Renewable Minnesota

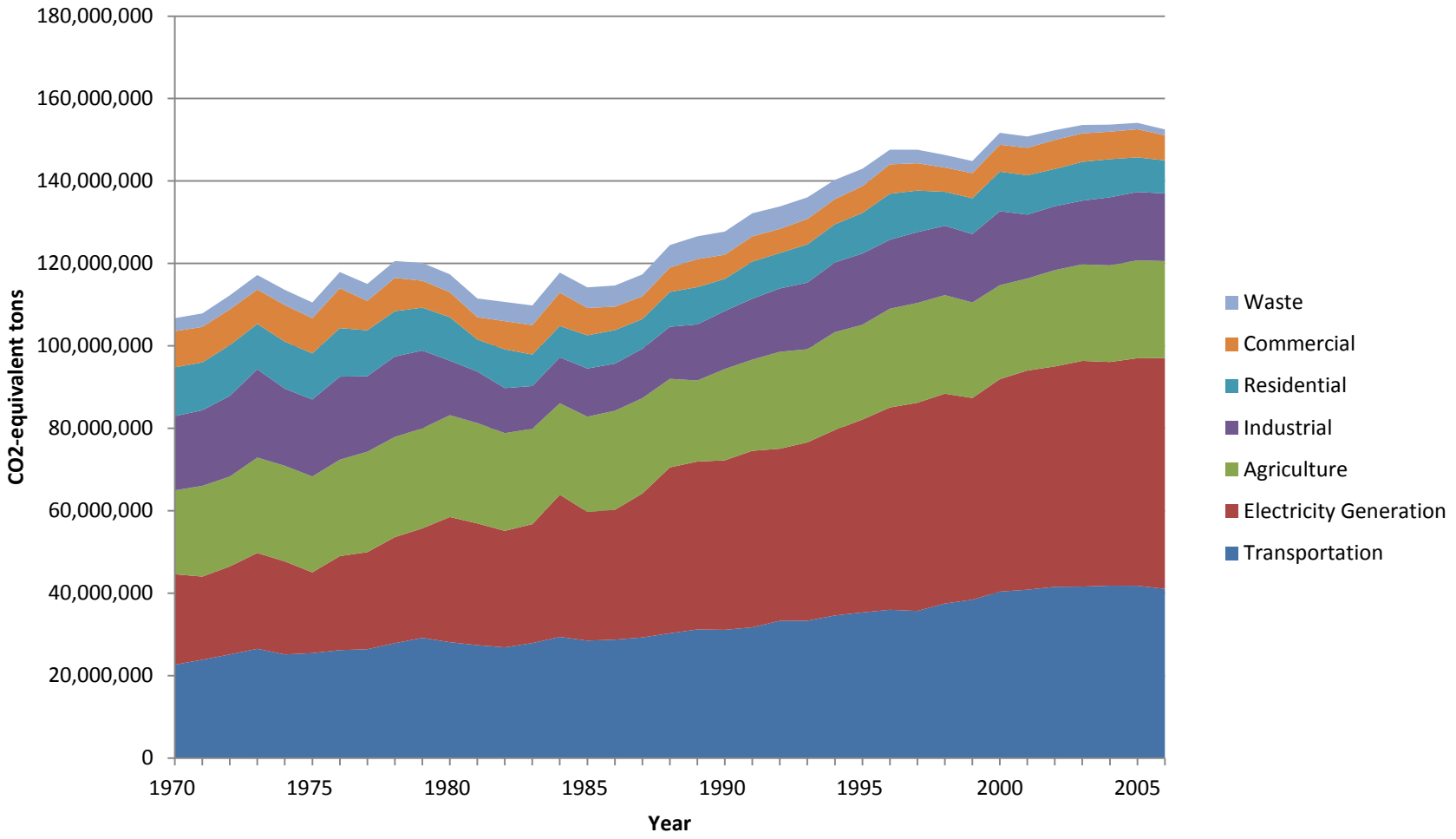
A technical and economic analysis of a 100% renewable energy-based electricity system

Presented by Dr. Arjun Makhijani, President, IEER
St. Paul, MN, March 13, 2012

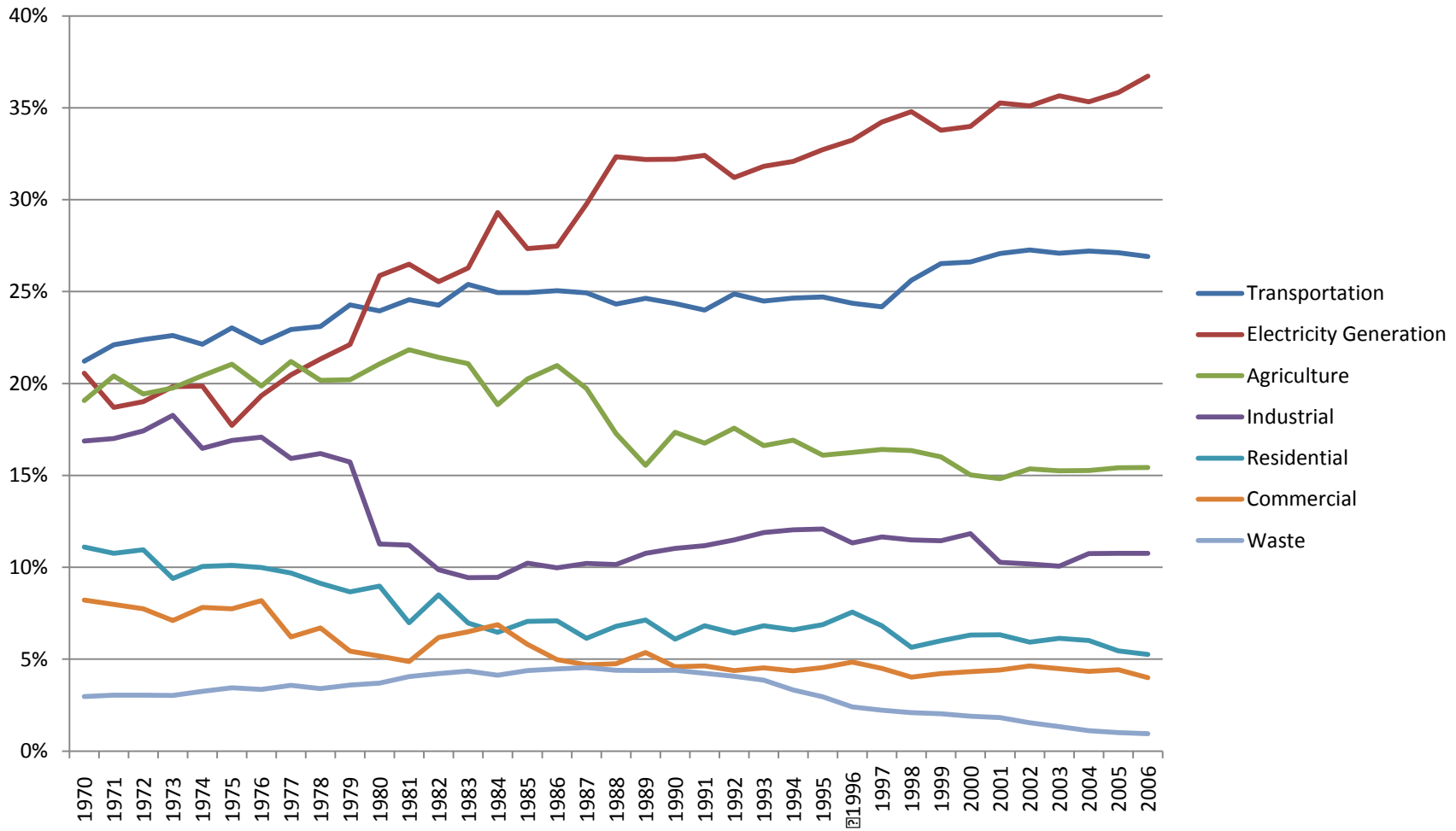
Goals of the study

- Examine the technical feasibility of a 100% renewable electricity sector in Minnesota with only-in-state resources – i.e., complete phaseout of nuclear and fossil fuels with the same level of reliability as today
- Compare the cost of such a system with current costs – rates per kWh and overall, with and without additional efficiency measures
- Examine qualitatively the integration of demand dispatch, combined heat and power, various levels of storage could be combined to create a secure, distributed renewable grid.
- Recommend next steps

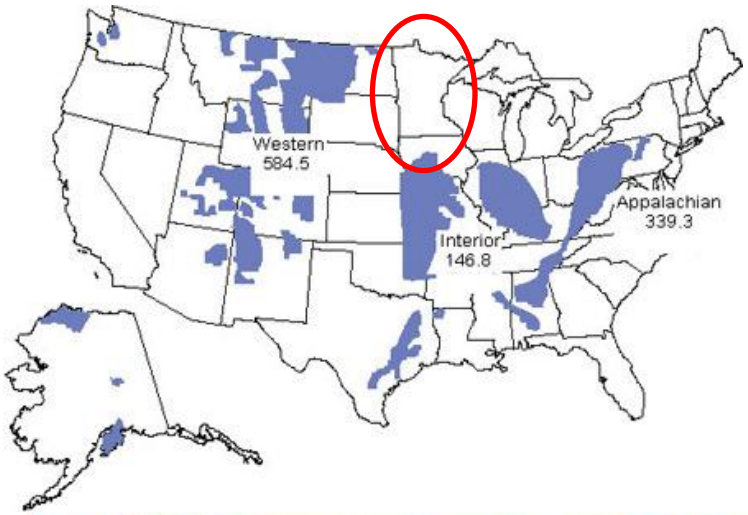
Greenhouse Gas Emissions in Minnesota by Sector, 1970-2006



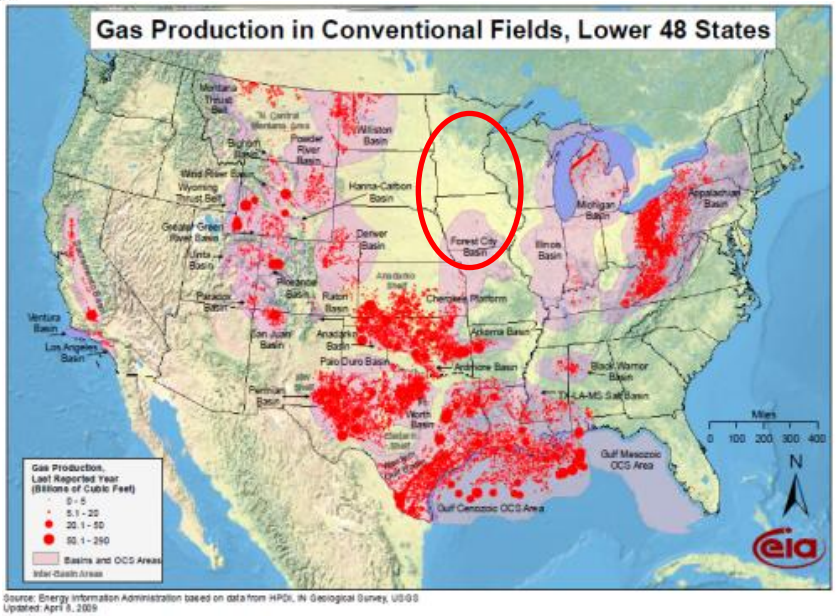
Percent of total greenhouse gas emissions in MN by sector, 1970-2006



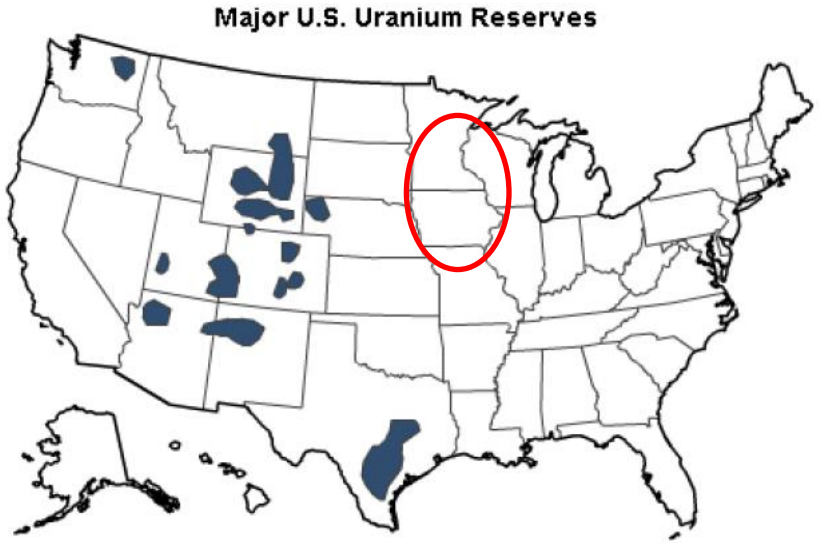
Coal Resources



MN has no in-state coal, natural gas, or uranium

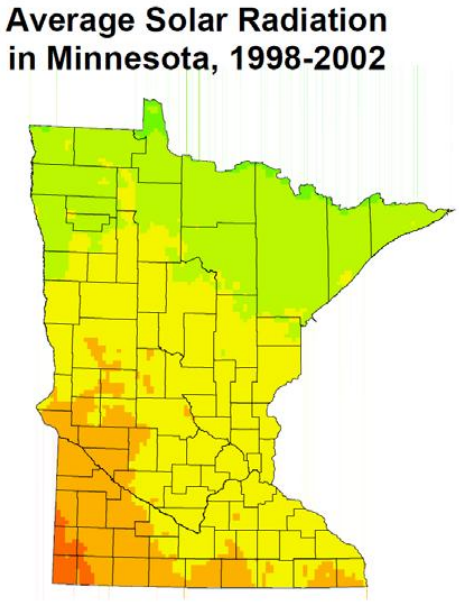


Source: Energy Information Administration based on data from HPDI, IN Geological Survey, USGS
Updated: April 8, 2009

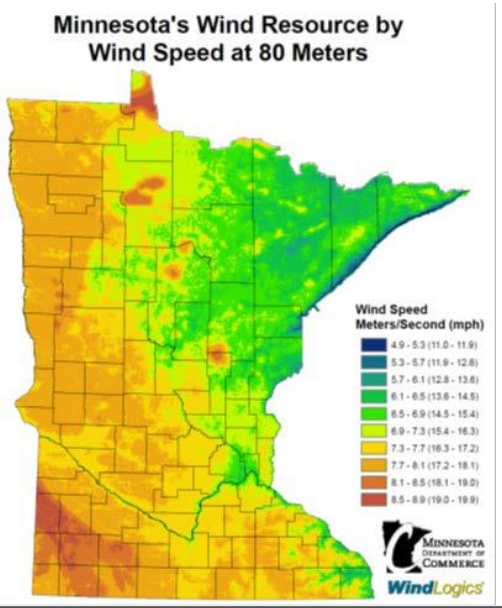


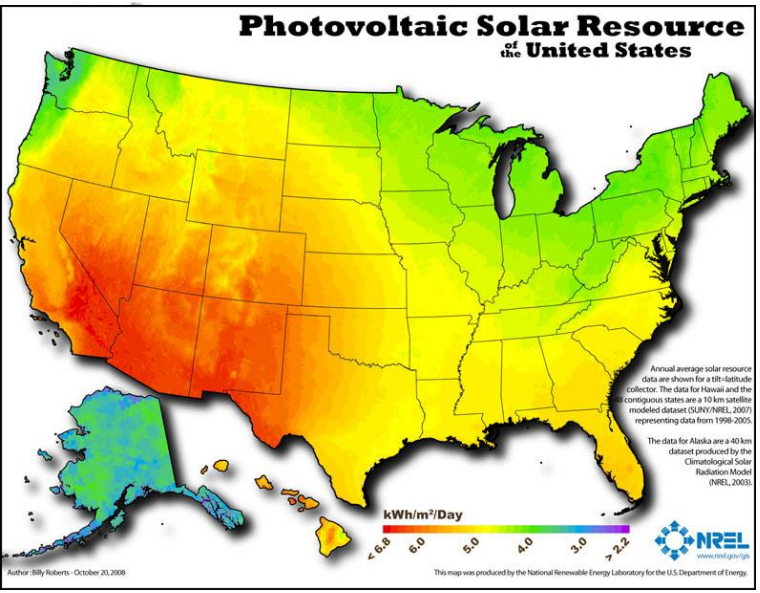
Sources: Based on U.S. Department of Energy, Grand Junction Project Office (GJPO). National Uranium Resources evaluation. Interim report (June 1979) Figure 3.2; and GJPO data files.

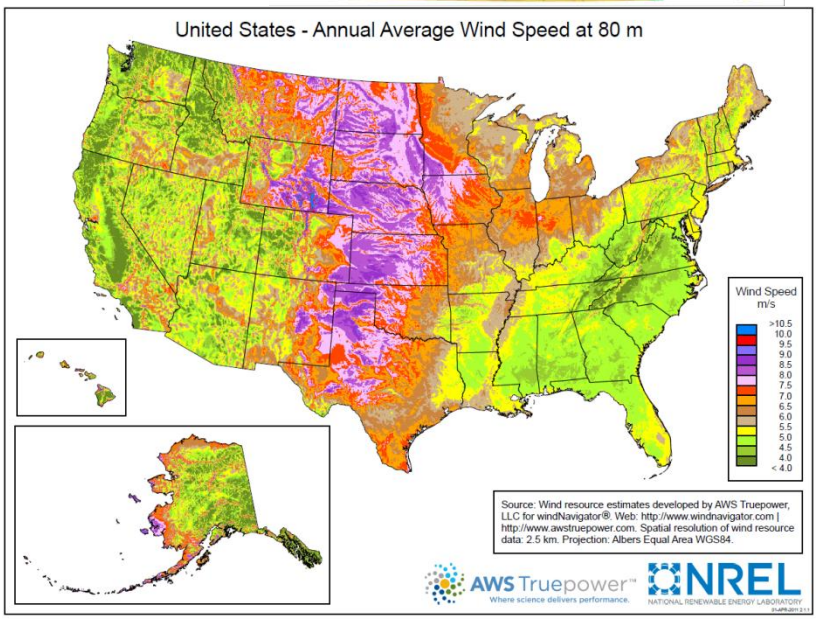
Map sources: Coal: http://www.eia.gov/energyexplained/index.cfm?page=coal_where; Gas: http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm; Uranium: http://www.eia.doe.gov/cneaf/nuclear/page/reserves/ures.pdf



MN has ample wind and solar resources







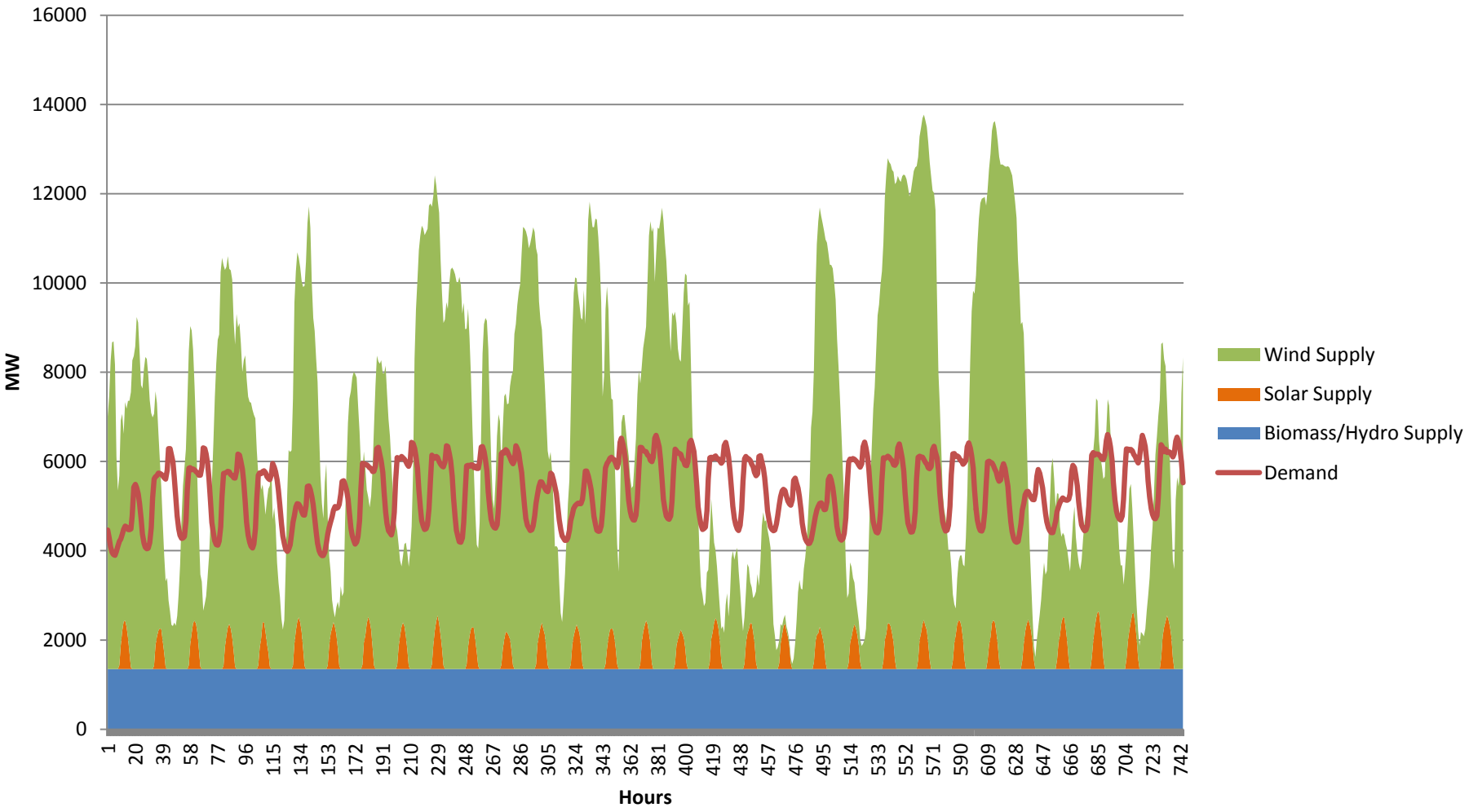
Potential for renewable energy greatly exceeds demand

- 2007 statewide electricity sales = 68 million MWh
- Xcel Energy FERC planning area ~70% of state's electricity demand
- Excellent wind resources ~20 times 2007demand
- Good to excellent wind resources ~30 times demand
- Solar: quality not as good as US Southwest but much better than Germany. Rooftop installations could produce 24% of demand; plus ground-mounted such as parking lots, along highways, etc.

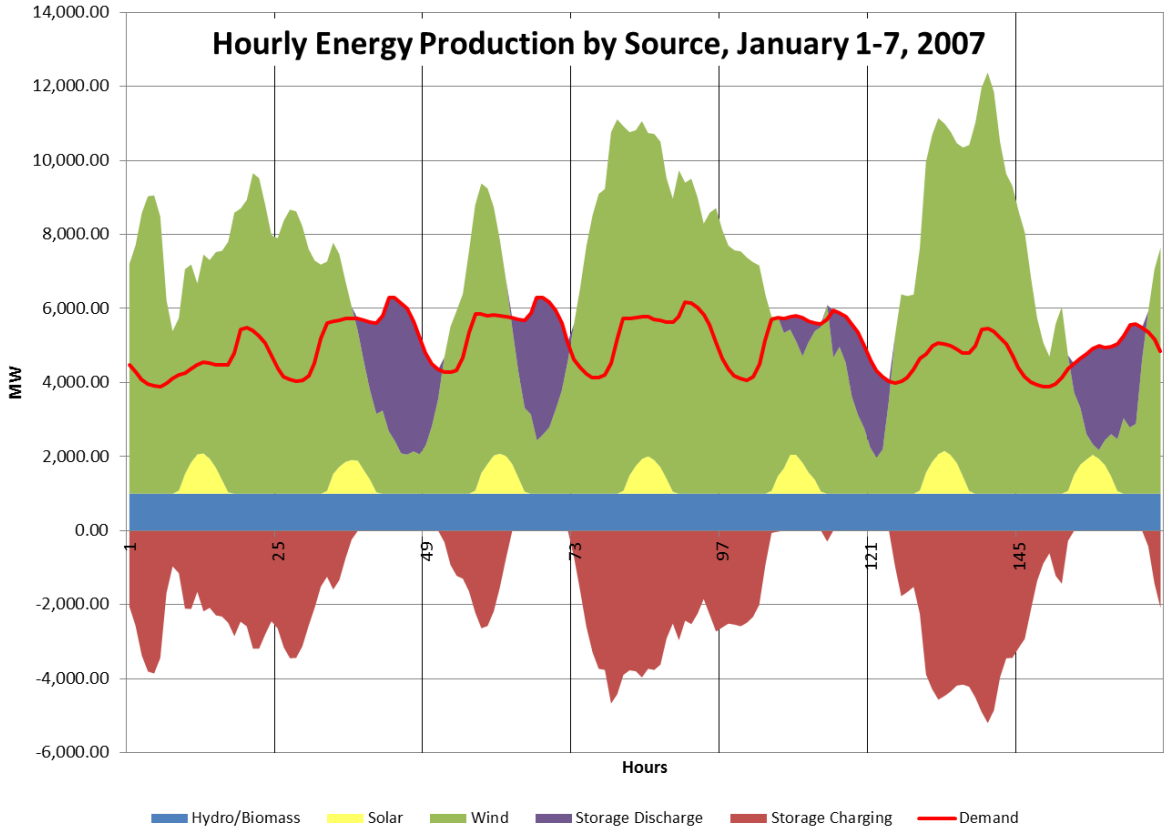
Key assumptions in analysis:

- Only in-state resources
- Same level of reliability as today
- Industry averages for cost estimates
- No changes in individual behavior
- Assume use of single storage technology (compressed air storage for quantitative evaluation)

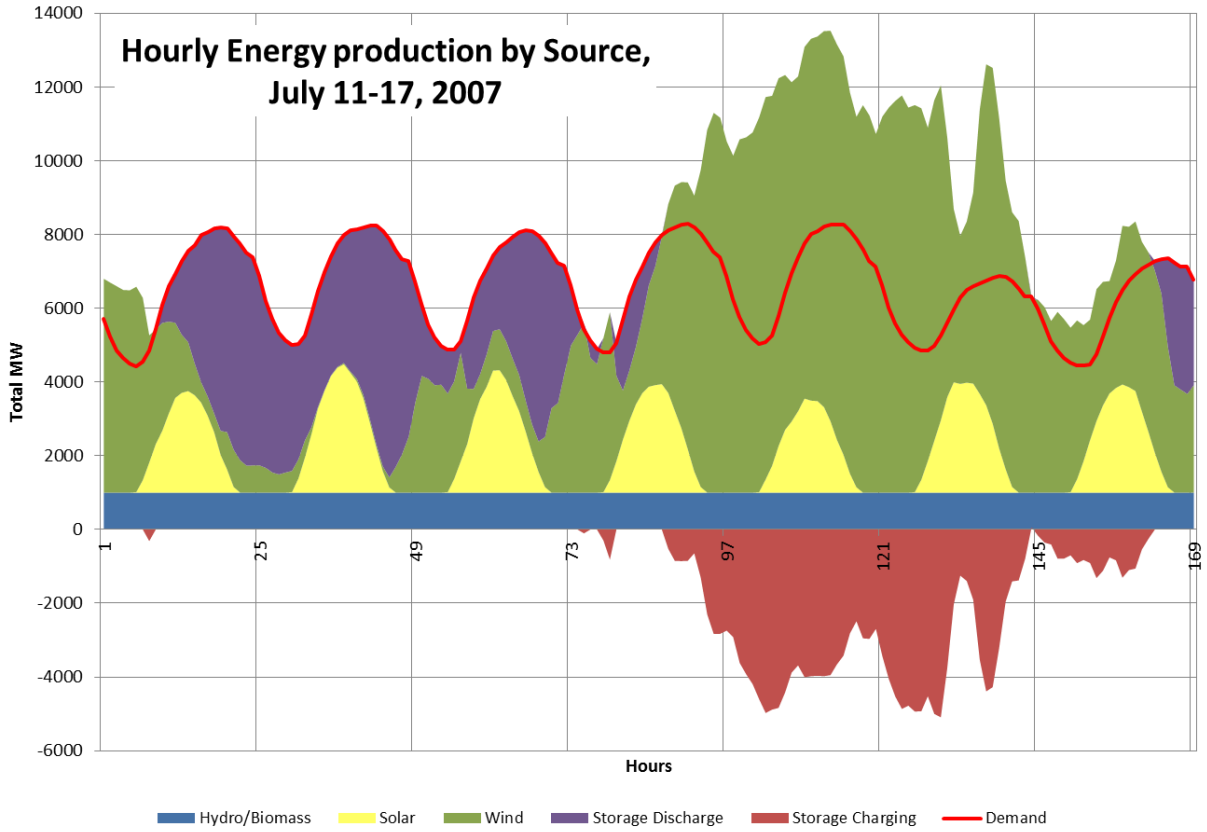
Total Renewable Energy Supply and Demand - January 2007



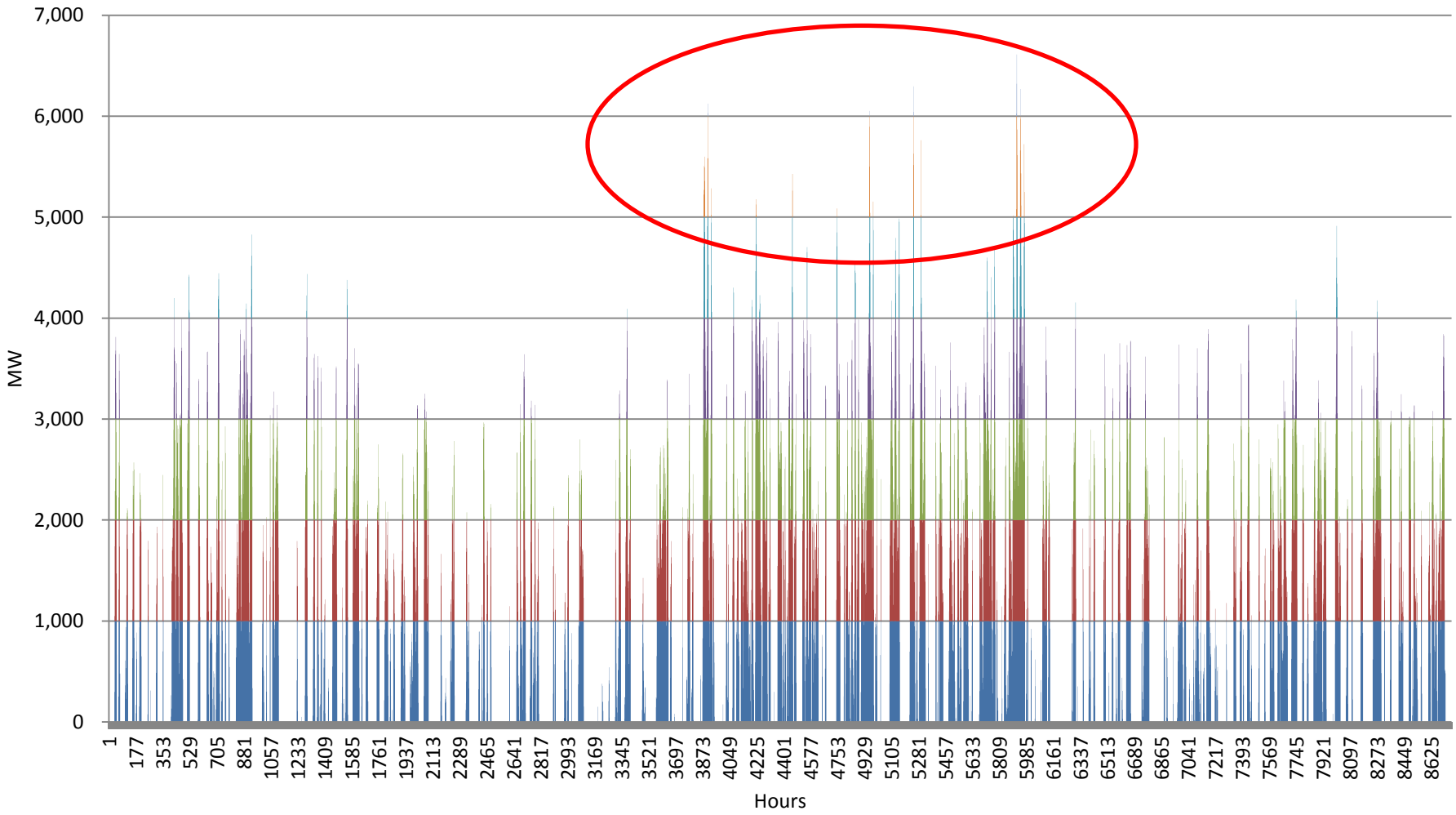
One week in the winter: wind + solar + hydropower/biomass + storage meeting demand 24/7.



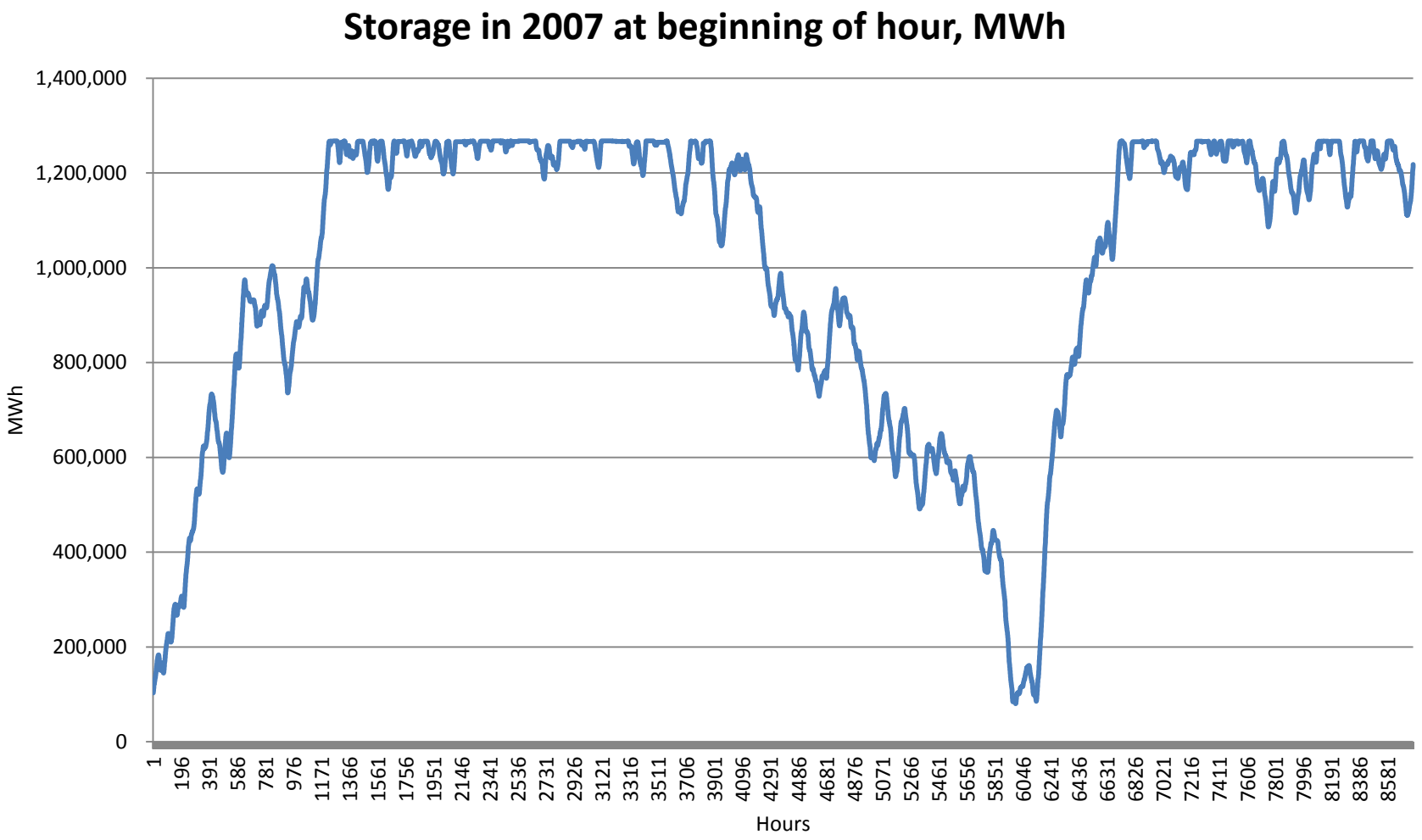
One week in the summer: wind + solar + hydropower /biomass + storage meeting demand 24/7.



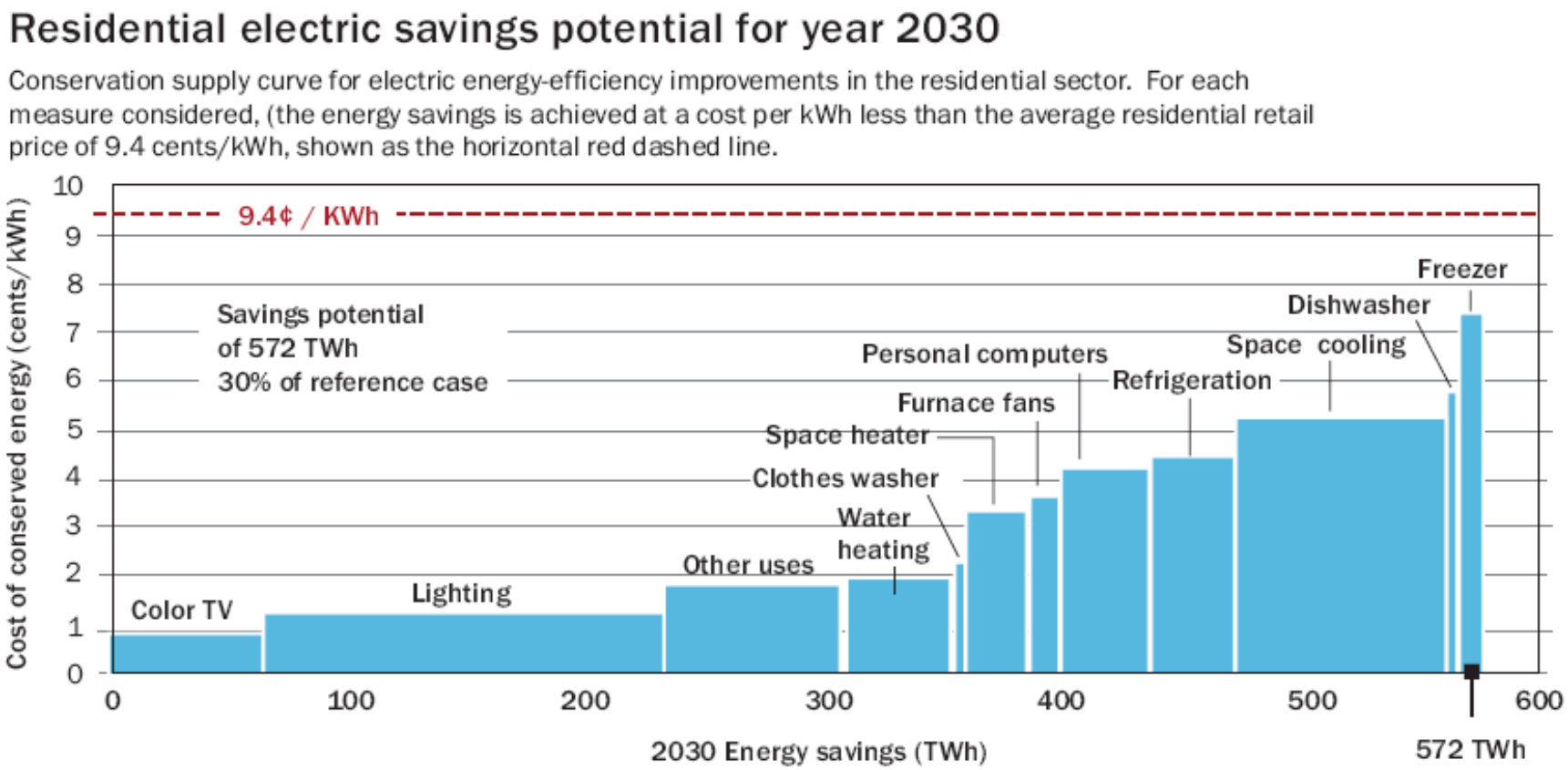
Capacity of storage (CAES expander) needed – highest capacity is used only 55 hours



Storage, hour-by-hour, 2007 data

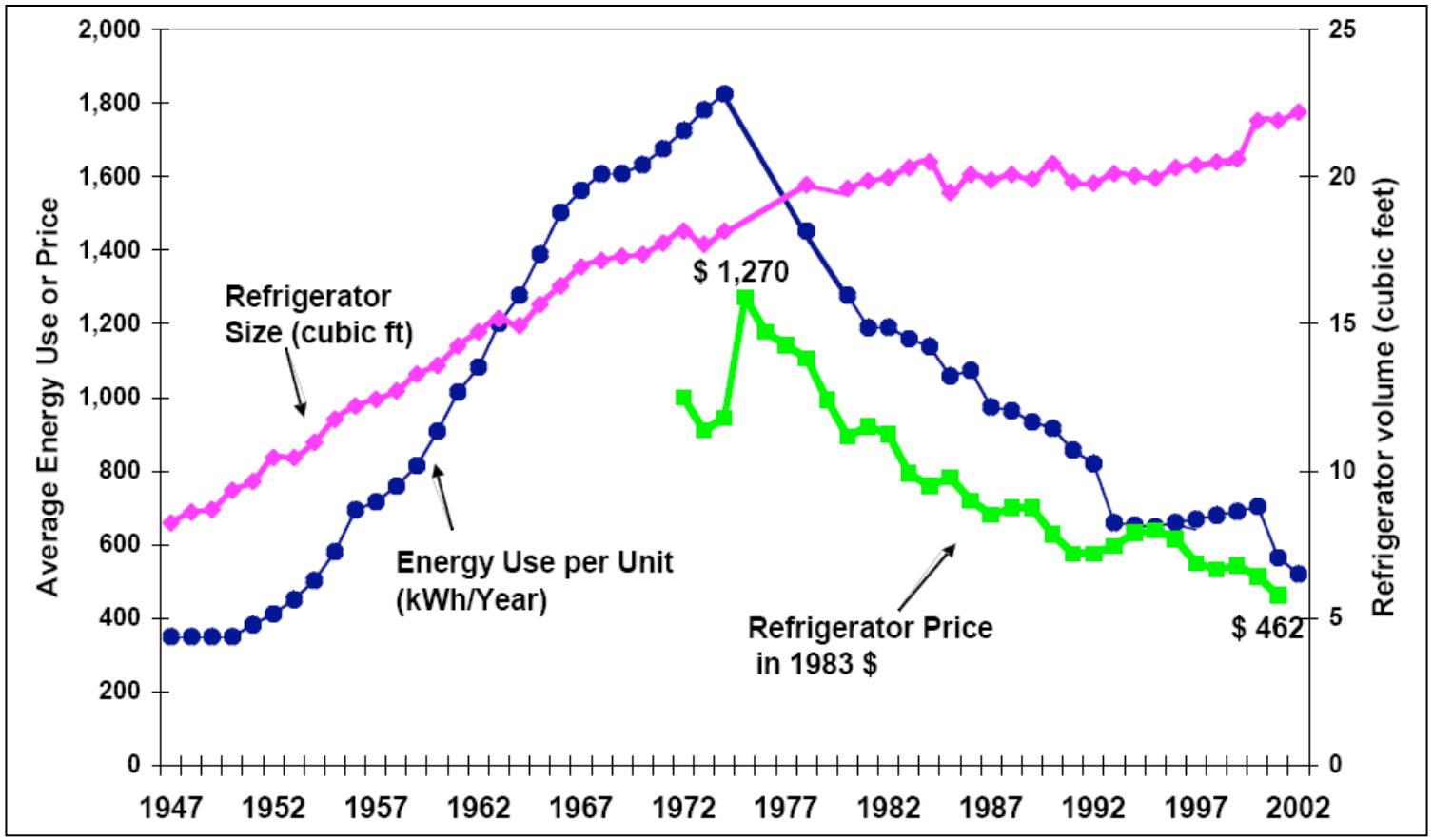


Supply curve for residential electricity (Source: American Physical Society)



Source: APS 2008 Figure 25 (p. 76). Used with permission, from the American Physical Society's report: "*Energy Future, Think Efficiency*" (2008)

A role for efficiency standards: refrigerator example



Source: Rosenfeld 2008 Slide 8 (crediting David Goldstein)

Base case: Solar and wind $2000/kW in 2025

	Base case	Efficiency Tranche 1	Efficiency Tranche 2
Level of efficiency	No efficiency change	Medium efficiency (33%)	High efficiency (additional 17%)
Cost, $/MWh	$176 for generation	$30 for efficiency Tranche 1	$100 for efficiency Tranche 2
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 elec. 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

Solar and wind $1,500/kW in 2025

	Lower cost case	Efficiency Tranche 1	Efficiency Tranche 2
	No efficiency change	Medium efficiency (33%)	High efficiency (additional 17%)
$/MWh	$154	$30	$100
Average cost of electricity services $/MWh at different efficiency levels	$154	$113	$104
Annual services supplied by generation, MWh	8.68	5.82	4.34
Annual services supplied by efficiency, MWh	0	2.86	4.34
Annual elec. bill for generation	$1,336	$895	$668
Annual cost of efficiency	$0	$86	$234
Total annual cost for electricity services (generation plus efficiency)	$1,336	$981	$901
Total annual cost for in 2010	$920	$920	$920
Cost difference: renewables – 2010	$416	$61	($19)

Conclusions

- A fully renewable electricity sector is technically feasible. Resources are plentiful and can accommodate growth.
- Cost is at the lower end of estimated nuclear costs (without taking account of nuclear subsidies such as insurance and uncertainties about waste, and project delays)
- Would create about 50,000 jobs (continuous)
- Without efficiency, the cost will likely be higher, but with efficiency the overall cost of electricity services would be about the same
- Can be made more efficient using demand dispatch and other technologies; probably more economical by reducing relational peaks, storage requirements, and spilled energy
- Attention needs to be paid both to short term and seasonal variations in demand and relation to solar and wind supply

Recommendations

- Minnesota should set a firm direction and adopt a goal of an efficient, fully renewable electricity system by 2050.
- Minnesota should commission an official detailed model of the electricity sector that would include:
- A detailed analysis of energy efficiency, role and extent of combined heat and power, demand dispatch, and various levels of storage, combined to reduce relational peaks, spilled energy, and system costs.
- A review of the role that plug-in hybrids and electric vehicles could play in a renewable electricity sector and the infrastructure needs of both for the vehicles themselves and for the grid.
- An exploration of the feasibility for compressed air energy storage and pumped hydro energy storage (both natural and human constructed) sites in Minnesota.
- An econometric model that reliably couples electricity rates and demand that would be a macro-economic complement to the micro-technical assessments of efficiency on which costs are usually estimated.
- A demonstration project at the university or small community level of a fully renewable, efficient system with an intelligent grid and demand dispatch.
- The Public Utilities Commission might consider initiating and participating in a similar project at the regional Midwest Independent Transmission System Operator (MISO) level. This would allow an exploration of the ways in which a project for a fully renewable, efficient, and reliable system covering the entire MISO system could be made more economical than a state-by-state approach.

"Renewable Minnesota: A technical and economic analysis of a 100% renewable energy-based electricity sector for Minnesota"

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Download the full report, executive summary, press release, and this presentation at http://www.ieer.org/renewableminnesota.