Comparison of Hydrogen Imports vs. Product Imports

- Old and new viewpoints on hydrogen application through an example of hydrogen-based direct reduction ironmaking -

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Summary

Hydrogen is extremely difficult to transport. Even if it were possible to produce cheap hydrogen outside of Japan, an increase in the cost for conversion to hydrogen carriers and transportation is inevitable when importing hydrogen to Japan. Changing the viewpoint, a question may arise; which is more economical, to import hydrogen for the purpose of manufacturing a product, or to manufacture that product in the country where the hydrogen is produced, and then import the product.

This paper analyzed that question using the example of hydrogen-based direct reduction ironmaking. The results of this analysis showed that the cost of supplying direct reduced iron to Japan by manufacturing it in the country that produces the hydrogen, and then importing it to Japan, is much cheaper than the cost of using imported hydrogen to produce direct reduced iron in Japan. The point that the result raises is how we should consider the economics of manufacturing products domestically using imported hydrogen, rather than only focusing on the comparison of the import cost of hydrogen carriers.

With Japan's high dependence on imports for energy, resources, and products, there is a need to curb the outflow of national wealth by making an effort to minimize import costs. There are many products produced using hydrogen other than direct reduced iron, so the results of this analysis cannot be generalized. However, if the dependence on imports is inevitable then we should elaborate the option to import products manufactured using hydrogen abroad, rather than persisting on importing the hydrogen which is quite difficult to transport physically. It is important to make an assessment according to the situation of the industry and the supply chain of the individual product.

It is also necessary to remember that the direct reduced iron used for this analysis is an intermediate product. Accordingly, consideration should include optimization of the overall supply chain by minimizing any hollowing out of the industry, such as by retaining the blast furnaces, electrical furnaces, and other processes required for the manufacture of final products in Japan[1], including the downstream supply chain, which uses the imported direct reduced iron.

From another point of view, if domestic product manufacturing should be retained to avoid hollowing out of the industry, then it would be meaningful to look into the potential of domestic hydrogen for minimizing the outflow of national wealth at the very least, assuming the same cost level for imported and domestic hydrogen. But even in that case, it is necessary to minimize the conversion to hydrogen carrier and transport with a view to curbing costs. In order to do so, it is worth considering shifting the industry to regions where renewable energy is abundant and relatively cheap, as an example that the shift of data centers to Hokkaido in recent years shows. This would contribute to the expansion of renewable energy through the increase in demand.

It is unable to escape the principle that it is more efficient to directly use hydrogen as a gas near the location where hydrogen is produced, rather than converting hydrogen to a hydrogen carrier. Depending on the hydrogen application, discussions are required based on multifaceted viewpoints that address the impact on the economy and industry, without taking hydrogen

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[1] The use of the imported direct reduced iron as feedstock in blast furnaces and electrical furnaces (supplementing iron ore and scrap iron which is not suitable for direct reduction) can significantly reduce CO_2 emissions when compared to conventional ironmaking (using blast furnaces and electric furnaces), but the energy required must still be decarbonized (such as by using CCS). Doing so would enable the ironmaking industry to optimize use of the furnaces and downstream processes while achieving progress in decarbonization.

imports as a given.

1. Introduction

Hydrogen is expected to play an important role in decarbonization. However, when considering the use of hydrogen, it is necessary to remember that the transport of hydrogen is extremely difficult. How to economically transport large amounts of hydrogen from foreign countries over long distances has long been a challenge for Japan, and numerous hydrogen carrier technologies are being developed. But from a different viewpoint, there is an alternative option to use the hydrogen where it is produced, rather than transport it. This paper compares the economics of the manufacturing of domestic products using imported hydrogen, as feedstock for industry, versus the use of hydrogen to manufacture products overseas and then import those products. The advantages and disadvantages of the two options will be discussed.

2. Hydrogen-based direct reduction ironmaking for an example

Technological development is being carried out mainly in the areas of blast furnace hydrogen reduction, large electrical furnaces, and hydrogen-based direct reduction ironmaking, in order to decarbonize the steel industry.[2,3,4] With regard to blast furnace hydrogen reduction, research and development are progressing on both the COURSE 50 Project, which aims to reduce CO_2 emissions by 30%, and the Super COURSE 50 Project, which aims to reduce CO_2 emissions by 50%, through the use of hydrogen reduction and CCUS. With regard to large scale electrical furnaces, research and development are being carried out for producing high-grade steel using iron scrap.

In comparison, whereas numerous technological challenges remain for hydrogen-based direct reduction ironmaking[5], similar natural gas (methane)-based direct reduction ironmaking has a long history which was commercialized in 1969 and has since vastly expanded production volume[6]. The research, development and demonstrations for hydrogen-based direct reduced ironmaking are also promoted in recent years[7] and drawing more attention than ever[8], which leads to commercialization represented by a contract that Midrex Technologies, Inc., a subsidiary of Kobe Steel will provide the world's first commercial steel plant using 100% hydrogen-based direct reduction for the Swedish steelmaker H2GS AB in 2022[9].

Based on this background, the following sections compare the costs in a case where hydrogen-based direct reduction iron is manufactured in Japan using imported hydrogen and in a case where Japan imports hydrogen-based direct reduction iron manufactured overseas.

3. Cases

The two cases are shown in Fig.1. For the case in which imported hydrogen is used in hydrogen-based direct reduction ironmaking in Japan (H_2-Import Case: top of Fig.1), liquid hydrogen (LH), methylcyclohexane (MCH), ammonia (NH3), and synthetic methane (e-CH_4) are chosen as the hydrogen carriers used to import the hydrogen. LH, MCH, and NH3 are gasified, dehydrogenated, and cracked, respectively after being imported to Japan to be converted to hydrogen gas that is fed into the reduction furnace (shaft furnace) to produce direct reduced iron (DRI). Meanwhile, e-CH_4 is directly fed into the reduction

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[2] Document 3 "Hydrogen Use in the Ironmaking Process" - Project Research and Development, Social Implementation Directions, Energy Structural Transformation Domain Working Group, Green Innovation Project Subcommittee, 5th Industrial Structure Council, Ministry of Economy, Trade and Industry.

[3] Nippon Steel (https://www.nipponsteel.com/csr/env/warming/future.html)

[4] Course 50 （https://www.course50.com/technology/technology01/）

[5] Hydrogen-based direct reduction has several technical challenges, such as the need to heat the hydrogen because it is an endothermic reaction like blast furnace hydrogen reduction, and the tendency for the iron ore to become powdered or solidified during the reaction. High-grade iron ore representing only about 10% of the total volume traded is used to avoid the latter challenge, but there is a need to develop technology that allows the use of low-grade iron ore. Also, the solid direct reduced iron produced through hydrogen-based direct reduction includes the veins and other impurities in the iron ore. Therefore, it is necessary to separate those components by melting the direct reduced iron in a blast furnace or electrical furnace.

[6] Kobe Steel (https://www.kobelco.co.jp/products/ironunit/dri/)

[7] Kobe Steel (https://www.kobelco.co.jp/releases/1201993_15541.html)

[8] Kobe Steel, Midrex Technologies (https://www.kobelco.co.jp/releases/1210984_15541.html)

[9] Kobe Steel (https://www.kobelco.co.jp/notices/files/20230317_2_01.pdf)

furnace (shaft furnace) without being converted to hydrogen gas, since natural gas (methane)-based direct reduction ironmaking is already commercialized. Ammonia-based direct reduction ironmaking, though expected[10], is not included in the analysis, since the technical specifications such as the reaction mechanism and the capital costs are unknown. Note that the case where domestically produced hydrogen is used will be analyzed as a reference. The iron ore is imported by Japan.

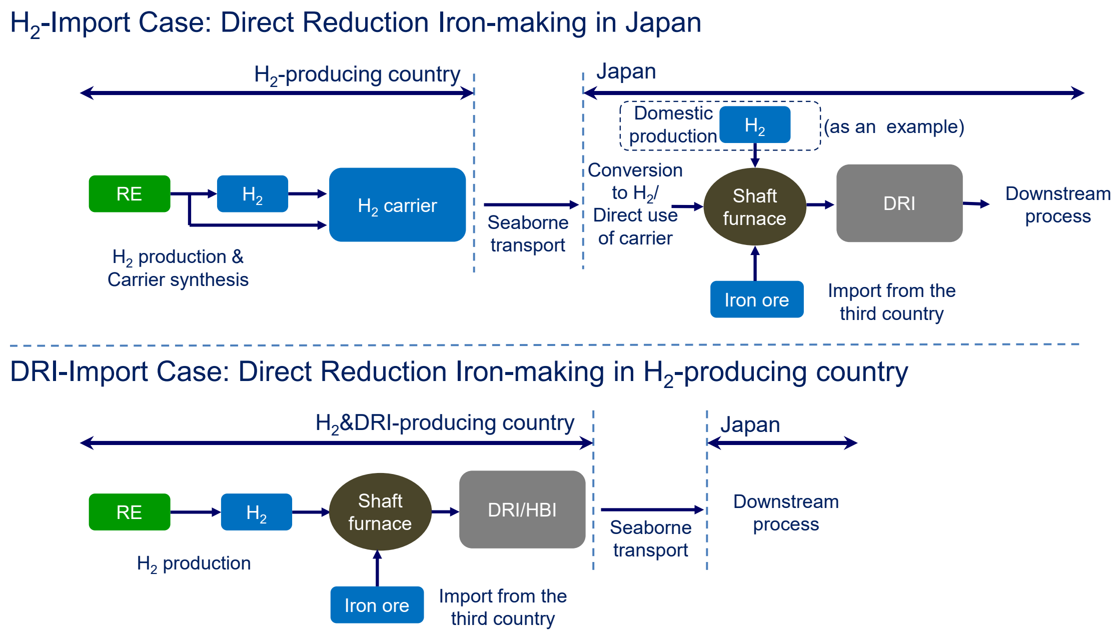

Figure 1: Supply chains for the Hydrogen-Import Case and DRI-Import Case

Note: Water (for water electrolysis hydrogen production) and CO_2 (for methanation) are also required, although not indicated in the figure.

Note: Under the Hydrogen-Import Case, methane-based direct reduction ironmaking is carried out when synthetic methane is used as the hydrogen carrier.

Note: Under the DRI-Import Case, the DRI is converted to HBI via compression molding for convenience of maritime transport.

Note: Domestic hydrogen Case is presented as a reference.

The case where direct reduction ironmaking is performed overseas (DRI-Import Case: bottom of Fig.1) assumes that the DRI is manufactured in the country where the hydrogen is produced. Hydrogen gas is fed into the reduction furnace (shaft furnace) to produce the DRI, which is then converted to hot briquetted iron (HBI) for shipment to Japan. The iron ore is imported by the country where the DRI is manufactured (where the hydrogen is produced). The DRI production process results in numerous pores in the material, which can be heated and ignited easily when combined with oxygen, so the long-duration storage and maritime transport are constrained due to safety concerns[11]. However, HBI, in which the pores have been reduced through compression molding, is capable of being transported seaborne and is traded globally[12,13,14].

It should be noted that this study regards DRI as the final target product and does not accurately describes the overall flow of the ironmaking process for the sake of simplicity in discussions, in spite of the fact that the downstream process such as electrical

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[10] Document 3 (p. 23) and reference document 2, Energy Structural Transformation Domain Working Group, Green Innovation Project Subcommittee, 5th Industrial Structure Council, Ministry of Economy, Trade and Industry.

[11] Some DRIs need to be sealed (inerted) with inert gas, such as nitrogen, to ensure safety when transported by sea (https://www.piclub.or.jp/ja/news/10789).

[12] "MIDREX® Process: Bridge to Ultra-low CO_2 Ironmaking," Vincent CHEVRIER, Lauren LORRAINE, Haruyasu MICHISHITA, Kobe Steel Engineering Reports /Vol. 70 No. 1 (Jul. 2020)

[13] "MIDREX® Process," Masaaki Atsushi, Hiroshi Uemura, Takashi Sakaguchi, Kobe Steel Engineering Reports /Vol. 60 No. 1 (Apr. 2010)

[14] Journal of the Japan Society of Mechanical Engineers (https://www.jsme.or.jp/kaisi/1239-36/)

furnace to which the DRI is fed is required.

With regards to synthetic methane (e-CH_4), one of the hydrogen carriers, there is an innovative technology[15] for the production of e-CH_4 in addition to the existing technology. This innovative technology uses renewable electricity to synthesize methane directly from water and CO_2, so hydrogen is not involved. Therefore, renewable energy is used as the input for all hydrogen carriers so that the different hydrogen carriers and different cases can be compared on a level playing field. Table 1 summarizes the reducing agents for direct reduction ironmaking.

Table 1: Reducing agents for direct reduction ironmaking

Case	H_2 carrier	➡	Reducing agent
H_2-Import Case	Imported LH	Gasification	Hydrogen
	Imported MCH	Dehydrogenation	Hydrogen
	Imported NH_3	Cracking	Hydrogen
	Imported e-CH_4	—	Methane
	(Domestic hydrogen gas)	—	(Hydrogen)
DRI-Import Case	Hydrogen gas	—	Hydrogen

Note: Ammonia can be used for ammonia-based direct reduction ironmaking without being split into hydrogen. However, it is not included in the analysis as the technical specifications are unknown.

4. Assumptions

Existing research [1] is referred to for the cost of each imported hydrogen carrier (the price for arrival in Japan including the conversion process to hydrogen gas) and existing research [2] is referred to for the technical specifications and capital costs for direct reduced ironmaking. [1] assumes approximately 2.9 billion Nm^3-H_2/year of hydrogen imports, which is slightly different from the 2.0 billion Nm^3-H_2/year in direct reduction ironmaking volume assumed in [2], but the difference is not adjusted by a scale factor. No location factor will be considered for the capital costs of direct reduction ironmaking. The domestic hydrogen unloading port and the overseas hydrogen production location are both assumed to be located adjacent to their respective reduction furnaces (shaft furnaces), ignoring hydrogen transportation facilities.

Table 2 shows the cost of hydrogen in each case. The cost of the hydrogen which is produced overseas at JPY 20/Nm^3-H_2 increases 1.5 to 2.5 fold when arriving in Japan after hydrogen carrier synthesis and international shipment. All other assumptions are described in the Appendix.

Table 2: Procurement cost of hydrogen in each case

Case	H_2 carrier	Procurement Cost
H_2-Import Case	Imported LH (Gasification)	JPY 53/Nm^3-H_2
	Imported MCH (Dehydrogenation)	JPY40/Nm^3-H_2
	Imported NH_3 (Cracking)	JPY 45/Nm^3-H_2
	Imported e-CH_4	JPY 32~38/Nm^3-H_2
	(Domestic hydrogen gas)	(JPY 42 /Nm^3-H_2)
DRI-Import Case	Hydrogen gas	JPY 20 /Nm^3-H_2

Sources: Estimated based on [1] and references in [1]. Synthetic methane is converted to hydrogen calorific value of 107-126 Yen/Nm^3-CH_4

The range of values refers to the difference between existing and innovative technologies.

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[15] Tokyo Gas (https://www.tokyo-gas.co.jp/news/press/20221220-02.html)

5. Estimation results

Figure 2 shows the estimation results. As a whole, fixed costs (CAPEX) for DRI are very minimal, and variable costs (OPEXs) account for the majority. No huge difference among cases is observed in the "OPEX: others" that is dominated by iron ore procurement cost.

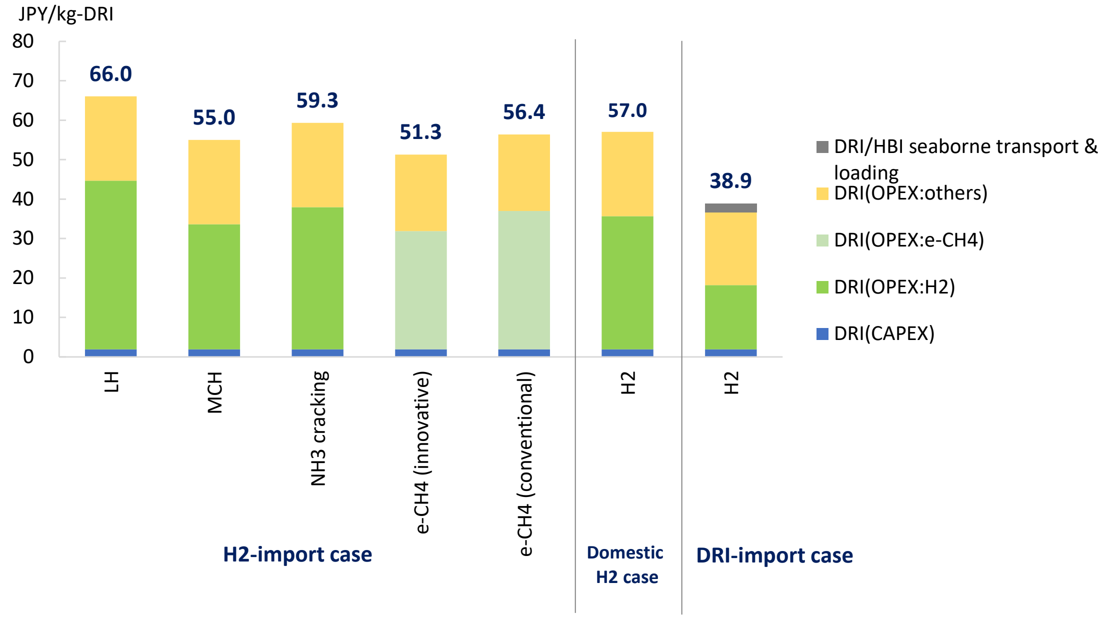

Figure 2: Procurement costs for direct reduced iron

Note: It should be noted that the compositions of hydrogen-based direct reduced iron and methane-based direct reduced iron are slightly different.

Note: "OPEX: others" includes the cost to import the iron ore and the energy used by the reduction furnace, but the iron ore import cost accounts for the majority.

The most significant difference is observed in OPEX of hydrogen or e-CH_4. The difference in the procurement cost of DRI among hydrogen carriers is almost identical to the difference in the cost of hydrogen in the H_2-Import Case as shown in Table 2. However, compared with H_2-Import Case, the DRI-Import Case is substantially inexpensive. This is because the cost of converting and transporting the hydrogen carrier is much higher than the cost of transporting the DRI/HBI. It also should be noted that there is no major difference between the case of direct reduced ironmaking using domestic hydrogen and the H_2-Import Case.

6. Implications

It could be interpreted that the estimated result that the cost of the DRI-Import Case (the supply cost to Japan) is lower than the H_2-Import Case merely highlighted the obvious fact that the cost of conversion to a hydrogen carrier and subsequent shipment increases greatly even if the production cost of hydrogen overseas is cheaper. However, this estimated result still suggests how we should address the economics of manufacturing products domestically using imported hydrogen, rather than focusing on the comparison of the import cost of hydrogen carriers.

With Japan's high dependence on imports for energy, resources, and products, there is a need to curb the outflow of national wealth by making an effort to minimize import costs. There are many other products produced using hydrogen other than direct reduced iron, so the results of this analysis cannot be applied generally. However, if the dependence on imports is inevitable then we should consider the option to import products manufactured using hydrogen abroad, rather than persisting on importing the hydrogen which is quite difficult to transport physically. It is important to make an assessment according to the situation of the industry and the supply chain of the individual product.

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References

[1] Otsuki, Shibata, "Estimation of Production and Supply Costs of Synthetic Methane, etc.," 9th Public-Private Conference on Methanation Promotion, November 22, 2022

[2] "Evaluation and Technical Issues of Direct Hydrogen Reduction Ironmaking Processes," Center for Low Carbon Society Strategy, May 2022.

Appendix (Estimate assumptions)

Direct Reduction Ironmaking

			DRI in Japan		DRI in oversea
			H_2	e-CH_4	H_2
Capacity			2.5 million t-DRI/year		
Fixed expenses	CAPEX		JPY 28.5 billion		
	Annual expense rate		15%		
	Labors		100 persons		
	Unit labor cost		JPY 5 million/person		
Variable expenses	Unit	Iron ore	1,417kg/t-DRI		
		H_2	800 Nm^3/t-DRI	—	800 Nm^3/t-DRI
		Natural gas	50 Nm^3/t-DRI	279 Nm^3/t-DRI	50 Nm^3/t-DRI
		Electricity	135 kWh/t-DRI		
	Unit cost	Iron ore	JPY 12,000/t		
		H_2	JPY 40~53/Nm^3*1	—	JPY 20/Nm^{3*}1
		Natural gas	JPY1.1/MJ	JPY 3.0~3.5/MJ^*1,2	JPY 0.4/MJ
		Electricity	JPY 17.9/kWh		JPY 6.2/kWh

Sources: Assumed and estimated based on references [1], [2] and the sources listed in these documents.

Note: Natural gas is used to increase the carbon content in the DRI.

*1: See Table 2 in the text.

*2: Price of imported e-CH_4.

Seabourne Transport of DRI

Deadweight (Cape size bulker)	150,000 ton	Estimated from “Trend of the World and Japanese Ship Building”, Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism, July 2022
Ship price	USD 50 million /ship	
Loading/unloading facility	JPY 1 billion	Miscellaneous information

Note: Voyage distance is assumed to be 12,000 km based on [1]. The number of vessels required is estimated based on the annual volume of DRI/HBI transported with estimates for ship speed and days required to load/unload. Fuel consumption (MJ/km) of the cape size bulk carrier is estimated based on the relationship between loaded weight and fuel consumption of LH_2, MCH, and NH_3. Fuel used is assumed to be green ammonia, with the cost estimated based on [1].

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