A Steely Story

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1. Introduction

I have written about the Iron & Steel Industry before (see below). This is because the legacy processes used by this industry are major contributors to greenhouse gas (GHG) emissions and thus climate change. Also, this industry is currently a major energy consumer. Regarding that latter, "*Iron and Steel Mills and Ferroalloy Manufacturing (NAICS 3311) is the fifth largest consumer of fuels among U.S. manufacturing sectors.*"[1] See the diagram below for more information on energy consumptions and GHG emissions. Note that 1,481 TBtu is about 341,214.1 MWh.

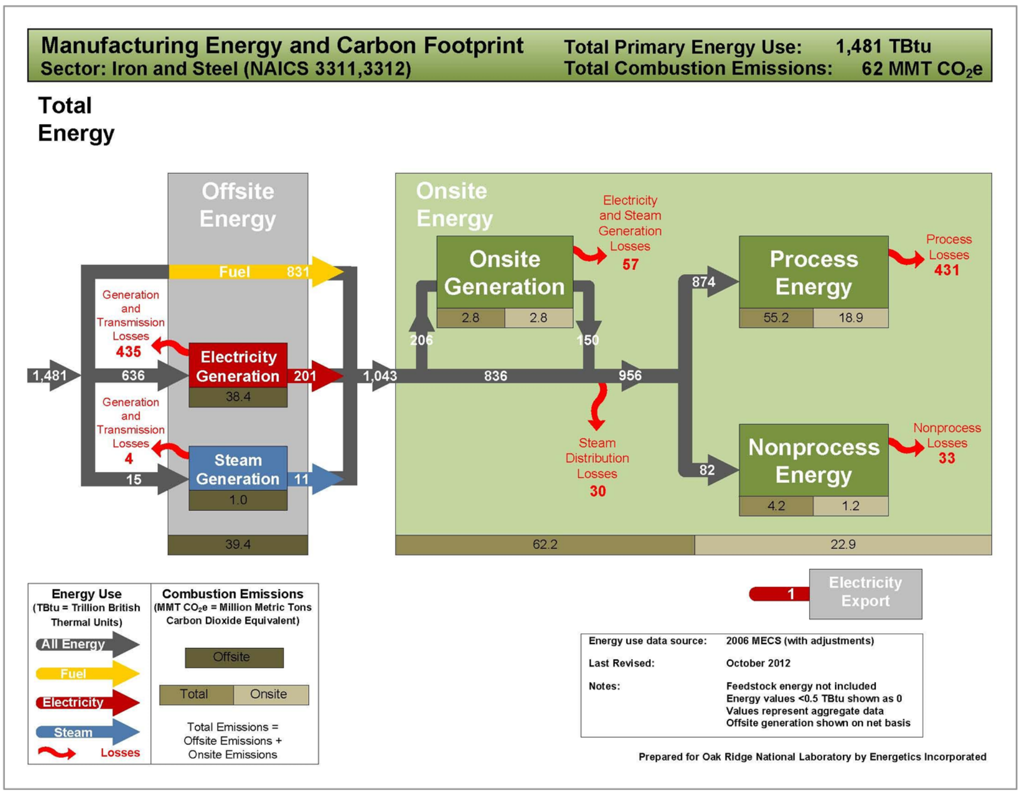


Fig. 2.6-2. Total energy and carbon footprint for the iron and steel sector

I originally posted "part 1" of an earlier series on this subject, "*I Like Smoke and Lightning, Heavy Metal Thunder*" in 2018, and then in 2022 I added parts 2 & 3. These are summarized and linked below.

I Like Smoke and Lightning, Heavy Metal Thunder: *This paper is about the metals industrial subsector, how these industries use energy and how they are evolving. The subject of this paper contains a segment on the largest industrial producer of these emissions, the Iron and Steel Industry Group.*

https://www.energycentral.com/c/cp/i-smoke-and-lightning-heavy-metal-thunder

[1] https://www.energy.gov/sites/prod/files/2013/11/f4/energy_use_and_loss_and_emissions_iron.pdf

I Like Smoke & Lightning, Heavy Metal Thunder, Part 2: *This paper is the second in a series about the metals industrial subsector, how these industries use energy and how they are evolving. There are several pieces of new news regarding the iron/steel and aluminum sectors in this industry. These will be covered in this part.*

https://energycentral.com/c/ec/i-smoke-lightning-heavy-metal-thunder-part-2

I Like Smoke & Lightning, Heavy Metal Thunder, Part 3: *This post is the third in the series. This series is about the metals subsector, and more specifically this post, is about the Iron and Steel Mills and Ferroalloy Manufacturing Industry Group.*

One reason that I am writing this is that, in an earlier post I said: "I believe that hydrogen will have a strong role to play in our path to a greenhouse-gas (GHG) free future."

The day after I finalized the above wording I was reading an issue of Time, and came across a pilot plant that was recently completed in the EU that made iron without greenhouse gases. I will describe the plant in this post, but guess what it used to reduce the iron ore to iron. Yep, hydrogen.

https://energycentral.com/c/ec/i-smoke-and-lightning-heavy-metal-thunder-part-3

2. Steel

This subsection title is a comprehensive book on the primary subject of this paper that I came across a month or two before the date of this post. First, I must say that this is a really big book. The book is physically large, printed on high- quality stock, and it is lavishly illustrated. The text thoroughly chronicles the evolution of this industry.[2]

For readers interested in purchasing this book, I have included a reference to the Amazon site for this below. I believe that it is out of print, because it is only available as used volumes from Amazon, ranging in price from the mid-$20s to $40. I managed to find one in very good condition that I bought from a local library.

One other definition and short history: this section's title, Steel, is an alloy of iron and other substances. Mother Nature initially performed this feat, and early humans discovered that meteorites were hard and tough metals, but they really didn't know why. They did eventually determine that this strange material came from the sky, and they could heat it up and beat it into various shapes since it didn't crack or crumble like stone.

I bit later early man found elemental nuggets of other metals, mainly copper, gold and silver, that also could be beaten into a shape. Around 4,000 BC humans discovered that certain other stones (rather than metal-nuggets) could be placed in a hot fire for some time, and when the fire was extinguished, a shiny metal lay at the bottom of the fire pit. Initially, this discovery started the "Copper Age," followed by the "Bronze Age," and finally the "Iron Age." Iron was first smelted by the Chalybes people[3] around 1800 BC.

[2] Brooke Stoddard; Steel, From Mine to Mill, The Metal That Made America, 2015, https://www.amazon.com/Steel-Mine-Mill-Metal-America/dp/0760347425

[3] The Chalybes peoples were mentioned by classical authors as living in Pontus and Cappadocia in northern Anatolia during Classical Antiquity. Despite the ancient Greeks connecting the Chalybes to Scythians, some modern historians argue the Chalybes were a Georgian tribe. Historian Kalistrat Salia claims the Georgian ethnicity of the Chalybes is "indisputable." According to Sallia, the Zans, a Kartvelian ethnic group from present-day Turkey, are their descendants.

3. Edited Content

Since we provided a brief history of iron-making in the prior section, we will continue this into the first steels, via some accidents and detours.

The first alloying element used to make early steel from iron was carbon. This is mainly because iron was refined from ore in a charcoal fire initially, and charcoal is almost 100% carbon. In fact, the first proto-steel was not called steel, it was called wrought iron. During the Han dynasty (202 BC – 220 AD), new iron smelting processes led to the manufacture of new wrought iron implements for use in agriculture. The iron was heated until red-hot and then beat (wrought) with a hammer. The hot metal that smiths pulled from the fire and wrought only contained a tiny amount of carbon (0.02 to 0.1%), but this was enough to make it malleable and strong, thus useful for many applications.

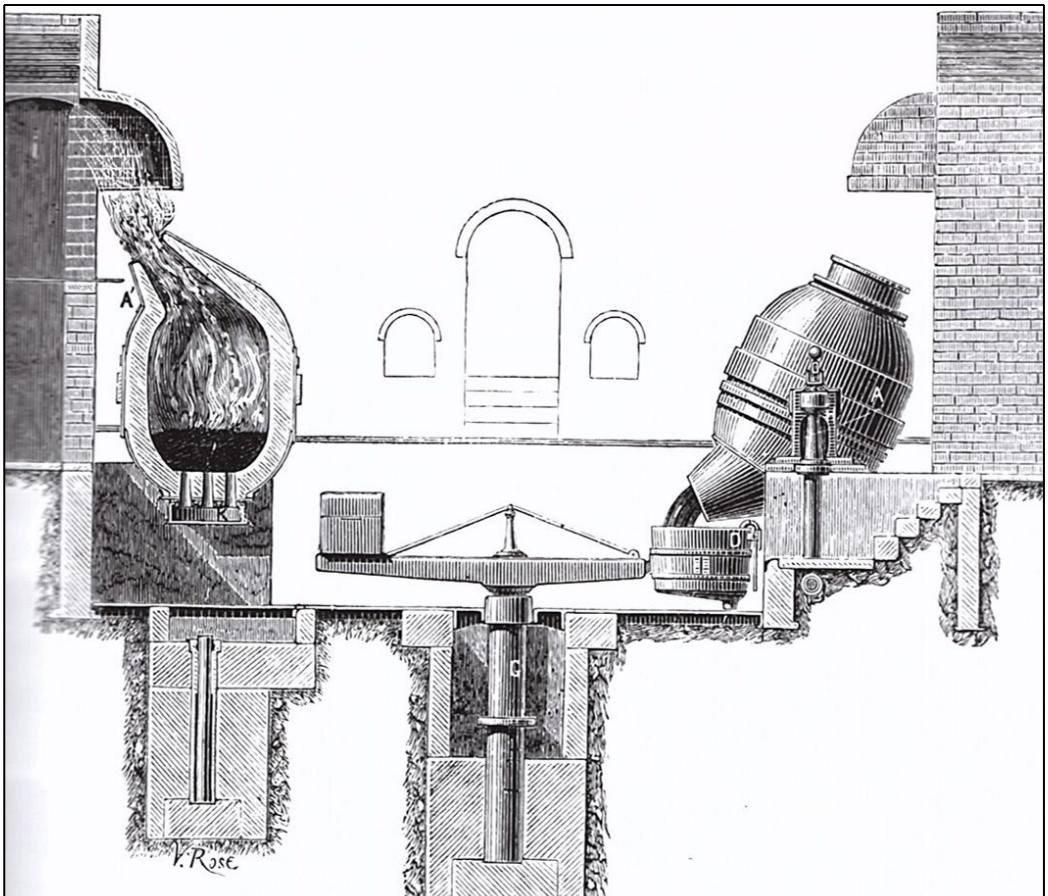
However, wrought iron could not be melted and poured into molds like bronze. Although liquid iron occasionally oozed out a really hot fires, it had absorbed too much carbon (2 to 4%) and thus was brittle when reheated and would crack under a smith's hammer. Still, this iron could be cast by heating in a hot fire and pouring it into molds. Thus, this was known as cast iron. However, there was no middle-ground between wrought iron and cast iron, although humans during this time knew that something like this existed from using meteorites, and infrequent alloys of iron with a small percentage of nickel and/or manganese that formed naturally. Since they had no way of measuring carbon-content nor the content of other metals, they did not know about the wide-gulf in carbon-content between wrought iron and cast iron nor the effects of alloying metals.

However, during this period, smiths had discovered a work-around. They would leave bars of wrought iron in white-hot charcoal until the bar's surface became white-hot. This allowed carbon to migrate into the surface of the bar, which could then be forged into a blade that would hold an edge much better than normal wrought iron without shattering like cast iron. In later years, other smiths expanded on these techniques, and made many of the famous sword blades from the Roman Empire through the Middle Ages.

Reference 2 goes into great detail on the slow advancement in steel-making from the Middle Age until much more modern times. Slowly human iron-making technology advanced until by the 1800s iron began to dominate industrial production, and became much less expensive to make. This progress peaked from 1850 to 1950, a period which Reference 2 calls the century of steel. Rather than following this, I will pick out two revolutionary advancements.

In the first advancement, steel-makers were still struggling with chemistry of their product in 1865. The problem of adjusting the carbon content of steel had been solved by an English Gentleman by the name of Henry Bessemer, who invented the Bessemer converter (Image on the next page). This would blow air through molten iron until almost all of the carbon was burned out (converted to gasses like CO and CO_2), and then add in the proper amount of carbon, and eventually other alloying agents. The problem was that this did not work with all iron ore.

With some sources of iron ore, the Bessemer converter worked perfectly, but with other ore-sources the iron came out brittle. It turned out that iron ore from many ores contain phosphorus. Phosphorus will not burn out in the Bessemer converter, and this is what made the resulting steel brittle. Eventually, this embrittling was linked to phosphorus.



An 1879 engraved illustration shows the Bessemer converter at left during a “blow
And right pouring out the finished steel.

An English police clerk by the name of Sidney Gilchrist Thomas, liked to dabble in chemistry. When he heard of the “phosphorus problem,*”…After some tinkering he figured that if the lining of the converter were changed from one that was chemically acid to one that was chemically basic, and that if a basic flux such as lime were thrown in, then the phosphorus would combine with the lining and then become trapped in the flux as part of the slag, undesirable and unincorporated elements that floated on top of the heavier iron below and could easily be separated…*

The Thomas design was incorporated into Bessemer converters very quickly, and solved the phosphorus issue. There was also another positive result for farmers: the slag produced was rich in trapped phosphorus. “*Phosphorus is a vital component of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). The structures of both DNA and RNA are linked together by phosphorus bonds. DNA is the genetic "memory unit" of all living things, while RNA reads the DNA genetic code to build proteins and other compounds essential for plant structure, seed yield, and genetic transfer. Phosphorus is also a component of adenosine triphosphate (ATP), the "energy unit" of plants. ATP forms during photosynthesis and is involved in energy storage and transfer. It is present from the beginning of seedling growth through to the formation of grain and maturity.*”[4]

[4] https://shuncy.com/article/how-does-phosphorus-help-plants

Thus, when the slag solidified it could be crushed into powder and became a major ingredient in early fertilizers.

Steel was suddenly inexpensive and consistent enough to be used for major infrastructure, like major railway tracks (and the train engines that ran on them), bridges, buildings and other structures. Since the late 1800s were a period of major infrastructure expansion in the US, the Steel Industry here benefitted greatly and expanded rapidly.

There were two other historic events that greatly benefitted the steel industry, although they greatly damaged society: WWI and WWII. Steadily improving iron technology could produce better weapons, these were in great demand during these two wars. Primary products were cannons, armored tanks, small arms, and especially large battle ships, aircraft carriers, and other ships. This created huge demand for steel in the US, especially during World War II, and afterward during the cold war.

An unfortunate side-effect was that the steel industry became complacent. Although labor and management had an uneasy truce during this period, since both were benefiting greatly, in the period thereafter (1990s until now), competition from off-shore became fierce. The U.S. Steel Industry could not compete, and started shrinking. By the 2010s US Steel and Nucor were the largest U.S. Steel Makers and only ranked 13^{th} and 14^{th} world-wide.

Today the industry has become internationalized. In terms of steel production, China ranked first in 2013 and produced about half of the world-wide output (859 million tons out of 1,770 million tons). Japan ranked second (122 million tons), the U.S. third (96 million tons), India: fourth, Russia: fifth, and then South Korea. Then and now, China benefits from their rapid industrial expansion like the U.S. saw in the late-1800s and early-1900s.

Although many steel firms are now multinationals, they are also rapidly automating their steel-making processes for lower prices, higher quality, and steels better tailored for each application.