

# The Metallurgical Mystery of Verne's Island Iron Furnace

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## Abstract

*One mystery of Verne's famous Lincoln Island (Mysterious Island, 1874) continues: Did Verne use coal in his island's Catalan ironmaking furnace? Using coal in a Catalan furnace would have represented a significant prediction (albeit somewhat in retrospect), foreshadowing the rise of the modern blast furnace and the Steel Age, which would require coal-based blast furnaces. In the 1870s, the use of coal in iron-reducing furnaces was limited due to sulfur and other impurities, despite offering productivity, cost, and labor improvements necessary for mass steel production. Coal would be the key to the future world of iron and steel. Iron was made mainly in charcoal furnaces of various types before 1875. Verne's fictional Catalan furnace was designed to address the problem of using coal instead of charcoal to reduce iron by going back to the future.*

*Unfortunately, translation issues, word etymology, the Victorian technical lexicon, and the evolving technical lexicon with the rise of the Industrial Revolution may have obscured Verne's remarkable insight into coal, iron, and steel technology. While most common translations use coal for the French word "charbon." Chardon was used in French before 1890 for the English words carbon, charcoal, and coal, allowing much leeway for translators. Historical and metallurgical analysis can help resolve the issue of coal use in a Catalan furnace, but together with the analysis of transitions and lexicon, they suggest that Verne predicted the revolutionary role of coal technology in iron and steel making.*

## Introduction

Manufacturing various ferrous products, such as cast iron, wrought iron, and steel, is based on the use and control of carbon chemistry. Carbon is the fuel and reducing agent to free iron from its oxide ore. Carbon level defines the properties of iron alloys, such as cast iron (more than 2 percent carbon), steel (.3 percent to 2 percent carbon), and wrought iron (under .1 percent), moving from high carbon to lower carbon. The general overview is that iron alloys become harder but less malleable and less easy to work with as carbon levels increase. Higher carbon allows the iron alloy to be smelted and remelted at lower temperatures, making it easier to cast directly into a shape.

The three ferrous products, wrought iron, steel, and cast iron, all have unique properties for engineering applications. Wrought iron toughness makes it perfect for chains, hand tools, and wire, which the island colonists produced from the Catalan Forge. Verne's colonists, however, needed saws and axes to survive, which required a second operation of steelmaking from the Catalan furnace iron. Verne describes the two steelmaking options available in *Mysterious Island* (1874): "The first, obtained by the decarbonation of the metal, gives natural or puddled steel; the second, produced by the carburization of the iron, gives steel of cementation." <sup>ii</sup>

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

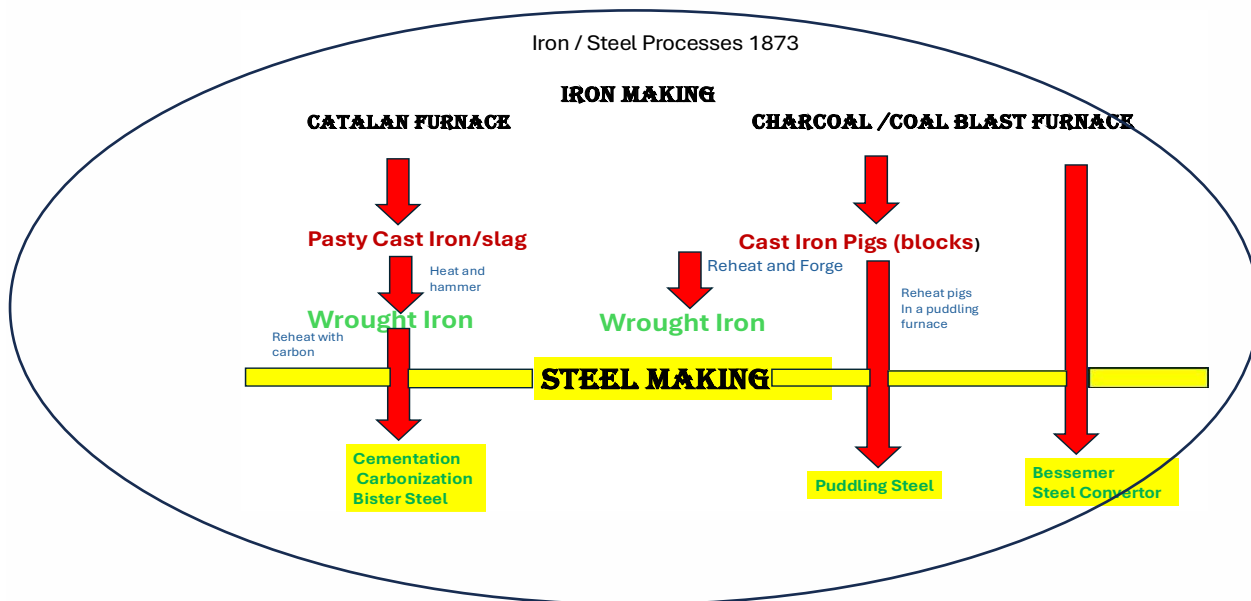
The Catalan operation is essentially a combination of releasing iron from its ore and then working and forging the hot, high-carbon pasty product to burn out the carbon, resulting in low-carbon wrought iron suitable for use in picks and tongs. This process is fully described in Jules Verne's *Mysterious Island* (1874), utilizing the "Catalan Forge" process.

To make hard tools such as axes and saws, carbon needs to be added back to wrought iron, and Verne's island colonists used the cementation (blister steel process) to make steel. The other way to make steel is to take a high-carbon product from a smelting furnace and remove carbon by puddling, the Bessemer process, or oxygen to burn out the carbon. Verne deals with the puddling process in his *Begum's Millions* (1878). The future of iron and steel production depended on the substitution of coal for charcoal in the larger blast furnace.

The blast furnace produces high-carbon liquid cast iron (pig iron) for further processing into wrought iron or steel. While a few iron blast furnaces experimented with coal in the late 1860s, the limitations were significant, and there is no historical record of coal being used in the smaller Catalan iron furnaces. Verne anticipated the future of coal in the ironmaking process. Verne knew the quality and economic value of iron from hard anthracite coal, noting its high carbon content and low impurities in the *Underground City* (1877).<sup>iii</sup> In *"From the Earth to the Moon"* (1872), Verne selects the pioneering anthracite coal ironworks, Cold Springs Foundry, opting for anthracite coal iron over charcoal iron for his fictional space cannon due to its superior quality. While it is unclear whether he is using anthracite coal in *Mysterious Island* (1874), the coal prediction appears to be far from a guess. Verne's selection of coal over charcoal ironmaking was anchored in current science and furnace chemistry. Verne details his knowledge of iron reduction chemistry in *Mysterious Island*, a subject that only a few chemistry professors at major universities could have articulated. Verne in *Mysterious Island* (1874) uses the exact future requirements needed to substitute coal for charcoal in ironmaking furnaces. With the combined consideration of lexicon, translation, context, history, manuscript, and metallurgical issues, it can be said that Verne foresaw the future of coal in reducing iron ore. Verne goes back to the Catalan process to suggest coal could be used in iron smelting.

To prove Verne used coal in his Catalan iron furnace, you must address three issues: (1) the technical and metallurgical feasibility of substituting coal in a Catalan Furnace (2) Verne's improved Catalan furnace design versus historical Catalan furnaces (3) a possible translation problem and word etymology with the words coal and charcoal. This review of Verne's island furnace reaffirms Verne did indeed substitute coal for charcoal, auguring the future of coal over charcoal in iron blast furnaces and ushering in the Steel Age.

## The Catalan Ironmaking Process, The Blast Furnace, and Steelmaking



When Verne started writing *Mysterious Island* around 1872-73, coal, iron, and steelmaking technology were rapidly evolving. Iron making was on the verge of a potential revolutionary change with the advent of coal. Verne notes in *Mysterious Island*, which was first published in 1874, the importance of coal: “This is the cause of the wealth of the mines in Great Britain, where the coal aids the manufacture of the metal [iron].”<sup>iv</sup> In 1871, most of the world’s iron was being produced in charcoal furnaces, but coal was making inroads in Britain and America as forests were being used up and wood was in short supply. Wrought iron was still predominant over steel in construction. The Bessemer steel process had just overtaken the Catalan process, blister and puddled steel production. Andrew Carnegie, in 1871, hesitated to invest in steel, unsure of its future. However, by 1875, Carnegie had built the world’s first massive steel mill. The coal impurities limited its quick conversion in the iron and steel industries. In 1871-73, the path of metallurgical technology was far from clear. Verne was able to predict the future of coal, iron, and steel technology. To do this, Verne demonstrated the chemistry of iron-making, tracing it back to the earliest iron-making furnaces. Verne reflects the future of coal by going back in history to suggest its possible use in the primitive Catalan furnace. If coal could have been used in the Catalan furnace, its future in blast furnaces was assured.

The Catalan ironmaking furnace was a precursor of the blast furnace. While the iron reduction chemistry was the same, the Catalan furnace produced a pasty product that was forged into malleable wrought iron, suitable for ductile products such as soft iron tongs and pliers, as seen in *Mysterious Island*. Wrought iron could also be processed further by cementation into steel, a process that was employed on *Mysterious Island* to create hardened tools, such as saws and hammers.<sup>v</sup> The charcoal blast furnace operated at a higher temperature than the Catalan furnace, producing liquid cast iron pigs (50-pound bricks). These pigs could also be processed into wrought iron or steel via puddling, as Verne notes in *Mysterious Island* (1874). A later novel, *Begum's Millions* (1879), centers the story around puddling steel.

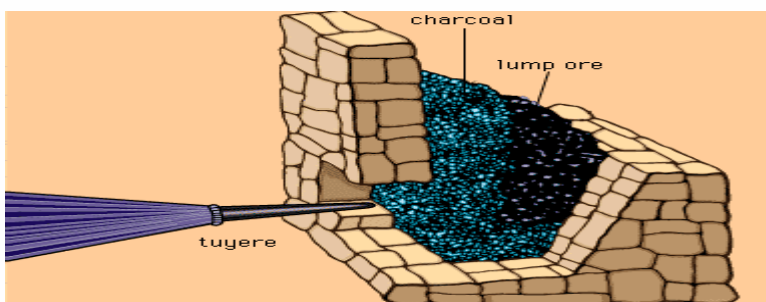
The Catalan forge process for making malleable wrought iron dates back to the 1500s, when it was used to produce small batches of iron. Based on Verne’s furnace description, his island furnace could produce a

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

50-pound batch of iron in a day. There is no historical evidence that a primitive Catalan furnace ever used anything but charcoal. By the late 1700s, the charcoal iron blast furnace had become the primary method for mass-producing iron, as opposed to the batch-oriented charcoal Catalan process, although some local Catalan operations continued into the 1890s. The higher stack and resulting higher temperature enabled continuous iron production by the charcoal blast furnace. A Charcoal iron furnace might produce *100 tons* a day.

A Catalan furnace would be more than sufficient for the needs of Verne's island colonists. Still, the real point of interest was Verne's substitution of coal for charcoal as a fuel and reducing agent, foreshadowing the rise of iron and steel. The actual reduction chemistry, known as the "Boudouard Reaction," applies to both furnaces and fuel types.

The prerequisite of the Steel Age was the production of quality iron in large and efficient blast furnaces, which required coal technology rather than charcoal. Verne's island iron furnace would augur the future. Verne had followed the progression and development of iron furnaces from wood charcoal to anthracite coal (hard)<sup>vi</sup> to bituminous (soft) coal<sup>vii</sup> as a fuel and reducing agent in ironmaking throughout his career. Verne's use of coal in a primitive Catalan furnace augured the ironmaking revolution that would lead to the Steel Age. There is no historical record of coal being used in a Catalan furnace, yet Verne applied his knowledge of iron reduction chemistry to use coal, and in this case, he is going back to the future.



Still, some argue that Verne's use of coal might have been a translation problem and requires a thorough discussion of these problems, since the words "chardon" and "houille" are used interchangeably for coal. "Chardon" was used for the English words carbon, charcoal, and coal, and Verne used it for all three. Verne used the word "chardon" predominantly in *Mysterious Island* (1873) and earlier novels, while using the word "houille" in his novel *In Underground City* (1877),

### **Translations, Etymology, and Victorian Lexicology of Coal**

The French word "charbon" is used in Verne's manuscript of *Mysterious Island* (1874) to describe the Catalan furnace.<sup>viii</sup> Using the word "charbon" would suggest a possible translation problem due to the changing technical lexicology of the period from 1870 to 1890. Charbon, in French, was used before 1890 for the words carbon, charcoal, and coal. Still, all principal English translations of *Mysterious Island* (1874), such as the 1875 translation by W. G. Kingston, the 1875 translation by Stephen White, and the 2001 translation by Jordan Stump, used coal as the fuel in Verne's island furnace. My lexicological effort supports that Verne likely used coal, not charcoal, in Cyrus Smith's iron furnace. The proof, however, necessitates a thorough examination of translation issues.

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

The ability to fully appreciate Verne's use and understanding of coal technology requires a good translation, an understanding of French habits of speech, knowledge of 19th-century metallurgy, French industrial history, and an awareness of French idiosyncrasies. And maybe even more importantly, an understanding of the etymology of the French words "charbon" and "houille".<sup>ix</sup> In the history of 19th-century coal technology, you have an evolutionary mix of English words, including charcoal, coal, anthracite coal, bituminous coal, and coke, as well as the French words "charbon" and "houille." The confusion with the word coal by translators in technical writing was noted as early as 1860.<sup>x</sup> One issue is clear: before the 20<sup>th</sup> century, French and English dictionaries used "charbon" for coal and charcoal<sup>xi</sup>. Verne himself uses "charbon" for both as well. In Verne's French texts, *Journey to the Center of the Earth* (1864), *20,000 Leagues Under the Sea* (1870), *Mysterious Island* (1873), and *Begum's Millions* (1879), "charbon" and "houille" are both used for coal. In *Underground City* (1877), Verne uses "houille" throughout. In his 1879 novel, *Begum's Millions*, while both words are used, "houille" is favored. However, the coal in *Begum's Millions* is being used as a heating agent in the steel puddling process, not as a reducing agent of the iron ore. By the 1880s, the use of "charbon" for industrial coal had significantly declined in favor of "houille" for coal, which may reflect the industrial conversion from charcoal to coal in furnaces that occurred in the early 1880s.

Researching these issues suggests Verne meant coal<sup>xii</sup>, but with reasonable doubt. The French edition<sup>xiii</sup> of *Mysterious Island* (1874) uses the French word "charbon" for English words for coal, charcoal, and the element carbon. Charbon is used 42 times in *Mysterious Island*. Houille is another French word used for mineral coal. The word "houille" is used 16 times in *Mysterious Island*.<sup>xiv</sup> When Verne uses "houille," it always applies to the mineral coal, coal mining, the coal industry, or coal in the ground. The use of "charbon" is not as clear. There are many places where "charbon" is clearly used for coal.<sup>xv</sup> There is one page where Verne refers to the same coal product as "houille" and "charbon."<sup>xvi</sup>

One issue is clear: before the 20<sup>th</sup> century, French and English dictionaries used "charbon" for coal and charcoal. In Verne's French texts, *Journey to the Center of the Earth* (1864) and *20,000 Leagues Under the Sea* (1870), "charbon" and "houille" are both used for coal. The Book of Royal Phraseology (1828), still a reference in the 1870s, uses "chardon de terre" for coal. This phrase occurs only four times in *Mysterious Island* when Verne references mineral coal. When Verne refers to a "charcoal burner," the French word "charbonnier" is used. The 1874 Technological Dictionary<sup>xvii</sup> uses charbon for both charcoal and coal, but also uses houille for "mineral" coal. The term "chardon de terre" for coal is also allowed. These references seem consistent with the usage in *Mysterious Island* (1874).

The use of the word "charbon" for coal significantly declined in favor of "houille" for coal in technical articles of the period after 1877. The *Underground City* (1877) is Verne's novel centered on coal. There is one fascinating paragraph in *Underground City* where Verne addresses the use of the word "houille" itself. "Whether the French word for coal (houille) is derived from farrier Houillos<sup>xviii</sup>, who lived in Belgium in the twelfth century, we may assume that the [coal] beds of Great Britain were the first ever worked."<sup>xix</sup> In *Underground City* (1877), when Verne refers to coal veins, coal the mineral, coal heating, and coal organizations he uses "houille" throughout. Still, there was no need to deal with charcoal in the novel. Yet even in his many novels with context considered Verne is not consistent with his uses of "houille" and

“chardon.”

In *Mysterious Island*, he uses the word "houille" to refer to coal collecting and surface mining. The exception is “houille” which is the word used for coal to fuel his pottery kiln.<sup>xx</sup> However, in pottery making, coal is used solely for heating and plays no chemical role in the process. **In his sections on the Catalan process, only the term "charbon" is used in the French text of *Mysterious Island*, with one exception referring to the collection of coal for use in the Catalan furnace.**<sup>xxi</sup> Verne refers to collecting mineral coal (houille) used in the Catalan furnace. Yet even here, Verne uses "charbon" to refer to the same coal in the furnace in the following sentences in Chapter XV. In *Twenty Thousand Leagues Under the Sea* (1870) Verne again refers to the same coal as charbon, while using houille when referring to the veins of this same coal.<sup>xxii</sup> This is consistent with Verne's approach to use houille for coal, if it is related to mining or veins of coal.

Verne uses “charbon” for elemental carbon in the steel in *Mysterious Island*, but the context is clear to be the chemical element. The best textual proof that coal was used in the furnace is probably in Chapter XV,<sup>xxiii</sup> which has a range of various contexts. The metallurgical context clarifies that Verne is using coal in his Catalan furnace.

While very few, these possible translation contradictions are problematic. There is a possible explanation for these: the changes may have been made in the manuscript. We know Verne's editor, Jules Hetzel, made extensive “cuts, additions, and changes”<sup>xxiv</sup> of several pre-publication manuscripts of *Mysterious Island*. There is enough confusion that the lexicology and context alone cannot be totally conclusive about the use of coal. A deeper understanding of the technology of coal and the Catalan furnace operation is required for a proof of Verne's use of coal.

## **Feasibility-Furnace, Ore, and Coal**

### **Jules Verne's Amazing Iron Furnace**

Replacing charcoal as a fuel and iron-reducing agent was a limiting factor in manufacturing large quantities of iron and steel needed for Verne's ships, cannons, buildings, and floating islands. The use of coal in iron and steelmaking represented a major technological revolution that ushered in the Steel Age. Verne in *Mysterious Island* (1874) suggests the potential of coal to replace charcoal in iron and steelmaking several years before it came into everyday use.

Verne uses coal to replace charcoal in his island furnace, and coal would become the critical factor in increased blast furnace iron (and steel) production. Coal and blast furnace technology are prerequisites for producing high-quality iron, which is essential for steel making. The use of coal was evolving at the time of Verne's writings. Verne uses his knowledge of coal technology to establish the credibility of his prediction of coal blast furnaces and their chemistry. In *"From the Earth to the Moon"* (1865), Verne uses the actual Cold Springs Foundry (West Point Foundry), a pioneer in replacing charcoal with raw coal in blast furnaces, producing the best high-quality iron, for his moon cannon in 1865.

Maybe the most remarkable passage in *Mysterious Island* (1874) is Verne's description of his Catalan furnace and iron reduction chemistry: “*Thus arranged, under the influence of the air from the bellows, the coal would change into carbonic acid [carbon dioxide], then into oxide of carbon [carbon monoxide], which*

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

would release the oxygen from the oxide of iron."<sup>xxv</sup> Verne demonstrated a detailed and current understanding of iron furnace reactions in 1873. This knowledge would have been limited to a few scientists at the time. The understanding of the role of carbon monoxide in blast furnace chemistry was being researched at the University of Paris in the 1880s. Still, less than a handful of chemists were aware of the details. Verne knows about advancing chemical science and is not writing for children. Interestingly, the early translations omitted these detailed chemistry sections in *Mysterious Island*. The complete theory of carbon monoxide reduction was not widely known until Octave Leopold Boudouard of the University of Paris published his "Boudouard Reaction" (a carbon redox reaction) in 1901. Yet Verne fully and correctly describes the furnace reaction in *Mysterious Island (1874)*. Generally, the Boudouard reaction sequence is best applied to using coal rather than charcoal, but the reaction is thermodynamically and kinetically complex, depending on factors such as surface reactivity, temperature, and air flow.

While the intuitive understanding of carbon dioxide to carbon monoxide reduction had been practically applied since the seventeenth century, its chemistry remained enigmatic until Boudouard's publication in 1901. Only recently has the history of blast furnace chemistry and its theoretical understanding been thoroughly documented.<sup>xxvi</sup> Remy Nicolle called this historical journey to the complete knowledge of early furnace chemistry an "epidemiological breakthrough," starting with the long-forgotten geologist Jacques-Joseph Ebelmen (1814-1858) and "integrating the work of French scientists Chaudron, Boudouard, Le Chatelier, the German Reichardt and Russian Kitaiev."<sup>xxvii</sup> Verne in 1873 could have drawn from Joseph Priestley, Humphrey Davy, Michael Faraday, and Le Chatelier's earliest works on carbon oxidation, but more likely, Jacques-Joseph Ebelmen (1814-1858), who first noted the reoxidation reaction of a chemical equilibrium mixture of carbon monoxide, carbon dioxide, and carbon. Ebelmen's work on iron reduction chemistry remained under the radar until it was "rediscovered" in 1901 by Boudouard. It appears that Boudouard independently devised the carbon reoxidation equation that French chemist and geologist Ebelmen had discovered and documented his studies in the blast furnace in the 1850s. Verne was well aware of Ebelman's work and often referred to Ebelmen's scientific work when writing about volcanic gases.

Ebelmen proposed the carbon dioxide/monoxide reactions in iron furnaces based on his volcanic gases in 1841. Verne, because of his love of volcanoes, followed Ebelmen's work as a resource for his early works.<sup>xxviii</sup> Verne makes note of Ebelman in his 1863 novel *Journey to the Center of the Earth*<sup>xxix</sup>, but he misspells it as "Ebelman." Ebelmen's work was fully discussed in the 1869 publication *The Metallurgy of Iron and Steel* by American Henry Osborn. Osborn used Ebelmen's study to develop the theory behind Verne's description of the Boudouard reaction in blast furnaces.<sup>xxx</sup> Osborn published *The Metallurgy of Iron and Steel* at the same time Verne started his *Mysterious Island* manuscript, and it could have been a resource for Verne.

Perhaps most important is that Ebelmen's 1840s study and definition of blast furnace chemistry and his redox carbon reaction were based on coal experiments, not charcoal, which would also support that Verne could have used coal in his Catalan furnace! In addition, Henry Osborn (as Verne) highlights the pioneering work in using anthracite coal to replace charcoal. Still, using coal in Verne's primitive furnace required some adjustments to drive the Ebelmen/Boudouard reaction as effectively as charcoal, but Verne again proved to be an expert metallurgist.

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

While coal was being experimented with in blast furnaces and Verne knew this, there is no historical record of coal being used in the small Catalan furnace. Even blast furnaces of the time were predominantly charcoal-fueled. Verne clearly demonstrates he understood current iron furnace chemistry, but was coal used in Verne's Catalan Furnace? Verne makes it clear that he is using coal in the Catalan furnace when he locates his furnace "near the veins both of coal and ore."<sup>xxxix</sup> Interestingly, the manuscript uses "houille" for coal in the paragraph. But was it feasible to use coal in a primitive Catalan furnace? Why not simply use charcoal?

Verne's island colonists used the Catalan Forge process, which was, at the time, a charcoal process. Verne, however, substitutes coal for charcoal. The question might be asked. Why didn't his colonists just use charcoal, which could have been made from wood on the island? Early on, the colonists had located a massive supply of driftwood and were using it for fires; however, driftwood is a poor choice for charcoal production due to its high salt content. The colonists lacked steel axes and saws to cut the forest wood for charcoal, and they would need raw steel to manufacture the tools. The colonists recognized the need for tools with the approach of winter, necessitating the production of iron tools for building, and noted that "the most rapid method of [iron ore] reduction" was required. Their discovery of surface coal offered a means for speedy iron production. Verne rules out a blast furnace for making iron because it was a long and multi-step process.<sup>xxxii</sup> Verne correctly chooses a Catalan furnace but breaks with the current technology, substituting coal for charcoal.

Even if they had access to cut wood, producing furnace-quality charcoal could take many weeks and would require building special kilns. Charcoal making for an iron furnace is a lengthy process that requires axes to cut wood, air seasoning of the cut wood, and weeks in charcoal kilns to convert the wood into charcoal. It would not likely have missed Verne's pen if such a charcoal-making process were used. Verne, by using coal, was extrapolating iron technology into the future by going back to the past, using it in a Catalan furnace.

The technology for substituting coal for charcoal in iron making was not fully developed in 1873. To consider the technical feasibility of using coal, the critical factors of coal type and quality, ore type and quality, and furnace factors, such as air blast would need to be addressed. First, we must explore the chemical feasibility of substituting coal for charcoal. When comparing charcoal and coal in the context of the Ebelmen/Boudouard reaction and its potential in Catalan furnaces, charcoal generally exhibits a higher reactivity towards carbon dioxide (CO<sub>2</sub>) than coal, meaning it will produce carbon monoxide (CO) more readily due to its larger surface area and higher porosity, making it more efficient in the Boudouard reaction at lower temperatures compared to coal. Therefore, the question is whether producing iron in a coal-fired Catalan was technically possible. Verne's novel addresses all the technical issues in his usual scientific detail. The Catalan Forge process is effective at removing contaminants, such as silicates, but it does not effectively remove detrimental impurities, including sulfur and phosphorus. In particular, the type of coal and its quality were paramount in eliminating impurities in the iron produced.

Verne addresses this shortcoming of using coal in a Catalan furnace to make it more efficient, using high-quality coal, high iron content ore, furnace material inspection, eliminating ore and coal sulfur impurities, and a powerful air blast. Verne would address all of these in his iron-making on the island. Verne's final inspection of all input furnace materials would be critical to controlling sulfur, as iron pyrite (iron sulfide)

## The Metallurgical Mystery of Verne's Island Iron Furnace

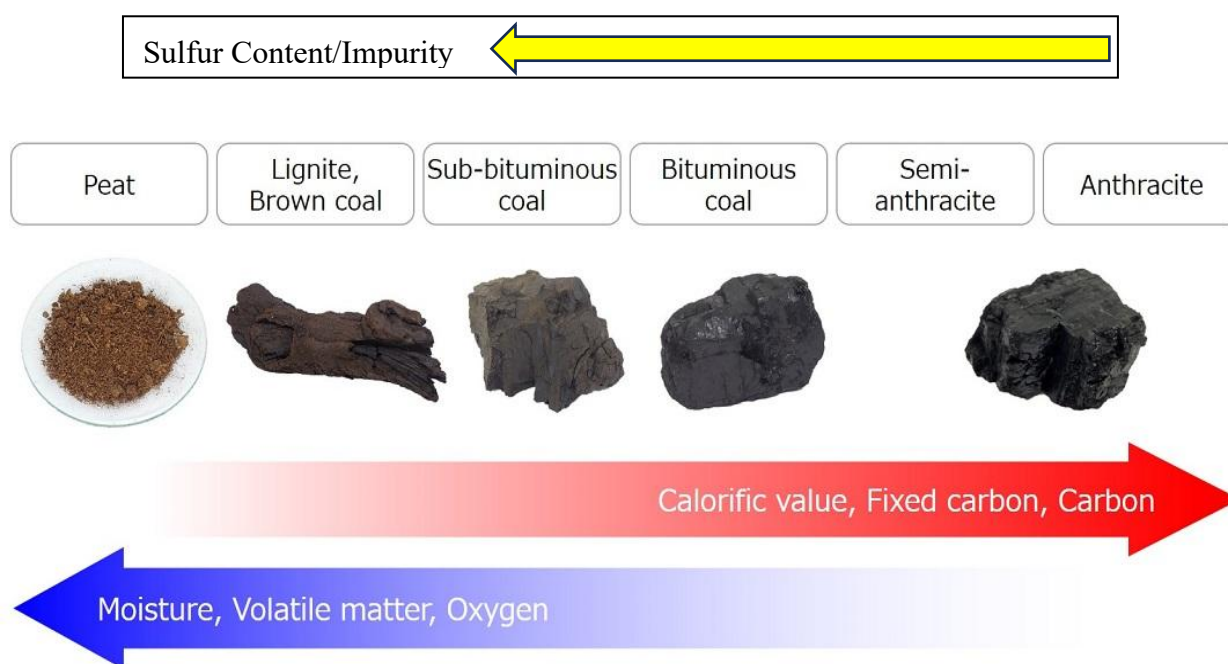
crystals were noted around the island's coal, iron ore, and limestone deposits. However, many more adaptations to the Catalan furnace would be needed.

The foremost concern is the quality of the coal. In experiments using coal in early blast furnaces, excessive sulfur was found in the produced iron, degrading its engineering properties.

### Coal Type and Quality needed

The use of coal to make iron would usher in the Steel Age. The advancement of ironmaking and the conversion of iron to steel were based on the various sources of carbon fuel used. Verne believed in the future of coal and demonstrated his expertise in coal in geology, chemistry and use in his novels such as, *Paris in the Twentieth Century* (1863), *Journey to the Center of the Earth* (1864), *20,000 Leagues Under the Sea* (1870), *Mysterious Island* (1874), *Underground City* (1877), *Begum's Fortune*, (1879), *The Vanished Diamond* (1884), and *Purchase of the North Pole* (1889).

Additionally, Verne predicted and chronicled the progression from charcoal to anthracite coal to bituminous coal to coke in the steelmaking process in his literary novels, spanning from 1860 to 1905, known as *Voyages Extraordinaire*. Charcoal, for centuries, was used to produce primitive iron and steel. In the 1830s, a dramatic decline in forests for charcoal production led to a search for a replacement. The difficulty was the high quality of iron produced by the purity of charcoal versus coal. Charcoal was free of two very detrimental iron impurities, sulfur and phosphorus. Coal offered potential but came with technical difficulties, such as sulfur impurities. Verne had defined the geology of coal formation in *Journey to the Center of the Earth*, *Mysterious Island*, *The Underground City*, and *Begum's Fortune*. The properties of coal were also known by Verne, with anthracite being the closest to charcoal in carbon, calorific heating value, and low impurities.



Although there is no historical record of coal being used in Catalan furnaces, some Catalan-type regional furnaces in China, dating back to the twelfth century, utilized coal. These Heilongjiang furnaces were

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

very similar to Verne's Catalan furnaces, only 2-3 meters high. The archaeology of these furnaces suggests that the iron produced was high in sulfur and not directly suitable for heating and beating into wrought iron.<sup>xxxiii</sup> Of course, Verne's colonists' goal was to produce wrought iron via the Catalan Forge operation to be hammer forged into tools. High sulfur content in iron, especially during hot working processes like beating, hammering, rolling, or forging, can lead to "hot shortness," where the iron becomes brittle and prone to cracking. Verne's colonists would have to control sulfur by coal type, ore selection, elimination of coal and ore impurities, material preparation, process design, and furnace design to make tools.

Still, Verne realized the advantage of coal because it was found near iron ore deposits. Verne notes that Britain's nearby coal and ore deposits, which fed its blast furnaces, were a source of wealth. Historians now call the use of coal in British iron furnaces as the birth of the Industrial Revolution. The British and South Wales coal fields could be surface mined like on *Mysterious Island*, and iron ore was found on the surface with it.<sup>xxxiv</sup> Verne's geological mentor, Louis Figuier, noted the huge economic advantage of coal and iron being found together in Britain.<sup>xxxv</sup> Similarly, the great American ironmaking regions of the 1800s, such as the Juniata Valley in New York and the Hanging Rock districts in Ohio, had dual coal and iron fields. Verne emulates this metallurgical favor of Providence on his fictional island.

The economic savings in production at dual deposits of iron ore and coal did not automatically result in the production of high-quality iron. The revolutionary first coal-blast furnaces at Coalbrookdale, operated by Abraham Darby in the early 1800s, produced cast iron that was too high in impurities (sulfur and phosphorus) to be made into wrought iron, but it did produce good castings.<sup>xxxvi</sup> While Coalbrookdale's coal was considered good quality, it was not primarily low-sulfur anthracite, so impurity levels varied. Early on Coalbrookdale used hand inspection and sorting to reduce some sulfur, but more would be needed. By the 1830s, Coalbrookdale had stopped using raw coal and moved to coked coal, which is a form of burnt coal. Coking allowed for the use of higher sulfur bituminous coal. Coking removes sulfur, but Verne makes no mention of the time-consuming and complex process of coke making by his colonists. The extensive nature and ancillary processing of coke making would not have been overlooked by Verne in *Mysterious Island*, which might rule out coke as his furnace fuel. By 1870, Darby could significantly reduce sulfur content using the steam engine to deliver a powerful air injection to the furnace, allowing for a mix of coal and coke.

Verne did address the possibility of sulfur in coal and other furnace ingredients in his detailed design of the Catalan island furnace. All coal types can contain iron pyrites (iron sulfide), and Verne notes that some of the coal beds on the island had schistose pyrites. Verne also notes in general that pyrites were common on the island, but Verne's Catalan process is focused on a sulfur-free charge needed for toolmaking. Iron pyrites (also known as "fool's gold") in coal have shiny gold/silver veins. The gold/silver veins (schistous) in coal could be readily inspected by hand. Verne's colonists easily inspected and hand-cleaned the mineral furnace charge. Here, Verne is emulating the hand cleaning of coal at Britain's Coalbrookdale furnaces in the early 1800s. Verne follows the use of "breaker boys" at Coalbrookdale to hand break coal into small pieces, cleaning, improving ignition, and chemical reactivity. Verne's breaking of the coal into small pieces was a crucial factor in achieving success. Charcoal is more porous and reactive than coal, leading to faster combustion, so crushing and breaking coal for the furnace was critical. The type of coal would be an important factor in whether coal

could be used or the Catalan process adapted for coal type.

Verne was more likely to have used the raw coal-fired iron furnaces of South Wales, rather than Coalbrookdale, as the model for his island iron-making operation because of their use of raw coal. The British pioneer of using raw coal in blast furnaces was Dave Thomas, who utilized the hard anthracite coal of South Wales in the 1820s. Thomas hoped to replace coke made from bituminous coal with raw anthracite coal found locally, along with iron ore. Thomas's problem was the limited supply of pure anthracite coal in Europe. In 1840, David Thomas moved to America to develop the anthracite coal industry for the eastern iron furnaces of the United States. These American anthracite furnaces would become renowned for their iron quality. These American furnaces, such as the West Point Foundry, became famous for their production of massive Civil War cannons. Verne was aware of the pioneering work on anthracite coal in America. Cold Springs was an early adopter of anthracite coal in the 1840s and successfully mass-produced iron made from anthracite in the 1860s, while most of the iron industry still used charcoal for fuel in America. In *From the Earth to the Moon* (1865), Verne uses the actual Cold Springs Foundry (West Point Foundry) to produce the cast iron for his moon cannon because of its quality.<sup>xxxvii</sup> Anthracite coal had the lowest of all coal impurities, such as sulfur, making it very competitive with charcoal. Diminishing forests accelerated the use of anthracite coal. France was experimenting with anthracite for iron making in the 1870s. The 1878 Paris Exhibition offered the potential for importing American anthracite for French iron-making furnaces.<sup>xxxviii</sup> Anthracite iron smelting transitioned to using coke, a product of bituminous coal, which replaced anthracite in the 1880s.

Verne is unclear whether he used pure anthracite coal or a mix of anthracite and bituminous coal in his island Catalan furnace. In *Mysterious Island* (1873), Verne appears to have accurately predicted the rise of coal replacing charcoal as the fuel in ironmaking furnaces required to produce steel. More importantly, this coal technology would be necessary to make the switch from iron to steel economical during the Victorian Industrial Revolution. When *Mysterious Island* was published in 1874, some steel mill blast furnaces, primarily in the United States and England, were utilizing coal. By the late 1880s, steel mills had fully converted to anthracite coal and bituminous coal.<sup>xxxix</sup> Of course, bituminous coal requires coking, thus eliminating impurities such as sulfur, which is detrimental to iron properties. Possibly lacking the best anthracite coal, Verne had to address sulfur control in his overall Catalan furnace process. Verne achieves this effectively in the design of his Catalan furnace, utilizing a powerful air bellows system and precise control over input materials. Sulfur in the coal is not the only source of sulfur in ironmaking. Verne chose his ore carefully to favor coal use, as iron ore could also contain sulfur and phosphorus impurities that would affect the furnace smelting temperature.

### The Type of Iron Ore and Quality

Some early Catalan forges used lower-quality bog ores of hematite ( $\text{Fe}_2\text{O}_3$  or  $\text{FeCO}_3$ ), Verne, however, uses magnetite iron ore of Swedish chemistry for his fictional Catalan furnace. Again, Verne demonstrates a detailed knowledge of Osborn's 1869 textbook on the chemistry of the first blast furnaces and the potential use of coal in ironmaking furnaces. Osborn notes that in 1869, a large number of Catalan furnaces (charcoal-fired) were still operating in New York because of the availability of rich magnetite ores.<sup>xl</sup> Verne notes in

*Mysterious Island* (1874) the importance of magnetite ( $\text{Fe}_3\text{O}_4$ ) in improving the use of coal in the redox reaction based on Ebelmen and Osborn's chemical studies.<sup>xli</sup> Thermal studies today suggest hematite would be a better ore to use in a Catalan furnace, although the ability to reach high temperatures could favor magnetite.<sup>xlii</sup> The literary evidence appears conclusive that Verne used magnetite in his Catalan furnace, and with good reason, since magnetite's purity and low sulfur content made it a better input for making iron and steel tools.

Verne noted the iron was magnetic (natural lodestones), which is associated with magnetite ore. More importantly, he notes the existence of magnetite lodestones, which are commonly found and collected on the surface, as done by Verne's island colonists. Magnetite iron ore ( $\text{FeO}$ ,  $\text{Fe}_3\text{O}_4$ ) has little or no sulfur, offering an iron with a significant tool-making advantage from Verne's island furnace. Verne describes the iron ore as high quality, like "Swedish ore, dark grey and octahedral crystal structure."<sup>xliii</sup> These are the defining attributes of magnetite. The more common hematite iron ore is reddish or greyish-red in color, with a rhombohedral crystal structure, which typically does not exhibit a visible crystal structure. Verne clearly rules out hematite for his furnace ore.<sup>xliv</sup> Verne's use of a Swedish magnetite type ore represented the world's highest iron content, ranging as high as 70 percent iron and known as sulfur-free. In 1873 and to this day, Swedish magnetite is considered the world's best ore. Additionally, the successful use of raw coal at Cold Springs involved magnetite iron ore. Verne also notes another essential component of his island ore that it was found "enclosed in its fusible gangue [silica], was perfectly suited to the mode of reduction."<sup>xlv</sup> Silica would be the flux needed to smelt iron at a lower temperature.

Like the coal, inspection of the ore by Verne's colonists would be necessary to separate impurities. Additionally, Verne's colonists' inspection involved the crushing of furnace materials to enhance their chemical reactivity. Still, some adjustments would be needed in the Catalan process, even with the high-quality type coal and iron magnetite.

## **Verne's Catalan Furnace Design**

Verne's substitution of coal for charcoal in his primitive Catalan Forge in *Mysterious Island* (1874) was a key insight and prediction about the future role of coal in ironmaking. Verne was not looking back as much as forward. Verne clearly believed the iron reduction chemistry made it possible to substitute coal for charcoal in a Catalan furnace as well as in a blast furnace, if the proper coal, iron ore, processing, and furnace design were improved. Verne was well aware of the success of the Cold Springs Furnace coal and the difficulties at Coalbrookdale furnace caused by sulfur impurities. Early furnace coal experiments employed slag control, a powerful air blast, and furnace design to overcome sulfur problems. However, in 1874, most iron was produced in charcoal furnaces due to the sulfur content in coal.

Examining the issues with the Catalan Furnace design and process, which utilized coal, Verne made the necessary adaptations. Verne would have known that Catalan Forge processes used charcoal, but he also knew many pioneering iron blast furnaces were replacing charcoal with coal. The Cold Spring furnace in New York used raw coal, but could raw coal be used in a small Catalan furnace? Charcoal was the only known fuel source in the European Catalan furnaces. There is, however, a record of some experiments in 1665 using coal

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

mixed with charcoal in a Catalan-type furnace in China; however, the iron produced was of low quality due to impurities such as sulfur.<sup>xlvi</sup>

Verne would have to face the problem of sulfur in his coal-fired Catalan furnace. Sulfur remained the major roadblock to shifting blast furnaces from charcoal to coal in the 1870s. As noted earlier, even Abraham Darby's first coal iron-making blast furnaces had sulfur impurity problems. Darby solved the problem later by using the Newcomen steam engine to power the air bellows and the high furnace stack, creating a draft. But again, the Catalan furnace lacked the high stack of Darby's blast furnace, and he lacked the steam engine's powerful air blast that increased the temperature of the limestone slag in the furnace to remove sulfur. Verne spent several pages designing powerful air-blast technology for his fictional, smaller Catalan furnace, which would improve sulfur contamination in the final iron produced. The key to successfully using coal in a Catalan furnace would be the use of a strong air blast.

Verne described his Catalan Furnace: "The next morning, Smith, accompanied by Herbert, went to look for the simplified Catalonian process practised in **Corsica**. This method properly required the construction of ovens and crucibles in which the ore and the coal, placed in alternate layers, were transformed and reduced. But Smith proposed to simplify matters by simply making a huge cube of coal and ore, into the centre of which the air from the bellows would be introduced. This was, probably, what Tubal Cain did. And a process which gave such good results to Adam's grandson would doubtless succeed with the colonists of Lincoln Island."<sup>xlvii</sup>

Verne emphasized that his was a Corsica Catalan Furnace, noting the method was "the simplified Catalonian process practised in Corsica."<sup>xlviii</sup> Still, even Corsica furnaces were a charcoal process. Verne's reference to the Corsican practice seems more related to the early use of a trompe or mechanical air blast, which Verne would need for coal.<sup>xliv</sup> Verne also details the hand and counterweight bellows blast system. The Corsica Catalan air blast was hand/gravity developed by the Romans. Many 1800s Catalan forges used water-powered bellows requiring a fast-moving water source. Water wheel bellows systems could be inconsistent in delivering a strong air blast, and Verne's island lacked a fast-moving water source. Verne designed a primitive but powerful system using animal skins and rigging. Coal supplies much higher heat, but a strong air blast would have been required to achieve smelting temperature. Verne metallurgy is again accurate because the Boudouard reaction is most effective at higher temperatures, which can be achieved through the use of an air blast and coal. Verne notes that the air blast increased temperature, as "facilitating the chemical transformations."<sup>1</sup> Besides improving ore reduction chemistry, high temperature allows for

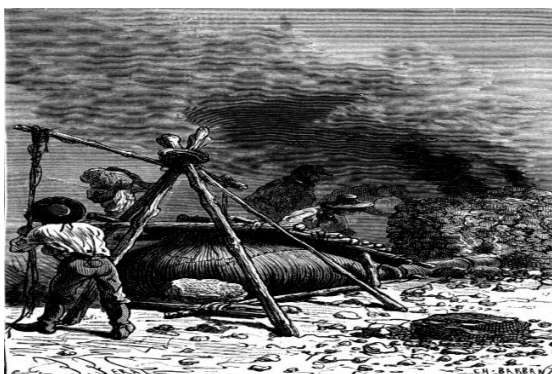


Illustration from Mysterious Island

the development of a slag to remove more sulfur. Verne multiplies the air blast effect by a focused tuyere on “cube” mass of ore and coal, which was the Corsican practice for charcoal. Verne adds another piece of technology by using his own formulated refractory clay. Verne adds lime and silica sand to the island clay to create a heat-resistant clay that he uses for his furnace tuyere, as well as for crucibles in steel making and cooking pottery.<sup>li</sup> Verne does not specify the use of lime for sulfur control in the furnace; it was being studied in the 1860s and fully discussed as a sulfur removal agent in Osborn's 1869 furnace textbook. Whether intentionally or not, Verne's lime refractory clay would have a sulfur removal agent in his coal-fired Catalan furnace, coupled with a strong blast.

Verne's description of the strong air blast in his Catalan furnace compares well to Osborn's Blast Furnace textbook description in 1869: “A kind of blast machine, called Widholm's bellows [ leather accordion type], is extensively used in Sweden, Russia, Germany, and France. As it works well, as the expense of its construction is small, and its application to the Catalan forge is very simple.”<sup>liii</sup> The use of a strong bellows system would have been needed to substitute coal for charcoal in the Catalan furnace. Verne notes the importance of a strong air blast for success,<sup>liiii</sup> and Verne dedicates several pages to describing the development of powerful bellows from seal skins. Verne modifies the Widholm system with a large pear-shaped skin bellows. Lime refractory clay, tuyere placement, and strong blast would be key in the evolution of the modern blast furnace and the Steel Age.

## **Steelmaking**

Verne, with his coal technology, set the environment for the Steel Age. Verne, born in a world of high-carbon cast iron and low-carbon wrought iron, recognized the future of medium-carbon steel in the 1860s, even before Andrew Carnegie. Verne's understanding of coal technology, blast furnace chemistry, and steel metallurgy is advanced and visionary. Verne was one of the earliest to predict the Steel Age for the world navies. Verne saw in the 1850s that steel's lightness, compared to wrought and cast iron, with steel's strength-to-weight ratio, would soon replace the iron ships of the 1860s. Verne had followed the experimental building of the first steel-hulled blockade runners in the Civil War in 1859. Verne would become the prophet of steel construction.

Verne highlights the steel application in British shipyards for the American Confederacy's fleet of blockade runners, which increased speed, tonnage, and prevented cotton fires. Verne realized the dangers of transporting southern cotton in wooden-hulled ships. He wrote a novel based on a ship cotton fire in *Survivors of the Chancellor: Diary of J. R. Kazallon, Passenger* (1875). The *Chancellor* was a copper-sheathed wooden ship with iron fittings. Verne describes the problems with the cotton fire and the wood hull in detail, highlighting the need for steel hulls.

Verne designed four famous futuristic fictional steel ships, the *Nautilus*, the *Dolphin*, the *Forward*, and the *Queen and Czar*<sup>liv</sup>. Verne's submarine, the *Nautilus*, was a double-hulled steel vessel designed for deep-sea exploration. The *Dolphin* was a steel-hulled Civil War blockade runner. The *Forward* was Verne's steel-hulled icebreaker for arctic exploration. The *Queen and Czar* was a modular steel vessel for African exploration. These ships used the emerging Civil War steel technology of the 1860s. The widespread use of

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

steel in actual ship construction would have to await the commercialization of the Bessemer steel process and the development of the modern blast furnace in the 1870s. Verne, however, knew steel was the future of shipbuilding and incorporated steel into his novels. In 1877, Verne utilized steel in the construction of the hull of his steam-powered personal yacht, the *Michel III*. Verne took the future of steel beyond ships. In *Steam House* (1880), Verne builds a steam-powered steel elephant. In *Mathias Sandorf* (1889), Verne builds steel-hulled electric torpedo boats. In *Propeller Island* (1895), Verne builds a 10-mile self-propelled steel island.

Verne's steel projects were always ahead of the available supply and process technology. The amount of steel needed for shipbuilding in the late 1860s was initially supplied by the blister process and puddling, as noted by Verne in *Mysterious Island* (1874). The quantity of steel produced from blister cementation and puddling would limit the large shipbuilding applications of steel. Future shipbuilding would require the production of iron from coal blast furnaces and the Bessemer steel-making technology. Major acceptance of steel for the world's navies did not come until the 1890s.

The Catalan forge process does not produce steel but a lower-carbon product of wrought iron. Verne used the blister steel process to produce steel from wrought iron, employing the cementation process, in his *Mysterious Island* (1874). Catalan Forges and blister steel making allowed for small batches of steel and tool making. The Bessemer process/coal blast furnace combination would be needed to produce economic quantities, which Verne required for his future world of steel.

When Verne published his steelmaking novel, *The Begum's Fortune*, in 1879, Andrew Carnegie and Alfred Krupp started revolutionizing steelmaking with coal technology. The key to mass steel production was the large-scale iron production from a coal-fired blast furnace, which required coke from coal and a Bessemer steel converter, a development that emerged in the 1880s. Although Alfred Krupp's famous and feared steel cannons still employed a unique combination of charcoal and iron, wrought iron puddling, and blister steel, this combination, detailed by Verne in *Begum's Fortune* (1879), remained in use into the twentieth century. Verne's *Mysterious Island* (1874) and *Begum's Fortune* (1879) detailed the state of the art of iron and steel making and projected the mass usage of steel.

## **Conclusion**

*Mysterious Island* (1874) provided a textbook for the study of iron and steel chemistry and manufacture. Verne demonstrated an amazing depth of knowledge in the very cutting-edge theory of iron making. Verne's use of coal in *Mysterious Island* remains an interesting prediction of the future of coal technology needed to enter the Steel Age. Did Verne use coal in his island's Catalan ironmaking furnace? It is a complex research question for a metallurgist, but it illustrates the issues involved in Verne research in general. These issues include translation issues, word etymology, the Victorian technical lexicon, and the changing technical lexicon with the rise of the Industrial Revolution.

Verne utilizes a small furnace, the primitive Catalan furnace, to apply advanced technology and blast furnace chemistry. Going back to the future, Verne applies state-of-the-art theory in his fictional island furnace, projecting the use of coal for iron reduction.

## *The Metallurgical Mystery of Verne's Island Iron Furnace*

It can be concluded that Verne uses coal, and there is metallurgical and technical support that it would work in a Catalan furnace. In particular, Verne applies the necessary science to control sulfur impurities in coal. Verne's use of coal and sulfur control was a precursor to the future of coal technology in the iron and steel revolution. With coal as a fuel, the blast furnace and the Bessemer converter made the quantity of iron available for commercial steelmaking. Thus, the steel shipbuilding industry would meet the steel demands needed for Verne's dreams of the 1860s and 1870s.

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<sup>i</sup> The publication date of 1874 is based on the first French edition. English editions are 1875. Verne was working on a manuscript in early 1873, so we can assume he was probably dealing with the iron technology of 1872

<sup>ii</sup> Jules Verne, *Mysterious Island*, org. 1874, page 145 of Sidney Kravitz translation

<sup>iii</sup> Jules Verne, *The Underground City*, 1877, Sarah Crozier translation, Luath Books, 2005. Chapter –“On the Road,” p. 16

<sup>iv</sup> *The Mysterious Island: Bilingual Edition (English - French) (French Edition)*, Amazon Kindle Edition, location 448

<sup>v</sup> Jules Verne, *Mysterious Island*, org. 1874, page 145 of Sidney Kravitz translation

<sup>vi</sup> Anthracite is harder than other coal types; therefore, it is known as hard coal. Other types of coal are considered sedimentary rocks, whereas anthracite is a metamorphic rock. It exists in limited amounts worldwide and could not have supported the exponential growth of the steel industry.

<sup>vii</sup> Bituminous coal is the most abundant type of coal. It is soft and contains a substance called bitumen, which is similar to tar. The carbon percentage in bituminous coal is normally between 77-87%. And there is water, hydrogen, sulfur and few other impurities. Coking is required to turn it into an iron furnace fuel.

<sup>viii</sup> Amazon Bilingual edition of *Mysterious Island*, Jan 2, 2015, p. 464

<sup>ix</sup> There is one fascinating paragraph in *Underground City* (1877) where Verne addresses the use of the word “houille” itself. “Whether the French word for coal (houille) is derived from farrier Houillos, who lived in Belgium in the twelfth century, we may assume that the [coal] beds of Great Britain were the first ever worked.

<sup>x</sup> A. Hume, “A Few Notes on Coal,” *Ulster Journal of Archaeology*, First Series, Vol. 8 (1860), pp. 172-174 “Many of the mistakes which have arisen on this subject are attributable to the ambiguity of the term employed. Thus a “coal” may mean, first, an ember or coal-of-fire,; second, a piece of charcoal; or, third, the mineral coal in any of its forms”

<sup>xi</sup> The *Book of Royal Phraseology* (1828) uses “chardon de terre” for coal.

<sup>xii</sup> I am presenting working with the *Journal of Historical Metallurgy* on the translation and lexicon of coal/charcoal in steel and ironmaking processes.

<sup>xiii</sup> *ibid*

<sup>xiv</sup> French text p. 447 Amazon Bilingual edition, Jan 2, 2015. Source of text is not clear, so there is still a question. Agnes Kinloch Kingston (1824–1913) used this French text in her (and her husband) translation.

<sup>xv</sup> *The Mysterious Island: Bilingual Edition (English - French) (French Edition)*, Amazon Kindle Edition, locations 380, 376, 427, 446, 463, 464

<sup>xvi</sup> *The Mysterious Island: Bilingual Edition (English - French) (French Edition)*, Amazon Kindle Edition, location 464

<sup>xvii</sup> Louis Tolhausen, *Technological Dictionary In The English, French, and German: Containing About 76,000 Technical Terms and Locutions employed in the Arts, Trades, and Industry In General*, Leipzig Bernhard Tauchnitz, 1874

<sup>xviii</sup> “Belgian miners have a tradition that the existence and use of coal was revealed to an old blacksmith, a poor but worthy man, by an angel from heaven” from *Coalmines: A Sketch of Coal Regions of the Globe*, Andrew Roy, 1876

<sup>xix</sup> Jules Verne, *Underground City*. Kindle edition, page 340

- <sup>xx</sup> *The Mysterious Island: Bilingual Edition (English - French) (French Edition)*, Amazon Kindle Edition, locations page 397
- <sup>xxi</sup> Page 447 Amazon Bilingual edition of *Mysterious Island*, Jan 2, 2015. French/English *Ansi que le mineral, la houille scens peine et loin a la surface du sol / the coal as well as the ore was collected without trouble on the surface of the ground*
- <sup>xxii</sup> Jules Verne, *Vingt mille Lieues Sous Les Mers - Twenty Thousand Leagues Under the Seas [Bilingual] (French Edition) Kindle Edition, Location 2877*
- <sup>xxiii</sup> Jules Verne, *Mysterious Island*, org. 1873, pages 137 -147 of Sidney Kravitz translation and the corresponding section in *The Mysterious Island: Bilingual Edition (English - French) (French Edition)*, Amazon Kindle Edition, locations 448-449
- <sup>xxiv</sup> William Butcher, *Jules Verne: The Definitive Biography*, Thunder's Mouth Press, New York, 2006, p. 232
- <sup>xxv</sup> Jules Verne, *Mysterious Island*, org. 1874, page 143 of Sidney Kravitz translation
- <sup>xxvi</sup> Remy Nicolle, "The History of Iron Furnace using the Physical -Chemical Blast Furnace Model," *EDP Sciences*, 2023  
And A. Rist, N. Meysson, "A Dual Graphic Representation of Blast Furnace Heat and Mass Balances," *Journal of Metals*, 19, 1967, pp. 50-59
- <sup>xxvii</sup> <sup>xxvii</sup> Remy Nicolle, "The History of Iron Furnace using the Physical -Chemical Blast Furnace Model," *EDP Sciences*, 2023
- <sup>xxviii</sup> Interestingly, most of Ebelmen's work was lost until its application by chemist Robert Arbuckle Berner (1935 – 2015).
- <sup>xxix</sup> Jules Verne, *Journey to the Center of the Earth*, 1863, Page 5 of the Butcher Translation, Oxford Press and Page 39 the Lowell Bian Translation and Footnote one.
- <sup>xxx</sup> Henry Stafford Osborn, *The Metallurgy of Iron and Steel Theoretical and Practical: in All Its Branches; with Special Reference to American Materials and Processes*, Philadelphia: Henry Carey Baird, Industrial Publisher, and London: Trübner & Co , 1869, pp. 400-415
- <sup>xxxi</sup> Amazon Bilingual edition of *Mysterious Island*, Jan 2, 2015. French/English *Ansi que le mineral, la houille scens peine et loin a la surface du sol*, page 456
- <sup>xxxii</sup> *Ibid* p. 137
- <sup>xxxiii</sup> Donald Wagner, 'Blast Furnaces in Song-Yuan,' *ESATM, Vol 18, 2001*
- <sup>xxxiv</sup> Jules Verne, *Mysterious Island*, org. 1874, pages 136 and 137 of Sidney Kravitz translation
- <sup>xxxv</sup> Louis Figuier, *The World Before the Deluge*, (org. 1866), Jefferson Publications, 2016, p. 88
- <sup>xxxvi</sup> Donald Wagner, 'Blast Furnaces in Song-Yuan,' *ESATM, Vol 18, 2001, p 57*
- <sup>xxxvii</sup> Jules Verne, *From the Earth to the Moon*, editor Walter James Miller, annotated edition, Thomas Crowell, Publishers, 1978 pp. 71, 78, 83
- <sup>xxxviii</sup> *Scientific American Supplement*, August 17, 1878
- <sup>xxxix</sup> Reminiscences of the early anthracite-iron industry, Samuel Thomas, an address delivered before the American Institute of Mining Engineers, at the California meeting, September 1899.
- <sup>xl</sup> Henry Stafford Osborn, *The Metallurgy of Iron and Steel Theoretical and Practical: in All Its Branches; with Special Reference to American Materials and Processes*, 1869, p. 283
- <sup>xli</sup> See Verne comment on *Mysterious Island*, org. 1874, page 137 of Sidney Kravitz translation and **pp. 400-415 in Osborn**
- <sup>xlii</sup> Miškovičová, Z., Legemza, J., Demeter, P., Buřko, B., Hubatka, S., Hrubovčáková, M., Futáš, P., & Findorák, R. (2024). An Overview Analysis of Current Research Status in Iron Oxides Reduction by Hydrogen. *Metals*, 14(5), 589
- <sup>xliii</sup> Jules Verne, *Mysterious Island*, org. 1874, page 137 of Sidney Kravitz translation
- <sup>xliv</sup> *Ibid* page 137
- <sup>xlv</sup> *Ibid* page 143
- <sup>xlvi</sup> Donald Wagner, 'Blast Furnaces in Song-Yuan,' *ESATM, Vol 18, 2001, p.54*
- <sup>xlvii</sup> Jules Verne, *Mysterious Island*, org. 1874, pages 482 to 485 of Sidney Kravitz translation
- <sup>xlviii</sup> Jules Verne, *Mysterious Island*, org. 1874, page 143 of Sidney Kravitz translation

<sup>xlix</sup> The Journal of the Society of Arts, Vol. 24, No. 1238 (AUGUST 11, 1876

<sup>i</sup> Jules Verne, *Mysterious Island*, org. 1874, page 143 of Sidney Kravitz translation

<sup>ii</sup> Jules Verne, *Mysterious Island*, org. 1874, pages 121 (composition), 143 (use as tuyere), 145 (use as crucible for steel) of Sidney Kravitz translation

<sup>iii</sup> Henry Stafford Osborn, *The Metallurgy of Iron and Steel Theoretical and Practical: in All Its Branches; with Special Reference to American Materials and Processes*, Philadelphia: Henry Carey Baird, Industrial Publisher, p.544

<sup>iiii</sup> Jules Verne, *Mysterious Island*, org. 1874, page 141 of Sidney Kravitz translation

<sup>iv</sup> **Dolphin** from *The Blockade Runners* (1865), and the **Queen and Czar** from *The Adventures of Three Russians and Three Englishmen in South Africa* (1872), the **Forward** from *The Adventures of Captain Hatteras* (1874)