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A Rational and Pragmatic Off-Ramp to a Decarbonized Future

How a US co-firing strategy can significantly lower carbon emissions and provide a secure and known future demand for coal and pellet producers

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Introduction

This white paper describes a ready-to-deploy strategy that provides a gradual transition to a less carbon intensive power generation sector. The strategy has many benefits; not the least of which is that it provides reliable and low-cost and lower carbon intensive power to the grid using existing power plants.

The strategy provides security for future demand to the producers of solid fuel for power plants (coal and pellets) while also providing significant economic and environmental benefits. At the heart of the strategy must be a credible and verifiable sustainability policy that assures that the carbon stocks of our working forests are not depleted.

The foundation of the strategy is to blend a low carbon renewable solid fuel (wood pellets) with coal[1] for power generation. The implementation of the co-firing strategy would support a gradual increase in the proportion of renewable solid fuel toward a goal that would result in a 30% reduction in CO_2 emissions by the year 2030[2]. Upon achieving that goal, those higher efficiency power stations that participate in the strategy would still be using about 65% coal in their power boilers.

The strategy is rational and pragmatic and recognizes that the US power system, particularly in the eastern US load centers, is heavily dependent on coal generation for base load. Because of this high level of dependency on coal fired power plants, the grid cannot tolerate the sudden removal of the coal stations. The substitution of natural gas for coal seems pragmatic given low natural gas prices. But over the next 15 years it is unlikely that natural gas prices will remain low[3]. Furthermore, the same or better carbon benefits can be achieved by 2030 by following a co-firing strategy.

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[1] See FutureMetrics' papers about how wood pellets produced from sustainable renewing feedstock are carbon neutral in combustion. As long as the stock of carbon in the working industrial forests of the US and Canada is not reduced, there is no net new carbon added to the atmosphere by the use of refined wood pellets made from sustainable tree farming. See the section later in this paper on this topic.
[2] This is the goal of the Clean Power Plan.
[3] See FutureMetrics' white paper on this topic. As LNG export grows, NG prices in the US will be set by global prices not those prices based on the captive pipeline-constrained just-in-time market that currently exists. Also as compressed natural gas (CNG) becomes more mainstream as a transportation fuel, demand for NG within the US

This gradual off-ramp to a more decarbonized power sector provides security to the producers of coal and wood pellets by providing a certainty of demand to 2030 and beyond for the solid fuel needed to power the grid. The strategy requires the use of existing power plants that use pulverized coal as fuel. The strategy requires that nearly all of the existing coal supply infrastructure remain operating. The co-firing strategy gives the coal-dependent power sector a gentle non-disruptive glide path toward a less carbon intensive future.

How to further decarbonize the power grid and maintain grid reliability and stability in the 2030's and beyond will depend on technological progress in a broad span of areas that theoretically hold promise but are today not feasible.

What is feasible and proven to work today is co-firing wood pellets, refined from renewable and sustainable feedstock, with coal. Co-firing wood pellets with coal in pulverized coal power plants is common and ordinary in Europe, the UK, South Korea, and soon China. The US is currently the world's largest producer of sustainable wood pellet fuel for power plants. But not one ton of the approximately 7 million tons produced in the US and Canada is used in the US. Hundreds of shiploads per year leave US ports heading to nations that recognize not only the carbon emissions mitigation benefits but also <u>the simplicity of co-firing refined wood pellet fuel in pulverized coal power boilers</u>. The US and Canada have the capacity to significantly increase the production of renewable power plant fuel for co-firing for domestic use. **This can be achieved while remaining well within the boundaries of the <u>essential sustainability requirements</u> that support the carbon benefits that are derived from blending renewable wood pellets and coal**.

<u>If US policy supports a co-firing strategy there is no shortage of winners</u>:

- The **environmental benefits** are immediate and quantifiable. To lower carbon emissions by 10% requires a ratio of pellets to coal of about 11.24% pellets and 88.76% coal[4].
- The **power generation assets** that are fueled with pulverized coal gain a significant new value as the only pathway that allows low cost renewable co-firing. At a co-firing rate that results in a 10% CO_2 reduction, the increase in the cost of generation is estimated to be less than one penny per kilowatt-hour.
- The **coal producers** have a secure long-term market for their product with a certainty for demand over the next several decades. Co-firing is not possible with natural gas turbines.
- The **pellet producers** have a new and gradually increasing market also with known demand. Many underutilized industrial working forests are not in optimal locations for the existing pellet export market. Those locations, and new locations released from demand by the declining pulp and paper industry, can be responsibly developed to produce renewable refined solid fuel that is 100% compatible with existing pulverized coal plant fuel systems.

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will significantly increase. Both of those trends will push NG cost per MWh well above that of coal and a mix of coal and pellets under a co-firing scenario.

[4] This will vary slightly based on different energy contents of coal and pellets.

- And **US workers** benefit from a carbon mitigation solution that not only maintains jobs but increases the demand for labor. Natural gas plants require very little labor in the fuel supply chain relative to coal and pellets. Wind and solar power plants require no labor for the fuel supply.

All this and no change in how power is supplied to the grid. Unlike wind and solar, thermal power stations provide the foundation of a stable and reliable power grid. For every MW of wind and solar capacity, there has to be a MW of coal, natural gas, hydro, or nuclear capacity to make sure the lights stay on when the wind is not blowing and the sun in not shining.

Why the Grid Cannot Operate without Coal Plants Now

The US power grid was built on coal. The future of power generation will be based far less on coal than it is today. That trend is already happening. Low cost natural gas is driving utilities to build new gas turbine power stations. Tighter emissions regulations are causing coal stations to face significant pollution control upgrades. The combination of a higher capital basis after pollution control upgrades and less competitive fuel price is driving the generation sector into natural gas.

But coal is still a major part of the system. Across the US, looking at generators of 250 MW or larger, coal represents 50.25% of all the megawatt-hours generated. Natural gas generates 22.06%[5].

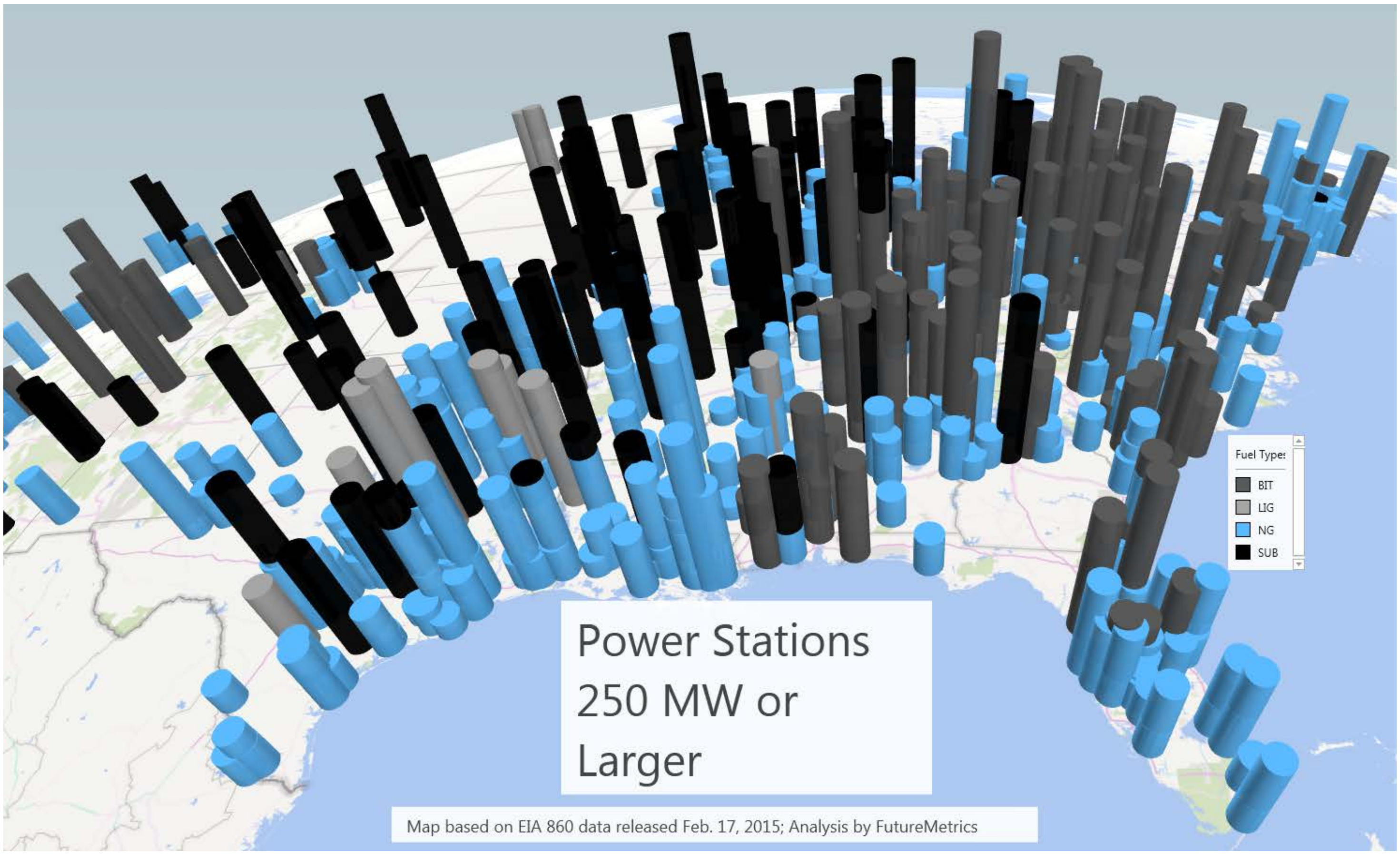
At current prices, coal is still the lower cost fuel. At $55/ton for coal and $5.50/MMBTU for natural gas, the fuel cost per MWh of electricity is $23.77 for coal and $31.28 or NG[6]. But the lower capital cost and lower fixed and variable O&M costs for NG results in a lower total cost per MWh. That would change if natural gas prices for power plants go to $9.19/MMBTU. At $9.19/MMBTU and $55/ton, the total cost per MWh is the same for NG and coal.

Is it wise for utilities to put all of their generation into NG? We think not.

The co-firing strategy that this paper discusses shows another reason, other than the risk of having too much of the generation portfolio concentrated in NG, to maintain and operate some of the existing coal stations.

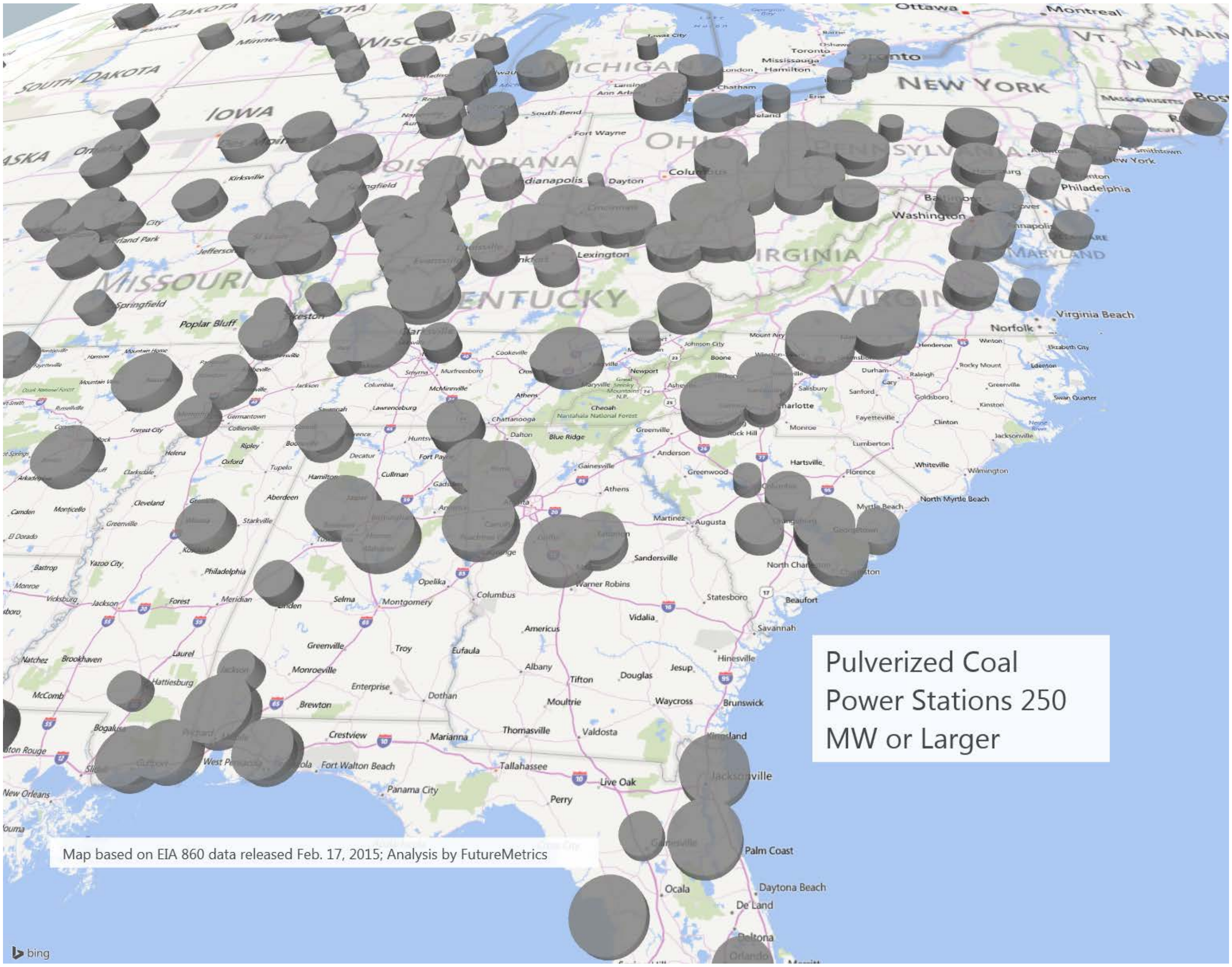
The map below shows all of the coal and natural gas power plants in the US. The height of the bars represents the power outputs of the plants (light grey to black represents lignite, bituminous, and subbituminous coal).

[5] Data from EIA-860 Annual Electricity Data, Feb. 17, 2015; analysis by FutureMetrics.
[6] Assumes 38% efficiency for coal and 60% efficiency for a combined cycle gas plant.



The larger stations are coal fueled. A few are mixed with both coal and NG. The upper Midwest and eastern load centers are dominated by coal (a table on page 6 shows the primary generation sources for all electricity in those states).

The map below shows just the coal power stations. The diameter of the cylinder corresponds to the size of the power plant.



Of all power plants with generation capacities of 250 megawatts or more, coal fired power plants represent 265,400 megawatts of the total of 528,100 megawatts. Large baseload generation from steam cycle thermal plants is necessary for grid stability. Perhaps someday large grid-scale battery storage of gigawatt-hours of power will be possible. Until that day the proportion of constantly varying and intermittent wind and solar that can supply the grid is limited. Furthermore, if the wind is not blowing and the sun is not shining, conventional generation sources have to be able to fill the demand gap.

The total power generated from all sources in the US is 1,164,000 MWs. The table below shows the breakdown of primary generation sources in selected eastern states.

	Primary Generation Sources					
	Coal	Natural Gas	Nuclear	Solar	Wind	Other or Mixed Fuels
West Virginia	86.4%	7.1%	0.0%	0.0%	3.4%	3.2%
Kentucky	71.3%	24.6%	0.0%	0.0%	0.0%	4.1%
Indiana	65.2%	21.9%	0.0%	0.2%	5.0%	7.7%
Ohio	56.8%	30.7%	6.3%	0.1%	1.3%	4.8%
Missouri	54.9%	27.7%	5.2%	0.0%	1.9%	10.3%
Michigan	36.7%	36.4%	12.9%	0.0%	3.5%	10.6%
Alabama	35.1%	38.0%	15.0%	0.0%	0.0%	12.0%
Illinois	34.0%	32.4%	24.4%	0.1%	7.0%	2.2%
North Carolina	33.7%	39.0%	16.6%	1.0%	0.0%	9.7%
Arkansas	33.5%	44.5%	11.3%	0.0%	0.0%	10.6%
Georgia	32.7%	43.5%	9.8%	0.1%	0.0%	13.9%
Pennsylvania	30.8%	28.1%	21.7%	0.1%	2.8%	16.5%
South Carolina	25.2%	26.0%	27.6%	0.0%	0.0%	21.2%
Virginia	22.3%	34.7%	13.8%	0.0%	0.0%	29.3%
Texas	21.3%	62.3%	4.3%	0.1%	10.3%	1.6%
Florida	16.5%	61.8%	5.6%	0.1%	0.0%	16.0%
Mississippi	16.5%	72.2%	8.2%	0.0%	0.0%	3.1%
Louisiana	12.4%	73.1%	7.3%	0.0%	0.0%	7.2%
New Jersey	10.3%	58.0%	20.1%	1.6%	0.0%	10.1%
New York	6.1%	48.8%	13.2%	0.1%	4.0%	27.9%

In 2013 those states consumed 576,000,000 tons of coal[7].

Perhaps in several decades the decarbonization of the power system will be based on nuclear, wind, solar, and other sources such as tidal and wave power. But today, in most states that do not have hydroelectric resources, fossil fuels dominate the generation mix.

This strategy of co-firing a renewing and sustainable low-carbon solid fuel with coal is a ready-to-deploy method of beginning the transition to a decarbonized grid while maintaining the reliable and necessary generation sources that currently are a significant part of the world's most reliable electricity grid.

What is the Cost and the Benefit of Co-Firing Wood Pellets with Coal?

Wood pellets are carbon neutral in combustion if produced from feedstock that is procured from sustainable sources. A necessary condition is that the procurement of the feedstock cannot diminish the stock of carbon held in woody biomass[8]. If wood pellets are to be co-fired in power plants for the

[7] Date from EIA, 2015, with analysis by FutureMetrics.

[8] FutureMetrics has a number of papers on this topic. Most recent is "Why the World Resources Institute has it Wrong on Wood Pellets" which is free for download from the FutureMetrics website. Also see the section later in this paper that illustrates this dynamic.

purpose of reducing carbon emissions, then a certification and auditing system will have be used to make sure that the fuel is indeed from 100% sustainable and renewing sources.

The carbon benefits of co-firing are well accepted in a number of other countries. Those countries, most of whom are major importers of US and Canadian industrial wood pellets, have policies in place that compensate the generator for the higher cost fuel. Part of that cost is the cost to ship from North America to Europe. US states and power plants embracing a co-firing strategy will not incur those shipping costs. The delivered price of the refined pellet fuel will be lower and the increased cost of generation much lower than for importers of US and Canadian pellet fuel. As is shown below, achieving on third of the CPP's 30% CO_2 reduction will cost less than one penny per kilowatt-hour.

Canadian wood pellets produced in British Columbia, where most of the Canadian industrial pellets are produced, have to pass thought the Panama Canal to get from western Canada to the UK and the other western EU countries that have carbon mitigation policies. Shipping costs per metric tonne to ARA range from $16.40 from Savannah, GA to $30.50 from Vancouver, BC[9]. That cost would be avoided for a US market for industrial wood pellets. The carbon footprint that is acquired in the supply chain would also be reduced as the carbon emissions from shipping are the largest component of CO_2[10] in the supply chain.

Current spot prices for exported pellets are about $150/metric tonne FOB from the Southeast US and about $139/metric tonne FOB southwest Canada[11]. In short tons that is $136 and $126 respectively. Assuming $15/short ton mill-to-port and port storage and ship loading costs, the "gate price" would be $121/short ton ($133 per metric tonne) at a US southeast pellet plant[12]. Current spot prices for export into the EU or UK are historically low primarily due to the strong dollar. In the model below we use $140/short ton for the "gate price" for pellets produced for the US power markets.

With some assumptions that are not dissimilar to actual values on transportation costs and on power plant efficiency and operating costs, we can calculate the added cost to the generator for co-firing refined renewable wood pellets with coal. At low co-firing rates almost no modification to the power plant is required. Wood pellets can be co-milled in the same pulverizers and the blended pellet/coal powder can be blown into the same burners. A slightly higher volume of blended pulverized fuel has to be sent to the burners to produce the same power output (there is no de-rating of the boilers).

At higher co-firing rates some modifications are required. We assume that the modifications specific to wood pellets are $500 per kW of nameplate capacity at a 100% co-firing (100% conversion from coal to

[9] ARA is Amsterdam-Rotterdam-Antwerp. Shipping prices are from the May 13, 2015 Argus Biomass Markets report. Prices also vary by vessel size. The prices shown are for 45,000 metric tonne loads. Prices for 25,000 mt loads are higher.

[10] See FutureMetrics' supply chain carbon dashboard at the FutureMetrics website.

[11] From the May 20, 2015 Argus Biomass Markets report.

[12] FutureMetrics does not represent that this price reflects the actual "gate prices" at any mill and is using this only for illustrative purposes.

wood pellets)[13]. A full conversion to pellets is unlikely under this co-firing scenario. For a 10% co-firing rate, the cost per kW is 10% of $500. As co-firing rates go up, the marginal differences in cost will be added to the total capital cost[14].

We also assume that the costs of complying with EPA emissions rules and other pollution control for coal plants is incurred at a rate of $330/kW of nameplate capacity.

We assume that the coal has a heating value of 12,500 BTU/pound and costs $55/ton delivered ($2.20/MMBTU).

If we assume a "gate price" of $140/ short ton ($154/metric tonne) and assume that the pellets are being trucked 100 miles at a cost of $0.16 per ton-mile, we have a logistics cost of $16.00/ton. The delivered cost is therefore $156/ton ($172/metric tonne). This is below current CIF rates in ARA[15]. We assume the pellets have a heating value of 17.5 gigajoules per metric tonne or 7415 BTU/pound.

The power plant is assumed to have a heat rate of 9,750 BTU/kWh which equates to an efficiency of 35%.

Putting all those values into a model in which the plant generates a small proportion of its MWh's from pellets and a gains a 10% reduction in CO_2, a 400 MW boiler line will use about 972,000 tons/year of coal and about 123,000 tons per year of pellets (11.24% pellets and 88.76% coal). The **increase in the cost of generation is only $0.0079/kWh (about 3/4 of a penny/kWh)** or $7.924/MWh.

The **89/11 blend of coal and pellets results in a 10.0% reduction in CO_2 emissions**. The CO_2 reduction calculation includes the supply chain CO_2 for both the wood pellets and the coal which is accumulated from mining or harvesting, transport, refining, etc. All of the CO_2 released in the combustion of the pellets is absorbed contemporaneously under the sustainability criteria requiring that the carbon stocks of the working forests are not diminished.

Why the US Working Forests can Supply Feedstock for the Co-Firing Strategy

The US and Canadian forest products industry already provide most of the world's industrial wood pellets for use in power plants. Assuming that the US and Canadian industrial pellet plants can operate at 80% capacity factor, by early 2016 North American will have the capacity to produce about 12 million metric tonnes per year of industrial wood pellets. This includes about 2.5 million tonnes per year of new capacity that is being built or is in early commissioning stages. The chart below illustrates this capacity.

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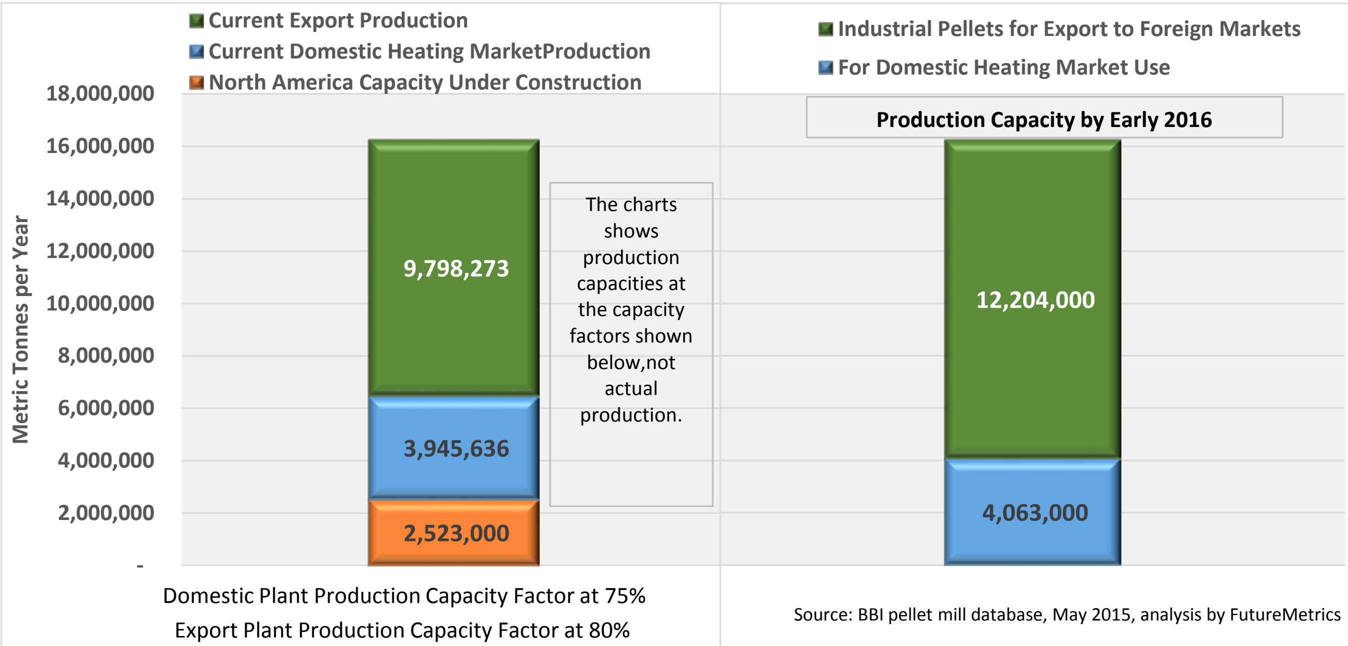
[13] This includes the costs of dry storage infrastructure and minor modifications to burners and possible increase in pulverizer capacity. The assumed cost per kW is based on data from EU, UK, and Canadian plants that are co-firing or full-firing pellets.

[14] All of the inputs, assumptions, and conclusions discussed herein can be viewed and adjusted in the **new FutureMetrics dashboard** for calculating the marginal cost of co-firing and viewing the carbon benefits of co-firing. The dashboard is free to use at the FutureMetrics website.

[15] CIF means "cost, insurance, and freight". It is the price of the pellets including all shipping costs, delivered to the foreign port. Current CIF ARA is about $166/metric tonne based on the May 20, 2015 Argus Biomass Markets report.

All of the pellets sold to European and UK power plants for co-firing or full-firing are certified as having been produced from sustainable feedstock.



The current industrial pellet production plants are located in the prime wood baskets of the southeast. Key inputs to the determination of the locations are based on an adequate supply of sustainable feedstock and on the ability of the operations to get the pellets to a port at a reasonable cost with a minimal carbon footprint.

The need to have relatively low cost mill-to-port logistics means that many underutilized working forests that are not well located for the export markets are excluded from the current industrial pellet plant site selection criteria.

The map on the next page shows the location of current industrial pellet plants as well as those reported to be under construction. The map also shows the locations of pulverized coal plants with capacities greater than 250MW.

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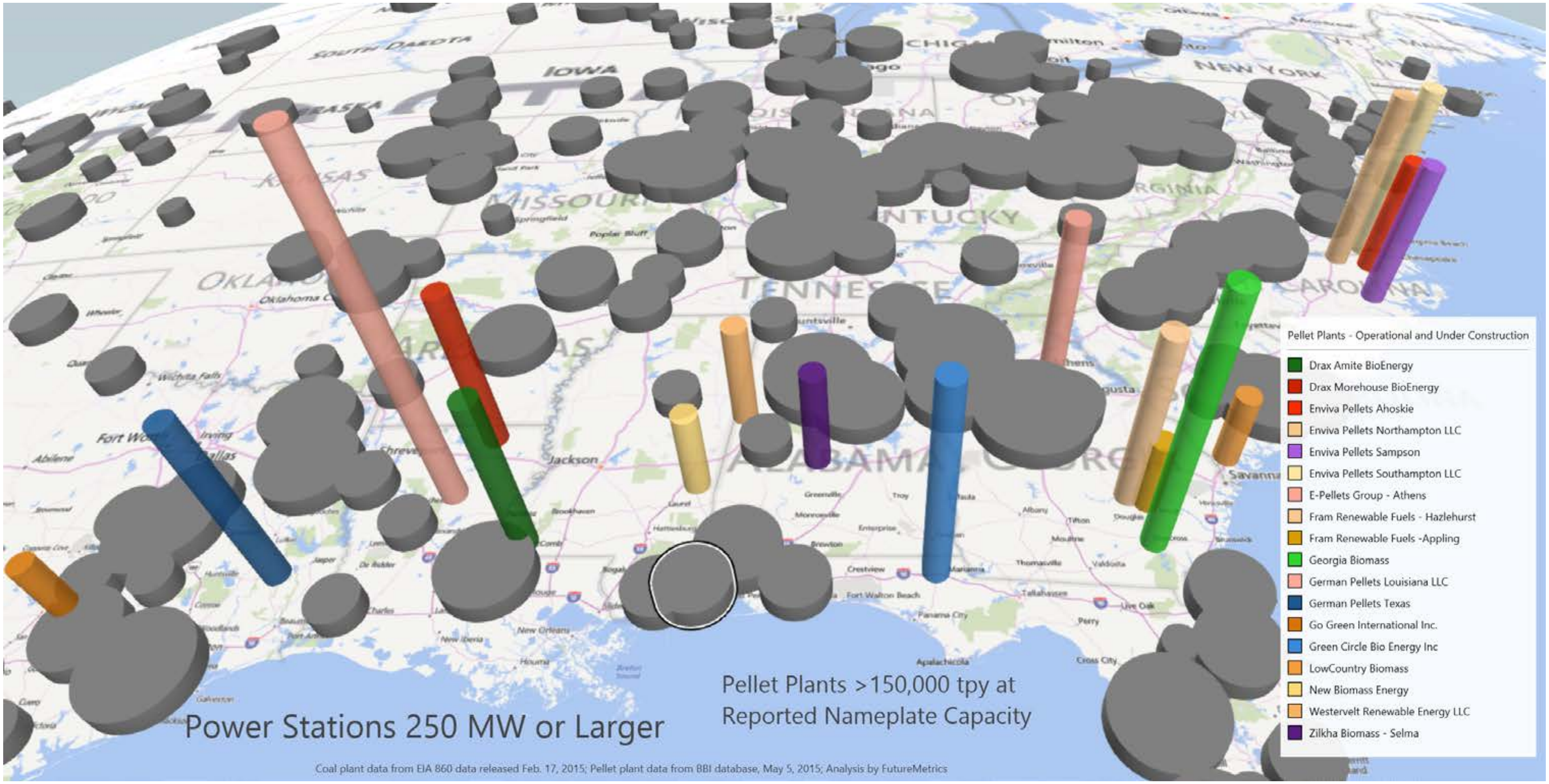
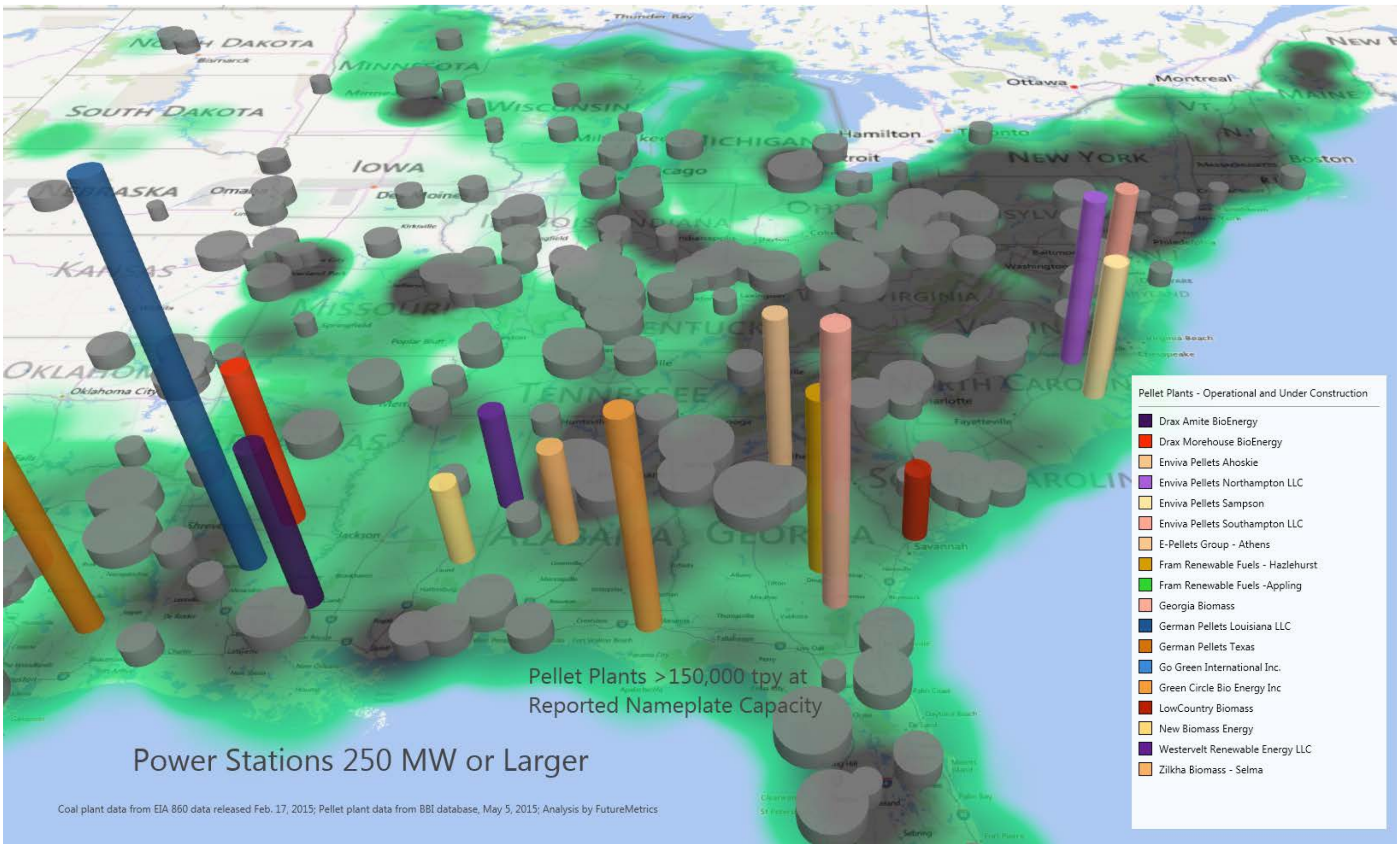


The industrial pellet plants are concentrated in locations that are near shipping ports and have high concentrations of sustainable fiber. In many of the locations the traditional users of the same wood fiber that is used in pellet production, pulp and paper mills, have closed.

The map below shows the eastern working forest inventory[16]. Darker coloring shows higher concentrations of wood fiber. The analysis excludes forests that are not open for management for the production of fiber for the forest products industry.



In some locations the traditional forest products users such as pulp mills, sawmills, and OSB mills continue to use the wood that has been grown for generations to supply those industries. In many states, those industries have significantly declined. Forests planted 20-40 years ago that were expected to be used in those industries will be stranded.

If there were co-firing in those states, those otherwise stranded assets would regain their value and the jobs that come with managing and harvesting and transporting would be renewed and sustained.

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[16] Data from US Department of Agriculture forest inventory database. The data is the estimated dry tonnage for all merchantable wood 4 inches in diameter or greater at the county level. All reserved lands are excluded.

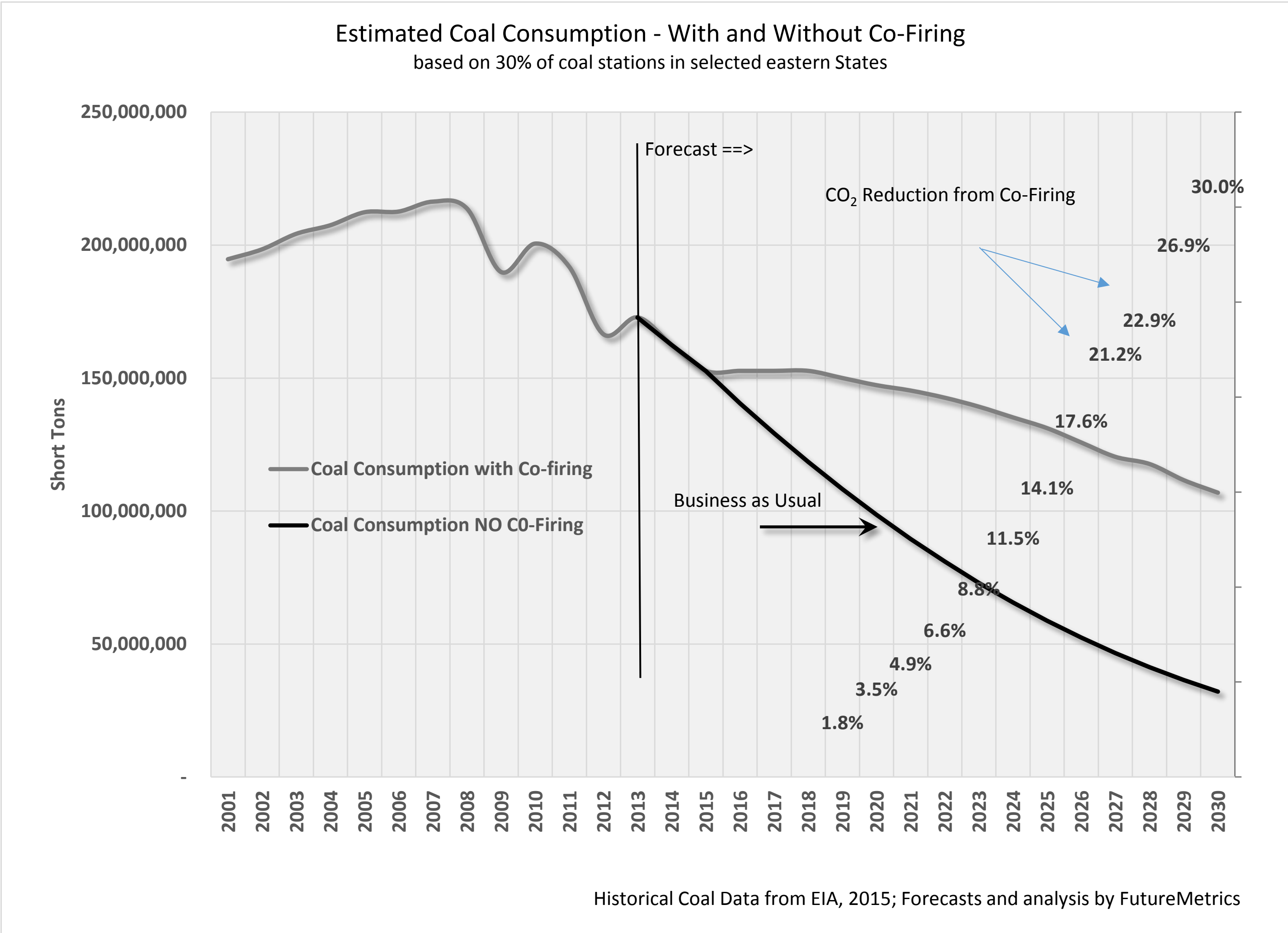
Some of the darker areas in the map above are in those states. Some are already being used by the industrial pellet producers at those locations that are favorable for transport from the mill to the ports. But there are large areas in the upper Midwest, the mid and upper Mid-Atlantic, parts of the Southeast, and the Northeast that would be optimal for providing fuel to the coal power stations in those regions or by rail to other areas.

The Off-Ramp to a more Decarbonized Power Sector Requires Coal!

We do not know how much of the coal power generation fleet will be replaced by natural gas between now and 2030. As with any critical input, it is never wise to rely fully on one source. If natural gas prices rise modestly, NG will no longer be the lowest cost fossil fuel. Even with low NG prices, coal plants should continue to be used because they are an important part of the transition from today to a less carbon intensive future for the power sector.

The off-ramp to a more decarbonized future must include coal fired plants.

The chart below shows the estimated off-ramp to a 30% reduction in CO_2 for those coal plants that participate in the co-firing strategy. The coal consumption values assume that 30% of the pulverized coal plants in the eastern states will adopt a co-firing strategy.



The analysis above assumes that without co-firing, and therefore without a fundamental reason to use coal stations, that there will be an 8% to 10% reduction in coal demand per year from now until 2030 as natural gas generation grows (following current trends). If the co-firing strategy is implemented and those coal plants are required to continue to use coal, then those coal stations in states that adopt a co-firing strategy continue to use coal.

The co-firing strategy should be preferred by the coal industry.

It is surprising to see a strategy that yields significant carbon benefits be a strategy that the coal producing sector should embrace. But it is true. Both coal and wood pellets are a solid fuel that is ready to use in hundreds of coal power plants. Blending the low carbon fuel with the high carbon fuel yields a compromise that achieves the goals of the Clean Power Plan.

Based on a gradual increase in the co-firing rate with the goal of lowering CO_2 in coal plants by 30% by 2030, the co-firing of pellets with coal would require about 3.0 million tons per year of pellets in the starting year.

The Off-Ramp to a More Decarbonized Future is based on conserving the Carbon Stocks Held in the US Working Forests

In the chart above the assumption is that 30% of the coal stations in the states shown in the table on page six co-fire. By 2030 those station would demand about 50 million tons per year of wood pellets or about 2.5 times more than the estimated 2016 total pellet production capacity of the US and Canada[17].

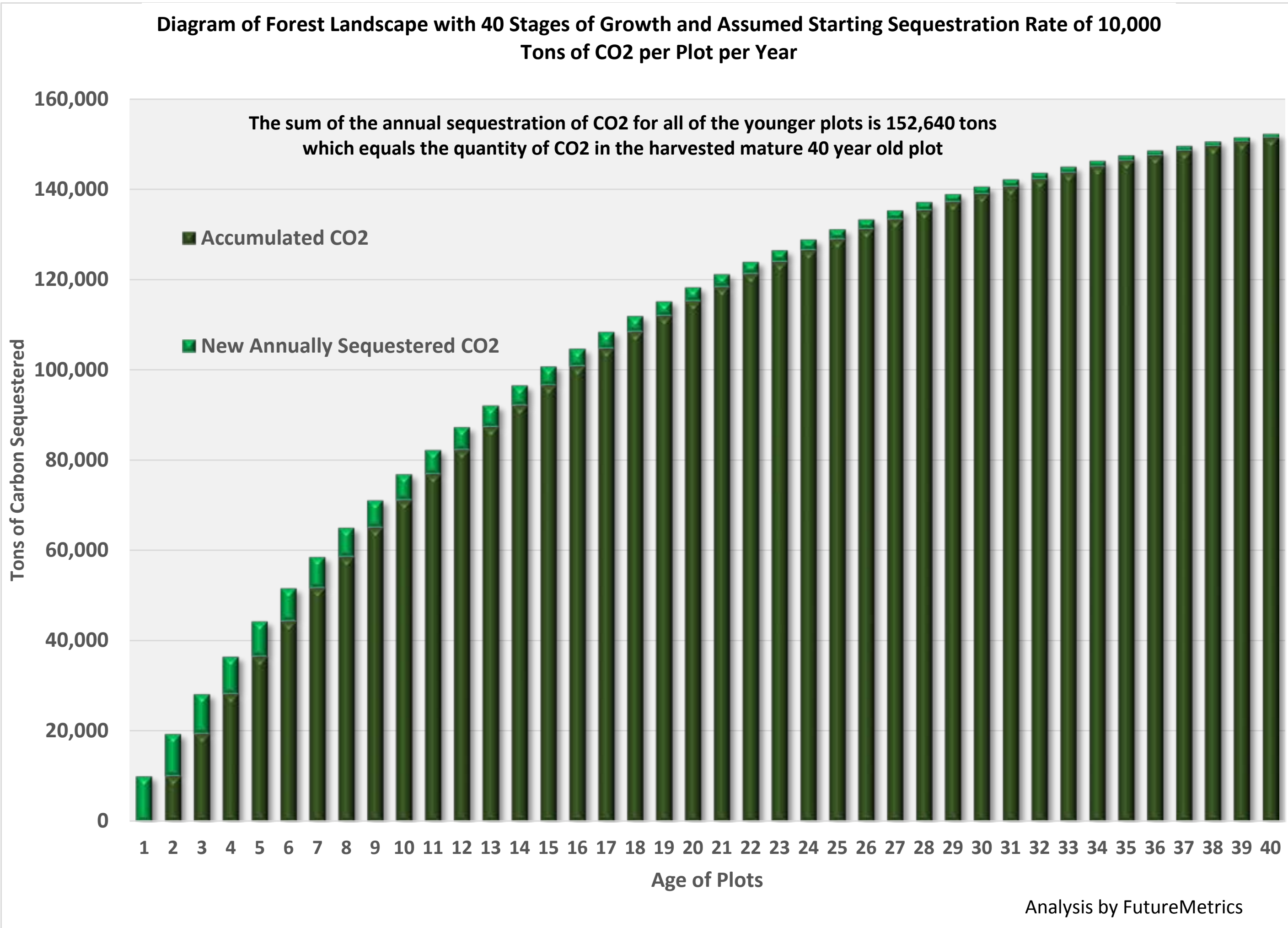
Can the US and Canadian working forests support the supply of the fiber needed to produce 50 million tons/year? Based on US and Canadian estimates of annual allowable harvest rates that would not deplete the forests and would sustain the carbon stock, the answer is yes. If the North American pulp and paper industry, which uses hundreds of millions of tons per year, continues to decline then there is more room to spare.

The limits to the co-firing strategy are the sustainability criteria that must assure that the forest carbon stock does not diminish. If that constraint is met, then every ton of carbon emitted from the pellet portion of the power plant fuel supply is absorbed contemporaneously.

This dynamic is illustrated in the chart below. In the illustration, the forest is harvested annually and after each harvest the forest is replanted. In this stylized example the landowner harvests one plot per year; the forty year old mature plot. The carbon sequestration rate is 10,000 tons per year the first year. There are 40 separate plots at 40 stages of growth from seedling to mature, and each plot sequesters carbon every year at a declining rate as the tree farm matures. The entire forest sequesters 152,640 tons per year. The accumulated carbon in the mature 40 year old stand exactly equals the carbon accumulated every year by all the younger stands. So although 152,640 tons of carbon are released by the fiber in the 40 year old plot when used as pellets for co-firing, 152,640 tons of carbon are sequestered in the same year by each of the other plots including the replanted plot on the site of the most recent harvest[18].

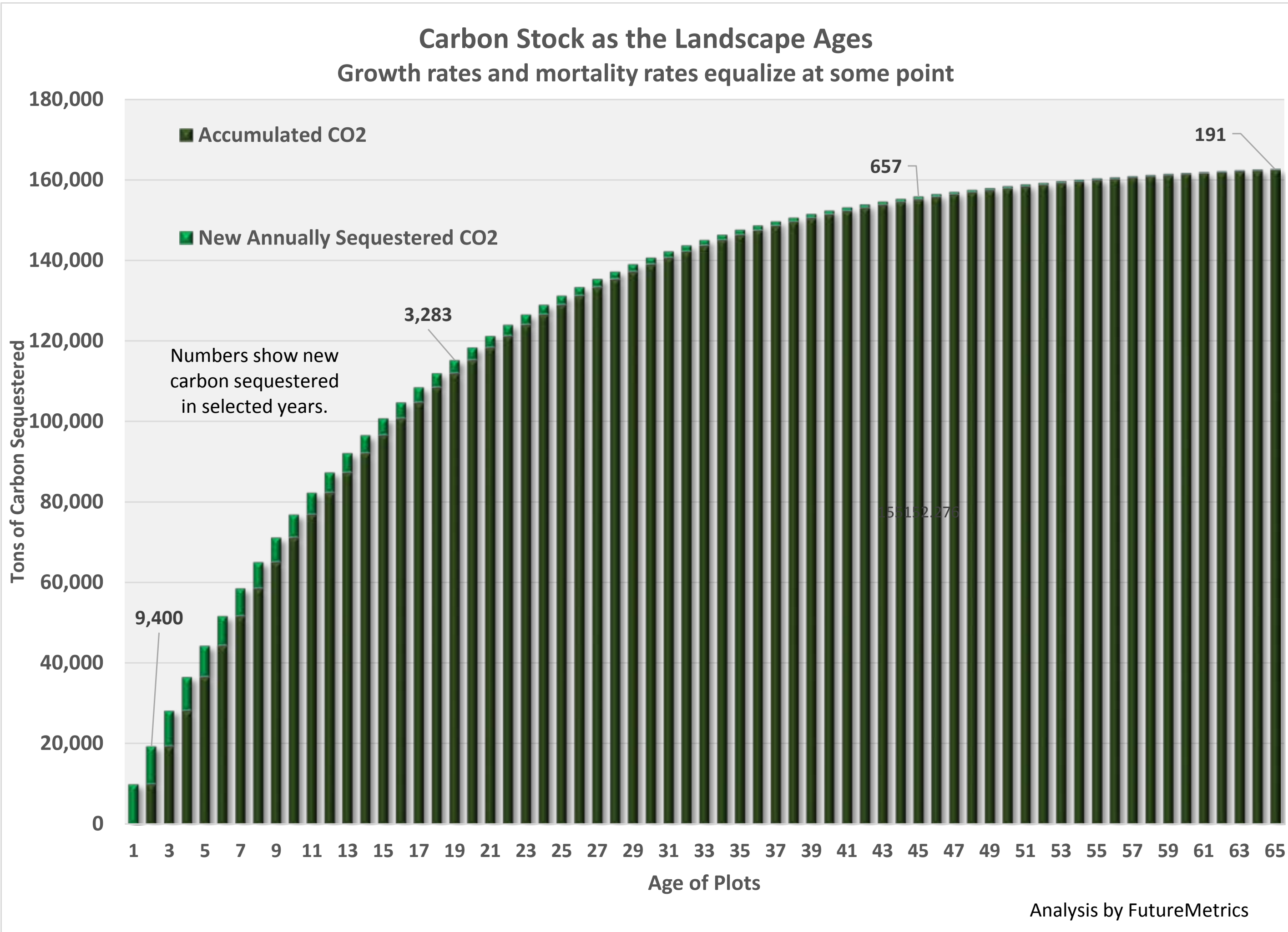
[17] Includes both industrial and heating pellets produced from current, under construction, and proposed mills in the US and Canada at nameplate capacities. Data is from BBI pellet mill database.

[18] Actual growth rates and sequestration rates vary with the age of the trees. But in the aggregate, as long at what is absorbed every year is equal to or greater than what is removed, then the carbon stock is maintained. Harvests leave behind parts of the trees so the carbon released is always less than the carbon sequestered. Sustainability criteria and the auditing that certifies the forest fiber as sustainable assures this.



The chart shows a harvest once per year. But demand for forest product are continuous: Harvesting, regrowth, and replanting happens every day. So the carbon released by the continuous use of pellets consumed daily for power generation is sequestered immediately by the continuous regrowth that occurs in balance with the harvest. The working forests can renew forever if they are managed properly.

Opponents of harvesting working forests for fuel often cite the loss of the carbon sink. As forests age, the rate of carbon capture slows. At some point all forests reach a carbon stock equilibrium at which the growth rate and mortality rates equalize. The carbon sink ceases to exist in older forests. The chart below shows how a forest landscape with 65 plots planted one year apart sequesters very little new carbon in the plots 45 to 65 compared to the younger plots.



A co-firing strategy that is predicated upon lowering carbon emissions must include criteria and auditing protocols to assure that the working forests and their carbon stocks are preserved forever.

Conclusion

Blending low carbon wood pellets with coal under a well-crafted policy can provide a non-disruptive pathway toward achieving the goals of the Clean Power Plan. The strategy does not burden the generators nor the ratepayers with high costs. The carbon benefits can be accrued for a fraction of the total cost of wind or solar power[19]. Unlike wind and solar and natural gas, the fuel supply for co-firing power plants sustains and grows jobs in the coal and wood growing regions of the US.

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[19] The levelized cost of generation includes not just the cost of the fuel but also the amortized cost of constructing the power plant and the fixed and variable operations and maintenance costs. The low capacity factors of wind and solar mean that for a given nameplate capacity, only 20% to 35% of that nameplate is generated on average. Each MWh has to carry a high burden of non-fuel costs. Just the capital cost per MWh generated for wind and solar is significantly higher than the fuel cost for coal and coal/pellet co-firing. Based on NREL LCOE data, 2015 and FutureMetrics analysis.

To discuss using coal as part of a carbon mitigation strategy is remarkable. If the coal generating parts of the power grid could be rapidly, responsibly, and cost effectively replaced in a very short time, this paper would not have been written. But those essential parts of our power grid cannot just be switched off.

What is needed is a pragmatic and rational solution to lowering CO_2 emissions. This paper has presented just that. Over several decades, in a non-disruptive way, the grid can achieve the goals of the Clean Power Plan.

The environmental benefits are real and quantifiable. CO_2 emissions can be lowered to 30% or more below the benchmark with a policy that unites the states with the power plants, the coal producers, and the pellet producers.

The economic benefits are real and quantifiable. Jobs will be created not destroyed, and power rates will remain low in every state that adopts this policy as part of the CPP compliance strategy. The certainty that the strategy will bring to the generators and to the producers of solid fuel will allow investment into both sectors. The new pellet plants needed to support the co-firing levels described above will require more than **$11 <u>billion</u>** in capital costs for new construction.

The time is now to begin the development of policies that will lead to an outcome that has no shortage of winners.