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Advanced Biomass Solutions for Coal Substitution in Power Generation

Optimizing carbon-beneficial coal replacement for power generation when white pellets are not optimal

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Overview of "Black" Pellets and the Process Characteristics of Torrefied and Steam Treated Pellet Fuels

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Cost analysis normalized for energy output

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Financial analysis, including sensitivity to changes in critical inputs

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Conclusions on suitability and economic competitiveness

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Acknowledgements and Disclaimers

This report would not be possible without the cooperation of the four black pellet technology providers reviewed herein.

TSI, Airex, Valmet, and Arbaflame provided FutureMetrics with data that allowed FutureMetrics to perform the analysis and create the opinions that are in this report.

The data that is shown in this report is with the explicit permission of TSI, Airex, Valmet, and Arbaflame.

Any reference to capital costs are high-level estimates by FutureMetrics that are within a wide range of potential values. They do not represent offers by the technology providers.

The objective analysis in this report is by FutureMetrics. The opinions in this report are those of FutureMetrics.

FutureMetrics does not endorse any particular technology provider or project developer. There are many other black pellet technology providers that are not included in this report. This does not imply that all of those technology providers are inferior.

Table of Contents

List of Figures and Tables

Glossary

ACFM	Actual Cubic Feet per Minute
BTU	British Thermal Unit
CAPEX	Capital Expense
CCR	Conductive, Convective, and Radiative Heat Losses
CO	Carbon Monoxide
CV	Caloric value
EFB	Empty Fruit Bunches
GJ	GigaJoule
GJ/h	GigaJoule per hour
GOP	Gross Operating Profit
HHV	Higher Heating Value
HMF	Hydroxymethylfurfural
kt p.a.	Kilotonnes (metric) per year
kW	Kilowatt
kWh	Kilowatt hour
lbs	British pounds = 454 g
LHV	Lower Heating Value
ME	Mass-Energy Balance
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
MW	Megawatt
MWh	Megawatt hour
OPEX	Operation Expense
POO	Point of Origin
POU	Point of Use
RFQ	Request for Quote
RTO	Regenerative Thermal Oxidizer
SB	Spruce Bark
SCADA	Supervisory, Control, and Data Acquisition
SE	**S**team treated with rapid **E**xpansion
t	Metric tonne (any ref. to tonnes is always metric)
t p.a., t/y, t/yr	Metric tons per year
WIP	Work-inProgress Inventory
WWT	Wastewater treatment system

Abstract

To get closer to committed GHG emission targets many countries have policies that either mandate an end to coal in power generation or penalize CO_2 emissions to the level at which switching from coal to renewable bioresources-derived solid fuel (typically pellets) is the lowest cost.

The preferred renewable power generation technologies, wind and solar PV, have a fundamental shortcoming; they cannot be turned on when needed, but only when the wind blows or the sun shines. Traditional power plants can be turned on or off based on demand.

As conventional coal plants often have many years of economically useful life, power generators can offer a carbon-beneficial solution to the intermittency and variability of wind and solar by substituting coal with a solid fuel produced from refined and upgraded renewable biomass. Biomass from forest residues (such as branches, parts of the harvest that are unsuitable for lumber or pulp), and sawmill residuals are the typical sources of the pellet fuel manufacturing feedstock. The inherent heating value is good enough, and the halide and ash content are typically low enough to offer an attractive alternative to coal.

Exploration of other bioresources such as straw, grasses, bagasse, corn stover, and agricultural waste streams is underway. However, as woody biomass is the easiest to use as a coal substitute, we will focus on that.

We base our analysis on assuming biomass sourcing strictly complies with sustainability criteria. The basic necessary condition for sustainability is that the harvest rate is less than regrowth rate. Under those circumstances, ligno-cellulosic biomass is carbon-neutral in combustion[1].

Using wood chips directly poses several problems. Woodchips have low volumetric energy density (high transportation costs). However, the major issue is that woodchips cannot be used in pulverized coal (PC) power boilers[2]. The solution is to use dried and densified finely milled wood fiber. The end product is typically in the form of pellets.

[1] FutureMetrics has many white papers and a few interactive dashboards on this topic. They are free download and use at the FutureMetrics website.
[2] PC power stations represent more than 95% of all utility scale power units. (source: Global Energy Monitor, Global Coal Plant Tracker, April 2024 Supplement release). Undried wood chips cannot be run through the power station's coal pulverizing mills and thus they cannot provide the fine particle size distribution needed by the PC station burners.

So-called "white" pellets[3] have a significantly higher energy density than wood chips. The particles they are composed of are sufficiently small to allow co-firing with coal or for use in a 100% conversion to pellets. Use of white pellets at ratios above ~10% will likely require that the burners and the fuel preparation and conveyance systems are modified.

The most significant challenge is the requirement for dry storage; white pellets disintegrate when exposed to water and lose their functionality. If a power generator wants to use them, they must invest substantially into dry storage facilities.

Fortunately, thermal treatment options that yield so-called "black" pellets bestow water resistance, higher volumetric energy density, and improved grindability to the product.

For some utility-scale pulverized coal (PC) power stations, black pellets may be the optimal choice[4] for replacing coal with carbon-beneficial solid fuel that is compatible with their fuel handling and fuel combustion design.

Torrefaction or steam treatment followed by rapid explosive decompression (thus the often called "steam explosion" pellet and referred to in this report as SE) are the two fundamental technologies suitable for producing black pellets. Both technologies are ready for commercialization from some technology providers.

As will be seen in the main body of this report, this FutureMetrics analysis finds that torrefaction's ability to produce a product with higher carbon content than SE has unique value for producing a substitute for geological carbon as a reductant used in the CO_2-intensive steelmaking process, or for biochar production (or other applications that require high fixed carbon). The report finds that SE is more suitable than torrefaction for producing a coal substitute for power generators.

The conclusion of this report that torrefaction is usually not the optional replacement for coal in power generation is not intended to suggest that torrefied products do not have a critical role in the transition to a decarbonized future. The International Biomass Torrefaction and Carbonization Council[5] (IBTC) "promotes sustainably produced torrefied or carbonized biomass on a global scale to efficiently replace fossil coal in all industries and applications or to permanently sequester atmospheric carbon into the soil." Torrefaction/carbonization is an important component in a portfolio of solutions for mitigating CO_2 levels in the air and oceans.

[3] They are called white pellets because the pellet's color is more or less the same as the wood it was made from. Black pellets have experienced some form of thermal treatment and have a dark brown to black color
[4] See the FutureMetrics white paper that provides a detailed analysis of when and why black pellets are the optimal choice HERE
[5] https://www.ibtc-council.org/ Note that IBTC has recently added the word "carbonization" to their name. This reflects a shift in their strategic focus toward the use of highly torrefied woody biomass as a carbon beneficial substitute in industries that use fossil fuel carbon, or for use as "biochar".

Due to the higher mass loss in the torrefaction process, typically 25-30%, and an energy loss of 12-15%, compared to the 10-12% mass loss and 5-8% energy loss from steam treatment, steam treatment is the more economical solution to power generator needs in terms of cost to produce a gigajoule (GJ) of delivered energy and still provide the beneficial characteristics that black pellet offer over white pellets.

The higher mass and energy losses with torrefaction result in the need for more tonnes of input to produce GJ's or MWh's of energy in the final pelletized output. This is illustrated in the following example. Table 1 below shows the calculation of annual wood costs for a hypothetical pellet factory for making white, SE, or torrefied pellets. The mass and energy losses and resulting GJ/tonne are calculated from these inputs.

For a 600 MW power station that runs at a 50% capacity factor, the cost of wood to produce the same energy input to the power station is about US$9.85 million per year higher for torrefied over SE. This is wood cost only. It is not the final delivered cost of the pellet fuel.

Generic Pellet Factory Feedstock Calculation	Pellet Moisture Content (MC) =>			6%	Mass Loss =>	0%	12%	30%
In US$					EnergyLoss =>	0%	6%	15%
	Annual tonnes	MC (Avg)	Price per Green Tonne	Bark (% of Roundwood)	Bark	White Pellets at 6% MC	SE Pellets at 6% MC	Torrefied Pellets at 6% MC
Sawdust	89,000	55.0%	$35.00	0%	-	45,000	40,000	32,000
Green Chips	178,000	50.0%	$38.00	0%	-	100,000	88,000	70,000
Planer Shavings	59,000	12.0%	$50.00	0%	-	55,000	48,000	39,000
Roundwood	89,000	50.0%	$32.00	10%	8,900	50,000	44,000	35,000
Total =>	**415,000**			**Totals=>**	**8,900**	**250,000**	**220,000**	**176,000**
	Weighted Avg=>	**45.7%**	**$37.78**	**Tonnes of Input per Tonne of Pellets =>**		**1.66**	**1.89**	**2.36**
			Wood Cost per Tonne of Pellets =>			$62.71	$71.26	$89.07
			Gigajoules (GJ) per Tonne =>			17.5	19.1	21.5
			Wood Cost per GJ =>			$3.58	$3.73	$4.15
			MWh's per Tonne =>			4.86	5.31	5.97
			Wood Cost per MWh =>			$12.90	$13.43	$14.93
			Biochemical Recovery? =>			No	Yes	No

Estimated Annual Wood Cost to Supply a 600 MW Station		
Approximate Total MWhs Produced at 50% Capacity Factor =>		2,628,000
Gross MWh Input assuming 40% Efficiency =>		6,570,000
White Pellets at 6% MC	SE Pellets at 6% MC	Torrefied Pellets at 6% MC
$84,750,000	**$88,240,000**	**$98,090,000**
Annual Wood Cost Increase over White Pellets		
$0	**$3,490,000**	**$13,340,000**
Annual Wood Cost Increase over SE Pellets		
	$0	**$9,850,000**

Table 1 - Wood Demand and Wood Cost per GJ and MWh for White, SE, and Torrefied Pellets

White pellets have the lowest annual cost of wood for the same delivered energy. But white pellets require that the power station invest in a large dry storage solution. For the hypothetical 600 MW station running at 50% capacity factor, a three-week supply of white pellet fuel is about 78,000 tonnes (see the June 2024 FutureMetrics white paper and dashboard on storage challenges for low capacity factor power stations free to view and use at the FutureMetrics website) . The amortized cost of the domes or silos spread over the relatively low number of MWh's generated at the 50% capacity factor may yield a lower net cost per MWh generated with the waterproof pellet fuel (see footnote 4 for a link to a FutureMetrics white paper discussing the white/black pellet decision algorithm).

For power stations for which higher-priced pellet fuel that can be stored in the open (and has other beneficial characteristics discussed in more detail below) is the optimal choice, this analysis concludes that since torrefied pellet cost per GJ is higher than for SE pellets without incremental benefits to the power station, the power plant owners/operators will likely choose SE pellets.

Therefore, most of this report about replacing coal in power generation is about SE pellets.

This report will summarize torrefaction and will discuss in detail the merits of two different SE technologies. We will compare technical and economic parameters under comparable conditions. In all cases, the black pellet product is suitable as a direct coal replacement without needing dry storage and requires only modest, and in some cases, no modifications to the burner and pulverizer systems.

We will discuss under what circumstances a continuous steam treatment process, as Valmet offers, or a batch process as provided by Arbaflame has distinct advantages. In both SE cases, the considerations include an attractive secondary revenue (and profit contribution) from reclaimed biochemicals from the steam treatment condensate.

We analyzed two torrefaction scenarios and two steam treatment scenarios from a technical perspective, including commentary on relative safety and robustness, and from an operational and economic perspective to help inform some strategic decisions[6].

We only looked at technologies that densify the product before pelletization to minimize transportation costs and potential pulverizer throughput constraints[7].

FutureMetrics has analyzed the suggested solutions from a techno-economic perspective, including safety aspects, operational aspects such as maintenance and equipment uptime, and the likely ability of the companies to promptly offer spare parts and services as needed.

This report is informed by several previous FutureMetrics in-depth studies of SE and torrefaction technologies and has been updated with contemporary input from technology providers.

We provide an economic comparison between pellets made with black pellet manufacturing technologies and white pellet manufacturing made under the same cost assumptions for feedstock, labor, external energy, and financing.

This report may help narrow the search, save time and cost, help choose the most robust technology, and minimize the potential for unexpected outcomes.

Before a specific black pellet plant project is approved, the models should be updated with the project-specific actual inputs to make the best decision and set correct expectations.

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[6] FutureMetrics is well-qualified to offer assistance and advice regarding the supply chain dynamics, market forecasts, and project execution.

[7] There are applications where torrefaction after pelletization (TAP) may make sense. The low bulk density of the TAP product precludes most longer distance transport. TAP to a high carbon content would appear to be a good pathway for a steel mill if the TAP plant is located next to or very near the steel mill.