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Micro-Scale Pellet-Fueled Combined Heat and Power:

A new distributed power solution for the smart grid of the future

By William Strauss, PhD

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There are two major markets for wood pellets: the industrial wood pellet markets in which the pellets substitute for coal in large utility power generation stations, and the premium heating pellet markets in which wood pellets are used to fuel pellet stoves, pellet boilers, and pellet furnaces[1].

This white paper is about the future of the pellet heating markets. Currently, premium heating pellets only produce heat in stoves, boilers, or furnaces. But a new product, developed by OkoFEN[2] in Upper Austria is poised to dramatically change how heating pellets contribute to the overall market for wood pellets. In the United States the systems will be assembled in Maine and sold under the Maine Energy Systems[2] "MESys" brand.

The new product is a small combined heat and power (CHP) system that runs on premium wood pellets. This new product, described in more detail below, crosses the boundary between heating pellets and industrial pellets. As we describe below, generating electricity at the micro level with renewable low carbon wood pellets can be part of a distributed power smart grid architecture that can complement small-scale solar, small-scale battery storage, and the growth in the use of electric vehicles.

Industrial and Premium Pellet Markets

The total global market for wood pellets is about 28 million metric tonnes per year. As the chart below shows, in 2016 global demand was about evenly split between the heating markets and the industrial markets. The industrial markets, whose end users are large pulverized coal power stations, will overtake the heating markets in 2017. From 2017 on, under current forecasts, the industrial pellet sector will dominate global demand for wood pellets.

[1] Pellet boilers produce hot water for hydronic heating systems and pellet furnaces produce forced hot air for ducted hot air heating systems. Pellet stoves are free standing heating appliances.
[2] http://www.okofen.co.uk/ OkoFEN's United States partner and distributor is Maine Energy Systems (MESys) www.MaineEnergySystems.com. William Strauss is a co-founder of Maine Energy Systems.

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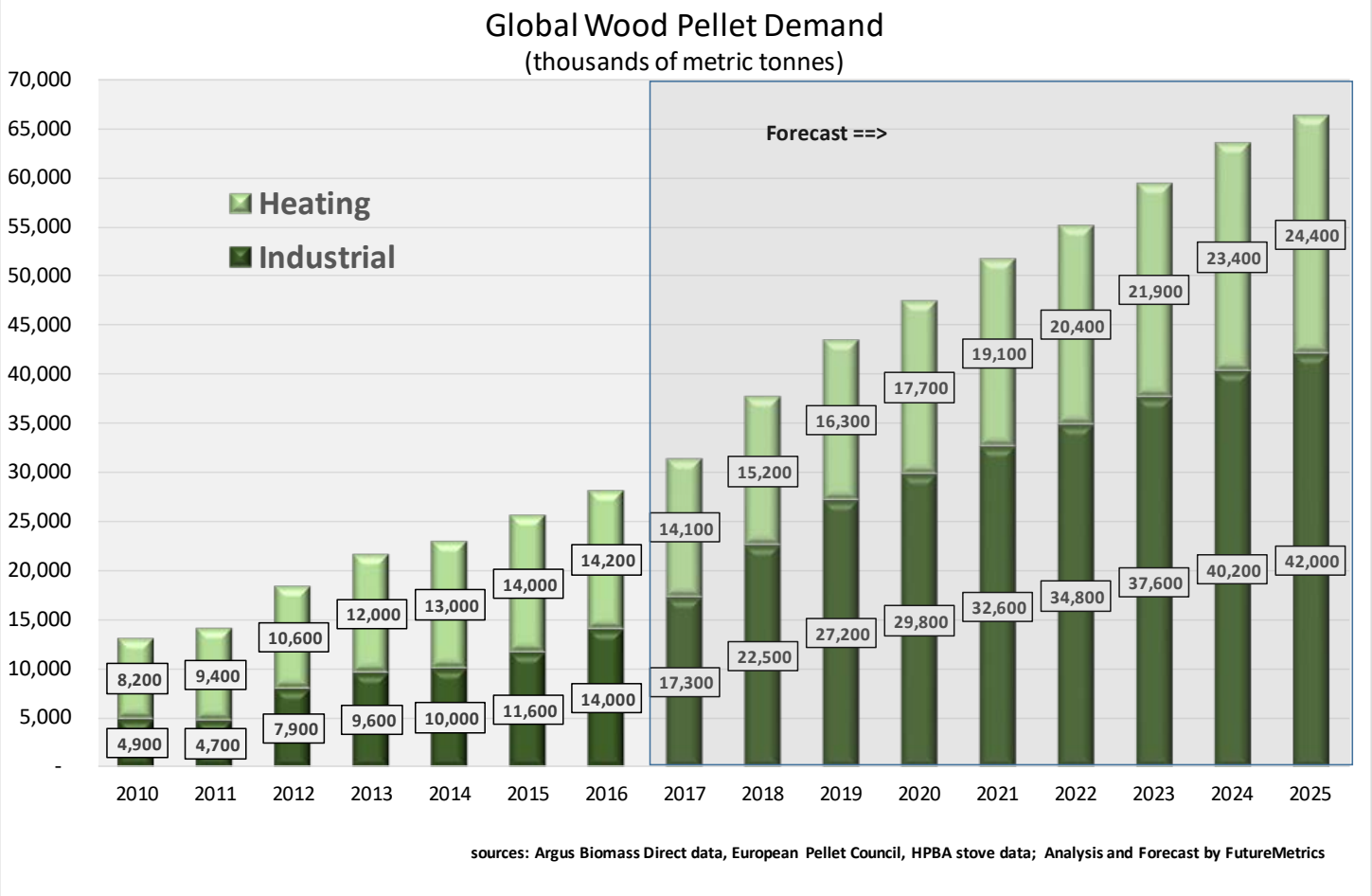


Premium pellet demand is forecast to be about 24.5 million metric tonnes in 2025. However, demand could be much higher if the vision set forth below becomes reality.

The New Combined Heat and Power System

The new micro-CHP system is built upon the foundation of the reliable and highly efficient OkoFEN pellet boilers. There are more than 60,000 OkoFEN pellet boilers installed in 17 countries. In the US, thousands of systems produced in Maine by MESys are heating homes, businesses, municipal buildings, schools, and other buildings. These fully automatic pellet boilers have proven their reliability and efficiency.

Now, in addition to heat, the pellet-fueled micro-CHP boiler also generates electricity. After several years of R&D and field testing, the micro-CHP systems are being deployed in Europe and are several months from full approval for sale in the US.

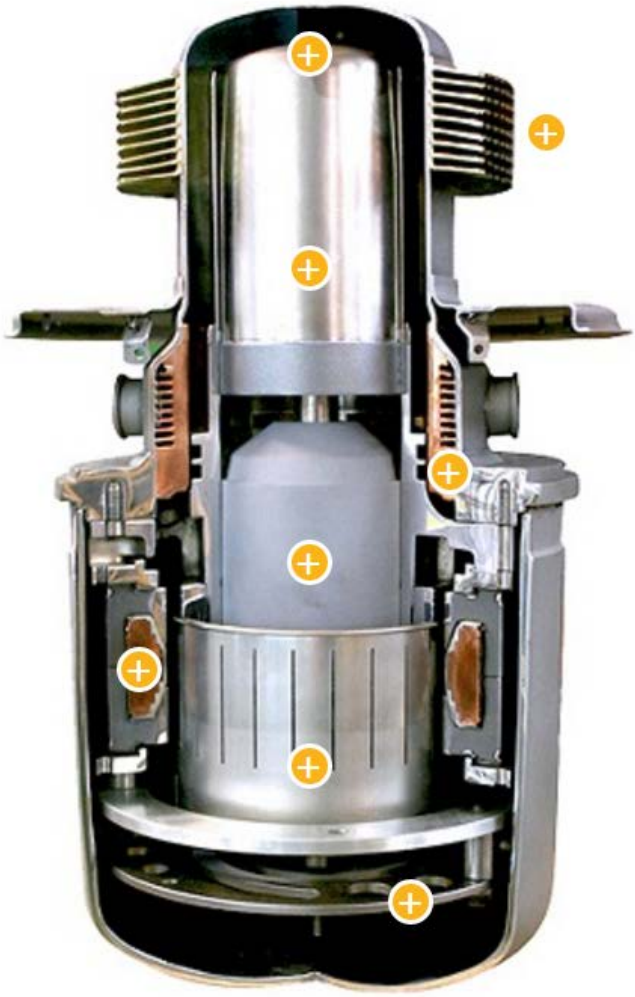
The CHP boiler produces up to 60 kilowatts of heat (about 205,000 BTU/hour) and up to 5 kilowatts of electricity. So, while the building is being heated by pellets, the CHP unit is also generating electricity.

The photo below shows the micro-CHP unit in the Maine Energy Systems product assembly building where it is being tested for US approval for sale.

Part of the external covering is removed for access to the internal components during testing. In the foreground is the internal pellet storage tank that is refilled automatically by a pneumatic conveyance system connected by the white hoses to a bulk pellet fuel storage bin. The domed top of the custom designed Sterling engine and generating unit can be seen behind and above the pellet storage tank. The entire system sits on a space that is about 40 inches by 36 inches (100cm x 90cm). In the bottom-left of

the photo is the small removable bin that automatically collects and compacts the ash. That bin needs emptying 4-8 times per year for the typical installation and the system alerts the owner via email and text when the bin is nearly full.

The image below shows the Stirling engine and generator.



How the Stirling engine and generator work[3].

1. The head of the Stirling engine is heated with the flame of the wood pellet fuel. The heat is then transferred to the working fluid of the Stirling engine (helium). The heating leads to a pressure increase.

2. With the heat supply and the cooling of the Stirling engine from return water in the heating loop, a temperature and pressure difference is generated. Through this temperature difference, the helium in the Stirling engine expands and contracts in a cycle and the piston is set in motion moving up and down 60 times per second.

3. This movement is converted by the linear generator inside the Stirling engine into 60 cycle AC electricity.

The entire micro-CHP unit has an average efficiency of 85%. That means that at full output in an optimal configuration the CHP system can produce about 205,000 BTU/hour (60 kilowatts heat) and 5 kilowatts of electricity. The system operates efficiently from about 20 kW (about 68,000 BTU/hour) of heat output to full output at 60 kw. The system modulates its output to follow the heating demand. Electricity output is proportional to heat output.

[3] For more on the system - http://www.okofen-e.com/en/pellematic_e_max/

60 kW's of heat output is more than is needed by most small and medium sized homes. In the coming months, a smaller version better suited for small to medium sized homes will be offered. But for large homes, many businesses, apartment buildings, small schools, clinics, libraries, municipal buildings, etc., this unit will match well with the heat demands while generating up to 5 kilowatts of power. In some applications with sufficient heat demand, two or more of the units can be placed in to a self-contained energy cabin[4].

Putting the Value of Small-Scale Pellet-fueled CHP in Perspective

To illustrate the benefits of producing both heat and power and to use an example that has metrics that are easy to understand, FutureMetrics has produced a dashboard that shows the cost to charge an electric vehicle (EV) using the electricity produced by the pellet-fueled micro-CHP system.

The dashboard calculates the cost to charge any one of 12 currently available electric cars from the power produced by the CHP system. The user can change many of the inputs. The inputs and outputs can be switched between a US version (using imperial units and dollars) and a European version (using metric units and Euros). The dashboard compares the "fuel" cost per mile or kilometer of the EV versus a gasoline or diesel car. The user can also compare the cost per kWh of charging the EV with the micro-CHP and with electricity from the utility. To see what a smaller unit would produce or what the current unit will produce when the heating demand is less than the maximum output, the user can slide the "heat output" control to lower values.

The dashboard is online and can be opened from HERE[5]. A screenshot of the dashboard is on the next page.

With the default inputs for the dashboard and comparing a gasoline fueled car with the BMW i3 EV, **it is 5.45 times costlier in the US to drive the same distance in a combustion engine car running on gas than it is with the EV charged by the micro-CHP**. Or to put in another way, gas would have to cost about $0.40/gallon for the two costs per mile to be equivalent. In Europe, given the higher cost of fuel, it is 13 times costlier to use diesel fuel per kilometer traveled than to use the electricity from the pellet CHP system.

At the default dashboard settings, it would take just over 7 hours to charge a fully discharged battery in the BMW i3 EV from the output of the micro-CHP[6].

[4] See http://www.maineenergysystems.com/autopellet-boiler-energy-box/
[5] For the dashboard to run you need Adobe Flash installed and enabled in your browser. The dashboard might not run on a Mac.
[6] The EV's will never be fully discharged. The dashboard allows the user to select the initial battery charge level. Each vehicle has different battery capacities and different stored power to range relationships. That data is embedded into the calculations.

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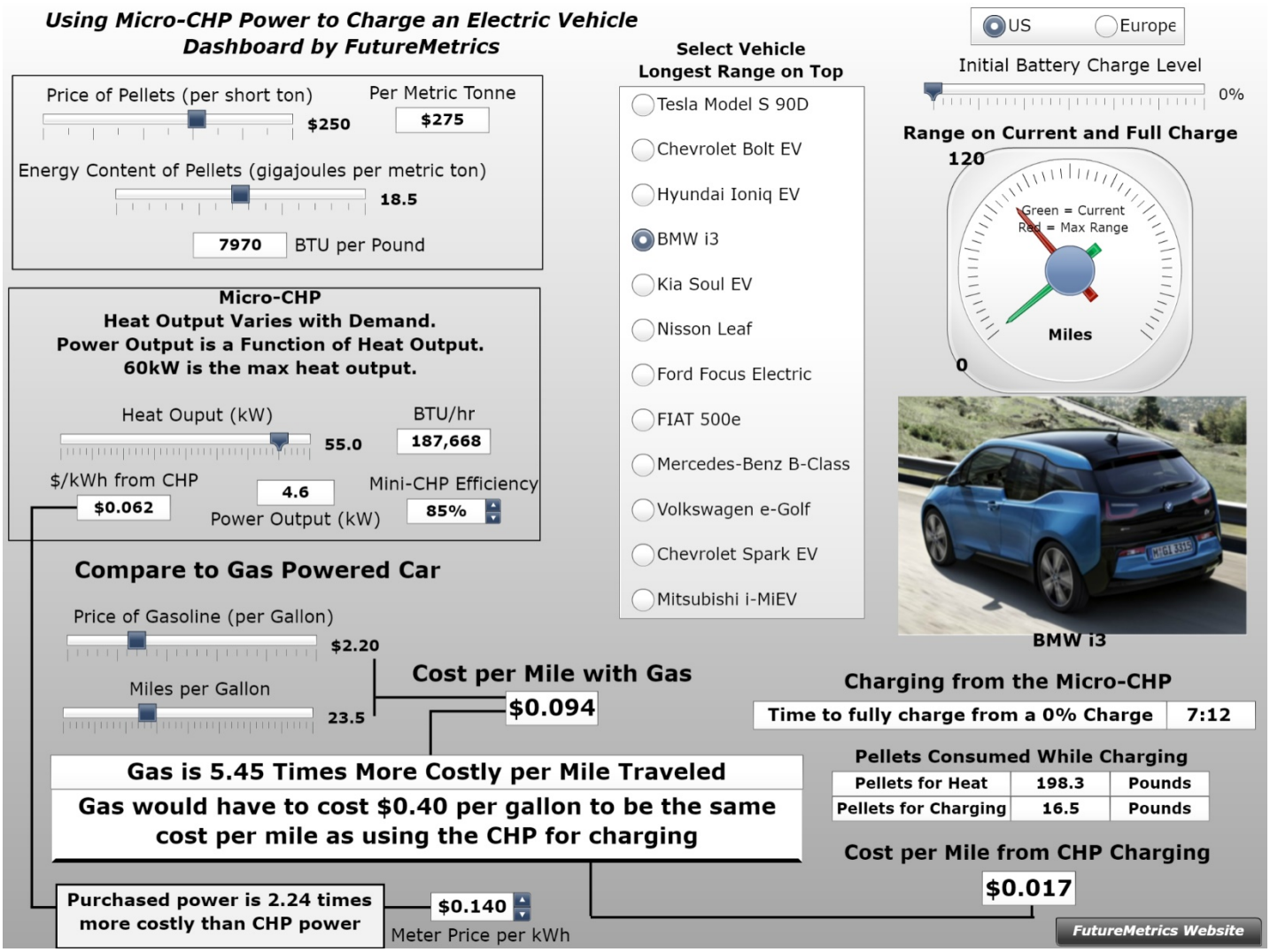
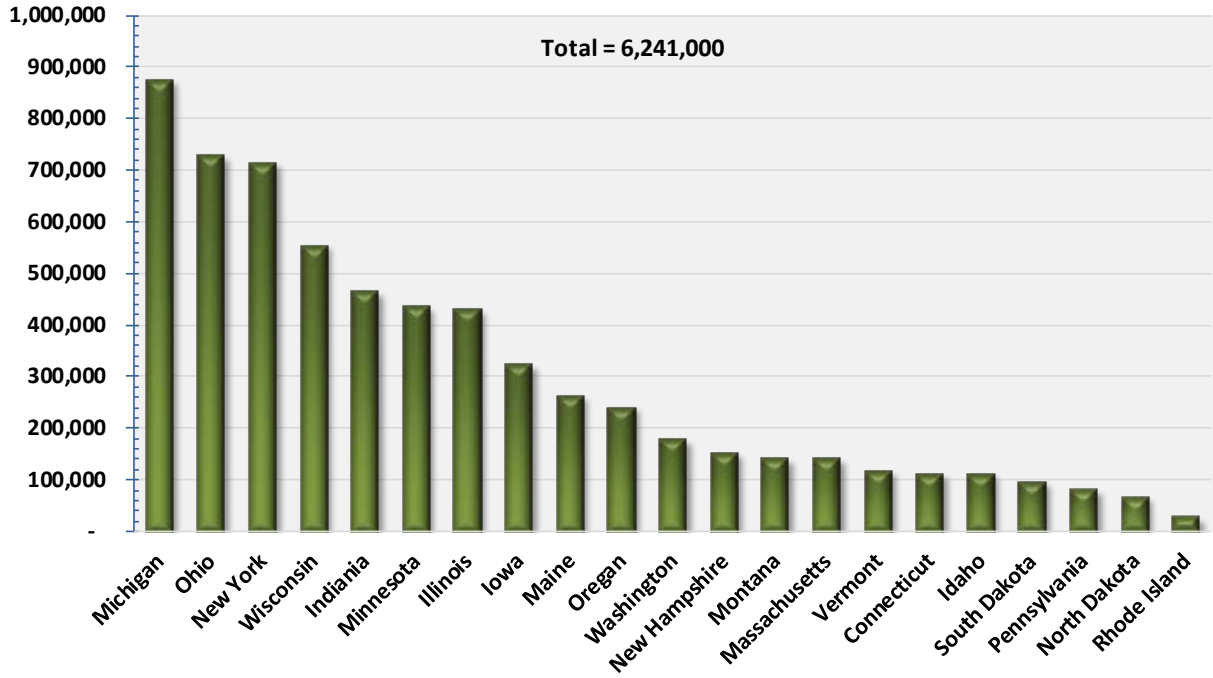


Small-scale pellet-fueled CHP has the potential to become a major part of the distributed generation smart grid of the future.

Furthermore, bridging the gap between the premium heating pellet sector and the power sector by providing low carbon heat and power produced from renewable pellet fuel provides a pathway to an invigorated and larger premium pellet market.

A Vision of How Micro-CHP will be Part of the Smart Grid and Invigorate the Market for Wood Pellets

Based on EIA and US census data and an assumption regarding natural gas pipeline penetration into rural areas, we estimate that there are about 6.2 million homes and businesses in the northern tier states that do not have access to natural gas for heat. The chart below shows the breakdown by state.



Many of those homes and businesses are in low population density areas and will never have natural gas pipelines run to their locations. We assume that 75% of rural locations that are currently not connected to natural gas never will be.

Some of the locations without natural gas distribution networks are also in proximity to areas in which the forest products industry has been a major part of the regional economy. Many of those locations already produce premium wood pellets and, given the decline in the pulp and paper sector, could produce much higher outputs if the demand for more wood pellets were there.

The rest of this analysis will focus on one state: Maine. Maine has all the right characteristics to be a leader in the deployment of pellet-fueled micro-CHP systems.

Based on EIA and US census data, Maine has the lowest proportion of homes and business connected to natural gas (5.8%). Because natural gas infrastructure does not reach most of Maine's small towns and rural areas, Maine has the highest dependency on heating oil and propane of any state in the US. Maine also has the highest proportion of people living in rural areas (61.3%) than any other state. Vermont is a close second with 61.1%. The next closest state is Montana at 44.1%. Most of Maine's occupied buildings will never connect to a natural gas pipeline.

Furthermore, Maine has suffered major losses in the pulp and paper sector over the last few years.

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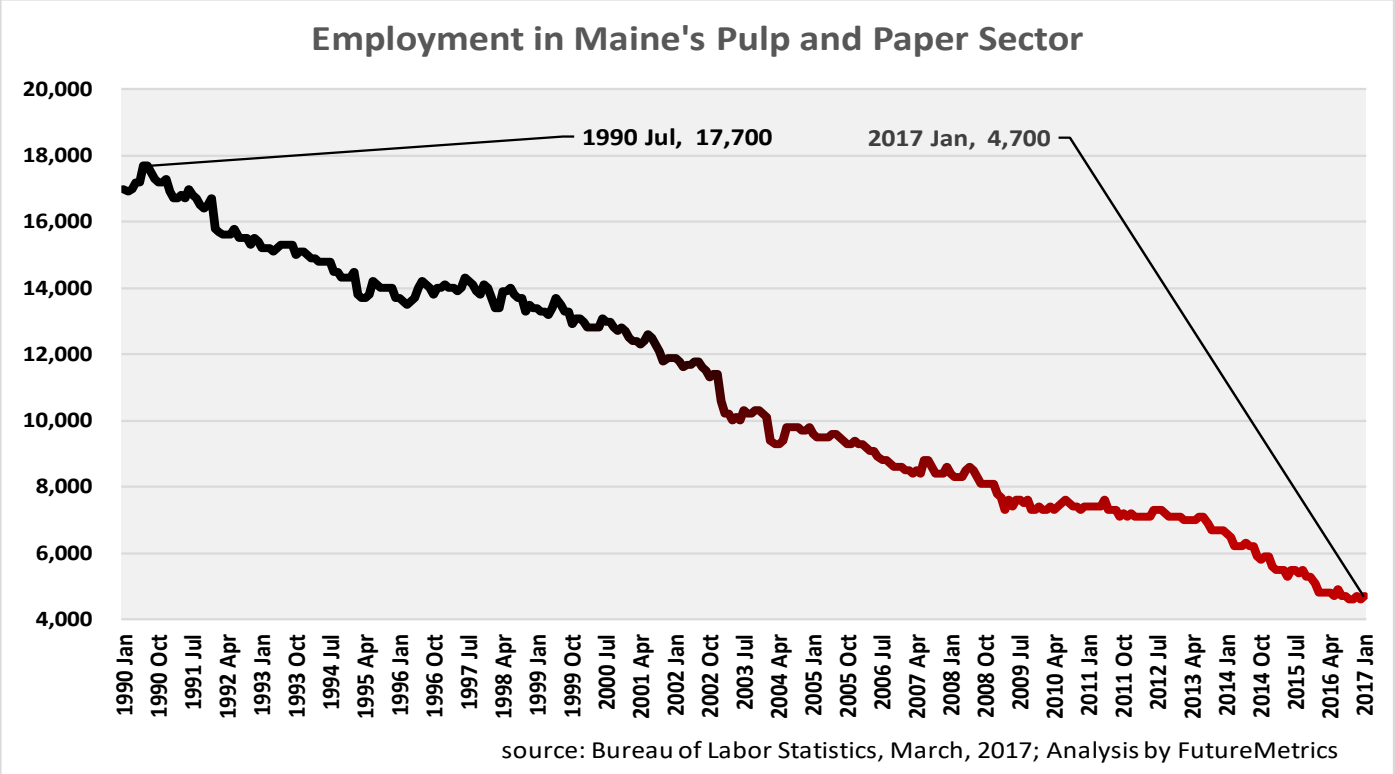
> "It's no secret that Maine has lost pulp mills in recent years. Bucksport, East Millinocket, Lincoln, Old Town, and Madison are now gone. The storied Androscoggin Mill in Jay is now a shadow of its former self (as measured by wood use), with Verso having moved beyond its "Skinny Andro" plan to something even leaner. **Across these mills, Maine has lost somewhere around 3 million tons of pulpwood (and mill chip) markets since 2014**. Put another way, the market has shrunk by 275 loads per day, every day. That doesn't count the biomass markets lost at these mills."[7]

The decline in the pulp and paper sector in Maine has been devastating to the regional forest products industry. The loss of about 13,000 jobs in the pulp and paper sector since 1990 is multiplied into a loss of employment in logging, chipping, and wood products trucking. That is further multiplied by induced negative job impacts across the spectrum of businesses in the Maine economy.



Now imagine that Maine is supportive of a strategy that encourages the replacement of heating oil-fueled central heating systems that use fuel that is imported into Maine with micro-scale CHP systems using wood pellets that are made in Maine.

[7] From a recent publication by Eric Kingsley, principal in the firm Innovative Natural Resource Solutions. The article is HERE.

Maine has about 550,000 households and about 40,000 businesses that employ workers. Based on EIA and census data, and assuming that 75% of buildings now using heating oil or propane will never use natural gas, we estimate that about 262,000 buildings have no chance of ever being connected to natural gas.

If we assume that 20% of the 262,000 occupied buildings in Maine not on natural gas are large enough to have a demand of 205,000 BTU/hour or more, and that they install the OkeFEN/MESys pellet-fueled CHP systems over the next several years, there would be about 52,400 micro-CHP systems providing heat and power in Maine. If the average output of electricity per unit over the heating season is 2.5 kW's, the average output from all of those systems would be about 131 megawatts. At peak power output during the cold winter months when the micro-CHP is outputting 5 kW's, the 52,400 units would be generating 262 MW's. The aggregated distributed power production would make the top ten list of power plant capacities in Maine; and during the cold winter months, the top five (the top four if Wyman is excluded[8]).

Plant	Primary energy source	Operating company	Net summer capacity (MW)
William F Wyman	Petroleum	FPL Energy Wyman LLC	811
Westbrook Energy Center Power Plant	Natural gas	Westbrook Energy Center	506
Maine Independence Station	Natural gas	Casco Bay Energy Co LLC	490
Bucksport Generation LLC	Natural gas	Verso Bucksport LLC	274
Rumford Power, Inc	Natural gas	Rumford Power	254
Oakfield Wind Project	Wind	First Wind O&M, LLC	148
Androscoggin Energy Center	Natural gas	Verso Paper Androscoggin LLC	137
Kibby Wind Power Project	Wind	TransCanada Maine Wind Development Inc	132
Great Lakes Hydro America - ME	Hydroelectric	Great Lakes Hydro America LLC	132
Somerset Plant	Wood	Sappi Fine Paper North America-Somerset	115

Source: U.S. Energy Information Administration, Form EIA-860, "Annual Electric Generator Report." January, 2017

Most of those MW's would replace power generated from natural gas transported to Maine from far away with fuel made in Maine. And all the heat that the micro-CHP systems produce would replace heat produced from heating oil and propane with heat produced from pellet fuel made in Maine.

Each unit would use about 30 tons of wood pellets per year[9]. Aggregate demand under this scenario would be about 1.56 million tons per year.

1.56 million tons per year may sound inconceivable for Maine which only has current pellet production capacity of about 300,000 tons per year. But that 3 million tons per year of wood chips that pulp mills in Maine have been taking in for generations, but are no longer using (and never will again), could produce

[8] The Wyman station rarely generates. The February, 2017 release of the EPA's Emissions & Generation Resource Integrated Database (eGRID) with 2014 data shows Wyman running only 3.9% of the hours in the year.
[9] The analysis assumes that the heating season is 150 days per year and that the systems will only produce heat for domestic hot water the rest of the year.

about 1.65 million tons per year of wood pellets; enough to fulfill this vision for the future. Furthermore, many of the jobs that have been lost would return.

This transition cannot happen overnight. This section of the white paper is titled a "vision" for good reason. But there is nothing in this strategy that is not possible. The technology exists, the sustainable wood supply exists, the economics for producing heat and power from pellet fuel makes sense, and Maine needs a way to revitalize its forest products industry.

Over the next decade, Maine could achieve this vision.

And it is not just Maine. Other northern tier states with declining pulp and paper industries could do the same. The upper mid-west states, which have millions of potential buildings not near natural gas pipelines could do the same. North of the border, many Canadian towns and villages that import expensive fossil fuels for heating and are surrounded by well-managed but underutilize forest resources could do the same.

The quantity of wood pellets that can be produced to fulfill this vison is always bounded by the limits of sustainability. If we call this "renewable" energy, it must renew: the stock of wood and carbon held in the working forests cannot be depleted.

There is a limit to how far this vision can go. But there are vast working forests in the US and Canada (and across the world) that have for generations supplied hundreds of millions of tons of sustainably produced feedstock to sawmills, pulp mills, and other wood products manufacturing industries. As demand patterns change within the traditional users of wood, this vision should be a part of what is next.

Some analysts predict that all new cars will be electric vehicles by 2035[10]. Perhaps well before that, for those of us that live in the parts of the world that have cold winters and well-managed and underutilized working forests, micro-CHP fueled by low carbon renewable pellet fuel will be supplying some of the electricity that will drive us to work.

[10] Sanford C. Bernstein, a consultancy, is referenced in this March 11, 2017 Economist story HERE.