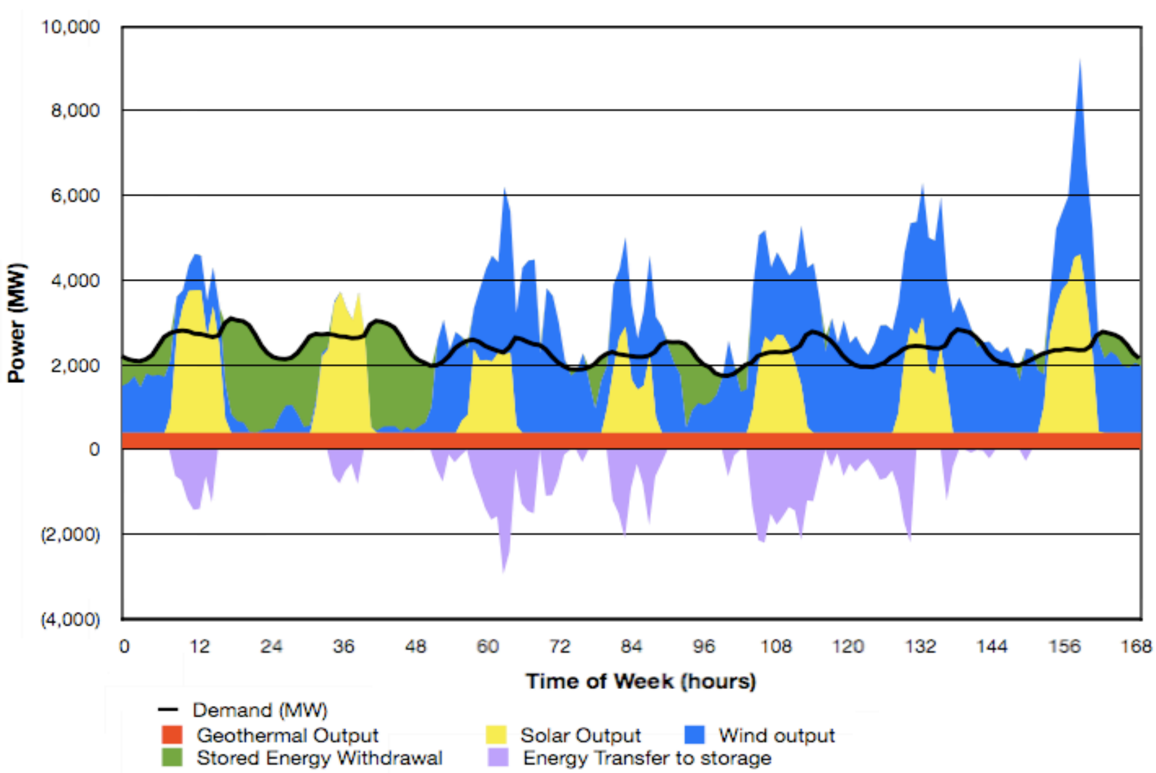
The basic approach of CAES is as follows: when electricity generation is greater than demand, the surplus is used to compress air which is stored in an underground cavern. When generation is less than demand, pressurized air is withdrawn from storage, heated with natural gas, and used to drive a turbine. (See Figure 3 in the Renewable Minnesota article on page 11.)

Figure 4 shows the hourly electricity demand (solid black line) during a winter week in 2003 and the electricity supply had generation been provided by the same mix of renewables as the eUtah scenario. In almost the whole week, surpluses of generation over demand are used to compress air into storage, seen below the X-axis. (Note that wind and solar energy increase at the end of the week. The storage is already full; this results in spilled energy. The generation at the end of the week above the black line with yellow and blue fill is spilled.)

7. Optimizing investments between the generation and demand sides of the system is important. Building up demand dispatch capability could reduce relational system peaks and hence also spilled energy in an electricity system with a high proportion of solar and wind. Properly integrating highly efficient structures, such as passive buildings, could do the same. Least-cost investment approaches will require much more integration of investments in the demand, generation, and storage elements at all levels from small to centralized than is typical at present. Using centralized storage without demand dispatch, local storage elements, etc., creates a need for very large centralized CAES storage system

FIGURE 4

A week in December 2003 with the eUtah supply and storage configuration. The storage system is assumed to be 75 percent efficient.



and, potentially, siting problems.

8. Energy efficiency lowers electricity bills. There are ample opportunities for reducing electricity use while maintaining the benefits provided, for instance, by having more efficient refrigerators, air conditioners, or television sets. Appliances and building standards supplemented by utility promotion programs are an effective way to have high penetration of efficiency measures and achieve close to the estimated cost savings. Varying levels of overall energy efficiency are included in the 5 scenarios, with higher levels in the eUtah scenario than in others. We did not take into account any change in the shape of the demand curve as a result of these efficiency improvements.

9. Water use is greatest in the Nuclear/CCS scenario and least in the eUtah scenario. Electricity generation is a large source of water use. The renewable scenarios would use 15 to 20 billion gallons less water per year than the BAU scenario in the year 2050. The Nuclear/CCS scenario uses more water than BAU due to the additional water requirements of carbon capture and storage. While the current costs of water do not indicate a significant cost reduction for the renewable energy scenarios, the opportunity cost of water could be very high. Utah's population is growing more rapidly than the rest of the country and the pressure on water resources is already considerable. Moreover, water-intensive technologies carry a greater risk of not being able to meet generation expectations in times of prolonged drought. Further, they compete with other water users like farmers, a problem that might become more serious as climate disruption increases.[4]

Recommendations

The eUtah report makes three main recommendations:

1. **Enact stronger building and appliance standards that reflect the potential for efficiency to reduce electricity bills.** The University of Utah's standards for new buildings could be a starting point for the commercial sector, with gradual further strengthening between now and 2030.

2. **Set a direction that is compatible with the Renewables/Natural Gas scenario for centralized generation components.** The short term direction for centralized generation indicated by this study is about the same as that being adopted by many utilities, including PacifiCorp: a focus on wind and combined cycle natural gas plants. But it is not sufficient to continue to focus mainly on new centralized generation. PacifiCorp's additions to wind capacity in the 2009 to 2020 period are planned to total more than 1,000 MW in its East sector, which includes Utah and Wyoming. Yet it appears to have no active plans to develop compressed air energy storage. Such storage could convert its currently intermittent wind capacity into a reliable and dispatchable resource of several hundred megawatts.

Since CAES is the most economical large-scale storage option in the Utah context, it is critical to begin to identify sites, estimate their cost and environmental impact, and conduct economic reviews of their location relative to other future elements in the electricity system, including transmission lines, and solar and wind generating facilities. Something similar to the Utah Renewable Energy Zones studies that identified and evaluated renewable energy resources in Utah is warranted. Some development is already occurring (for instance, the Magnum Gas Storage development near Delta, Utah), but more needs to be done.

3. **Lay the foundation for a low-risk, clean, reliable, 21st-century renewable electricity system.** Developing Utah's ample renewable energy resources would boost the state's economy, especially since the coal reserves in existing mines are rather limited. Among the potential renewable resources identified by the Governor in his draft Utah Energy Initiative are 7,800 megawatts of roof-top solar photovoltaics, about half of which are commercial rooftops. This distributed solar capacity is nearly 40 percent larger than the solar generation capacity needed in the year 2050 in the Renewables/Natural Gas scenario.

Integrating any significant fraction of this distributed generation into the grid in an economical manner (assuming the costs of solar PV decline as widely anticipated) will require new concepts of the grid to be tested, modeled, and implemented. For instance, if spilled energy could be greatly reduced or eliminated at modest cost, the cost increase to a residential bill of 100 percent renewable energy could be on the order of $100 per person per year by 2050—in an economy that would have grown from a per person GDP of about $37,000 in 2010 to more than $75,000 in 2050.

The economy that achieves a renewable electricity system will have technological leadership in the electricity sector and carry low financial risk. The air will be cleaner, water use will be far lower, and CO_2 emissions risks in the electricity sector will be nearly eliminated.

Two complementary efforts could help pave the way:

- **Create a demonstration city for a renewable, efficient, intelligent electricity system.** The City of St. George, Utah, together with the local electric cooperative Dixie Escalante Electric have pioneered a solar PV program in which individual homeowners can purchase a piece of a larger solar PV system. This provides economies of scale and portability. St. George could be a laboratory for developing a renewable, efficient, intelligent electricity system. In any case, a demonstration city (or a part of a city that is large enough to test the concepts and provide reliable data but small enough for the cost to be manageable) is needed to show how the various technologies that make up a smart grid would work with high levels of renewable energy, including distributed solar PV installations.

- **Create a 21st-Century Electricity Center.** The University of Utah is among the leading public universities in the United States and a leader in energy research. It has a sustainability program which includes highly efficient new buildings. A Twenty-First Century Electricity Center at the University could provide the leadership and intellectual heft needed to develop pilot projects, analyze the data, and develop and refine the models that will guide the way to a cost-efficient renewable electricity system. This includes using distributed as well as centralized elements, and is founded in an efficient consuming

Sharpen your technical skills with Dr. Egghead's *Atomic Puzzler*

Replacing Nuclear Power with Renewables

Alpha, Dr. Egghead's cat

The imaginary state of Minnutah, which currently has nuclear power capacity of 1,000 megawatts (MW), is interested in moving away from nuclear and increasing its solar capacity. Can you help Dr. Egghead's cat, Alpha, figure out how many solar panels would be needed to replace the generation from the state's nuclear reactors?

A typical nuclear power plant is designed to produce electric power almost continuously. Solar panels, on the other hand, only generate electricity when the sun is shining, so figuring out how much energy one can obtain from solar power is more than just reading the label on the box.

Help Alpha answer the following questions and she might send you a prize!

1. The average capacity factor for nuclear reactors is 90%, which means that the average reactor produces its rated power capacity 90% of the time. How much annual electricity generation in megawatt-hours (MWh) comes from Minnutah's nuclear capacity? (Hint: There are 8,760 hours in the year.)

2. How much annual electricity in watt-hours (Wh) can be generated in Minnutah from a solar panel with a peak power rating of 315 watts? (Hint: Minnutah's average capacity factor for solar power is 16%.)

3. How many solar panels from #2 would be required to match the annual generation from Minnutah's nuclear reactors determined in #1? (Hint: There are 1 million watts in one megawatt.)

4. One of the recommendations in *Carbon-Free Nuclear Free: A Roadmap for U.S. Energy Policy* (IEER Press, 2007) is to install solar PV on commercial rooftops and parking lots. Let's assume that the area of a typical parking lot at a U.S. strip mall is in the neighborhood of 42,000 square meters, and an average commercial building has a roof space of 10,100 square feet.

a. If we assume that one 315 watt solar panel is 1.25 square meters in area, roughly how many typical strip mall parking lots could host the number of solar panels from your answer in #3?

b. How many commercial building rooftops would be needed to host the number of solar panels from your answer in #3? (Hint: there are 10.76 sq. ft. in one square meter.)

BONUS QUESTION! How many solar panels could fit onto an average commercial building considered in #4?

THINK YOU KNOW THE ANSWERS? Send us your answers via e-mail (ieer@ieer.org), fax (1-301-270-3029), or snail mail (IEER, 6935 Laurel Ave., Suite 201, Takoma Park, Maryland, 20912, USA), postmarked by August 31, 2012. IEER will send a signed copy of each report featured in this issue, *eUtah: A Renewable Energy Roadmap* and *Renewable Minnesota*, to the person with correct answers. If more than one person submits correct answers by the deadline, the winner will be drawn at random. (People with degrees in physics or chemistry are not eligible for the prize!)

UTAH FROM PAGE 7

sector that communicates with production and storage centers.

We conclude by suggesting some steps in the short-term that would help put Utah on a path for a low-risk, clean, reliable, 21st-century renewable electricity system:

- Utilities in the state should develop at least 200 megawatts of geothermal capacity in the next ten years.
- Develop carbon capture and storage with natural gas combined cycle plants as a priority because it may be more economical than converting existing coal-fired power plants.
- Eliminate nuclear power from integrated resource planning because nuclear is the most risky element in options for the supply side and Utah stands no realistic chance of getting loan guarantees in the foreseeable future.
- Analyze the public health, water use, and job creation and training consequences of a transition from the present coal-dependent electricity sector to a renewable sector.
- Look for ways to export solar energy to Wyoming and import wind energy from there. The overall cost reduction by swapping Utah solar with Wyoming wind resources would be about $530 million dollars per year in the eUtah scenario in 2050, or almost $90 per person per year.

Endnotes

1. *eUtah: A Renewable Energy Roadmap*, a report commissioned by HEAL Utah and written by Arjun Makhijani, is available online at http://ieer.org/resource/reports/eutah-renewable-energy-roadmap. For details about the eUtah project, visit http://eutahproject.org.

2. The use of a small amount of natural gas for compressed air energy storage is assumed in the model developed in this report. This can be reduced by optimizing the renewable energy system in various ways. It can be eliminated should other storage methods, such as battery storage, become economical in the next ten to 15 years.

3. All costs in this report are unsubsidized generation costs only (including storage costs, where applicable). Specifically, transmission and distribution costs are not included. Figures for the year 2010 are estimated.

4. For instance, see: Michelle T. H. van Vliet, John R. Yearsley, Fulco Ludwig, Stefan Vögele, Dennis P. Lettenmaier, and Pavel Kabat. "Vulnerability of US and European electricity supply to climate change," *Nature Climate Change*, June 3 2012.

Background

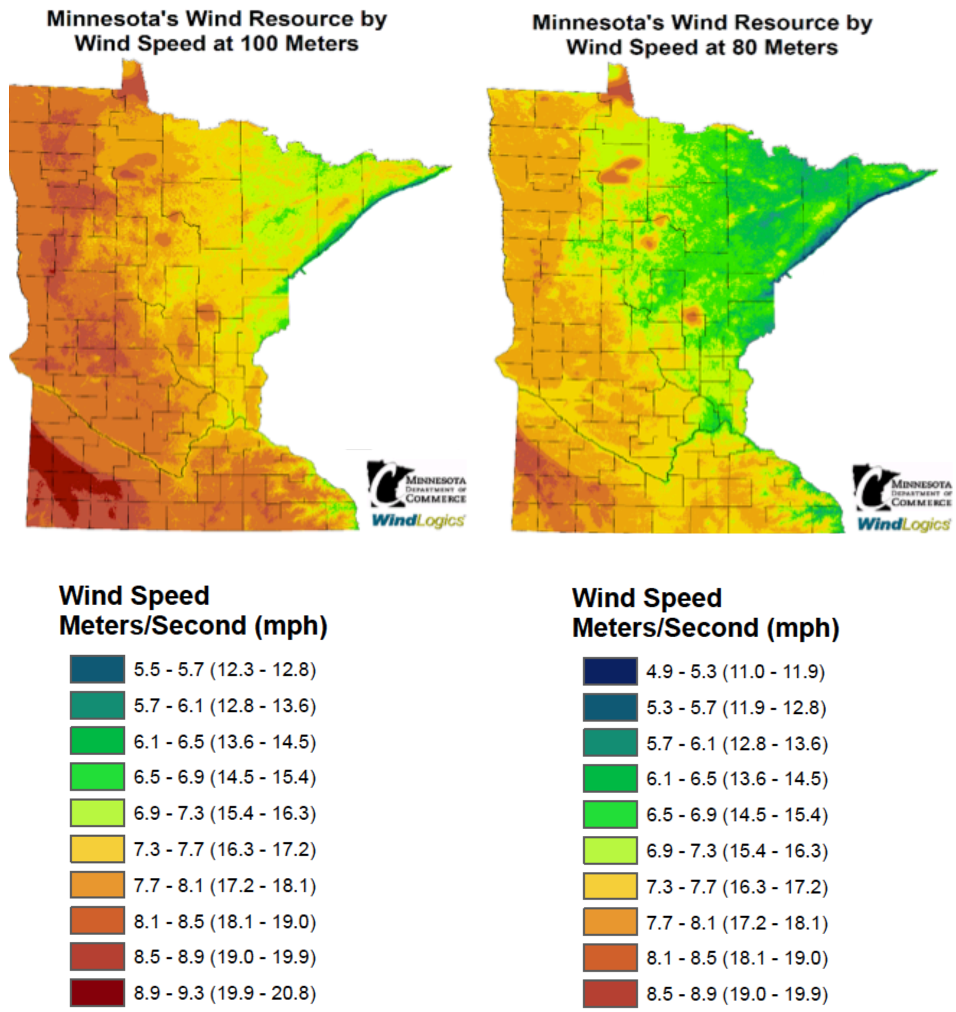
Minnesota is endowed with ample wind and solar energy resources, and has developed a strong public policy foundation to support development of these resources. In 1994 the state enacted a ban against the construction of new nuclear power facilities as a result of concerns with how to manage the state's nuclear waste. By removing the costly and time-intensive nuclear option from consideration for future electricity supply, regulators and utilities in Minnesota have been able to invest resources into expanding the use of renewable energy and energy efficiency technology in order to meet demand.

Subsequently, in 2007 the legislature enacted the country's strongest, at the time, Renewable Energy Standard (RES), requiring 25% of the state's electricity to come from renewable resources by 2050 (30% by 2020 for Xcel Energy). Additionally, the state set a goal of reducing greenhouse gas emissions 80% from 2005 levels by 2050.

The electricity sector has been a leading source of emissions, and has been the only sector to continually increase its emissions over the past 40 years. Given the difficulties in significant greenhouse gas (GHG) reductions from agriculture and transportation, it will require an almost complete elimination of emissions from the electricity sector in order to achieve the state's 80% GHG reduction goal.

FIGURE 1

Minnesota's wind resource at 100 meters and 80 meters above the ground.



Source: Minnesota Department of Commerce

Methodology

As the starting point for determining how much renewable energy generation would be needed for Minnesota to have a fully renewable electricity system, we gathered hourly electricity demand data from 2007 for Xcel Energy, the state's largest electricity provider.[2] We applied the same central reliability criterion that utilities use today – maintaining a capacity available at 12% above demand for each hour of the year. We used the best available industry data for costs and output of various renewable energy technologies. This approach limited the potential for error that comes from a more complex and resource intensive forecast model, while also providing a reasonable analysis of the feasibility of a fully renewable electricity system. We assume that the composition of renewable energy generation is a mix of commercial-scale wind energy and rooftop solar PV, due to economies of scale and the most likely application of each technology in Minnesota.

Wind energy potential

Figure 1 shows the average wind speeds in Minnesota at 80- and 100-meters above the ground. For estimating the hourly production of electricity from wind turbines in Minnesota, we used the outputs generated by the U.S. Department of Energy's Eastern Wind Integration and Transmission Study (EWITS). The EWIT study evaluated and computed the outputs for 121 sites in Minnesota for the years 2004, 2005, and 2006, identifying a total of almost 61.5 gigawatts (GW) of annual wind capacity potential across the state. We chose the data just for 2006 as representative for a typical year for our study, and did not take into account variations between years.

In reality, it is unlikely that the full potential at each site identified will be developed due to various economic and social reasons, so we assume that the installed capacity at each of these 121 sites is 5 percent of that site's maximum potential. We were able to vary this percentage in a basic attempt to optimize the overall system costs.

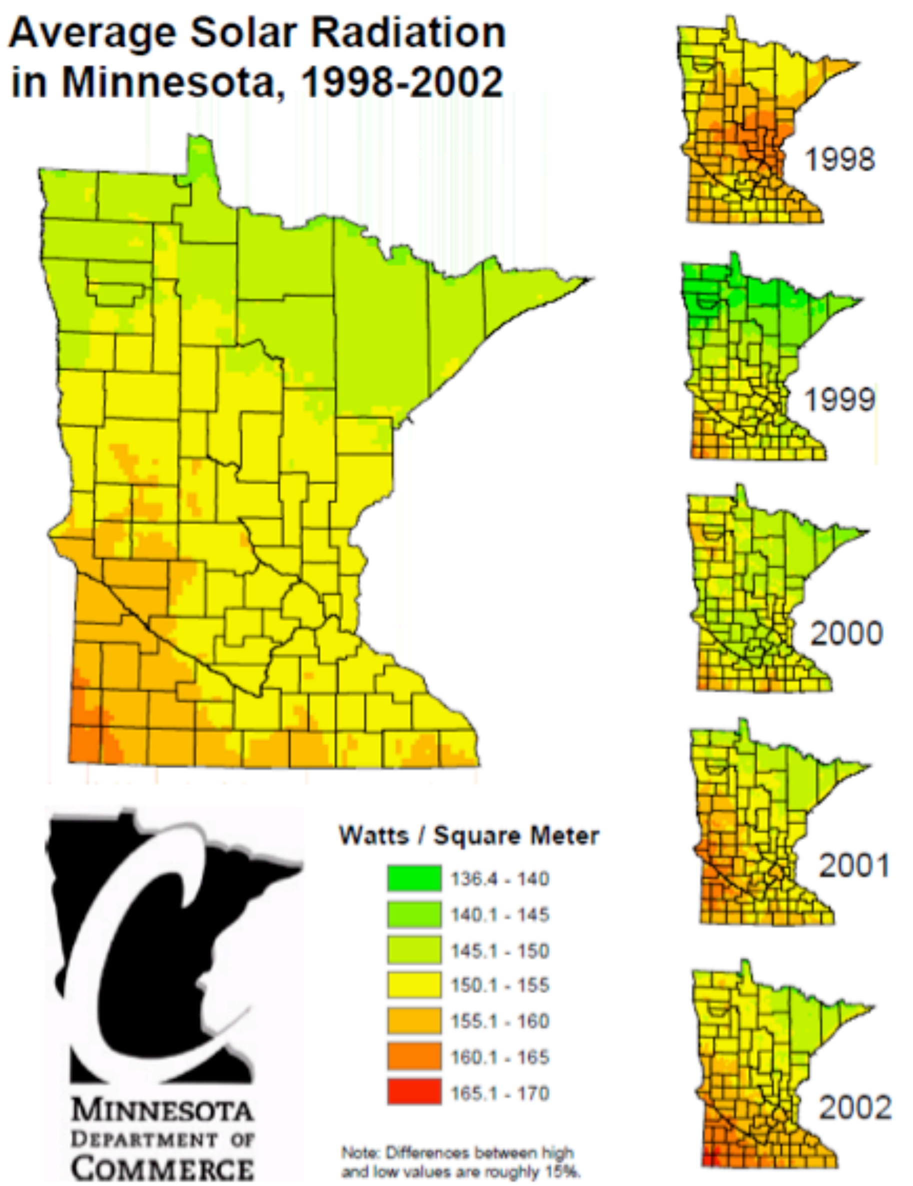
Solar energy potential

We focus on distributed solar photovoltaic (solar PV) technology as the most likely application of solar electricity technology for Minnesota because it would not compete for agricultural land, a primary use of land in rural Minnesota. Because solar PV is ideal for rooftop installations, there are many potential locations for solar energy generation. In fact, the Institute for Local Self-Reliance estimated that 24 percent of the state's electricity demand could be met with rooftop solar alone, not including solar installations over surface parking lots, or ground mounted solar.

We used the estimates of solar electricity generation from the National Renewable Energy Laboratory's National Solar Radiation Database. For each hour of the year, the database gives diffuse, direct, and total (global) irradiance at various locations around the country,[3] modeled from observed cloud cover, light spectrum, and site elevation. From this data, one can infer how much electricity can be generated at a given site, taking into account assumptions about the PV panel's orientation and efficiency.

For Minnesota, NREL has data from 54 sites across the state for specific years, and also for what it calls a "Typical Meteorological Year" which is what we chose for our calculations. Unlike the EWIT study, these 54 locations are not chosen for their generation potential. Since we do not try to optimize the locations of solar PV installations because it is expected that most PV generation in Minnesota would be on rooftops across the state, it is more representative of actual installations to consider data from a wide variety of locations. As shown in Figure 2, all portions of the state receive some measurable solar radiation throughout the year.

FIGURE 2



Source: Minnesota Department of Commerce

Energy storage

The storage technology that we used in our analysis is compressed air energy storage (CAES), which has a proven track record and has been used commercially for decades with coal-fired power plants in Germany and Alabama. Minnesota does have geology that may be suitable for CAES at many locations; however, more research is needed to identify specific sites. Using a single storage technology in our analysis allowed a straightforward determination of technical feasibility as well as cost, however in practice a mix of storage technologies, as well as demand dispatch, should be used. Efficiency measures can also be shaped to reduce storage requirements. Figure 3, on the following page, illustrates the main components of a CAES system.

A note about variable generation, a.k.a. intermittency

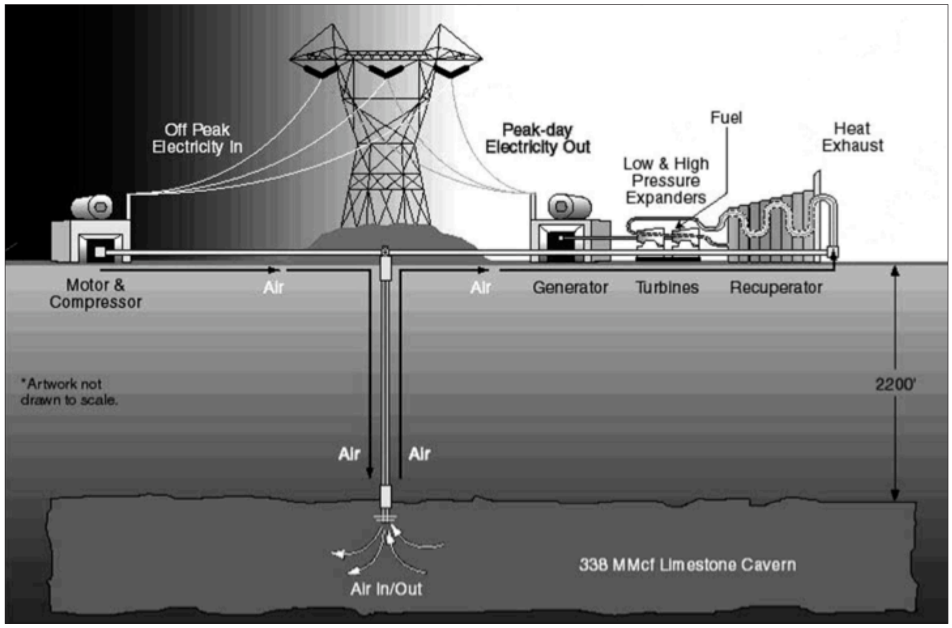
It is incorrect to assume that solar and wind energy cannot be the mainstay of an electricity generation system because they are intermittent. Intermittency can be dealt with in a number of ways such as energy storage and using combined heat and power to greatly reduce air-conditioning peaks.

Utilities already have ample experience managing variability in electricity demand. Because demand and supply have to be balanced at all times, using variable energy sources like wind and solar requires either the use of other forms of generation that can be ramped up relatively fast (to make up for fluctuations in the outputs of wind and solar power) or the use of storage so that excess generation during periods of high wind or solar insolation could be used later. We focus on the use of storage to balance this variability in order to show the feasibility of 100% renewable energy using technologies that are available today.

Further, wind turbines can now be equipped to receive and respond to dispatch signals every five minutes from the grid operator, making wind a dispatchable resource even though it is intermittent. In fact wind has officially been accepted as a dispatchable intermittent resource by the Federal Energy Regulatory Commission for the Midwest grid.[4]

FIGURE 3

Main elements of a Compressed Air Energy Storage system.



Source: Sandia National Laboratory

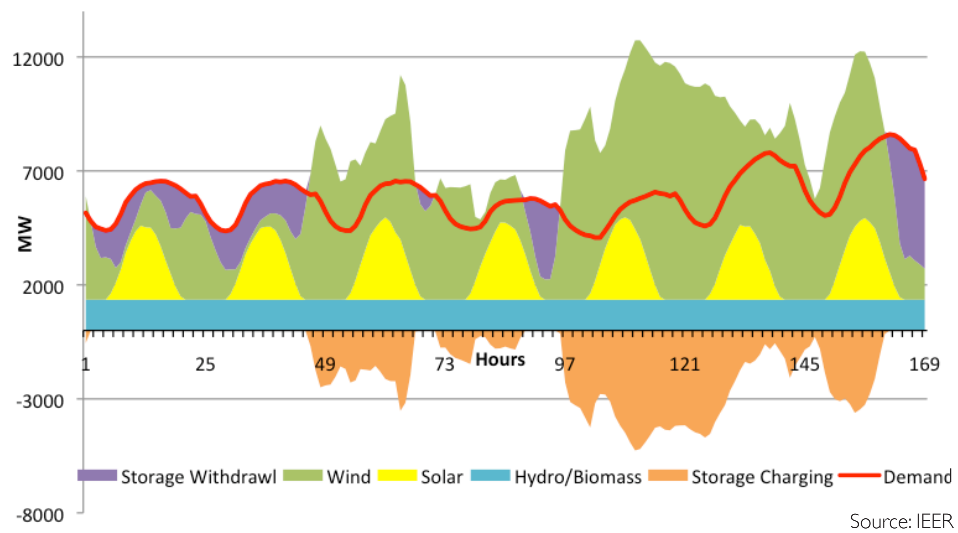
Findings

Figure 4 shows how a 100% renewable electricity system could supply actual electricity demand during a week in July 2007. The red line undulating across the middle of the graph indicates hourly electricity demand, which is constantly changing.

We found that Xcel Energy, in order to meet its annual hourly demand from 2007, would need to have roughly 12,300 megawatts (MW) of wind energy and 4,600 MW of solar energy connected to its system, combined with storage capabilities, existing hydropower purchases, and increasing in-state small hydropower and sustainable biomass.

FIGURE 4

Hourly supply and demand, with storage. July 11-17, 2007



Source: IEER

Combining the wind and solar estimates with the hourly demand for Xcel Energy gave us the amount of storage capacity required to provide 100% renewable electricity. (The shaded areas below the X-axis in Figure 4 represent the excess renewable generation that is put into storage.) Without modifying the demand of electricity, we determined there would be 55 hours of the year where the maximum amount of storage capacity would be needed, on the order of 5,000-7,000 MW of expander capacity for a CAES system. Accommodating these 55 hours of demand comes at great cost. Figure 5, on the following page shows that an additional 1,000 MW of storage capacity above 5,000 MW costs $1,126 per megawatt-hour (MWh), or $849/MWh more than the cost to provide 4,000-5,000 MW of storage capacity.

The use of this highest amount of storage capacity, from 5,000-7,000 MW, occurs generally at the end of the day during summer, though not every summer day, and when demand is relatively high but the percentage of solar and wind generation is low. These 55 hours may be regarded as the relational peaks in the system for the year that is modeled here and account for less than one percent of the year. (Actually, the top 1,000 MW of capacity (the 6,000 to 7,000 MW block) is used for just 9 hours in the year!)

Efficiency standards play an important role

The benefit we gain from electricity is not from the electrons, but from the things they power. We considered the impact that efficiency standards for appliances and buildings could have on reducing electricity demand and improving the overall economics of the electricity system without affecting lifestyles – in other words, the same output, such as lighting or cooling, is achieved but with less energy. Further, efficiency standards for buildings and appliances are the best way to overcome the so-called split incentive in buildings, whereby builders and landlords have little incentive to invest in energy efficiency improvements because they do not pay the utility bills.

The role of energy efficiency and demand dispatch

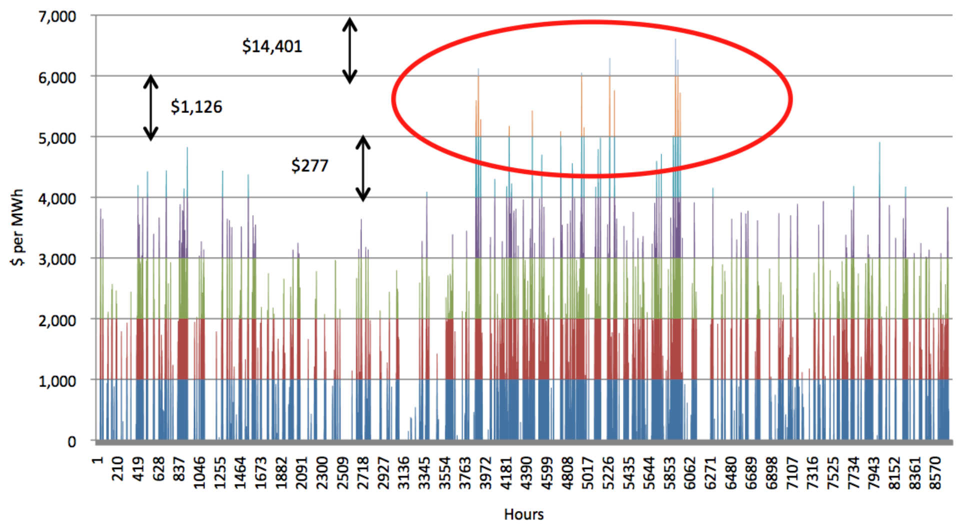
Meeting a large fraction of the growth of electricity demand with efficiency is economically preferable to solely relying on the state's ample renewable energy resources. When no attempt is made to reduce electricity demand or make demand more flexible, a fully renewable system results in a large amount of spilled energy. This is the equivalent of a large amount of capacity standing idle for much of the year, which occurs in the system we have today. The average capacity factor in 2010 for all Minnesota electric generation was about 42 percent.[5] The state's natural gas capacity was used even less, with a capacity factor of 9.4 percent, and the petroleum capacity factor was even lower at about 0.4 percent. These numbers clearly show that even the current system can be used more efficiently with targeted energy efficiency improvements coordinated with demand dispatch.[6]

The most flexible and economical way to structure a renewable system is to optimize generation, storage, efficiency, combined heat and power (CHP) capacity, and demand dispatch together. Among these five elements, demand dispatch, if available on a large enough scale (i.e., aggregated over a large enough number of residential, commercial, and industrial customers) can provide the greatest flexibility to a renewable system. Two demand dispatch elements already provide significant flexibility – air-conditioner cycling

FIGURE 5

The generation required from electricity storage, CAES in this case, as calculated for Xcel Energy customers in 2007 by IEER.

Note the circle indicates the highest capacity needs which only occur 55 hours of the year. The costs given are the capital costs in dollars per megawatt-hour for the expander capacity needed to supply the given level of generation from storage.



and interruptible industrial loads.[7] But demand dispatch can and should become much more varied – including appliances such as dishwashers, clothes washers, the timing of the operation of the defrost cycle in residential or commercial freezers, and even water and space heating systems.

How much will it cost?

If combined with a high level of energy efficiency, this 100% renewable electricity can be provided at an economical cost to ratepayers.

First, we estimated the overall costs per unit of supply – renewable generation plus storage, including the spare capacity needed to fulfill reliability requirements. Then we looked at what impact reducing electricity demand through broad energy efficiency improvements would have on rates paid by customers in a fully renewable system. We estimated the costs of generation using unsubsidized levelized costs for each new power plant built, which incorporates the cost of building and operating a generating facility over its lifetime including fuel, operations, and maintenance costs. Because the costs are adjusted for inflation, and because no loan guarantees, production tax credits, or investment tax credits are taken into account in our analysis, we can provide an "apples-to-apples" comparison of energy generation costs.

The overall cost difference when efficiency improvements are taken into account is about $6 to $7 per household per month - before reducing spilled energy and relational system peaks.[8] It is essential to note the difference between rates per kilowatt-hour (kWh) and total bill in this context. In a medium efficiency case, the electricity bill for the generation supplied will be moderately higher than at present and there will be a modest additional cost for efficiency upgrades. In a high efficiency case, the electricity bills for supply would actually be lower by more than $150 per year, but the energy efficiency improvements will require an upfront investment that more or less balances out the savings.

Table 1 on the following page shows the costs of a fully renewable electricity sector for three cases: a base case with no added efficiency investments, the medium efficiency case, and the high efficiency case.

TABLE 1

Residential cost comparison with full renewable system at various levels of efficiency in Minnesota.

(Calculations are based on residential data for 2010 found in the 2010 Minnesota Profile on the Energy Information Administration website http://www.eia.gov/electricity/state/minnesota/)

	Base case	Efficiency Case 1	Efficiency Case 2
Level of efficiency	No efficiency change	Medium efficiency (33%)	High efficiency (additional 17%)
Cost, $/MWh	$176 for generation	$30	$100
Average cost of electricity services $/MWh at different efficiency levels	$176	$128	$115
Annual services supplied by generation, MWh	8.68	5.82	4.34
Annual services supplied by efficiency, MWh	0	2.86	4.34
Annual electric bill for generation	$1,529	$1,024	$764
Annual cost of efficiency	$0	$86	$234
Total annual cost for residential electricity services	$1,529	$1,110	$998
2010 cost	$920	$920	$920
Annual cost difference	$609	$190	$78

MINNESOTA FROM PAGE 12

Conclusion and recommendations

One reason to increase renewables in the electricity sector is to provide a hedge against volatile fossil fuel prices and to provide a lower financial risk for investors. Another reason is that renewable energy-based electricity provides a better product to society. The electrons speeding through the wires of the grid are the same, but the social, health, and safety consequences are far different. People will literally breathe easier, water use will be lower, and there will be reduced risks related to carbon dioxide emissions.

While we have done the modeling for the demand of a single year (2007), realizing a fully renewable electricity sector will take 25 to 40 years, depending on policies, technology costs, and evolution of storage and demand dispatch technologies. Costs of renewable energy technologies are expected to decline substantially, especially costs of solar PV.

In order for Minnesota to economically achieve its goal of 80 percent reduction in greenhouse gas emissions, it will take an almost complete elimination of such emissions from the electricity sector. Thus, policy makers should set an official state policy of achieving a 100 percent renewable energy-based and efficient electricity system by 2050.

Minnesota policy makers should also commission a more detailed model of the state's electricity sector that would include analysis of energy efficiency potential in the state, and the roles of combined heat and power and demand dispatch. More research is also needed to identify the potential for compressed air or hydropower storage sites across the state, and ways in which various levels, types, and scales of storage could be joined to generation, efficiency, combined heat and power, and demand dispatch to reduce spilled energy and total system costs.

Endnotes

1. The report can be downloaded from http://ieer.org/resource/reports/renewable-minnesota-technical/

2. We chose the year 2007 as a representative of more typical energy use patterns, since it was the last year before the Great Recession.

3. Direct solar irradiance is the measure of the rate of solar energy arriving at the Earth's surface from the sun's direct beam, on a plane perpendicular to the beam. Diffuse solar irradiance is a measure of the rate of solar energy arriving on a horizontal plane at the Earth's surface from scattering of the sun's beam. Global solar irradiance is the total measure of incoming solar energy, both direct and diffuse, on a horizontal plane on the earth's surface.

4. United States. Federal Energy Regulatory Commission. Order Conditionally Accepting In Part and Rejecting In Part Tariff Filing and Requiring Compliance Filings. Midwest Independent Transmission System Operator, Inc. Docket No. ER11-1991-000. (134 FERC ¶ 61,141) [Washington, DC]: FERC, issued February 28, 2011.

5. Meaning that the fleet generated 42% of the maximum total possible electricity it could have generated, i.e. if the fleet had been operating 24 hours a day, 365 days a year.

6. Demand dispatch is when a sufficient amount of demand that can be un-met by the utility, usually through customer agreements, is aggregated and becomes a resource for the grid. Instead of increasing supply to meet demand, it allows grid operators to reduce demand to match the supply.

7. It is common for high-demand industrial customers to agree to interruptible power in exchange for lower electricity rates – i.e., in an emergency, the utility can cut off their power supply.

8. We used national estimates for energy savings and costs of various energy efficiency measures.

Dear Arjun

Dear Arjun,

Do solar PV systems really cost far more in the United States than in Germany? Why?

— Stumped in Stuttgart

Dear Stumped,

Spending more to save more is a well-established market principle in the United States. "Buy more to save more!" But sadly in the case of solar PV, we are not buying more. Just spending more and saving less.

It's true: Solar PV systems, especially small and medium scale ones, do cost much more in the United States. Figure 1 shows the German cost of solar PV per watt since 2006 and Figure 2 (following page) shows similar data for the United States.

While the charts are not exactly comparable, we can reasonably compare the combined range for residential and non-residential systems in the U.S. chart to the German chart of PV systems of less than 100 kilowatts (small and medium systems). The average German price at the end of the first quarter of 2012 was about $2.50 per watt (using an exchange rate of $1.30 = 1 euro). The average U.S. price was about $5 per watt – $4.63 per watt for non-residential systems and $5.89 per watt for residential systems, which are typically smaller than non-residential ones. These prices exclude taxes and subsidies. Figure 1 shows that the German price has declined about 10 percent since then.

So an apples-to-apples comparison says that the U.S. price of installed PV for the residential and commercial sector (that is, excluding large utility scale systems of several megawatts and larger) is about double that of Germany. DOUBLE!

The reasons are not clear, but here are some possible elements of the cost differences:

• There are far more solar installations in Germany, so solar installers don't have to spend a lot of time travelling to and from jobs. They are typically close by. To give you an idea, Germany, which has one-fourth the U.S. population, installed about 7,500 megawatts of solar PV last year while the U.S. installed 1,700 megawatts. And the rate of German installations seems to be increasing. Germany installed about 3,000 megawatts of solar in December 2011 alone.

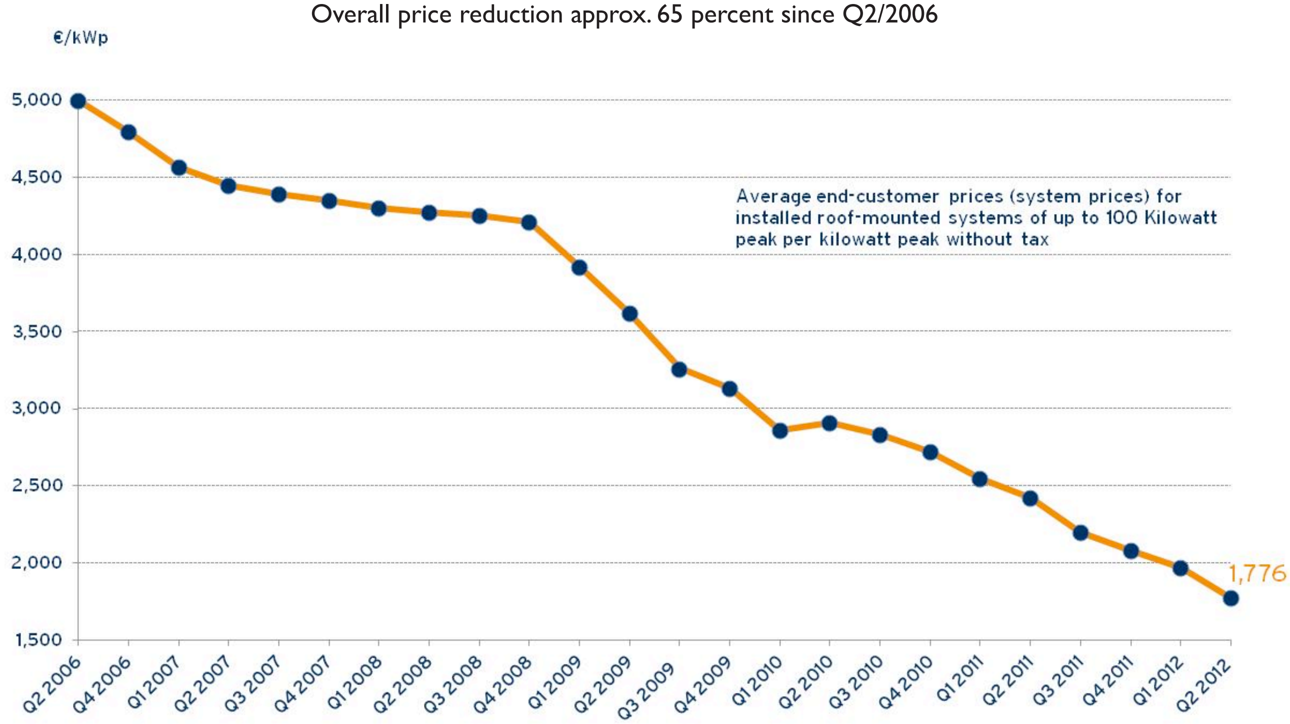
SEE **DEAR ARJUN** ON PAGE 15

FIGURE 1

German Solar PV system prices, no taxes and no subsidies included

PV system prices decrease steadily

Overall price reduction approx. 65 percent since Q2/2006



Source: German Solar Industry Association (BSW-Solar), April 2012.
Most recent updates are on the Web at www.solarwirtschaft.de/fileadmin/media/pdf/BSW_facts_solarpower_en.pdf

Dear Arjun, *continued*

The far larger number of installations in Germany may also mean more competition in the solar industry compared to the United States. Population density does not appear to be a factor since prices are higher even in the densely populated parts of the United States.

• The German structure of pricing and recovery is straightforward. There is a feed-in tariff, which is the price you get when you sell the solar electricity to the utility. That's it. This transfers funds from some ratepayers to others, with the amount depending on the difference between the feed-in tariff and the electricity rate. Feed-in tariffs have been reduced as prices of solar PV have declined. Since the utility is required by law to give that price, the prospective purchaser can easily compute whether the system is profitable; so can the bank that would provide the loan. Moreover, it is a low risk loan since the revenue stream is guaranteed.

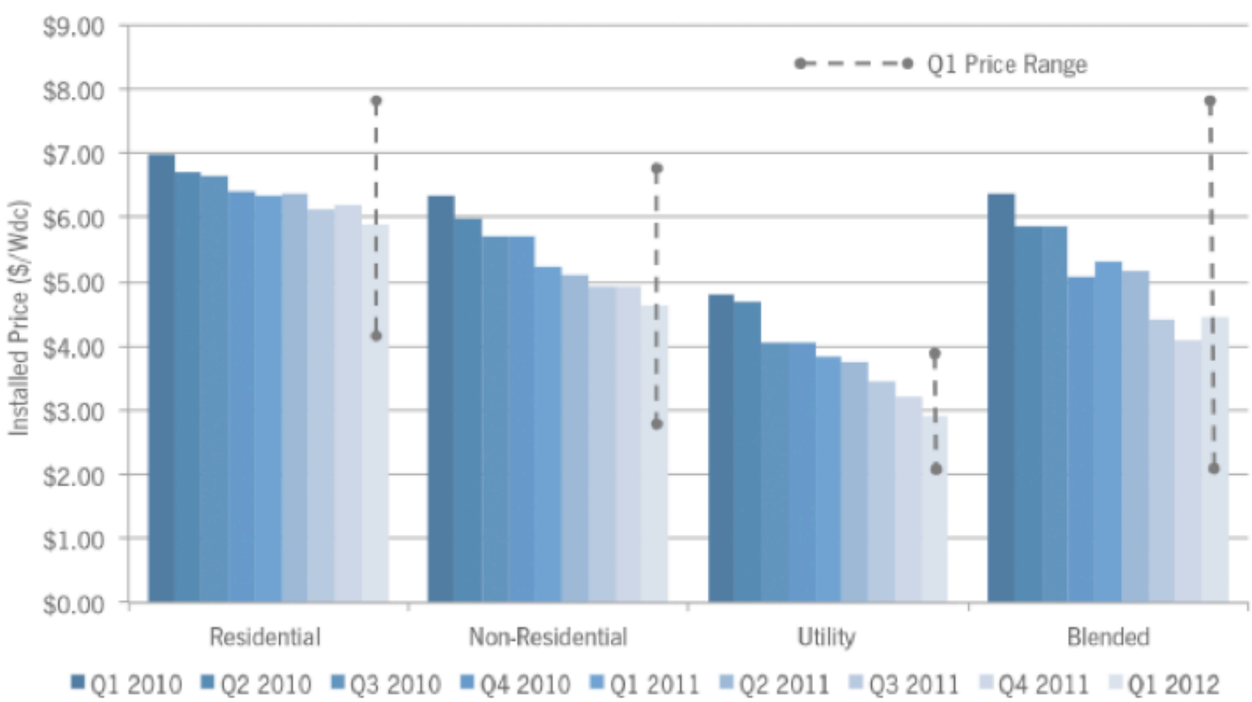
• Since there is only a feed-in tariff in Germany rather than a variety of tax breaks, rebates, and energy credits, at both the federal and individual state level like in the United States, there is much less paperwork and less overhead.

But even with all these factors, I am puzzled. There should not be a factor of two difference between the U.S. and German price. It would take a more detailed investigation of the costs of the various parts of the solar PV system to tease out the answer. We also need to understand whether the structure of U.S. subsidies allows the installers to charge a higher price compared to a situation where there is no government subsidy at all. The German feed-in tariff is a structure in which private residential electricity ratepayers subsidize those who are installing solar PV. The government is not involved in it, other than in creating the legal framework.

One thing is clear – whatever the causes of the lower price in Germany, the U.S. should aim to get the price down to the German level. It should also get on the same declining cost curve. At that level, residential and commercial solar PV would pay for itself in several areas of the country, such as New York and California, even without subsidies. With the federal investment tax credit of 30 percent, the number of places where no state or local subsidies would be needed would be even larger. In effect, subsidies can be decreased and the scale of solar PV installations can be greatly increased in the United States if we can figure out the price difference puzzle and get on a lower cost curve.

FIGURE 2

National weighted average prices, installed solar PV per watt, United States, no taxes and no subsidies included. Dashed lines show the price range for the first quarter of 2012.



Source: Solar Energy Industries Association and GTM Research. U.S. Solar Market Insight, Report, Q1 2012, Executive Summary. Washington, DC: SEIA, 2012. Page 7. On the Web at www.seia.org/galleries/pdf/USSMI-Q1-2012-ES.pdf.

New and improved: www.ieer.org

In honor of IEER's 25th anniversary, the IEER web site has gotten a makeover! We hope you find it even more welcoming and easier to navigate. Some of the new features:

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