Wood Pellets
How a simple solid fuel is an important component of a pathway to a more decarbonized future

Presented by William Strauss, PhD
President, FutureMetrics
Consultants to the World’s Leading Companies in the Wood Pellet Sector

Selection of Current and Recent Clients
Dr. William Strauss, President

Named one of the most influential leaders in the biomass sector in 2016 and 2017 by Argus Media. Recipient of the 2012 International Excellence in Bioenergy Award.

A leader in the industry for two decades.

John Swaan, Pellet Plant Operations

Recipient of the 2014 International Founders Award.


Seth Walker, Senior Economist

A leading and often cited researcher, analyst, and author in the wood pellet sector.

Has presented at dozens of conferences throughout the world.
Overview of Global Pellet Markets
The wood pellet markets have experienced growth rates over the last few years of about 10% annually: from about 19.5 million tonnes in 2012 to about 28.6 million tonnes in 2016.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Production (metric tonnes)</th>
<th>Increase (%)</th>
<th>2012 Production</th>
<th>2013 Production</th>
<th>2014 Production</th>
<th>2015 Production</th>
<th>2016 Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>19,469,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>22,096,000</td>
<td>Increase of 13.5%</td>
<td>19,469,000</td>
<td>22,096,000</td>
<td>26,154,000</td>
<td>27,015,084</td>
<td>28,609,814</td>
</tr>
<tr>
<td>2014</td>
<td>26,154,000</td>
<td>Increase of 15.4%</td>
<td>22,096,000</td>
<td>26,154,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>27,015,084</td>
<td>Increase of 3.3%</td>
<td>26,154,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>28,609,814</td>
<td>Increase of 5.9%</td>
<td>27,015,084</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Data from Food and Agriculture Organization of the United Nations, August, 2017, Analysis by FutureMetrics.
There are two major markets for pellets:

1. **Industrial pellets** used as a substitute for coal in large utility power stations;
2. **Premium heating** pellets used in pellet stoves and pellet fueled central heating systems.
Heating Pellet Markets – Driven by Economics (lowest cost heating fuel)
Industrial Pellet Markets – Driven by Policy

Average Growth from 2010 to 2025 is 2,880,000 Metric Tonnes per Year

Source: Historical data from Argus Direct, 2017 and beyond forecast and analysis by FutureMetrics
Why Pellets for Power?
Most of the countries of the world recognize the relationship shown in the chart below.

CO₂ Released from Fossil Fuel Combustion and Global Temperature Anomalies

- Total CO₂ from Fossil Fuels - Left Axis
- Global Temperature Anomalies - Right Axis

Anomalies compared to average of 20th century

The foundation of carbon emissions mitigation from the use of wood pellets is because the **NET** carbon added to the atmosphere from the combustion of wood pellets is **ZERO**.

The foundation for zero carbon emissions is the **SUSTAINABILITY OF THE FOREST RESOURCES**.

As long as the **growth rate** equals or exceeds the **harvest rate**, the net stock of carbon held in the forest landscape is held constant or is increasing.
Managed forests provide feedstock for many industries: lumber, pulp and paper, and pellets.

Sustainably managed forests cycle CO$_2$ continuously.

The sustainability of the forests (and therefore the carbon stock held by the forests) must be certified by independent third party audits for all pellets used in power plants.
The use of upgraded densified dried sustainably produced biomass-derived solid fuel as a substitute for coal in power plants and for heating fuel in homes and businesses is a well-established option that should be included in all strategies for a rational and pragmatic transition to a more decarbonized future.
Baseload generation with almost zero carbon emissions is only possible with two low carbon fuels.

Nuclear generation provides zero carbon in "combustion".

The only other fuel that provides zero carbon in combustion and dispatchable generation is industrial wood pellets.

Drax Biomass 450,000 ton per year pellet fuel production plant.

Pellet Production

Sawdust or Chips ➔ Dry ➔ Mill ➔ Densify in Pellet Presses ➔ Cool and Condition ➔ Store ➔ Transport
With relatively low cost modifications, a typical pulverized coal fueled power station will have no loss of uptime and no de-rate.

Wood pellets are used in large power boilers that rely on pulverized coal. Wood pellets pulverize and can substitute for coal. If properly modified, there is no lost of power output or reliability.
Spot Price History for Industrial Wood Pellets

Industrial Wood Pellets Spot Price in US Dollars (CIF ARA)

Average from 2009 thru 2015, $168.81

Average from 2009 to present, $160.79

Jan-16, $151.00

Jul-14, $185.00

Oct-17, $157.43

Jan-17, $111.99

Source: Argus Biomass Report, analysis by FutureMetrics
The cost of power generated from pellets in modified or converted coal power plants is higher than the cost of power generated from coal.

If the external costs of carbon emissions are considered, then policy has to close the gap.
In the countries that are co-firing or full-firing pellets, governmental policy aimed at lowering overall carbon emissions closes the gap.

Policies include subsidies to the generators and/or the ability to avoid penalties such as carbon taxes.
At a 10% co-firing ratio, the increased cost of generation is less than a penny per kWh.

Dashboard is free to use at www.FutureMetrics.com
For example, the UK has a “contract for difference” scheme. The generator gets the current wholesale power rate and the CfD policy makes up the difference.

The net revenue per MWh is at the guaranteed rate.

As the next few slides show, this supports a significant level of low carbon reliable baseload generation from pellets.
In Q2, 2017, power from pellets in the UK produced 3.5 tWh’s of power at a capacity factor similar to nuclear.

Check out the current UK production in real time at [http://www.gridwatch.templar.co.uk/](http://www.gridwatch.templar.co.uk/)
The power generated from pellets is shown in the orange line second from the bottom. The baseload from nuclear, pellets, and imported power form the foundation upon which the intermittency and variability of wind and solar sit.

Source: Electric Insights [http://electricinsights.co.uk/#/homepage?&_k=9d4yww](http://electricinsights.co.uk/#/homepage?&_k=9d4yww)

One year of data.

Next slide shows one week.
Over one week in the UK we can see how wind and solar fluctuate dramatically. The grid needs steady reliable low-cost baseload low-carbon power.
A snapshot of the UK grid on Sept. 5, 2017 at 10am

Wind, solar, pellets, and hydro peaked at a 51.5% share of demand on June 7th at 1 PM, with a combined output of 19.1 GW. Net carbon emissions went below 100 g/kWh.

Reliable baseload power from pellets
The substitution of wood pellets for coal either by co-firing or full conversions is a rational and pragmatic solution to moving toward a more decarbonized power sector.

Leveraging existing pulverized coal plants as part of the transition to a more decarbonized future should be part of the menu of solutions.

NO OTHER SOLUTION PROVIDES THE HIGHEST REDUCTION IN CO₂ EMISSIONS FOR THE LOWEST COST.
The Cost per Tonne of Avoided CO₂ Emissions is **Lower** from a Converted Coal Plant than from a New Natural Gas Combined Cycle Plant.
Currently, the US and Canada dominate the trade in industrial wood pellets into Europe, the UK, and Japan. Vietnam dominates the trade into S. Korea.

<table>
<thead>
<tr>
<th>Region</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017 (forecast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe and UK</td>
<td>4,866,320</td>
<td>5,655,327</td>
<td>6,669,874</td>
<td>7,407,511</td>
<td>8,570,000</td>
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<tr>
<td>Canada</td>
<td>-1,615,638</td>
<td>-1,607,239</td>
<td>-1,597,847</td>
<td>-2,252,201</td>
<td>-2,320,000</td>
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<tr>
<td>US</td>
<td>-2,730,078</td>
<td>-3,835,747</td>
<td>-4,368,301</td>
<td>-4,537,378</td>
<td>-5,220,000</td>
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<tr>
<td>Japan</td>
<td>79,052</td>
<td>92,539</td>
<td>232,060</td>
<td>346,518</td>
<td>670,000</td>
</tr>
<tr>
<td>S. Korea</td>
<td>484,668</td>
<td>1,849,639</td>
<td>1,469,184</td>
<td>1,716,346</td>
<td>2,530,000</td>
</tr>
<tr>
<td>Vietnam</td>
<td>-157,226</td>
<td>-742,794</td>
<td>-1,022,809</td>
<td>-1,254,955</td>
<td>-1,490,000</td>
</tr>
</tbody>
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source: Argus Direct, September 2017, Analysis and 2017 forecast by FutureMetrics
S. Korea Industrial Wood Pellet Demand - Major Exporting Countries

Source: Argus Direct; Analysis by FutureMetrics
US and Canadian Wood Pellet Mills – height of bar represents nameplate capacity

Source: Nameplate capacity as reported by Biomass Magazine, Sept. 2017, Analysis by FutureMetrics
The Emerging Markets for Industrial Wood Pellets
Growth in Japan is expected to be strong.

The Japanese buyers care about long-term contracts, rule of law, and sustainability.

Policy in Japan will support major growth.
By 2020 all of Japan’s major utilities will be required to decouple generation from transmission and distribution. Once decoupled, the FIT (¥21/kWh for 20 years) in Japan may be extended to the major utilities.

Co-firing wood pellets at in large utility pulverized coal boilers will take off quickly since little or no modification is needed to co-fire at low ratios.

Demand for industrial wood pellets could increase by many millions of tonnes per year by 2020.
Three demand scenarios:
1%, 5%, and 15% co-firing ratios.

<table>
<thead>
<tr>
<th>Capacity MW</th>
<th>Potential Demand at 1% co-firing</th>
<th>Potential Demand at 5% co-firing</th>
<th>Potential Demand at 15% co-firing</th>
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<tr>
<td>406</td>
<td>16,000</td>
<td>78,000</td>
<td>234,000</td>
</tr>
<tr>
<td>700</td>
<td>27,000</td>
<td>135,000</td>
<td>404,000</td>
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<tr>
<td>312</td>
<td>12,000</td>
<td>60,000</td>
<td>180,000</td>
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<tr>
<td>700</td>
<td>27,000</td>
<td>135,000</td>
<td>404,000</td>
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<tr>
<td>3,400</td>
<td>131,000</td>
<td>654,000</td>
<td>1,962,000</td>
</tr>
<tr>
<td>300</td>
<td>12,000</td>
<td>58,000</td>
<td>173,000</td>
</tr>
<tr>
<td>250</td>
<td>10,000</td>
<td>48,000</td>
<td>144,000</td>
</tr>
<tr>
<td>300</td>
<td>12,000</td>
<td>58,000</td>
<td>173,000</td>
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<tr>
<td>1,450</td>
<td>56,000</td>
<td>279,000</td>
<td>837,000</td>
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<tr>
<td>475</td>
<td>18,000</td>
<td>91,000</td>
<td>274,000</td>
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<tr>
<td>216</td>
<td>8,000</td>
<td>42,000</td>
<td>125,000</td>
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<tr>
<td>900</td>
<td>35,000</td>
<td>173,000</td>
<td>519,000</td>
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<td>1,000</td>
<td>38,000</td>
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<td>577,000</td>
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<td>192,000</td>
<td>577,000</td>
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<tr>
<td>1,000</td>
<td>38,000</td>
<td>192,000</td>
<td>577,000</td>
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<tr>
<td>2,000</td>
<td>77,000</td>
<td>385,000</td>
<td>1,154,000</td>
</tr>
<tr>
<td>1,200</td>
<td>46,000</td>
<td>231,000</td>
<td>692,000</td>
</tr>
<tr>
<td>1,000</td>
<td>38,000</td>
<td>192,000</td>
<td>577,000</td>
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<tr>
<td>1,000</td>
<td>38,000</td>
<td>192,000</td>
<td>577,000</td>
</tr>
<tr>
<td>600</td>
<td>23,000</td>
<td>115,000</td>
<td>346,000</td>
</tr>
<tr>
<td>1000</td>
<td>38,000</td>
<td>192,000</td>
<td>577,000</td>
</tr>
<tr>
<td>1000</td>
<td>38,000</td>
<td>192,000</td>
<td>577,000</td>
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<tr>
<td>20,209</td>
<td>776,000</td>
<td>3,886,000</td>
<td>11,660,000</td>
</tr>
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</table>

*source: Argus Direct, analysis by FutureMetrics*
Japanese Minimum Generation Efficiency Requirements - The Japanese regulators have set minimum generation efficiency requirements for all large coal power generation stations. The minimum requirement will be 41% and will have to be met by 2030. Currently only the ultra-supercritical pulverized coal plants meet this requirement.

The Japanese Ministry of Economy, Trade and Industry (METI) has allowed the formula for calculating efficiency to be modified to encourage the use of wood pellets as a substitute for coal to “change” the efficiency calculation. Typically, efficiency (or heat rate) is based on the energy output versus the energy input. For example, if 100 MWh’s of energy are put into the boiler and 35 MWh’s of electricity is generated, the efficiency is 35%.

The modification to the calculation is to allow any MWh’s generated from wood pellets to be subtracted from the denominator. Thus the calculation for the example would now be:

\[
\text{efficiency} = \frac{\text{power out (MWh's)}}{\text{total power in} - \text{power from pellets (all in MWh's)}}.
\]

If the plant were producing 35MWh’s and the total power is 100 MWh’s but the power from pellets is 15 MWh’s the “efficiency of the plant would be 35/(100-15) = 41%. In other words, power plants with efficiencies below 41% can co-fire wood pellets to achieve the minimum efficiency requirement.

Heat rate is also measures the efficiency of the system. It is the value of the energy input to a system, typically in Btu/kWh, divided by the electricity generated, in kW. The BTU content of a kWh is 3,412 BTU. The convert from efficiency to heat rate, divide 3,412 by the efficiency. For the 35% example, the heat rate is 3412/.35=9,748.
Estimated demand for pellets based only on meeting minimum efficiency requirements

<table>
<thead>
<tr>
<th>Type of Power Station</th>
<th>Share of Coal Generation</th>
<th>Output (GWh/year)</th>
<th>Actual Efficiency</th>
<th>Coal Consumption (Tonnes/year)</th>
<th>Target Efficiency</th>
<th>Co-firing needed get to Target (by weight)</th>
<th>Wood Pellets required (Tonnes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultra Super-Critical</td>
<td>60.12%</td>
<td>134,600</td>
<td>41.5%</td>
<td>44,938,500</td>
<td>41.52%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Super-Critical</td>
<td>27.82%</td>
<td>62,300</td>
<td>39.9%</td>
<td>21,649,800</td>
<td>41.00%</td>
<td>2.71%</td>
<td>899,520</td>
</tr>
<tr>
<td>Sub-Critical</td>
<td>12.06%</td>
<td>27,000</td>
<td>37.7%</td>
<td>9,927,800</td>
<td>41.00%</td>
<td>8.05%</td>
<td>1,226,264</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
<td>223,900</td>
<td>40.61%</td>
<td>76,516,100</td>
<td>41.00%</td>
<td></td>
<td>2,125,784</td>
</tr>
</tbody>
</table>

Source: data from Japan Federation of Electric Power Companies, Analysis by FutureMetrics
S. Korean RPS Mandates an Increasing Percentage of Power Generated from Renewable Sources. Utilities must buy RECs or pay a fine of 150% avg. REC price if they do not meet the RPS. The required proportion of power from renewables increases to 10% in 2024.

FutureMetrics has developed a model showing the power station’s ability/willingness to pay based on average day ahead prices for power in S. Korea and different REC prices which define the amount of the non-compliance fines.

The S. Korean market has uncertainty because REC prices are market based. FutureMetrics has a white paper on this subject. www.FutureMetrics.com
The substitution of wood pellets for coal either by co-firing or full conversions is a rational and pragmatic solution to moving toward a more decarbonized power sector.

Leveraging existing pulverized coal plants as part of the off-ramp to a decarbonized future should be part of the menu of solutions for every nation that has carbon reduction goals.

No other renewable strategy other than hydro can provide baseload or on-demand power.
Mountain biking in Norway in late June, 2017