The End of Big Iron

How Wind and Solar Became Cheaper than Hydro, Coal, and Nuclear



By Robert McCullough, Eric Shierman, Michael Weisdorf, and Louis Bengtson



ince the electrification of North America commenced at the start of the last century, the industry has focused on big iron. Larger projects offered efficiency in location and economies of scale. The end of this era is rapidly approaching as smaller, more maneuverable, and less expensive options take the center stage in electric utility planning.

Until recently the competition between renewables and traditional thermal generation was easy. Renewables were expensive and traditional thermal was cost-effective with serious negative externalities.

That traditional trade-off makes less sense today as the Levelized Cost of Energy (LCOE) from wind and solar generation has now dropped below the LCOE of hydro and most thermal energy resources. Moving forward, wind and solar investments offer electric utilities the benefits of clean production at lower prices than existing choices.

For aging nuclear and coal units, renewables actually cost less than operating costs.¹ Wind and solar's weaknesses are their intermittency, but they can be backed up by cheap natural gas peaker plants, and perhaps someday soon, batteries. Overall, in spite of claims by the owners of older fossil fuel units, the nation's capacity surplus is enormous.

History

The history of the electric industry often revolves around the conflict between J.P. Morgan and Samuel Insull to build North America's electric and gas infrastructure. The cost of early central stations was high – phenomenally high by our standards. The costs were so high that the utility franchise model was adopted across the U.S. and Canada. Under this structure, utilities were able to finance expensive central stations based on their monopoly rights in urban areas.

The system worked well – so well that the U.S. and Canada achieved a world leading adoption of electricity and natural gas. In the 1930s, the holding companies based on the franchise model were overextended. The restructuring of the industry that followed their collapse also brought about today's regulatory agencies – the SEC, FERC, and the CFTC, among others.

The basic investment problem was solved and fortified by a regulatory process that prevented the flagrant abuses of its early years. Much of it remains in place today.

Technological advances and economies of scale drove down the price of coal and natural gas-fueled plants until recently.² Nuclear units showed a dramatic reduction in costs over time until the 1980s when safety concerns added considerably to their costs.

In the 1980s, a technological shift to natural-gas-based generation reduced costs significantly. In 1991, the west coast of the U.S. and Canada adopted open wholesale markets that enabled economies beyond the traditional franchise area.

See Figure One.

The emerging cost advantages of renewables are changing the playing field yet again. As natural gas has gradually replaced coal and nuclear generation, wind and solar are exploiting their cost advantage – as well as a number of other advantages – over

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traditional thermal units.

Renewables can include a number of sources including hydroelectricity, solar, wind, geothermal, and biomass. As the price of solar and wind has plummeted, these sources are dominating new renewable generation.

See Figure Two.

A variety of data sources exist

that allow the evaluation of the cost of different generation options over the past one hundred years. One of these, the Federal Energy Regulatory Commission's Form 1 contains the capital cost and data in service for every investor-owned unit.³

This was one of the many regulatory innovations that followed the collapse of the Insull utility holding company during the 1930s. The majority of power plants in the United States are owned by investor owned utilities.

The following chart summarizes the thousands of plants and their per kilowatt capital costs using second degree polynomial curves.⁴

See Figure Three.

The green line shows the rapidly declining capital cost of wind and solar over the past decade. The chart is unnecessarily unfair to renewables since it does not include the cost of fuel, but the recent convergence of capital costs is worth observing.

When all costs are taken into consideration, the situation indicates that most traditional generating stations are no longer competitive. Moreover, recent studies indicate that thermal station operating cost competitiveness is falling behind the LCOE of renewables.

Levelized Cost of Energy

The LCOE measures the overall competitiveness of different



Source: U.S. Energy Information Administration, Monthly Energy Review, Table 7.2a, March 2018, preliminary data for 2017



generating technologies to compare the per-megawatt-hour cost of building and operating a plant over its assumed financial life.

Onshore wind now has a lower LCOE than even hydro. Solar has become on par with hydro, and their momentum for decline continues. The U.S. Energy Information Administration predicts that for new projects entering service in 2040, solar power will be significantly cheaper than hydro as shown in Figure Four.

See Figure Four.

These latest Energy Information Administration numbers are significant because their LCOE estimates of wind and solar power have been conservative compared to investment advisory services like Lazard's annual LCOE estimates, which come out every November. Last November Lazard found solar LCOEs under forty-six dollars per megawatt-hour.

Interestingly, even Lazard's estimates have been overtaken by the market. Xcel Energy conducted a request for proposal for their operations in Colorado last year. The bids they received rocked the industry.

See Figure Five.

Overall, Xcel received over fifty-two thousand megawatts of renewables with a weighted average price of \$20.1 per megawatthour. Unlike the forecasts from the U.S. Energy Information >>> Fig. 4

Total

CAPACITY-WEIGHTED AVERAGE LCOE FOR NEW GENERATION RESOURCES IN 2022 (2017 \$/MWh)

	Capacity factor	Levelized capital	Levelized fixed	Levelized variable	Levelized transmission	Total System	Levelized tax	Total LCOE including
Plant type	(%)	cost	0&M	0&M	cost	LCOE	credit	tax credit
Dispatchable technolog	jies							
Coal with 30% CCS	NB	NB	NB	NB	NB	NB	NA	NB
Coal with 90% CCS	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CC	87	13.0	1.5	32.8	1.0	48.3	NA	48.3
Advanced CC	87	15.5	1.3	30.3	1.1	48.1	NA	48.1
Advanced CC with CCS	NB	NB	NB	NB	NB	NB	NA	NB
Conventional CT	NB	NB	NB	NB	NB	NB	NA	NB
Advanced CT	30	22.7	2.6	51.3	2.9	79.5	NA	79.5
Advanced Nuclear	90	67.0	12.9	9.3	0.9	90.1	NA	90.1
Geothermal	91	28.3	13.5	0.0	1.3	43.1	-2.8	40.3
Biomass	83	40.3	15.4	45.0	1.5	102.2	NA	102.2
Non-dispatchable tech	nologies							
Wind, onshore	43	33.0	12.7	0.0	2.4	48.0	-11.1	37.0
Wind, offshore	45	102.6	20.0	0.0	2.0	124.6	-18.5	106.2
Solar PV	33	48.2	7.5	0.0	3.3	59.1	-12.5	46.5
Solar Thermal	NB	NB	NB	NB	NB	NB	NB	NB
Hydroelectric	65	56.7	14.0	1.3	1.8	73.9	NA	73.9

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RFP Responses by Technology Generation Technology	# of Bids	Bid MW	# of Projects	Project MW	Median Bid Price or Equivalent	Pricing Units
Combustion Turbine/IC Engines	30	7,141	13	2,466	\$4.80	\$/kW-mo
Combustion Turbine with Battery Storage	7	804	3	476	\$6.20	\$/kW-mo
Gas-Fired Combined Cycles	2	451	2	451	\$6.70	\$/kW-mo
Stand-alone Battery Storage	28	2,143	21	1,614	\$11.30	\$/kW-mo
Compressed Air Energy Storage	1	317	1	317	\$14.60	\$/kW-mo
Wind	96	42,278	42	17,380	\$18.10	\$/MWh
Wind and Solar	5	2,612	4	2,162	\$19.90	\$/MWh
Wind with Battery Storage	11	5,700	8	5,097	\$21.00	\$/MWh
Solar (PV)	152	29,710	75	13,435	\$29.50	\$/MWh
Wind and Solar and Battery Storage	7	4,048	7	4,048	\$30.60	\$/MWh
Solar (PV) with Battery Storage	87	16,725	59	10,813	\$36.00	\$/MWh
IC Engine with Solar	1	5	1	5	\$50.00	\$/MWh
Waste Heat	2	21	1	11	\$55.40	\$/MWh
Biomass	1	9	1	9	\$387.50	\$/MWh

430

111,963

238

58,283

Administration and Lazard, these are actual market prices.

While administered markets in U.S. eastern states routinely report prices significantly higher than the more competitive markets in the west, few industry participants have proposed eliminating the cumbersome administered market structures of MISO, PJM, NYISO, and their companions.

They often claim that western markets simply respect past investment in hydroelectricity. This is ironic since the marginal resources on both sides of the continental divide is fueled by natural gas. A more realistic explanation for the west's relatively lower wholesale prices is the existence of larger, more mature, and more competitive wholesale markets.⁵



The Industrial Advantage of Wind and Solar

We are used to thinking of alternative energy as a high-cost source primarily because of its novelty. The cost of wind and solar power generation have come way down in the same way most new technologies eventually enjoy economy of scale benefits and the diffusion of knowledge. Pocket calculators were once an expensive luxury; now they are just another free app on our phones.

Because wind and solar components are built in factories, the slope of their long-run price decline will remain steeper than other energy generating technologies that have to be custom built on location. Like the building of homes, there is some element of standardization in building power plants, but ultimately each project will be somewhat unique.

Utility-scale wind and solar are different. The bulk of the capital expenditure is on manufactured goods that do not need to be built on site. Thus, wind and solar are to traditional generating stations what manufactured homes are to custom-built homes. By cutting out the intensive need for itinerant construction labor at the site, wind and solar will continue to enjoy cost savings that traditional generation choices may not.

Wind and solar also possess another significant industrial advantage over hydropower: Just in Time delivery. This transformative concept, pioneered in the 1950s by the Toyota industrial engineer Taiichi Ohno, is a foundational principle of what we today call Lean Production.

Just in Time Delivery reduces input inventories to the minimum necessary to meet real time production needs. This reduces lead times in production, saves capital costs, and reduces waste.

So, in a Toyota plant, they would only want a hood when the assembly line needed a hood. Before the widespread adoption of Lean Production processes, a stamping plant would try to produce as many hoods as possible to reduce unit costs. These components would then be shipped all at once to the final assembly plant and stored.

As vehicles were built, the assembly plant would tap into

its large inventory of hoods. At some point, as the hoods' supply reached some minimal level, the stamping plant would then get another mass order.

Ohno figured out that the costs associated with the capital expenditures, storage, and waste from making so many hoods in advance were higher than the savings from lower unit costs from manufacturing the components all at once.

Instead, he accepted higher unit costs by supplying his assembly plants with hoods only as they were needed. There was thus no need to stockpile steel at the stamping plant and no need to stockpile hoods at the assembly plant. This reduced the cash needed for operations, and whenever the design of a vehicle model was changed, there was no longer a

pile of unusable hoods.

The principle of Just in Time delivery could also be applied to electric utilities' resource development. Wind and solar capacity can be delivered as needed, but major thermal and hydroelectric projects have to be built long before the load demand exists.

We see this problem with B.C. Hydro's development of the Site C dam. British Columbia does not need eleven-hundred megawatts of new installed capacity, but it may need more capacity decades from now. Their plan is to build the dam and export the excess capacity to the United States until their own province eventually needs this energy.

To get the project approved, B.C. Hydro has had to both overestimate its customers' future demand and overestimate the wholesale prices they will get selling this power in the Mid-Columbia market. The losses that will follow will have to be absorbed by either ratepayers or the government of British Columbia.

The Just in Time delivery approach would be to only build capacity as it's needed. Since traditional plants cannot be partially built over time. You either have no generation, or you have a generation producing energy substantially in advance of need.

Wind and solar farms, in contrast, can be built small and expanded as actually needed by consumers. By delaying the



procurement of capacity until it's needed, the electric utility will lower its financing costs, lower its depreciation costs, and the Just in Time procurement of wind and solar will avoid the losses incurred from overestimated load growth.

Transmission

The major transmission lines have tended to be oriented north to south. This reflects seasonal diversity between northern loads and southern loads. Traditionally, systems in the north are winter peaking since their consumers need energy for heating.

See Figure Six.

Southern systems tend to have summer peaks since a major energy use is for cooling. The massive transmission projects from the Canadian Rockies all the way to Los Angeles reflects this seasonal diversity.

The north to south transmission also serves hydroelectric projects since the spring thaw releases a major portion of the flows to hydroelectric projects. Northern systems reduce their needs during this period while southern systems are just beginning to experience warm weather.

Solar and wind generation turns this picture by ninety degrees. Both solar and wind have diurnal diversity. Wind tends to peak just before dawn. Solar, of course, peaks during peak hours. The transmission system should reflect the diurnal benefits of renewables east to west. This will have a major impact on portfolio effects of renewables discussed below.

Capacity

A frequent challenge to the growth of renewables is that the generation is intermittent. Both wind and solar are highly intermittent – with generation averaging approximately thirty percent of nameplate rating.⁶

Hydroelectric projects are also intermittent, although usually less than solar and wind. Even major thermal projects have a degree of intermittency with availability rates as low as eighty percent.

The industry's solution to the need for high degrees of reliability based on only partially reliable resources has been to assemble portfolios of resources. The presence of inefficient capacity markets, especially in the eastern administered market states, has driven the U.S. and Canadian capacity margin, the margin above the nameplate capacity of individual resources, to higher and higher levels.

The American and Canadian average in the most recent North American Reliability Corporation report has increased the capacity margin to 23.6 percent, which is almost twice the level required in traditional utility requirements. Certain sub regions, PJM,

for example, are expected to reach a reserve margin of 34.53 percent by 2023.

The concern over intermittency is real, but currently of secondary importance given the very high reserve margins currently in place in the U.S. and Canada. In the long term, there are three very viable solutions available: portfolio strategies, batteries,

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and simple cycle natural gas turbines.

Portfolio Strategies

Traditionally renewables were so expensive that only the very best sites were suitable for development. For example, there is a cluster of wind resources that surround the Tri-Cities area of southeastern Washington.

As mentioned above, this is a very inefficient portfolio. Any competent investment advisor would recommend diversifying the renewable resource by either adding resources further to the east – thus realizing the diurnal diversity of earlier daybreak or seeking renewables with a negative correlation to the resources in the Tri-Cities area.

As the price of renewables falls, the freedom to diversify the renewable portfolio has expanded significantly. Sites with less average generation that were not cost effective at high prices are now available for development to create a more balanced portfolio.

Batteries

One of the surprises in the responses to the Xcel RFP discussed above was the number of proposals that came with batteries to provide more stable generation. Xcel received 13,435 megawatts of wind proposals with batteries – enough to supply the energy needs of three large cities.

The key to the battery solution is economics. Lazard has recently introduced a series of annual studies on the levelized

Fig. 7		Hawa	IIIAN ELECTRIC			
Project name	Island	Developer	Size (MW)	Storage (MWh)	Total Cost (\$/MWh)	Implicit Storage Cost (\$/MWh)
Waikoloa Solar	Hawai'i	AES	30	120	\$80.00	\$100.00
Hale Kuawehi	Hawai'i	Innergex	30	120	\$90.00	\$116.67
Kuihelani Solar	Maui	AES	60	240	\$80.00	\$100.00
Paeahu Solar	Maui	Innergex	15	60	\$120.00	\$166.67
Hoohana	0'ahu	174 Power Global	52	208	\$100.00	\$133.33
Mililani I Solar	O'ahu	Clearway	39	156	\$90.00	\$116.67
Waiawa Solar	0'ahu	Clearway	36	144	\$100.00	\$133.33
Lazard Estimate						\$124.00

cost of storage as a companion to the resource cost analyses mentioned above. Last Fall's report showed the steep decline in costs continues apace.

As with wind and solar, there is evidence that technology has outpaced Lazard's calculations. Hawaiian Electric recently released the results of its solar plus battery storage RFP:

See Figure Seven.

Four of the seven winning bids at Hawaiian Electric were less than Lazard's most recent storage estimates.

Batteries are now being introduced into utility systems across the United States. The cost trajectory is encouraging enough to expect a greatly increased use in the near future.

Simple Cycle Gas Turbines

The most cost-effective option right now remains simply cycle turbines. They are relatively inexpensive, can be installed quickly,

Endnotes

- Generating facilities have fixed costs capital costs and operating costs fuel and O&M. The total cost of a new renewable plant is gradually falling below the cost of fuel and O&M for older thermal power plants.
- While technology has continued to improve, environmental concerns have added to the cost of thermal units over time, leading to a parabola effect on their costs.
- FERC Form 1 are available in scanned image format at elibrary.ferc.gov. In recent years FERC has also released the Form 1 data in database format.
- The second-degree polynomial fits the data well. However, it is an overly simplistic approach when attempting to capture technology, economies of scale,

The transmission system should reflect the diurnal benefits of renewables east to west.

and will be used to operate only when the collective renewables portfolio is unable to meet the minimum operating level. Their role will be comparable to local backup generators – available for need, but dispatched rarely.

Conclusion

There was a day when coal and

hydropower offered some of the lowest levelized costs of energy. Those days are over. Research from both Lazard and the Energy Information Administration shows wind and solar have become just as cheap, and in the case of land-based wind, cheaper than hydro. Xcel's recent RFP confirms their estimates.

The end of big iron has come.

environmental costs, and nuclear safety costs. In addition, although FERC accounting rules apply to all U.S. utilities, our review indicated that many of the FERC Form 1 used inconsistent reporting standards.

- 5. Wholesale market in the west date to the early 1980s. FERC approval of wholesale pricing took place in 1987. The last major hydroelectric price in the west dates from 1971. Since that date, resources have been primarily natural gas fueled.
- 6. The actual plate affixed to an electric generator contains its "name-plate" rating. This is generally regarded as the capacity of a thermal power plant. A wind farm might have a very high name-plate capacity, but capacity factors for wind farms are generally lower than those of traditional generators.

In the June issue of *Public Utilities Fortnightly*, we'll announce and feature the Fortnightly Smartest Communities. Your smart community might make the list. But only if you nominate it by the deadline, which "falls" on March 23rd. That gives you three weeks to send in your nomination.

Why March 23rd you say? That is the anniversary of one of the greatest leaps in history in creating the smart city of today and of tomorrow. It was on March 23, 1857 that the first commercial elevator safely lifted up and returned down.

Send your nominations to one of the smart staffers at *Public Utilities Fortnightly*, Alexandra Revel. Alex's e-mail is arevel@ fortnightly.com. Tell us the name of the community – city, county, whatever – and tell us why it's one of the smartest in these United States.