INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH

Renewable Energy States Factsheet: MN

RENEWABLE MINNESOTA: A TECHNICAL AND ECONOMIC ANALYSIS OF A 100% RENEWABLE-ENERGY BASED ELECTRICITY SYSTEM FOR MINNESOTA

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 factsheet, looks 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.[i]

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.

Then, in 2007, the legislature enacted what was at the time the country's strongest Renewable Energy Standard (RES), requiring 25% of the state's electricity to come from renewable resources by 2025 (30% by 2020 for Xcel Energy, the state's largest electric utility). Additionally, the state set a goal of reducing greenhouse gas emissions 80% across all sectors from 2005 levels by 2050.

As seen in Figure 1, the electricity sector has been a leading source of emissions, continuing to increase its emissions over the past 40 years. A significant reduction in electricity sector emissions is necessary if the state is to achieve any success in meeting its greenhouse gas reduction goals.

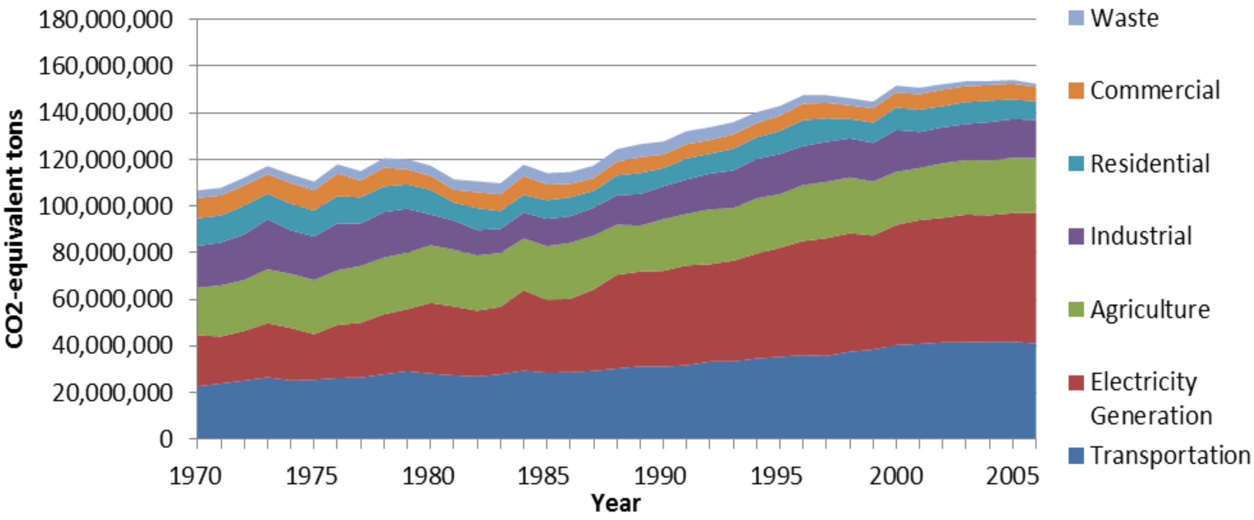

Figure 1: Total greenhouse gas emissions in MN by sector, 1970-2006. Source: IEER. Data source: Ciborowski and Claflin 2009 pp. 138-142

METHODOLOGY

As the starting point we gathered hourly electricity demand data from 2007 for Xcel Energy, the state's largest electricity provider.[ii] We then calculated the in-state renewable energy potential using estimates from the National Renewable Energy Laboratory and the U.S. Department of Energy, and used the best available industry data for costs and output of various renewable energy technologies. This approach limits the potential for error that comes from a more complex and resource intensive forecast model, while also providing a reasonable analysis of the technical 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 distributed solar PV; these are the most likely application of each technology in Minnesota, given the quality of the resources and the economics.

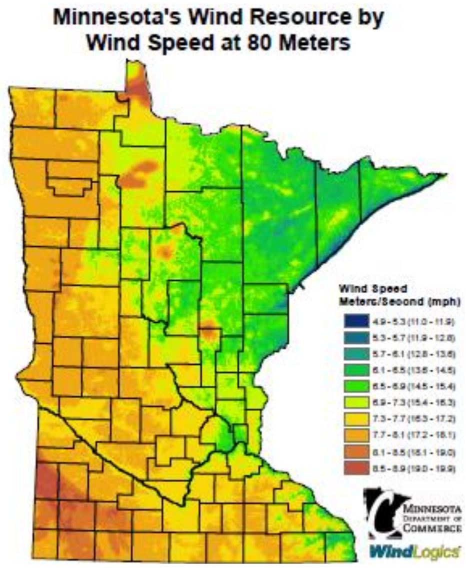

Figure 2: Minnesota's wind resource at 80 meters above the ground. Source: MN DOC 2006

There is ample wind energy resource in Minnesota. Recent estimates from the National Renewable Energy Laboratory indicate that wind energy alone could provide 25 times the state's annual electricity demand.[iii] Figure 2 shows the average wind speeds in Minnesota at 80 meters above the ground, with significant wind potential in the southwestern portions of the state, though all regions of the state have some site-specific wind energy potential that are not reflected in a general map. Similarly, all portions of the state receive some measurable solar radiation throughout the year as shown in Figure 3. 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 and because solar PV is ideal for rooftop installations.

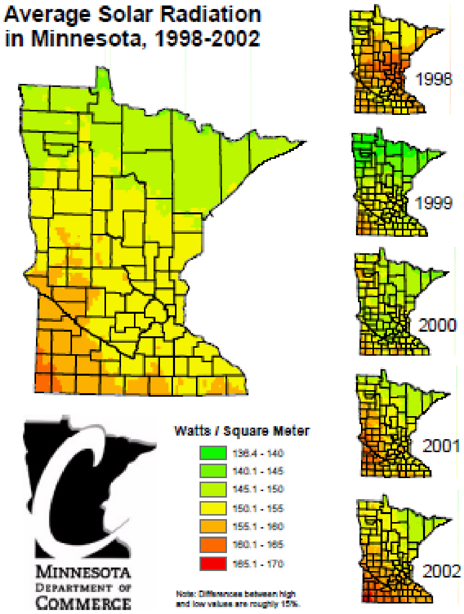

Figure 3 : Average solar radiation in Minnesota 1998-2002. Source: MN DOC 2004

MAIN FINDINGS

A renewable energy-based electricity sector is technically feasible, using available and proven technologies. The costs to implement a fully renewable electricity sector can be reduced, if it is implemented in the context of an intelligent grid. This includes two-way communication between producers and consumers, and distributed storage. 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, while the shaded areas below the x-axis represent the excess renewable generation that is put into storage.

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.

There are ample renewable resources in Minnesota. There is more than enough wind and solar energy potential to meet the entire 2007 demand of Xcel Energy's customers every hour and to accommodate growth in the foreseeable future. These technologies are already commercially available. While we have not examined the subject in detail here, there is evidence that the requisite amount of utility-scale storage technology can also be installed within the state. 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.

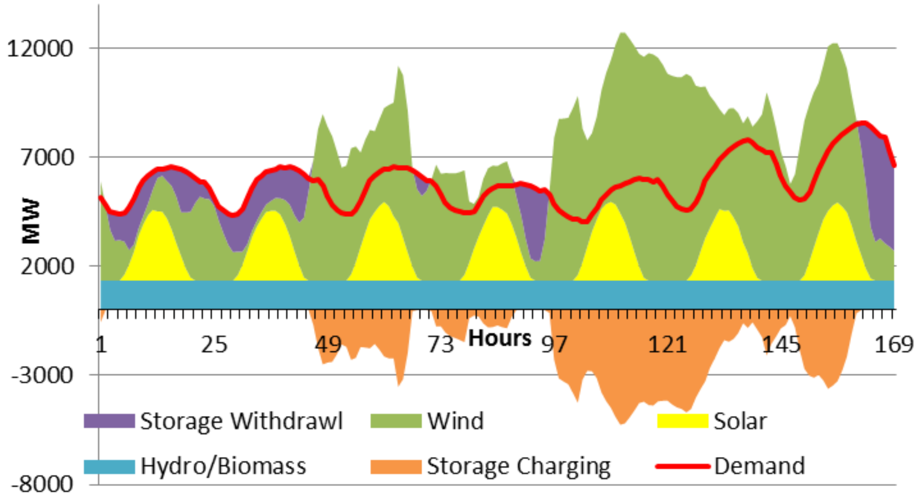

Figure 4: Hourly supply and demand, with storage. July 11-17, 2007. Source: IEER.

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

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 5.

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

PIONEERING A RENEWABLE GRID: DEALING WITH THE "RELATIONAL SYSTEM PEAK"

A principal insight that emerges from this study is that the conventional notion of a "peak load" needs to be replaced in designing an electricity system with a high proportion of solar and wind energy. At present the system peak is determined entirely by consumers – it is the time of highest simultaneous load on the system. In a renewable energy system with storage, depending on how it is configured, it is entirely possible that there may be plentiful electricity generated at such times of high demand. The crunch time may be during periods when the wind and solar supply are low relative to demand. So it is possible for a system "peak" – i.e., maximum use of generation from stored energy – to occur when demand is not at its highest. Indeed, this will often be the case. We have called this phenomenon the "relational system peak." Instead of the peak load that drives marginal investments in generation as at present, dealing with the relational system peak will require comprehensive consideration of investments throughout the system – generation, demand, efficiency, and storage.

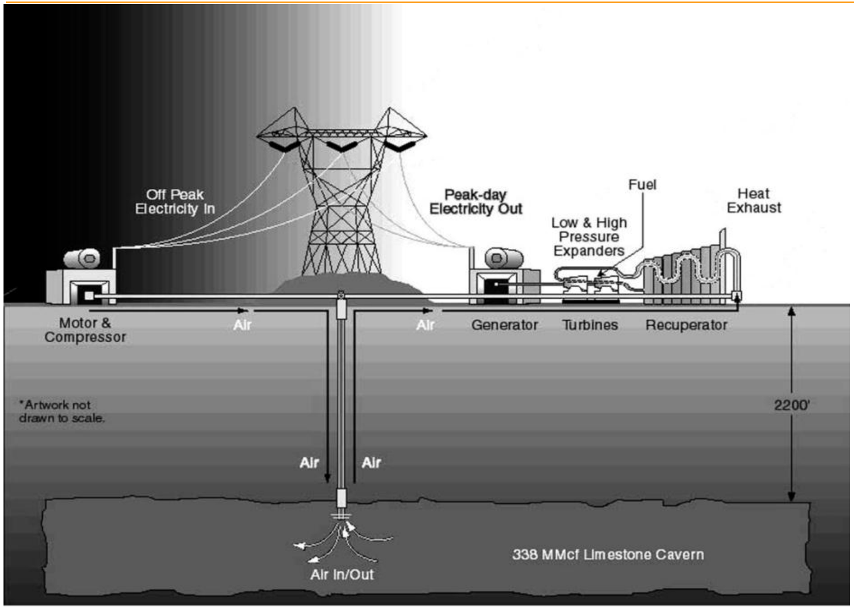

Figure 5: Main elements of a Compressed Air Energy Storage (CAES) system. Source: Sandia National Laboratory (Sandia 2001).

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.

Energy Storage will play a role in a fully renewable electricity sector. 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. Without modifying the demand pattern of electricity, we determined there would be 55 hours of the year where the maximum amount of storage capacity (5,000-7,000 MW expander capacity of a CAES system) would be needed. Accommodating these 55 hours of demand comes at great cost. Table 1 shows the incremental costs of each 1,000MW of additional storage capacity above 5,000MW.

The use of this highest amount of storage capacity 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.

An efficient, renewable electricity system can be achieved at an overall cost comparable to the present total cost. The added costs of renewable energy generation, as compared to the current generation from mature and fully-depreciated fossil fuel and nuclear generation facilities, can be offset by increasing the energy efficiency of household and building appliances. The net total costs of electricity services – lighting, cooling, running appliances, etc., would be about the same as today, but partitioned between generation, storage, efficiency, and transmission and distribution.

The costs of this system were estimated by calculating the levelized costs of each generation and storage technology needed to meet demand and 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

Table 1: The capital cost of electricity generation from storage (CAES in this case) for each 1,000 MW segment of storage capacity. The highest costs, highlighted, are associated with the need to have storage capacity from 5,000-7,000 MW, which is only needed 55 hours per year.

Generation segment (MW)	Hours segment is used	Avg. segment generation, MW	Total segment generation, MWh	Expander capital cost, $/MWh
0-1000	3,661	871	3,187,712	8
1000-2000	2,711	797	2,160,519	12
2000-3000	1,581	680	1,074,551	24
3000-4000	631	558	352,378	72
4000-5000	159	578	91,965	277
5000-6000	46	492	22,623	1,126
6000-7000	9	196	1,768	14,401

fully renewable system. 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. And overall bills would also decrease as the costs of renewable energy technology decrease over time. Compare the amounts in Table 2 which show the costs of the system at two different technology costs. At a high level of energy efficiency the total bills would actually be lower, but the initial upfront investment would balance out these savings until they are paid off.

Table 1: Cost estimates comparing $1,500 and $2,000 per kW for wind with a 20 year lifetime and solar PV with a 30 year lifetime

Level of efficiency	No efficiency change		Medium efficiency (33%)		High efficiency (additional 17%)	
Cost of solar and wind, $/kW	$2,000	$1,500	$2,000	$1,500	$2,000	$1,500
Cost, $/MWh	$176	$154	$30	$30	$100	$100
Average cost of electricity services $/MWh at different efficiency levels	$176	$154	$128	$113	$115	$104
Annual services supplied by generation, MWh	8.68	8.68	5.82	5.82	4.34	4.34
Annual services supplied by efficiency, MWh	0	0	2.86	2.86	4.34	4.34
Annual elec. bill for generation	$1,529	$1,336	$1,024	$895	$764	$668
Annual cost of efficiency	$0	$0	$86	$86	$234	$234
Total annual cost for residential electricity services	$1,529	$1,336	$1,110	$981	$998	$901
2010 cost	$920	$920	$920	$920	$920	$920
Annual cost difference	$609	$416	$190	$61	$78	($19)

Energy efficiency lowers the effective cost of electricity services and electricity bills. There are ample opportunities for reducing electricity use while maintaining the same level of services such as lighting and cooling and running computers. For instance, a more efficient refrigerator or air conditioner would provide the same level of cooling, but would use less electricity to do so. But the investment in the refrigerator would be a little more compared to an average model. Appliance and building energy standards, supplemented by utility programs, are an effective way to have high penetration of energy efficiency measures and achieve cost savings.

We do not assume any changes in lifestyles – rather we looked at the potential for energy efficiency savings from standards on various appliances. A 2008 study by the American Physical Society found that on average 30% of residential electricity use can be eliminated by increasing the efficiency of various appliances. We used these estimates since Minnesota’s cost of electricity is slightly higher than the national average, and therefore the examples in Figure 6 would be cost effective for Minnesota residential ratepayers.

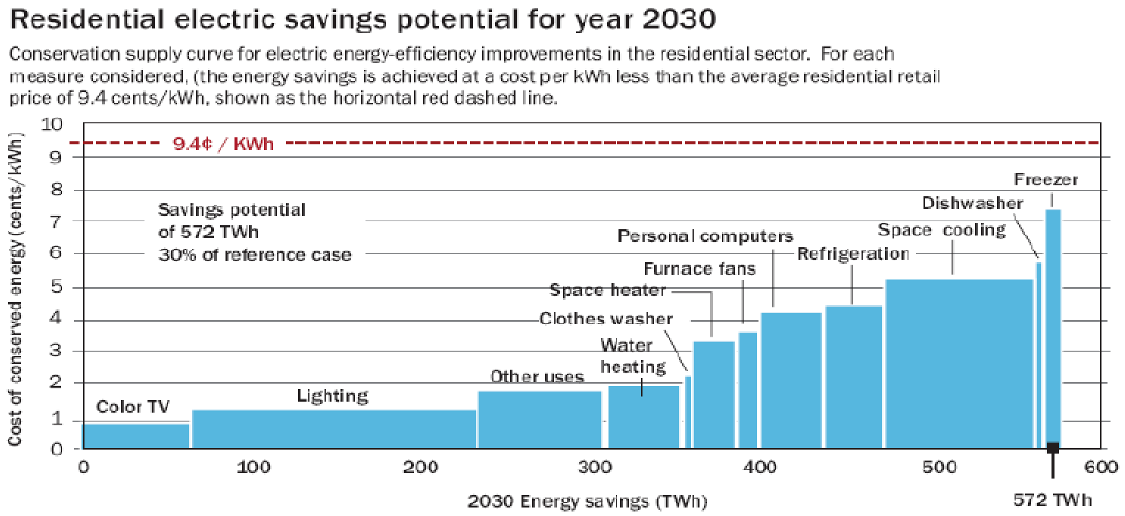

Figure 6: Supply curve for residential electricity efficiency improvements. Source: APS 2008 Figure 25 (p. 76). Used with permission, from the American Physical Society's report: "Energy Future, Think Efficiency" (2008)

RECOMMENDATIONS

In order for Minnesota to achieve any significant reduction in greenhouse gas emissions, dramatic changes to the electricity sector are necessary. We have identified a number of steps that can help position Minnesota to utilize its available renewable energy resources, as well as create a more informed technical and cost framework for transitioning to a renewable energy-based electricity sector:

- Initiate a detailed, state-wide energy efficiency study, including the technical and economic aspects and the effect of efficiency and demand dispatch investments on the electricity demand pattern and on relational system peaks.
- Require utilities to include increased renewable energy and storage in their Integrated Resource Plans by modeling what it would take to meet their projected demand with only renewable energy resources and the steps, time, and investment it would take to accomplish that goal.
- Initiate a study that would address how demand dispatch, storage, specific efficiency measures, and combined heat and power could be combined to reduce the costs of a fully renewable electricity system.
- Initiate a detailed exploration of the feasibility of CAES and other utility-scale storage options in Minnesota.
- Further refine the findings in this report by developing an optimized framework for reducing the relational system peak in a fully renewable electricity sector.
- Conduct similar studies at the regional level in cooperation with other Midwestern states.
- Adopt a state-wide goal for achieving a 100 percent renewable energy standard, with achievable benchmarks and milestones and a periodic review of progress every few years.

For further information contact:
Christina Mills
IEER Staff Scientist / Policy Analyst
christina@ieer.org
612-722-9700

Notes:
[i] The report can be downloaded from http://ieer.org/resource/reports/renewable-minnesota-technical/
[ii] We chose the year 2007 as a representative of more typical energy use patterns, since it was the last year before the Great Recession.
[iii] http://www.awea.org/learnabout/publications/upload/Minnesota.pdf