FutureMetrics™ LLC
8 Airport Road
Bethel, ME 04217, USA

Pellets Version 2.0 will Lower the Barriers for Pellet Fuel as a Coal Substitute in Utility Power Stations

Innovation yields products that are improvements on previous versions. It is time to move on to version 2.0 of wood pellets.

July 5, 2021

By William Strauss, PhD, President, FutureMetrics

Laurenz Schmidt, Senior Technologist, FutureMetrics

Version 1.0 of wood pellets, i.e., so-called “white” pellets, have been unchanged for decades. While the manufacturing of pellets has experienced incremental improvements that yield better process reliability, better product consistency, improved plant safety, and lower conversion costs per tonne, the final product is essentially the same today as it was 40 years ago.

This is surprising because white pellets have several inherent challenges that have to be managed for them to be used as a low-carbon fuel in large utility power stations. At the top of the list is their inability to withstand exposure to water. They also create fines when handled at every stage in the supply chain, often producing highly explosive dust. The 23 million metric tonnes of industrial white wood pellets that will be transported in 2021 need to be kept dry and require robust dust management (aspiration and filtration) systems when handled.

These challenges are mitigated with significant capital costs along the supply chain. The exporting port has to have covered storage with sufficient volume to store the equivalent of a shipload. The power stations have had to build large fuel storage domes or silos. The costs of this dry storage infrastructure are significant.   It contributes to about half of the total cost of the plant modifications needed to switch from coal to pellet fuel at the power station.

The promise of more advanced pellets has been around for at least two decades. So-called “black” pellets that do not lose their integrity when exposed to water have not, to date, gained significant market share.

This is despite other added advantages of black pellets. They have a higher bulk and energy density and thus are closer to coal in terms of gigajoules per tonne (GJ/t). Both their volumetric and gravimetric energy densities are higher than those of white pellets. More energy per cubic meter results in lower logistics cost per delivered GJ. They are harder and more brittle, resulting in better compatibility with the fuel pulverizers at the power station. Higher bulk and energy density and better grindability result in the need for fewer modifications to the fuel feeding and burner systems of the coal-fueled power station in order for pellet fuel to substitute for coal.

Black pellets promise to eliminate the need for dry storage at both the exporting port and at the power plant, lower logistics costs per delivered unit of energy, and lower the modification costs at the power station.

Over the past few decades, two primary technological pathways to advanced "black" pellets have been followed: (1) torrefaction and (2) steam explosion (SE).

The torrefaction pathway has been more popular but has also resulted in a history littered with failed projects. There are two primary reasons for the torrefaction project failures.

First, some of the torrefaction systems were unable to meet expected operational levels (output, consistency of product, operating/maintenance costs, and safety). Some torrefied pellets did not offer the advantages of water resistance[1] and/or low dust creation in handling. That history of failures may change as there are currently several torrefaction projects around the world that may overcome these challenges.

The SE pathway has not seen a history of project failures due to shortcoming in operational reliability or in the characteristics of the final product. The SE process yields pellets that can be reliably and safely produced, are water resistant, and are brittle. SE pellets produce very little dust when handled and they grind easily in the power plant's pulverizing mills.

But the second and universally common reason for both SE and torrefied pellets failing to take market share from white pellets has been that the total costs to produce black pellets has resulted in an inability to compete on the price of delivered energy ($/GJ) with white pellets.

Generally, SE projects have the same challenge as torrefaction projects in terms of offering a pellet at a competitive price.

The primary cost challenge with black pellets is that there is a significant loss of solid mass during the thermal reactions resulting in an energy loss from the initial calorific value of the dry feedstock[2]. Whereas with white pellets, every dry tonne[3] of wood fiber that is fed into the manufacturing process becomes pellet fuel, the thermal treatments of the wood fiber cause some of its solid constituents to become gasses. As a result, the output tonnage of solids on a dry basis (pellets) is less than the input tonnage on a dry basis (wood fiber). The reaction gas contains potential energy which is removed from the solids that become pellets. Thus, the output GJ of the solids (eventually pellets) is lower than the input GJ. These factors raise

---

[1] There is a recently approved ISO standard for measuring pellet water resistance. ISO 23343-1 is for the determination of water sorption and its effect on durability in thermally treated biomass fuel pellets.

[2] Mass loss for torrefaction varies by technologies and by the operating temperature of the reactor and the residency time of the wood in the reactor. On average the solid mass loss is about 25%. For SE the solid mass loss is about 13%. The corresponding energy losses are 10-12% and 5-6%, respectively.

[3] Wood is typically delivered to a pellet factory with a high moisture content. Most of the water in the wood is removed in all pellet processes (white and black). A dry tonne (often called a "bone dry tonne" or BDT) normalizes the mass for comparisons.

the “cost of goods” of black pellets versus white pellets by amounts that are related to the mass and energy loss percentages in footnote 2.

In a torrefaction pellet manufacturing plant, the gas is commonly combusted and used as fuel for heat energy. While there is value in using the gas for heat energy (essentially the avoided cost of fuel for the dryer and/or the torrefaction reactor), it is a low value compared to the market price of pellet energy.

In SE the mass loss is a mix of volatile compounds that, instead of existing as hot gases, are entrained in the steam and subsequent aqueous condensate. That condensate has traditionally been sent to a wastewater treatment system to digest the biochemicals and purify the water for discharge. Some methane is produced and used to supplement dryer fuel. While the mass loss is lower with SE versus torrefaction, the net cost of wastewater treatment added to the handicap of the increased wood cost per tonne of SE pellets versus white pellets.

Black pellets may be able to be priced at a modest premium over white pellets as the cost of using them is lower than with white pellets. There is some moderate monetary benefit to improved logistics costs. Also, avoiding the need to construct dry storage solutions removes a significant capital expense (CAPEX) for future power plant conversions to pellet fuel. However, power plants currently using white pellets have already sunk the cost into the dry storage solution and thus have no CAPEX benefit. In general, the monetary value to the end user of the benefits of black pellets has not been sufficient to justify their use over white pellets at the price needed by the black pellet producer to support a profitable black pellet factory.

There are some exceptions. Where the end-user can afford higher cost black pellet fuel[4], SE or torrefied pellets may be preferred.

But over the years, for the reasons outlined above, both torrefaction and SE not been able to break through to produce pellets 2.0 in any significant volumes for the power generation sector.

There is a solution to the solid mass loss and energy loss cost disadvantage.

The solution is to gain value from the mass loss.

The compounds produced in both the SE and torrefaction reactions have a market value that is much greater than the calorific value when they are used as fuel for dryer heat.

---

[4] For example, super-peaking power plants that operate at low capacity factors are well suited for higher cost fuel. They typically operate when power prices are high. Also, because they produce far fewer MWh’s per year, if they invest in dry storage, the amortized CAPEX burden is much higher per MWh. The Ontario Power Generation station in Thunder Bay Ontario ran exclusively on SE pellets for many years until its retirement. That plant ran on average only about 10 days per year. District heating systems that use coal that are decarbonizing may benefit from black versus white pellets.

As has been proven at scale, off-the-shelf technology can extract the valuable biochemicals from the SE reaction's condensate[5]. The ~13% solids mass loss from the SE process is primarily converted to acetic acid, formic acid, methanol, acetone, and most importantly, furfural. These compounds are entrained in the steam after the thermal treatment.

The steam is condensed, and the condensate is sent to a distillation system that removes furfural, and smaller amounts of methane and acetone. The acetic and formic acids are not economical to recover and are digested to produce biomethane for heat. The heat of condensation is recycled back to the pre-dryer. Furfural is a high-value green chemical[6] that has many uses and sells in the range of US$1,700 to US$2,300 per metric tonne. Furfural is a globally traded commodity with a robust CAGR expected. Currently China is the major exporter of furfural produced from agricultural residues.

For an SE plant that produces 184,000 tonnes per year of pellets, the expected annual furfural yield is about 1,960 tonnes. Assuming an FOB price of $1,800/tonne for the furfural, the net result is the equivalent of an additional US$17.90 net contribution per tonne of SE pellets produced[7].

BioChem Summary of Operating Cash Flows	$Millions per Year	Per Tonne of Pellets Equiv.
Biochem Revenues with furfural at $1,800 /MT	$3.93	$21.37
Total Biochem OPEX	$0.64	$3.48
Net Contribution	$3.29	$17.90

The time, pressure, and temperature of the steam treatment can be altered to maximize furfural production if higher furfural yield optimizes net cash flows.

The hydrolyzation of the hemicellulose in the woody feedstock into sugars and subsequent thermal dehydration of the sugars[8] is what produces the furfural during the thermal treatment. The conversion of the hemicellulose in the wood fiber leaves behind solids (cellulose and lignin) that are more hydrophobic that those comprised of non-thermally treated wood.

---

[5] Arbaflame has built and is operating a commercial scale plant in Norway that produces SE pellets and biochemicals. See HERE.

[6] There are possible ways to improve the value of furfural. Modifications to the process can yield either 5-(Hydroxymethyl)furfural or 5-(Chloromethyl)furfural. Both have a higher value than furfural itself and can be used as chemical platforms. The economics of the modified process needs to be calculated in detail. Easy to manufacture derivatives of the produced furfural, such as 2-Methyltetrahydrofuran and 1,5-Pentanediol also have higher market value than furfural.

[7] Based on data from Arbaflame and modeling by FutureMetrics.

[8] Hemicellulose is comprised of diverse sugars. See HERE,

In theory, torrefaction gasses can also be processed to yield furfural[9]. Torrefaction is a dry process. Most of the water contained in the green feedstock has been evaporated in the dryer prior to the torrefaction reactor. Thus, the hemicellulose may hydrolyze into sugars to a lesser degree and not yield as much furfural as the SE process does. However, to date FutureMetrics has not found any historical or current torrefaction project that does employ biochemical production. It may or may not be economical to extract biochemicals from torrefaction gas. Torrefaction gasses, when relatively cool, condense into viscous tars that may complicate the process.

Summary

Manufacturing plants all over the world are already producing a refined renewable low-carbon solid fuel that can replace coal as part of the decarbonization of the power sector. In 2021 about 23.3 million tonnes of white pellets will be used[10]. Robust future growth will, in part, depend on lowering the cost of both the power station modifications and the fuel itself.

Advanced thermally treated pellets can offer characteristics that significantly lower the capital cost and the time needed to modify an existing pulverized coal power station.

With biochemical extraction, the heretofore solids mass loss handicap is eliminated. The net value added from the biochemical offtake agreement can allow the black pellets to be competitively priced while still producing a competitive return to the investors and operators.

Enhancing this scenario are the potentials of optional biochemical production from other feedstocks. For example, feedstocks with higher natural sugar content, such as sugarcane bagasse, may yield higher furfural production.

Perhaps it is time for pellets version 2.0 to break through!

[Note: FutureMetrics has detailed studies available on torrefaction and SE.]

---

[9] Patrick Bergman, currently with Yilkins, is a pioneer in developing torrefactions systems. Patrick reported to FutureMetrics that he wrote a memo in about 2007 noting that biochemical extraction from the torrefaction reaction gasses may be economically optimal.

[10] FutureMetrics has a free to use mapping application on its homepage that allows the user to view international wood pellet trade flows. https://www.futuremetrics.com/