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Using Highly Carbonized Bioresources for Steelmaking

Leveraging the existing global pellet trade infrastructure to support the decarbonization of the steel industry

A look at "carbonization after pelletization" (CAP)

At least 10 years ago when we first learned of efforts to take traditional white pellets and torrefy them, FutureMetrics was highly skeptical of the efficacy of the idea.

The mass losses of some 25% to 30% incurred when torrefying wood fiber means that the bulk density of the pellets drops from a typical 650 kg/m^3 to 450 to 500 kg/m^3. The energy losses at that level of torrefaction are about 12% to 15%. Even with the higher energy density per tonne, the net of the bulk and energy density results in less energy per cubic meter than traditional white pellets. Wood pellets for energy were invented to maximize the quantity of energy in a cubic meter. The torrefaction after pelletization (TAP) strategy degrades the logistics advantages[1].

<u>But FutureMetrics has changed its mind about thermally treating white pellets</u>.

It is not the markets for carbon beneficial solid fuel alternatives to coal in power generation that FutureMetrics sees as the place for TAP, it is in the steel making sector. TAP understates the degree of thermal treatment needed to reach the high levels of carbon content required for refining iron ore into crude iron. Thus, the term "carbonization after pelletization" or CAP.

The Steel Sector is a Major CO_2 Emitter

The global steel sector is responsible for about 7% of global carbon dioxide emissions[2]. Of the estimated 37.5 billion tonnes of CO_2 emitted globally in 2024, about 2.7 billion tonnes will come from the steel making sector.

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[1] FutureMetrics has produced a comprehensive analysis of torrefaction and steam explosion technologies. For more, visit the FutureMetrics website.

[2] COP27: UN report shows pathways to carbon-neutrality in "energy intensive" steel, chemicals and cement industries | UNECE

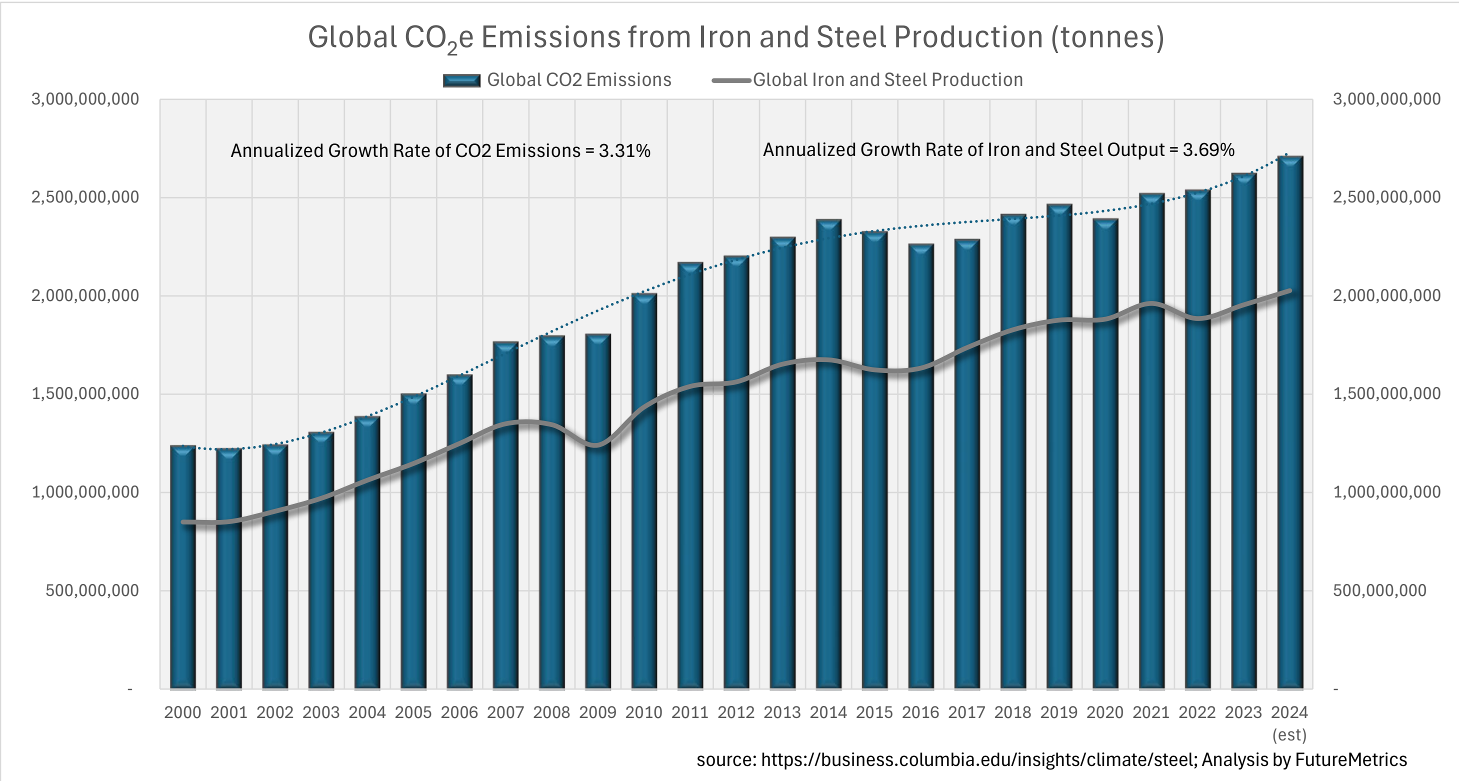

Figure 1 – Global CO_2 Emissions from Iron and Steel Production

Most of CO_2 emissions in the steel manufacturing sector come from blast furnaces. Blast furnaces produce about 73% of global iron and about 80% of global iron and steel CO_2 emissions[3]. Blast furnaces take in iron ore (an iron oxide, usually hematite: Fe_2O_3), some limestone, and carbon produced from coal called coke, and remove the oxygen from the Fe_2O_3 molecules to produce a crude iron. The crude iron is further processed and is used to produce a variety of types of steel.

The reaction that changes hematite to iron releases significant quantities of CO_2[4]. Every tonne of crude iron produced in a blast furnace produces about 2.33 tonnes of CO_2.

There are 990 operating blast furnaces in the world with nameplate capacity of about 1.45 billion tonnes per year of iron production[5]. The actual capacity factors for individual mills is not known. Thus, to match the estimated CO_2 total emissions from the nearly 1000 operating blast furnaces we apply an aggregated capacity factor of 65%. Many of the newer mills (and there are many very new blast furnaces as Figure 3 below shows) operate at higher output levels. Some mills are old and likely operate at lower capacity factors. Figure 3 shows that there are many operating plants that are quite old.

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[3] https://worldsteel.org/steel-topics/sustainability/sustainability-indicators-2023-report/

[4] Both the carbon and carbon monoxide (and oxygen in highly controlled quantities) in the blast furnace reduce the iron ore to iron and generate carbon dioxide: $Fe_2O_3+3C \longrightarrow 2Fe+3CO_2$ and $Fe_2O_3+3CO \longrightarrow 2Fe+3CO_2$

[5] Based on data in the Global Energy Monitor, Global Blast Furnace Tracker, April 2024 (V1) release.

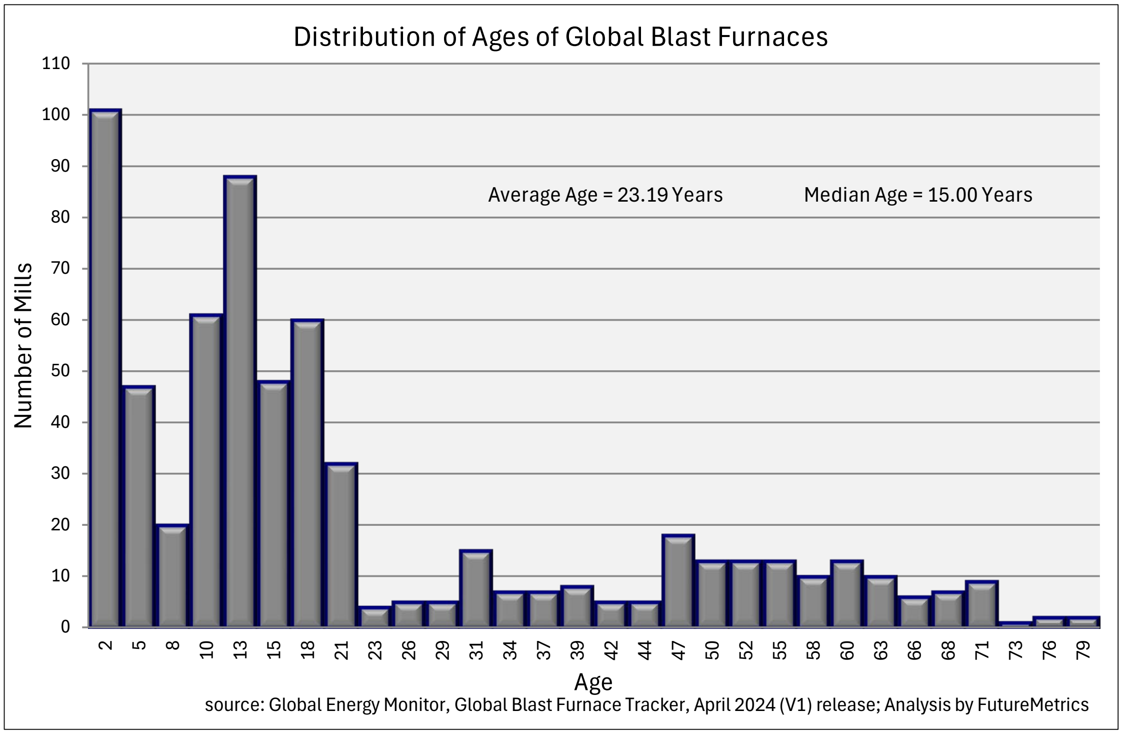

Figure 2 - Ages of Operating Blast Furnaces

The high number of new blast furnaces in recent years is part of a continuing trend in capacity growth. As of mid-2024, about 207 million tonnes per year of new production capacity has been announced and about 100 million tonnes per year of production is under construction. Assuming the new mills have an 85% capacity factor, that is an additional 609 million tonnes per year of CO_2 emissions.

Decarbonizing the Steel Making Sector is Critical to Reaching CO_2 Emissions Targets

The challenge is huge. There are 1,848 steel mills in the world, many of which take input from nearly 1,000 blast furnaces. Figure 4 on the next page links to an interactive map of every steel mill in the world.

	Number of Steel Mills	Percent of World Total
China	743	40.2%
Europe	269	14.6%
India	180	9.7%
United States	97	5.2%
Rest of the World	559	30.2%

source: "Global Energy Monitor, Global Steel Plant Tracker, April 2024; analysis by FutureMetrics

Table 1 - Locations of Global Steel Mills

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Click on the image (or this LINK) to open an interactive map of all 1,848 steel mills. Zoom in on any mill. Click on the link for further information.

Figure 3 - Steel Mills Map

There are two other primary methods of producing crude steel other than refining iron ore in blast furnaces: using electric arc furnaces (EAF) to melt recycled scrap, and using natural gas as a reductant and using EAF to melt the iron. The natural gas process is expensive, only represents about 7% of global steel production, and emits about 1.33 tonnes of CO_2 per tonne of crude steel (about 40% less than a blast furnace but still a significant source of CO_2 emissions).

About 80% of steel scrap is recycled in EAFs. EAF production accounts for about 22% of global steel production. CO_2 emissions from EAFs are significantly lower than blast furnaces; at about 0.66 tonnes per tonne of crude steel. But with rapidly growing demand (especially in China in the past few decades), EAF production from recycled steel cannot match the growing demand.

The major emitters, both in proportion to iron output and in absolute numbers, are blast furnaces. Click on Figure 2 to go to the FutureMetrics interactive dashboard that quantifies emissions.

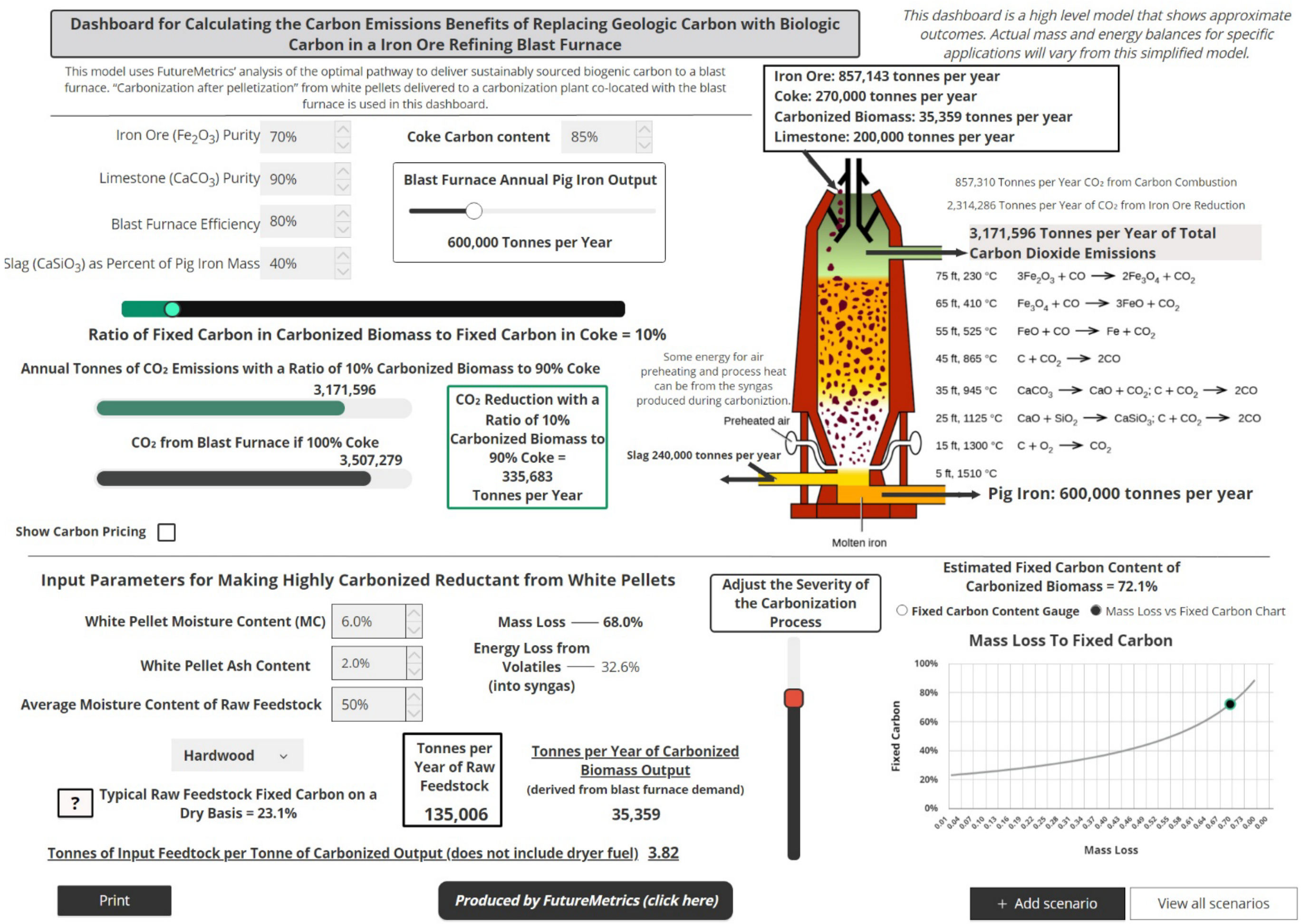

Table 2 – FutureMetrics' Blast Furnace Dashboard

Replacing Geologic Carbon with Biologic Carbon

Using carbon from coke derived from coal as a reductant is by far the lowest cost option available today. Large scale use of renewable hydrogen is on the horizon but will take several decades to rise to prominence[6].

There are, however, several carbon beneficial solutions that can move the steel making sector in the right direction[7].

One easy to deploy solution is to replace the coal-derived carbon with carbon produced from sustainably sourced bioresources.

Blast furnaces using carbon-based reductant will always emit CO_2 from the chemical reaction that separates the oxygen atoms from the iron atoms. But the source of the carbon atoms needed for changing typical iron ore (Fe_2O_3) into crude (pig) iron (Fe) matters in terms of net impact on CO_2 concentrations in the earth's atmosphere[8].

Making a high carbon content product from bioresources is already a proven technology.

There is no mystery to the process of exposing biomass to high temperature over time in an oxygen starved reactor to drive off volatile matter and leave behind a higher carbon content material. Thus, the moniker "black" pellets, which are produced from torrefaction.

For fuel for power production, torrefied pellets are suitable in selected, but so far, limited circumstances[9].

Longer time and/or higher temperatures in the process yields "carbonization". That product is suitable as a replacement for coal/coke in blast furnaces.

The cost per tonne of carbon from bio-carbonization is higher than from coke produced from coal. That issue must be addressed by policy that internalizes the costs of CO_2 pollution from mined minerals (coal, oil, NG) and its effects on climate, weather, and oceans. In some jurisdictions where the costs of CO_2 pollution now and in the future are explicitly recognized, current and evolving rules are creating incentives to mitigate CO_2 emissions from the use of fossil fuels; just like existing rules regulating emissions of other pollutants that harm the air, water, and land.

There are safety, logistics, and technical challenges associated with the use of biocarbon. The carbonized material has low density and is dusty making long distance transport costly. Densification solves some of that. But highly carbonized product will not pelletize without a binder so densification is challenging. Long-distance transport has serious handling and storage safety concerns as well which adds significant cost per delivered tonne.

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[6] The emissions from using hydrogen to separate oxygen from iron oxide is H_20 (water).
[7] See IEA report HERE that discusses ideas for more sustainable steelmaking.
[8] The rapid increase in the use of coal, oil, and natural gas (methane) have put the earth's systems out of balance. See the recent FutureMetrics white paper that goes into detail about the imbalance in the earth's systems due to the release in the span of a few hundred years of the carbon that was stored over hundreds of millions on years. HERE.
[9] See the recent FutureMetrics white paper that discusses the use of thermally treated pellets for power generation. HERE.

Most challenging, however, is the fact that the process of driving off most of the volatile compounds produces a lot more “syngas” than is needed for operating the reactor and pre-drying the feedstock. That means that there must be a nearby user of the syngas that has a 24x7 demand.

The Optimal Solution for Using Bioresource Derived Carbon

The optimal solution is to carbonize the material next to the blast furnace operation. The carbonized material only needs to be conveyed a short distance, and the excess syngas can be sent to the blast furnace or steel mill for use in their processes[10].

There are two fundamental strategies for supplying carbonized biomass from a carbonization reactor to a co-located blast furnace:

(1) If there are sufficient sustainable bioresources near the location of the blast furnace, then the bio-material can be sent to the carbonization plant in its raw form. For woody biomass this will be sawmill residuals such as chips and sawdust, or forest residuals with no higher value use. The residuals can then be converted into the high carbon content product used to reduce ore to crude iron.

(2) The more flexible and universally applicable solution is to send standard wood pellets to the carbonization plant and then convert the so-called “white” pellets into the high carbon content material needed by the blast furnace.

FutureMetrics has modeled both strategic pathways.

There are limited opportunities for option (1) because the blast furnace has to be located centrally to the sustainable supply of bioresources. Long distance transport of raw feedstock is a limiting factor for all forest products industries, including sawmills, pulp mills, pellet producers and, in this case, biocarbon producers. The potential for dedicated high yield crops surrounding the steel making operations may offer a viable way to increase the supply.

All solutions must follow the basic constraint that the net carbon held in the bioresources supplying feedstock cannot be depleted. In short, the growth rate has to equal or exceed the removal rate in order to prevent net additions of CO_2 into the atmosphere.

Option (2) opens up the potential to leverage the already well-established industrial pellet supply production and shipping infrastructure for use by steel makers. Pellets are already shipped around the world in large quantities for use as fuel in power stations that are gaining significant carbon emissions benefits from the substitution of pellets for coal.

[10] The syngas from the carbonization of woody materials contains a menu of chemicals including CO_2, CO, CH_4, acetic acid, formic acid, acetone, methyl acetone, and tars. The syngas can be used to preheat the air going into the blast furnace.

Decoupling the supply of bio-based feedstock from the location of the carbonization process allows the use of this steel making decarbonization strategy in almost any blast furnace location.

What About Cost?

As noted above, the lowest cost carbon for refining iron ore is from geologic carbon. But that metric is based only on the costs of production that blast furnaces currently face in most locations. Increasingly, CO_2 pollution is being formally regulated[11]. At some cost per tonne of CO_2 emitted, the use of alternatives to geologic carbon become the lower cost strategy.

The pathway to high carbon content iron ore reductant for both coal and white wood pellets requires processing. Both processes are similar. Both expose the metallurgical coal[12] or pellets to high temperatures in an oxygen starved oven or reactor.

The conversion of white pellets to a carbonized material (>75% fixed carbon content) results in significant mass loss (see the dashboard referenced in Figure 2).

The Next Growth Market for the Wood Pellet Sector!

The steel making sector is a significant contributor to the climate change crisis. There are several ways to lower CO_2 emissions when converting iron ore to crude (pig) iron. One pathway is to substitute some or all of the geologic carbon used in the refinery with carbon atoms produced from sustainably sourced renewing carbohydrates.

The carbonization-after-pelletization tactic, when the CAP mill is co-located with the blast furnace, can directly supply not only solid high fixed carbon content reductant, but can also supply the gaseous by-product of the thermal treatment process. That syngas contains a significant amount of energy.

Using the approach of carbonizing white pellets at the location of the blast furnace de-risks the supply of biogenic carbon because it instantly opens a well-established multi-source supply base of white pellets and their corresponding logistics systems.

[11] As many FutureMetrics white papers have discussed and as Dr. Strauss has said in many speeches, the increased frequency and severity of the consequences of climate change will accelerate decarbonization policy.
[12] https://en.wikipedia.org/wiki/Metallurgical_coal