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How Compliance with Renewable Portfolio Standards can be Low Cost and Job Creating:

The benefits of converting old pulverized coal plants to use pulverized renewable advanced solid biofuel.

By William Strauss, PhD, November 2014

This white paper shows that converting old pulverized coal power plants to use advanced solid biofuels rather than coal provides a ready-to-go solution for compliance with states' renewable portfolio standards (RPS). The strategy does not cost jobs. In fact the strategy creates new jobs. This strategy is the lowest cost pathway to compliance with RPS requirements and provides a renewable solution for the intermittency of wind and solar.

The strategy provides:

- **The lowest cost renewable power generation solution;**
- **Dispatchable and/or baseload power that is available when needed;**
- **More jobs per megawatt-hour of energy than any other generation technology.**
- **Very low carbon footprint**

What is advanced solid biofuel?

Advanced solid biofuel is a dense solid pellet shaped fuel derived from renewable woody biomass. It can be either "white" or "black".

White pellets are refined and compressed woody biomass fiber. Black pellets are compressed from either torrefied or steam exploded wood fiber. Some black pellets are waterproof which provides a logistical advantage over white pellets. **Both types of pellets provide a fuel that is homogenous, consistent, very low in moisture, and easy to handle and pulverize** (more on pulverizing fuel below).

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As long as the source of the woody biomass is from sawmill residuals (sawdust and shavings) or from trees that are sustainably managed as long-term rotated crops for supplying feedstock to the forest products industry, then the fuel derived from those sources is 100% renewable and is carbon neutral in combustion[1]. Just as is the case with any fuel that has to be extracted, transported, and refined, there is a carbon footprint associated with the electricity used in the refining process and the transportation fuels such as diesel that are used in the supply chain. But in combustion, as long as the growing stock of woody biomass is not reduced, every ton of carbon released in combustion is recaptured contemporaneously by new growth.

That is not the case with fossil fuels. Thus energy generated from sustainably sourced biomass is not only 100% renewable but is also a low carbon emission solution to power generation.

How is coal used in a power plant? How can advanced solid biofuels replace coal?

Most coal fired power stations are "pulverized" coal plants. Those plants convey coal into pulverizing machines that crush the coal into a fine powder. That powder is pneumatically conveyed from the pulverizers to the burners. The burners are mounted in the sidewalls of the power boiler. The coal dust is blown into the burners and combusts very rapidly; almost like a liquid fuel.

Sidewall Pulverized Coal Burners

Two years ago the concept of using pulverized wood pellets in large coal fired power stations to completely replace coal was unproven. That has changed with three large power plants proving that using white and black pellets in power stations not only works, but allows the power station to consistently and reliably generate the same amount of electricity as they did with coal.

The Drax station in the UK has converted two 650 MW lines to run on 100% pellets. The first unit that Drax converted has almost two years of operating time. That unit produces the same output and efficiency under pulverized white pellets as it did with coal. It also generates about the same number of MWh's as it did with coal.

[1] See papers at www.FutureMetrics.com on this topic.

The other two conversions were by Ontario Power Generation (OPG). The OPG Atikokan, Ontario 240 MW station has fully converted and also has proven that pulverized white pellets can equal pulverized coal in terms of output and reliability.

OPG's Atikokan 100% White Pellet Fueled Power Station

Pulverized Pellet Fuel Burner in the Atikokan Power Plant

OPG's Thunder Bay, Ontario 310 MW station has also been repurposed to use black pellets. The black pellets used by Thunder Bay are waterproof and are stored in the same yard that used to store coal. That facility has also proven that using advanced solid biofuel as a coal replacement does not lower the output or reliability of the generating station.

Co-firing pellets with coal in relatively low ratios has also been successful in a number of power plants around the world. At low co-firing rates (3%-10%) the pellets can be metered into the coal conveyors ahead of the pulverizers with no modifications to the pulverizers or burners.

Currently Korea Southeast Power Co.'s (KOSEP) Yeongheung power station near Seoul is co-firing 3% white pellets with coal. The 5,000 MW station consumes about 9.7 million tons of coal and about 300,000 tons of white pellets annually. There was no modification to the power plant other than to build a receiving area for the advanced solid biofuel and a system for metering the pelletized fuel into the coal conveyors ahead of the pulverizers. The co-firing helps KOSEP to be in compliance with Korea's RPS requirements.

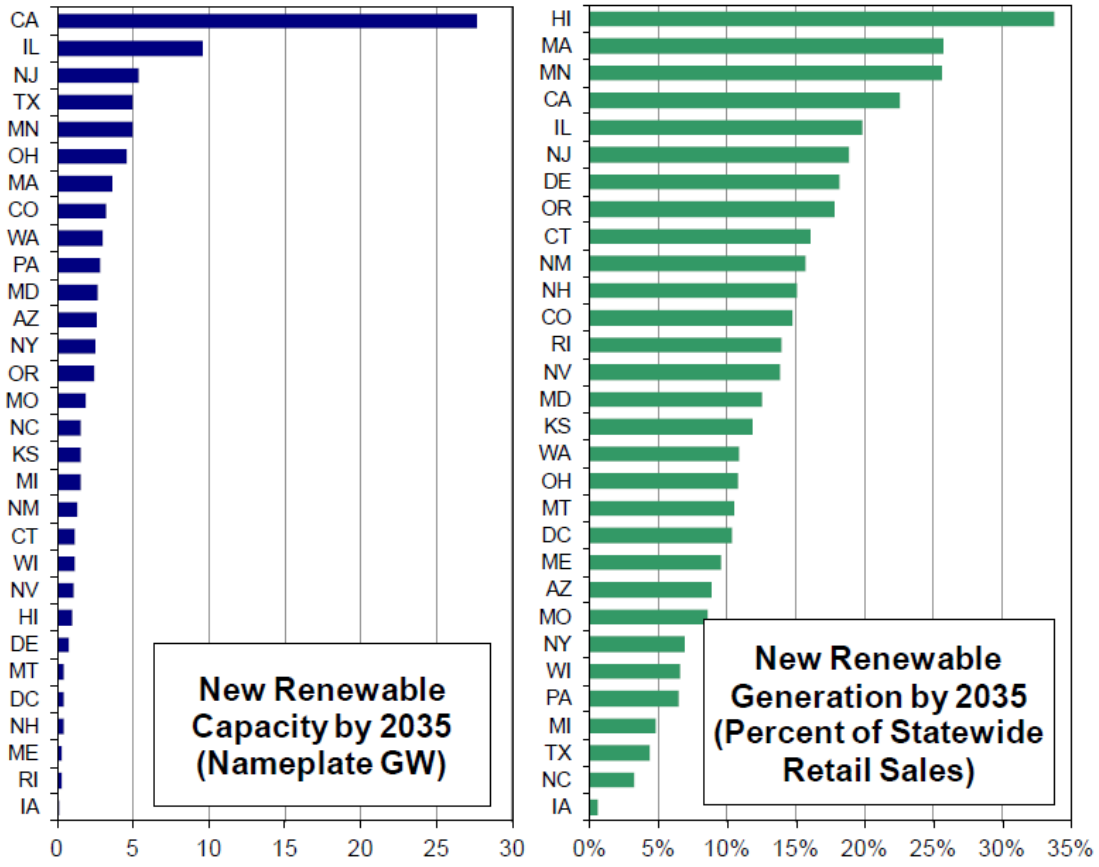
Yeongheung, Korea 5,000 MW Power Station

Grinding densified pelletized biofuel back into dust and burning the fuel in essentially the same hardware has been proven to be technically feasible. Furthermore, there is no de-rating of the power plant. Just as many megawatts can be generated from the renewable fuel as from coal in the converted plant.

A Strategy for Using Advanced Solid Biofuel in US Pulverized Coal Plants

Although the US does not have a carbon policy that would incentivize high carbon emitting power generators to mitigate their CO_2 emissions, 27 US states do have renewable portfolio standards (RPS). 11 other states have variants on RPS. RPS goals apply to 55% of retail electricity production in the US. RPS is a regulation that requires utilities to use renewable energy sources for power generation. The proportion of renewable energy generation required by

those states with RPS increases every year toward the goal that each state sets. The charts below[2] shows that there is significant growth expected in the use of renewables in the next two decades.



Most RPS states have also capped the rate impacts at well below 10% (13 states are below 5%). Going forward, the lowest cost renewable power will be favored.

The RPS systems provide incentives to the generators by issuing renewable energy certificates (RECs) for each MWh generated from renewable sources[3]. RECs are traded in the open markets and have values ranging from a few dollars to over $50 per REC (depending on the state in which the power is generated and the source). Some special solar RECs (SRECs) trade in the hundreds of dollars per MWh.

The pathway to that lowest cost renewable power for RPS compliance that also has the benefits of being available on demand (dispatchable) or continuously (baseload) is via the conversion of older pulverized coal power plants to use advanced solid biofuels. And as is shown below, the job creation benefits are unmatched by any other power generation solution.

[2] From "Renewables Portfolio Standards in the US: A status update," Lawrence Berkeley National Lab, presented at the National Summit on RPS, November, 2013.

[3] RPS rules also provide a penalty for noncompliance. Alternative compliance payments (ACPs) are a penalty paid by the generator for shortfalls in their renewable portfolio. ACPs are typically many multiples higher than REC prices providing incentive to the generator to produce renewable power..

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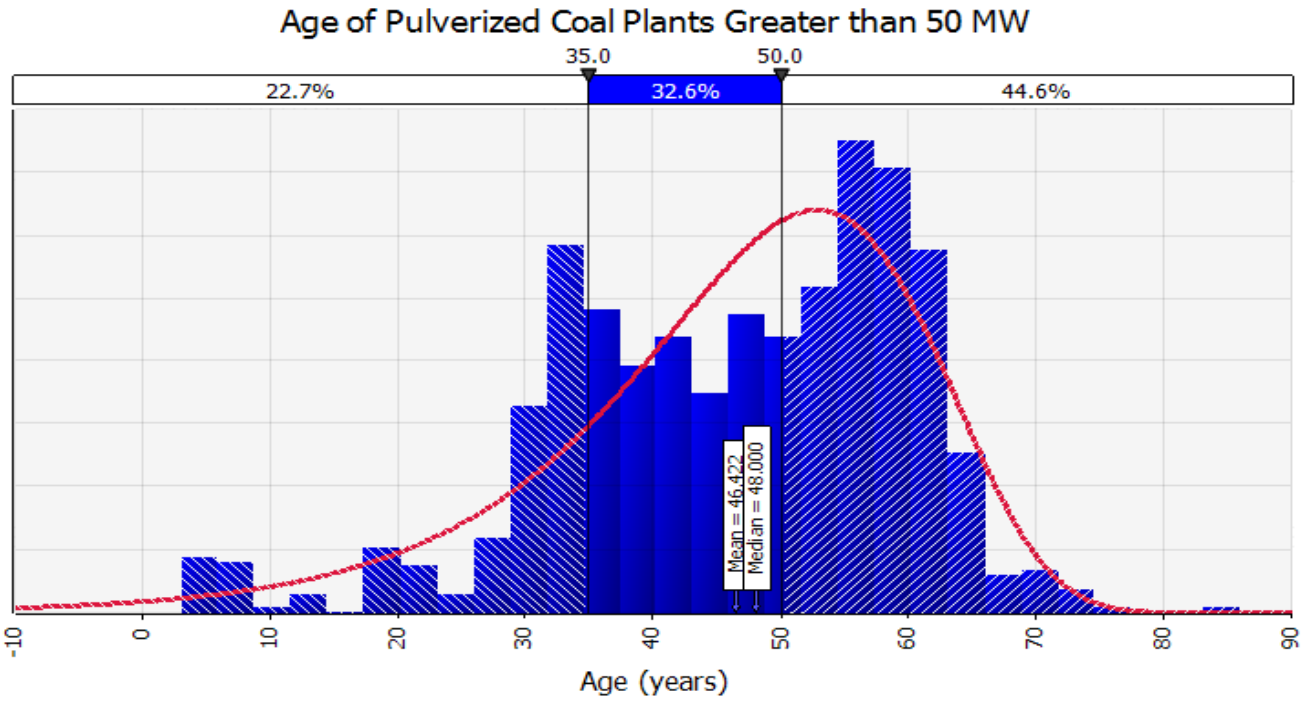
Why are Older Pulverized Coal Power Stations a Pathway to Lowest Cost RPS Compliance?

As was noted above, large generating stations throughout the world, including North America (OPG in Canada), are showing that using advanced solid biofuel does not degrade the power plant's output or reliability.

But what about cost?

The analysis that follows shows that converting older coal plants is the lowest cost solution to RPS compliance. Furthermore, thermal generating stations that can be switched on as needed can complement the wind and solar component of the renewable power portfolio. Every MW of wind or solar power needs a MW of thermal generation (or hydro where available) to keep the grid balanced when the wind is not blowing and the sun is not shining. As is shown below, MW's of power from plants running on pelletized refined biofuel are cheaper than wind or solar. And those plants also solve the intermittency problem with renewable power (rather than relying on coal peaking plants).

The median age of a pulverized coal plant in the US is 48 years. The chart below shows the distribution of the 428 50MW or larger pulverized coal plants in the US[4].



As the chart shows, 77.3% of the plants are older than 35 years. Only 22.7% of the plants are less than 35 years old. 44.6% of the US pulverized coal plants larger than 50 MW are more than 50 years old. Most of the older plants do not comply with emissions regulations for sulfur, mercury, and NOx and are facing expensive retrofits to their flue gas cleaning systems.

[4] Data is from the EPA Emissions & Generation Resource Integrated Database (eGRID), February, 2014. Distribution modeling is done with Palisade @RISK software.

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In the examples that follow, we assume that any coal plant that is converted to use pelletized biofuel is at least 35 years old and therefore fully paid off. This will impact the total cost of generation.

There are four broad components that add up to the total cost of generation: the amortized capital cost to build the plant, the fixed and variable operations and maintenance (O&M) costs, the capacity factor, and the fuel cost.

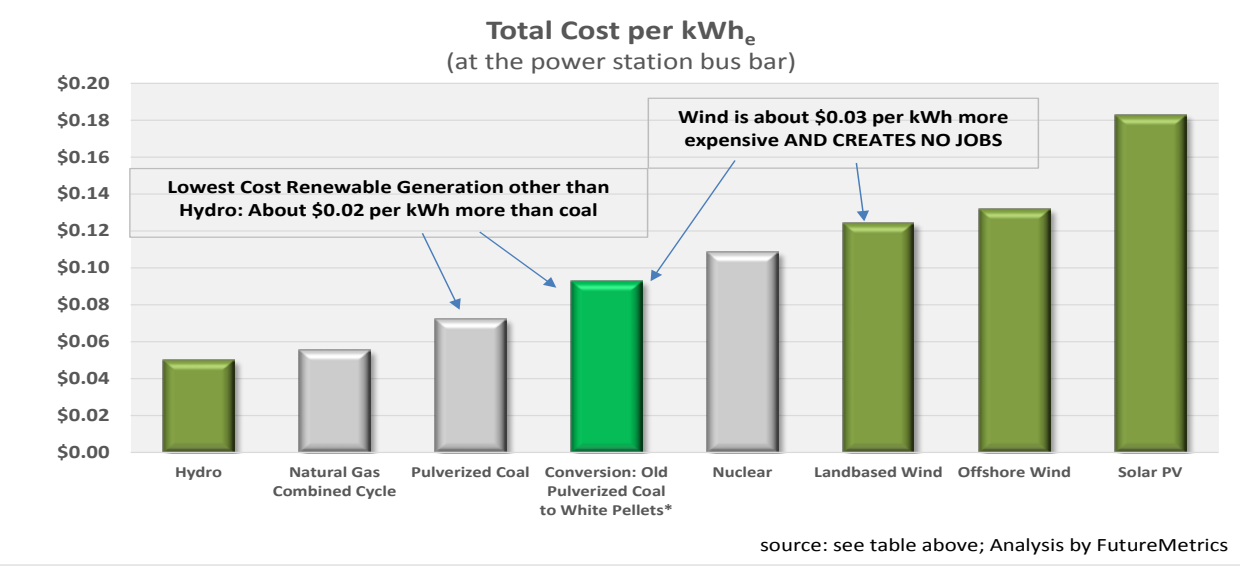
Capacity factor strongly impacts the costs per MWh of electricity generated (MWhe). Capacity factor is the ratio of actual power production to the theoretical maximum if the plant were to run at 100% of its nameplate 365 days a year. Wind and solar PV have low capacity factors so the amortized capital cost and O&M cost burden on each MWh of electricity produced is much higher.

The table and chart on the following page shows the analysis. The table and chart below do not recognize the benefits of renewable energy certificates (RECs).

Green shading for renewable solutions			Capital Costs amortized over	35 years		Utility Natural Gas at $5.50 per MMBTU	Coal at $60 per ton	Coal at $2.72 or per GJ	Pellets at $145 per ton	Pellets at or $8.79 per MMBTU	Pellets at or $8.33 per GJ
				at	10.00%	Pellet Gross Energy =>			8,200 BTU/lb.	17.4 GJ/MT	
	Construction or Conversions for Coal Plant per kW	Size (MW)	Capacity Factor	Install Cost	Annual Capital Cost Amortization	Annual Output (MWh_e)	Fixed Capital Cost per MWh_e	Fixed and Variable O&M per MWh_e	Fuel Cost per MWh_e	**Total Cost per MWh_e (at the power station bus bar)**	(Assumed Power Plant Efficiency)
Hydro	$ 3,500	1000	90.0%	$ 3,500,000,000	$ 362,913,968	7,884,000	$ 46.03	$ 4.10	$ -	**$ 50.13**	
Natural Gas Combined Cycle	$ 1,230	580	90.0%	$ 713,400,000	$ 73,972,236	4,572,720	$ 16.18	$ 1.70	$ 37.53	**$ 55.41**	38.0%
Pulverized Coal	$ 3,100	500	90.0%	$ 1,550,000,000	$ 160,719,043	3,942,000	$ 40.77	$ 5.60	$ 25.75	**$ 72.12**	50.0%
Conversion: Old Pulverized Coal to White Pellets*	$ 650	500	90.0%	$ 325,000,000	$ 33,699,154	3,942,000	$ 8.55	$ 5.50	$ 78.92	**$ 92.97**	38.0%
Nuclear	$ 6,400	1125	90.0%	$ 7,200,000,000	$ 746,565,877	8,869,500	$ 84.17	$ 11.80	$ 12.50	**$ 108.47**	
Landbased Wind	$ 2,350	50	25.0%	$ 117,500,000	$ 12,183,540	109,500	$ 111.27	$ 13.00	$ -	**$ 124.27**	
Offshore Wind	$ 3,230	50	35.0%	$ 161,500,000	$ 16,745,887	153,300	$ 109.24	$ 22.80	$ -	**$ 132.04**	
Solar PV	$ 4,340	100	30.0%	$ 434,000,000	$ 45,001,332	262,800	$ 171.24	$ 11.40	$ -	**$ 182.64**	

*Assumes CAPEX is only for the conversion since the plants are over 35 years old and all installed CAPEX costs have been recouped.

Source of Data: "Levelized Cost and Levelized Avoided Cost of New Generation Resources in the AEO", 2014, EIA, April 2014; "Cost and Performance Data for Power Generation Technologies", Prepared for NREL by Black & Veatch, February, 2012; Analysis by FutureMetrics

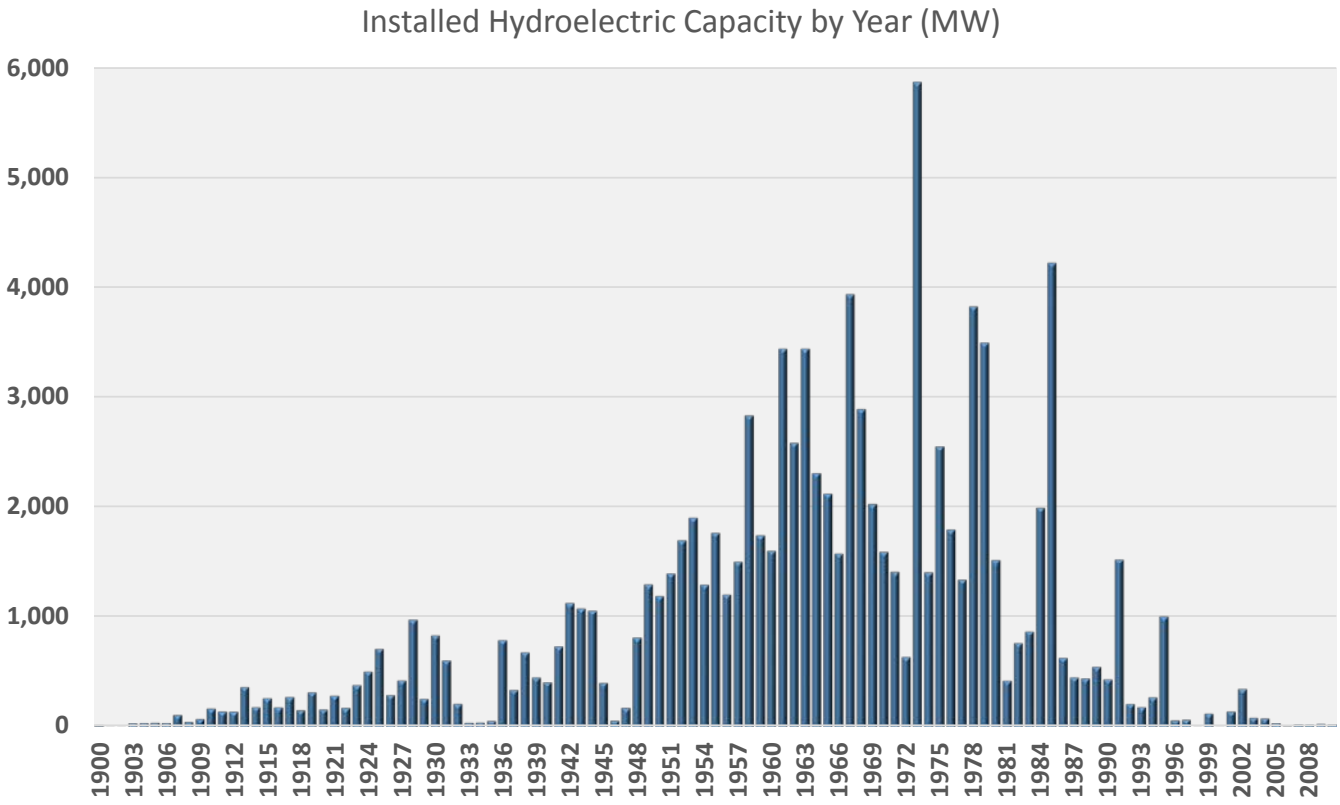


source: see table above; Analysis by FutureMetrics

The table shows the assumed costs for each fuel[5]. For pelletized advanced biofuel, the assumed cost per short ton is $145 (about $160 per metric tonne)[6]. At that price, pelletized biofuel is 3.06 times more expensive than coal per unit of energy in the fuel.

Fuel cost is not the only significant component of the total cost of generation. If it were, then wind and solar, with free fuel, would provide cheap electricity. For wind and solar PV, with low capacity factors, the amortized fixed capital cost component is higher than any of the fuel costs for the thermal generation technologies.

Thus, although pelletized biofuel is 3.06 times more expensive than coal, the total cost of generation with pelletized fuel is only 1.29 times higher than coal. Other than hydro, pelletized biofuel is by far the lowest cost renewable baseload or peaking solution for power generation. Hydro, while low cost and renewable, has been almost fully exploited in the US and/or is not available in many locations.



Source: EIA Annual Electric Generator Report, 2014, Analysis by FutureMetrics

If the power plant converts to waterproof "black" biofuel, the conversion cost is much lower. More than 50% of the capital cost for conversion from coal to white pellets is for dry storage and dust/explosion control[7]. Eliminating the capital cost for dry storage lowers the total cost of generation for waterproof pelletized fuel by about $5.00/MWHe. The assumption is that the waterproof black pellets cost the same per unit of energy as white

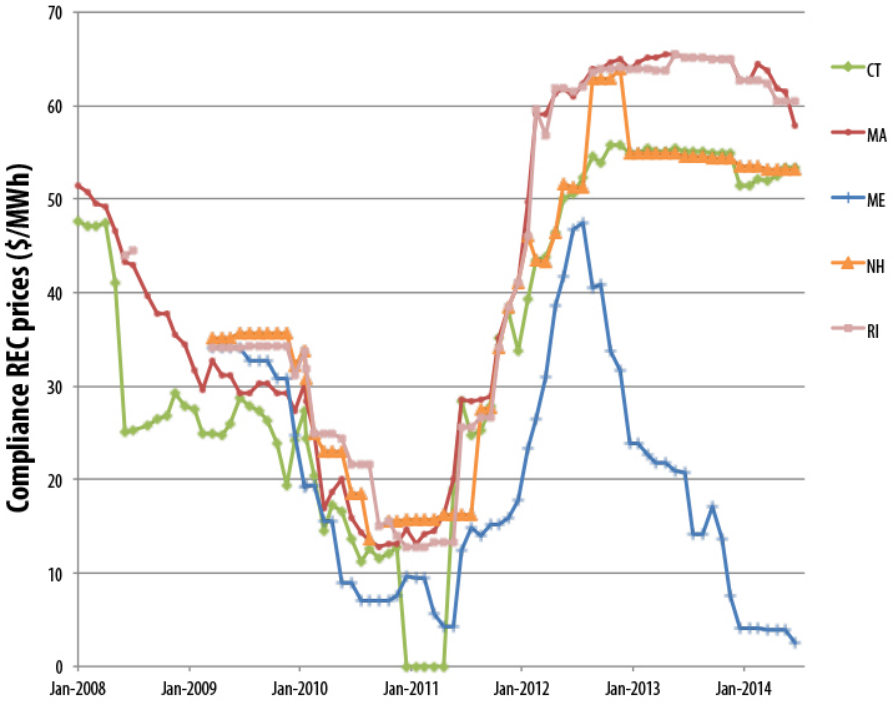
[5] Based on EIA data, October, 2014.

[6] This is slightly higher than the current FOB price for industrial pellets shipping from North American ports to the UK and Western Europe. Source: Argus Biomass Markets, October 29, 2014. Since producers can get pellets on the ship for $145/ton FOB (which includes $10-$15 of port storage and loading costs) the assumption is that rather than rail the pelletized fuel to a port and also incur port storage and ship loading costs, they can rail the fuel to a power plant for the same FOB price.

[7] Data on conversion costs from OPG and Drax projects.

pellets. In the table above the cost per GJ is $8.33. Assuming that the waterproof black pellets contain 21.0 GJ/MT, the price would be $35 per short ton higher or $170 per short ton.

The analysis does not include the benefits of the RECs. Compliance REC prices vary with markets but have traditionally traded in the range of $10 to $60 per REC (or per MWhe generated). The chart below shows pricing history for the New England states[8].



Based on the assumptions in this analysis, REC prices exceeding $20 will put generation costs from pulverized pellets on par with pulverized coal.

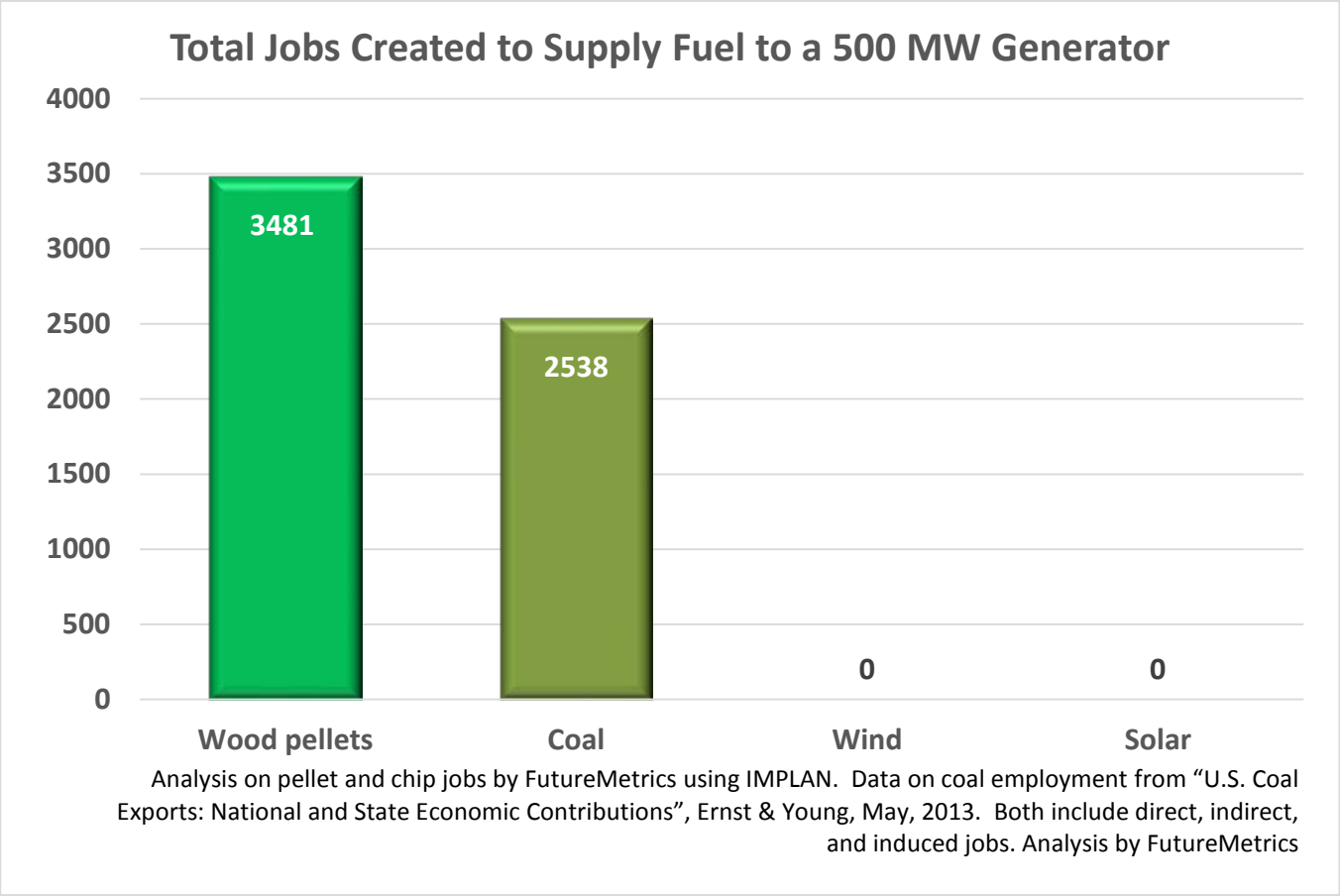
Job creation or destruction?

Pelletized biofuel is 3.06 times more expensive than coal for a reason. The supply chain requires more labor.

Every one million tons of pelletized fuel produced creates and sustains over 1800 jobs in the harvest, raw material transport, conversion into the refined and densified form, and transport to power plants. For each million tons of coal produced, 1320 jobs are created[9]. Coal energy content varies by type and moisture content. On average, a ton of coal has about 1.2 times more energy than a ton of white pelletized biofuel. Both the lower energy density and higher cost of production for the refined and densified biofuel means that **the number of jobs necessary to get the same energy to the power plant is higher for pelletized biofuel versus coal**.

[8] From the US Dept. of Energy, 2014.

[9] Analysis on pellet jobs by FutureMetrics using IMPLAN. Data on coal employment from "U.S. Coal Exports: National and State Economic Contributions", Ernst & Young, May, 2013. Both include direct, indirect, and induced jobs.



Analysis on pellet and chip jobs by FutureMetrics using IMPLAN. Data on coal employment from "U.S. Coal Exports: National and State Economic Contributions", Ernst & Young, May, 2013. Both include direct, indirect, and induced jobs. Analysis by FutureMetrics

Converting from pulverized coal to advanced solid biofuel will have a significant positive net job impact in the fuel supply chain.

The typical argument against renewable power solutions such as wind and solar is that they will result in a higher electricity price and that this will harm industry and consumers. As the analysis above shows, wind and solar generation does result in significantly higher power prices than power generated from advanced solid biofuels; and wind and solar are a generation pathway that require no labor for fuel provisioning.

Conclusion

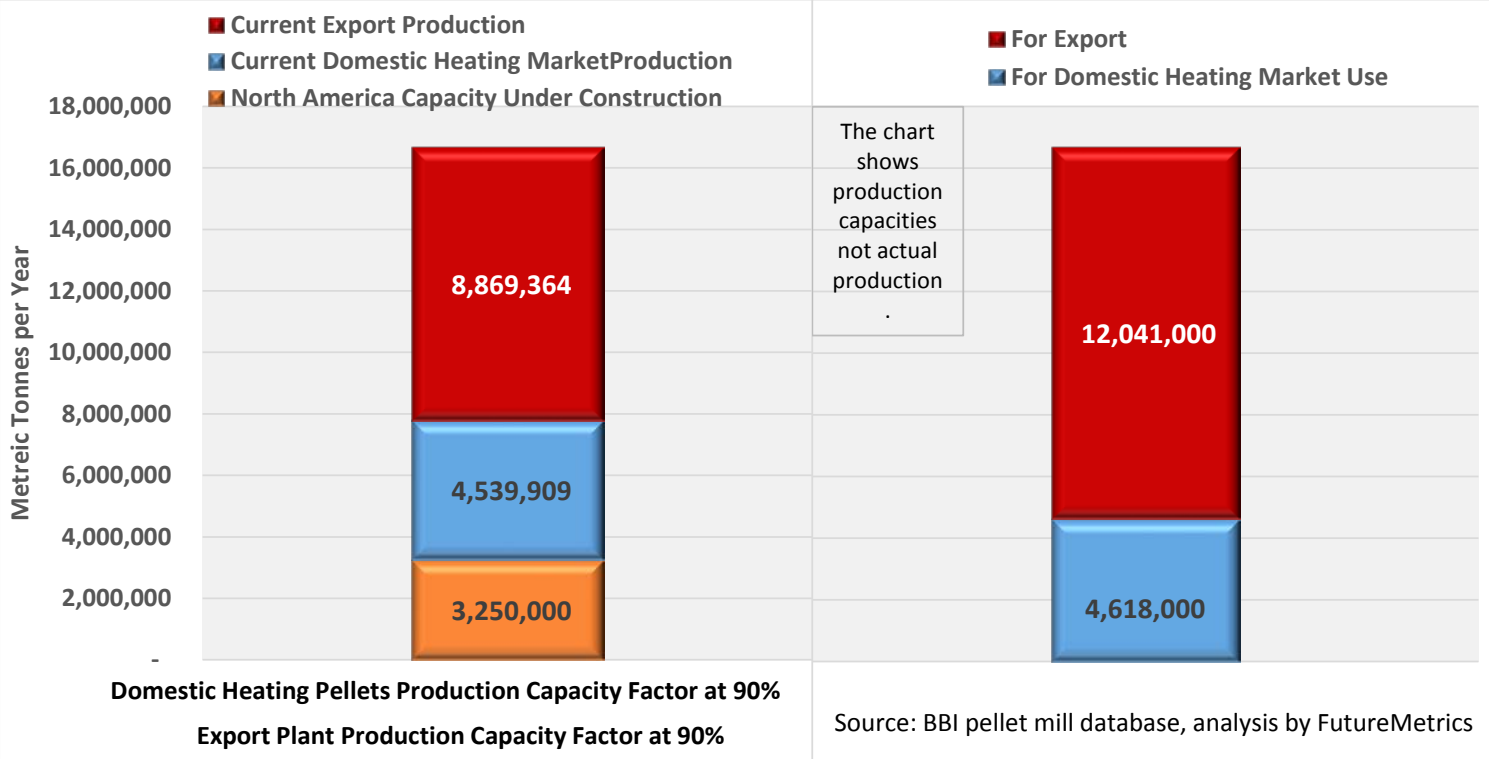
The best solution for new renewable power generation that has baseload and peaking characteristics is from converting older pulverized coal plants from coal to renewable low carbon advanced solid biofuel. Although the low carbon characteristics of this strategy currently have almost no tangible monetary benefit for US generators, the renewable characteristics do.

When there is a carbon policy in the US at some point in the future, the generators will have a built-in benefit. For every MWhe not generated by coal, on average, about 1400 pounds of CO_2 is not emitted. For a 500MW power station, that adds up to about 3,350,000 tons per year.

It is unlikely that wind and solar will solve the intermittency problem in the short to medium term. Even if large power storage solutions are developed, they will incur new capital costs that will have to be amortized over another 35 years; and that will add to the total cost of generation which is already very high. There is no way to change the intermittency of wind and the fact that the sun never shines at night. Conversion of older coal plants is a renewable solution to intermittency.

White pellet supply chains are well established. The quantity of power that can be generated by pulverizing renewable advanced solid biofuel is limited to the sustainable quantities of renewable woody biomass. The stock of trees in the working forests cannot be depleted. However, within that sustainability boundary, a significant proportion of older pulverized coal plants can be converted.

By mid-2015, North America will have the capability to produce and export more 12 million tons per year of white pellets for power plants in the UK, Europe, and South Korea.



Many new pellet manufacturing projects could be developed if the demand were to increase. There is no shortage of sustainable, and therefore forever renewing, feedstock in the traditional fiber baskets of the US and Canada. And with the ongoing changes in paper demand, more and more wood will be available to be converted into advanced solid biofuels from the working forests that are managed to produce new feedstock forever.

This is a strategy that does not need R&D, does not need massive subsidies, and does not need any significant new infrastructure.

Right now there is a low cost, reliable, ready to deploy, renewable solution to our peaking and baseload power demand that will result in the creation of more jobs than any other power generation technology.