The Iron Age & Coal-based Coke: A Neglected Case of Fossil-fuel Dependence

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As an old-fashioned scientist, I prefer hard engineering realities to all those interminably vacuous and poorly informed policy "debates" that feature energy self-sufficiency (*even Saudis import*!), sustainability (*at what spatial and temporal scales*?), stakeholders (*are not we all, in a global economy*?) and green economy (*but are not we still burning some 9 billion tonnes of carbon annually*?).

High regard for facts and low regard for wishful thinking has forced me to deal repeatedly with many energy illusions–if not outright delusions–and to point out many complications and difficulties to be encountered during an inevitably lengthy transition from an overwhelmingly fossil-fueled world to economies drawing a substantial share of their primary energies from renewable sources.

Steel & Coal-Derived Coke

Here is another challenge for the energy transformationists, one that is both inexplicably neglected and extraordinarily important: *steel's fundamental dependence on coal-derived coke with no practical substitutes on any rational technical horizon*.

Those with a warped understanding of the real world might scoff: *steel*? Is not the electronics everything that matters in the post-industrial world? Yes, according to scientifically illiterate media and to the ceaseless self-promoting noise coming from assorted software companies. But, contrary to these naïve perceptions of reality, ours is still very much the **Iron Age** and not a Microprocessor Age.

We had prosperous and vibrant economies long before solid state electronics was invented (that is before December1947 when the first transistor was demonstrated at the Bell Labs) and before the first microprocessor was released by Intel (that is before November 1971). But no aspect of modern, or post-modern, economy is imaginable without steel: so many things that surround us made of it (from car bodies to cutlery, from shipping containers to skyscraper skeletons), and just about everything around us made with it as steel tools and steel machines are used to produce countless metallic, plastic, wooden and stone products and as steel is the dominant material in complex engineering assemblies ranging from massive offshore drilling rigs to supertankers, and from reinforced concrete to the world's longest bridges.

And although more and more steel now comes from recycling the old metal (melted in electric arc furnaces), and a small amount is produced by direct reduction of iron using natural gas, most of it (70% in recent years) still begins as pig (cast, hot metal) iron smelted in large blast furnaces. These massive columnar structures –- the largest ones taller than 30 m, with volume exceeding

5,000 m3 and with annual energy needs in excess of 2.5 million tonnes of coal equivalent –- are charged with iron ore, limestone (the fluxing agent) and coke.

Global scale of primary iron smelting in blast furnaces has become immense, rising from less than 50 million tonnes in 1900 to 580 million tonnes in 2000 and to nearly 930 million tonnes in 2008, with China alone producing just over half of it. Virtually all primary iron production goes to make steel by reducing the iron's high carbon content (more than 4 %) to mostly between 0.1-1 % C and by alloying it with other metals.

Coke, made by pyrolysis of coal, has several critical roles in the smelting process: it high mechanical strength supports the ore and limestone charge, it provides a permeable medium for the ascent of reducing gases and the descent of molten slag and metal within the furnace, it acts as the reducing agent (upward moving hot CO-rich gases reduce ore oxides into elemental iron) and it energizes the high-temperature melt. The total amount of coke charged per unit of produced iron has been gradually reduced by better furnace design and operation, by injecting oil or natural gas and more recently by resorting to high injection rates of pulverized coal and even by using pelletized plastic waste. As a result, average worldwide ratio of dry coke:hot metal declined from about 1:1 in 1950 to 0.65:1 by 1970 and to just 0.45:1 by 2008.

This means that the global iron production still needed about 420 million tonnes of coke in 2008 and hydrocarbons and coal injected into blast furnaces added up to an equivalent of another 100 million tonnes of coke. In a non-fossil world the only option would be to replace coal-derived coke (and injected fossil fuels) with charcoal made from woody biomass. Charcoal, nearly pure carbon produced by pyrolysis wood, is an excellent reducing agent and all cast iron was produced with it until the middle of the 18th century when Abraham Darby's pioneering use of coke began to spread among the English ironmakers. Traditional ironmaking used the fuel very inefficiently (commonly 8-10 tonnes of charcoal per tonne of hot iron) but modern smelting practices need no more than 0.75 tonne of charcoal per tonne of hot metal.

But compared to coke charcoal is a relatively soft material, with low compressive strength (less than a third that of coke), low abrasion rate –- and its production needs a great deal of wood. The first two drawbacks did not matter in small pre-industrial blast furnaces whose low height and small diameter had to accommodate only relatively small ore and limestone charge without crushing –- but large modern furnaces rely on coke's outstanding structural properties to support massive burdens. Adding substantial amounts of fine charcoal to pulverized coal injected into a blast furnace in order to lessen the reliance on fossil fuels is not an option because charcoal destroys coking properties of coals by reducing the degree of coal's fluidity. Conversion of the world's ironmaking to charcoal-fueled furnaces would have to be thus accompanied by a massive reversion to smaller, more costly and less efficient, blast furnaces.

Wood Isn't the Answer

Such a massive reversion would be very expensive and in practice highly unlikely, is technically possible; finding enough wood to produce all that charcoal would be another matter. Traditional charcoaling was extremely wasteful, with more than 10 tonnes of wood needed to produce a tonne of charcoal but even for the modern methods that were used commonly in Brazil during the 1990s (before a large-scale conversion to coke) the ratio of wood: charcoal was 4:1.

This means that a complete replacement of 520 million tonnes of coke (setting aside those nontrivial matters of differences in compressive strength and furnace size) would require nearly 2.1 billion tonnes of wood. Even if that wood were to come from such high-yielding species as tropical eucalypts, producing about 10 tonnes per hectare/year, today's iron smelting would require harvesting annually an area of 210 million hectares of well-managed tropical wood plantations –- or an area equivalent to half of Brazil's Amazon tropical rain forest.

This choice of enormous monocultural plantations replacing a highly biodiverse forest should not, one would hope, get a green approval –- but if the wood harvest for metallurgical charcoal were to come from the world's major concentrations of existing tropical, temperate and boreal forests then the impact would be even more extreme. Global harvests of roundwood have now reached about 3.9 billion cubic meters a year, and if metallurgical charcoal were to claim 2.1 billion tonnes it would mean that only about 10% of today's worldwide wood cut would be left for all timber (mainly for construction and furniture) and pulp (mainly for paper) needs.

Renewables Aren't the Answer

Renewable energies offer obvious, albeit imperfect and still rather costly, alternatives to fossil fuel-fired electricity generation. The harnessing of wind by large turbines and of solar radiation by photovoltaic cells will be two increasingly important components of modern electricity supply. Ethanol and biodiesel are much more problematic substitutes for liquid fuels refined from crude oil, mainly because of their low net energy returns and because of their many undesirable environmental impacts; however, the two biofuels work well in existing engines.

In contrast, we have no alternative to coke-based blast furnace smelting of iron that could produce annually nearly a billion tonnes of hot iron: direct reduction of iron ore using natural gas has been recently adding less than 60 million tonnes to the global output and there is no other coke-free iron ore reduction pathway.

Charcoal is the only non-fossil fuel that is a good coke replacement as far as the energy density is concerned (it has only about 5% less energy than coke) -– but an inferior replacement in terms of its critically important mechanical properties. But even if (a theoretic possibility) we were to rebuild the global iron smelting in order to conform to the scale of charcoal-fueled furnaces we could secure enough wood to support the current level of iron production only if we used nearly the entire global wood harvest to make metallurgical charcoal –- or if we replaced large areas of tropical rain forests by extensive plantations of fast-growing trees.

Conclusion

Arrival of the non-fossil world has a great appeal for green energy enthusiasts: they see the transition as highly desirable because of its environmental impacts, they are convinced it will give us sustainable energy supply, they claim that it will pay for itself, and all agree that it will leave us all better off.

But this new world of non-fossil energy will have its new iconic energy artifacts: tall towers carrying giant wind turbines; thousands of kilometers of high voltage lines transmitting wind-generated electricity from the Great Plains and solar electricity from the Southwest (or, according to an acutely fashionable European plan, from the heart of Sahara to France and Germany); deep geothermal wells bringing the Earth's heat to the surface; giant bioreactors producing inexpensive biofuels.

But ask where the steel for all those turbine and transmission towers, for all those drilling rigs and well linings, for all those tanks and pipes in biorefineries will come from. And also ask about how we will produce iron to get steel for all those biofueled vehicles, all those solar-heated buildings, all those rails and carriages for rapid trains running on wind and solar electricity, all those hulls for tankers transporting ethanol and biodiesel from tropical sugar cane and jatropha.

No amount of renewable electricity and no amount of bioethanol can smelt a billion tonnes of iron –- and all the charcoal that could be produced in a responsible and truly sustainable manner could be used to reduce only a small fraction of today's iron needs, and even a smaller one of the future demand. *There can be no doubt: coal-derived coke will be with us for generations to come.*