November 2018	Announcement
September 2019	Revision
June 2020	Revision

The Japan Iron and Steel Federation

JISF long-term vision for climate change mitigation
A challenge towards zero-carbon steel

Introduction

In November 2014, the Japan Iron and Steel Federation announced the "Commitment to a Low Carbon Society Phase II" with the target year of 2030. This plan is also reflected in Japan's NDC (2030 target) based on the Paris Agreement, and each member of the Japan Iron and Steel Federation is making constant efforts to achieve it.

The Paris Agreement invites all Parties to formulate and submit by 2020 a “long-term low greenhouse gas emission development strategies” to achieve the long-term goal (2DS target). Japanese government has set up the "advisory committee to establish the “national long-term development strategies based on the Paris agreement”.

In response to such domestic and international movements, in addition to the ongoing efforts to achieve the "Commitment to a Low Carbon Society Phase II", the Japan Iron and Steel Federation has decided to formulate the “long term vision for climate change mitigation” for 2030 and beyond, which aims to realize the “zero-carbon steel”.

1. A prediction of future steel demand and supply

Steel materials are excellent in many aspects required in basic materials, such as resource availability, manufacturing cost, diversity of functions, environmental burdens during production, recyclability, etc. Because of this, they support our lives as the main materials that make up social infrastructure and durable consumer goods, such as roads, railroads, buildings, cars and home appliances.

In the beginning, steel materials are produced by reducing iron ore, which is a natural resource, but steel has an excellent recycling characteristic (closed-loop recycling) which is not found in other materials, where most of the reduced steel materials are recovered as scraps and are reborn into new steel products after the end of life of finished products such as automobiles. As a result, steel materials once produced from natural resources are accumulated in the society while changing their shapes to various products (Fig. 1).

Figure 1. Lifecycle of steel and recycling (closed-loop recycling)

Figure 2 shows the accumulation of steel and the transition of nominal GDP in Japan. The per capita steel stock in 1958 was only 1 ton/person, but after going through the high economic growth period in the 1960's, it reached 4 ton/person in 1973. 15 years later (1988) it reached 7 ton/person, and in another 15 years (2003), it reached 10 t/person. During this time, the rate of steel accumulation has been +0.2t/person/year. After that, with the economic maturity of society, the accumulation of steel has been moderate (+0.06t/person/year). The total amount of current iron and steel stock is 1.36 billion t (FY 2015), which is 10.7 ton/person.

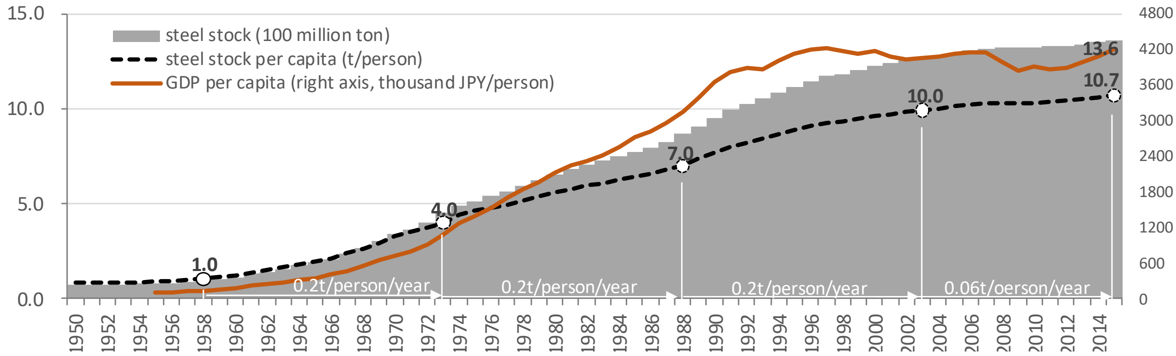


Figure 2. The trend of steel stock accumulation in Japan

Source: steel stock from the Japan Ferrous Raw Materials Association and nominal GDP from 2018 Fiscal Year Annual Economic and Fiscal Report by Cabinet Office, Government of Japan

Correlation between economic growth and the amount of steel accumulated per capita is observed also in countries other than Japan (Fig. 3). Moreover, as the population increases, the total steel stock amount expands. Steel stock in OECD countries is estimated to be around 10 ton/person, and it is estimated that the amount of steel stock will reach 10 ton/person in China in the first half of this century and India during this century (Figure 4).

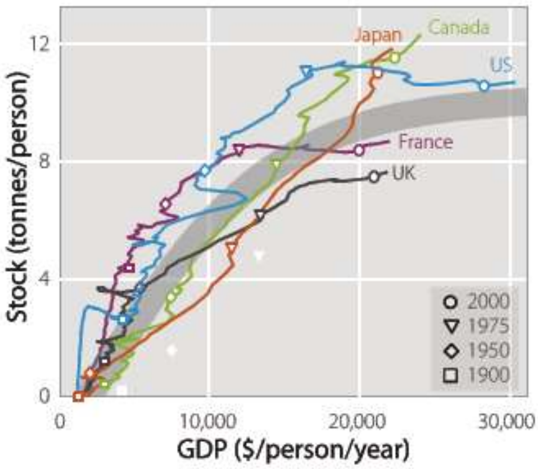


Figure 3. Relationship between GDP per capita and steel stock

Source: Muller, et.al, “Patterns of Iron Use in Societal Evolution”, Environ. Sci. Technol. 2011, 45

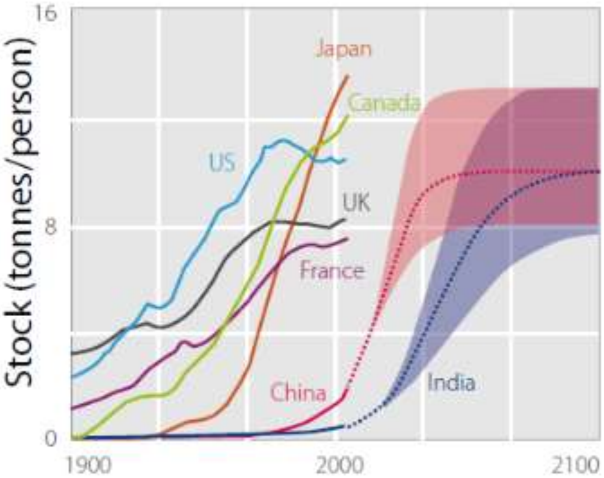


Figure 4. Transition of steel stock per capita

Source: “Sustainable steel: at the core of a green economy”, World Steel Association, 2012

Table 1 shows the global steel stock in 2015 and the estimated values for 2050 and 2100. The total amount of steel stock in the world in 2015 is estimated to be 29.4 billion tons and 4.0 ton/person. This is equivalent to Japan's steel stock level in 1973. The world population is expected to increase in the future as well. Moreover, as the world economy grows, it is assumed that in 2050 the total steel stock will reach 7.0 ton/person and 68.2 billion tons in total. It is a macro-level assumption that it will take 35 years for the world to increase the steel stock from 4 to 7 tons per capita, where it took Japan 15 years from 1973 to 1988, and that the world steel stock would reach 7 tons per capita 62 years later than Japan. While the uncertainty increases towards 2100, steel stock of 10 tons/person was assumed, supposing that the SDGs (Sustainable Development Goals) are achieved, and the same level of wealth as the current developed countries is realized across the world through economic growth and poverty eradication.

Table 1. Estimates of world population and steel stock

		2015	2050	2100
World Population (billion) *		7.38	9.77	11.18
Steel Stock	Per Capita (t/person)	4.0	7.0	10.0
	total (billion ton)	29.4	68.2	111.8

*from UN, World Population Prospects 2017

Table 2 forecasts the steel production that would be necessary to satisfy such steel stock accumulation. In 2015, actual steel production amounts in the world were 1.29 billion tons of actual steel material used in the final products and 1.62 billion tons of crude steel production. Among the iron sources were 1.22 billion tons of pig iron (including DRI) from the natural resource route, and 560 million tons of scrap from recycling route. For the future, as the demand for steel products increase (1.29 billion tons in 2015 → 2.13 billion tons in 2050 →

3.01 billion tons in 2100), crude steel production will also increase (1. 62 billion tons in 2015 → 2.68 billion tons in 2050 → 3.79 billion tons in 2100). As for the iron source, the amount of scrap used increases (560 million tons in 2015 → 1.55 billion tons in 2050 → 2.97 billion tons in 2100) as the generation of scrap increases mainly due to the expansion of steel stock. However, as scrap alone cannot meet steel demand, the production from the natural resource route is essential for keeping up with the steel stock accumulation. Therefore, almost the same level of pig iron production now (1.2 billion tons) will still be required in 2100. Figure 5 shows the forecasts of steel accumulation and supply and demand of steel until 2100 (the preconditions of calculation is given in Appendix I).

Table 2. Forecast of Steel Production

(billion ton)

	2015	2050	2100
Amount of steel in final products	1.29	2.13	3.01
Crude steel production	1.62	2.68	3.79
Pig iron production	1.22	1.4	1.2
Scrap consumption	0.56	1.55	2.97

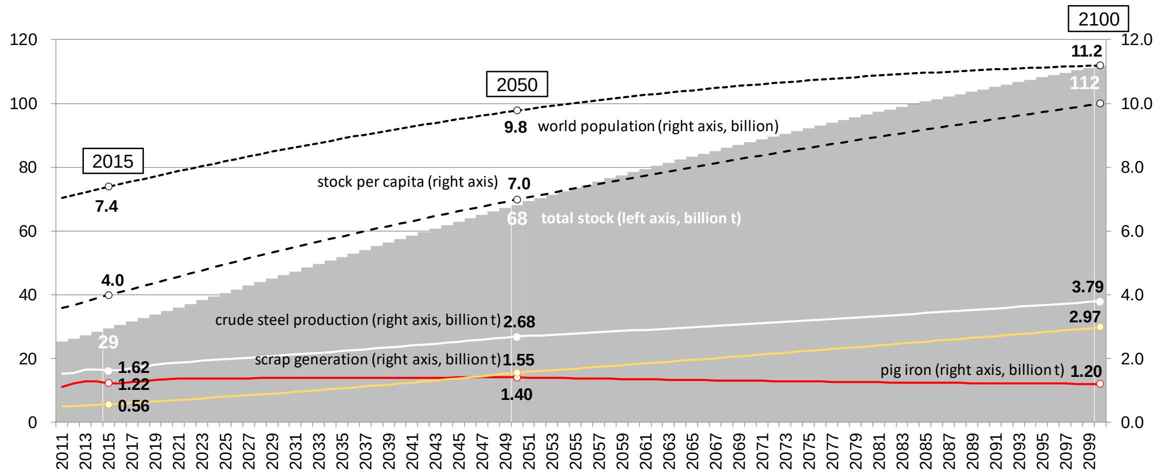


Figure 5. Forecasts of steel stock accumulation and steel production

2. Long-term global warming mitigation scenario of steel industry

<u>BAU (Business as Usual) Scenario</u>

The amount of crude steel production changes, while the CO_2 intensity stays at the current level for both natural resource route and the recycling route. The amount of scrap recovered (= used) increases with the expansion of steel stock etc., leading to a rise of the scrap ratio in the iron source. Since the scrap does not require the reduction process necessary for natural resources, the CO_2 emission per unit of crude steel produced will be reduced. However, the total amount of CO_2 emissions will increase due to the increase in the amount of crude steel production.

Maximum Introduction of BAT (Best Available Technologies) Scenario

Maximize the diffusion of existing advanced energy saving technologies to the world. IEA ETP 2014 assumes that the reduction potential by international diffusion of BAT is 21%, and that this will be achieved by 2050. Although the CO_2 intensity will be improved compared to the BAU scenario, the total amount of CO_2 emission will increase due to the increase in the amount of crude steel production.

Maximum Introduction of Innovative Technologies Scenario

It is assumed that the innovative technology currently being developed (COURSE 50: hydrogen-reduction portion, ferro coke, etc) will be introduced at the maximum level from 2030 to 2050, and the CO_2 intensity in the natural resource route will be improved by 10%.

Super Innovative Technologies Development Scenario

With the introduction of super innovation technologies (hydrogen-reduction steel production, CCS, CCU etc.) that are not yet in place and the achievement of zero emission of the grid power supply, it is assumed that "zero-carbon steel" will be realized in 2100. Based on the level of achievement in 2050, low level case (20% reduction in CO_2 intensity from the Maximum Introduction of Innovation Technologies Scenario), middle level case (50% reduction) and high level case (80% reduction) were estimated.

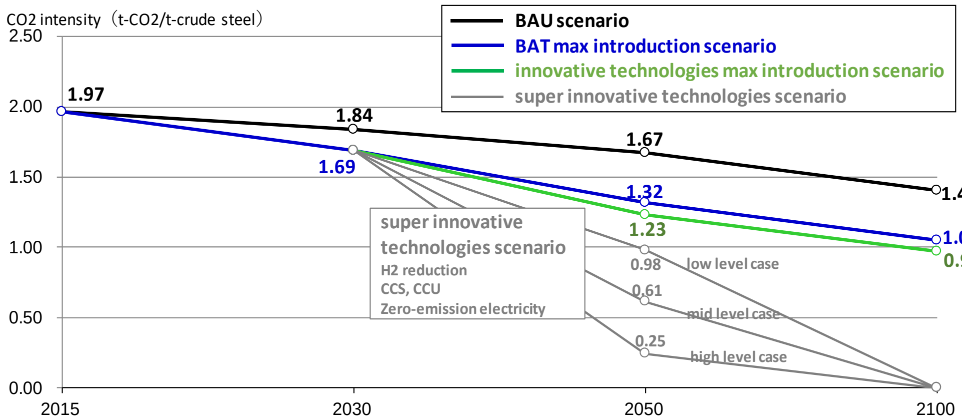


Figure 6. Transition of CO_2 intensity in long-term climate change mitigation scenario

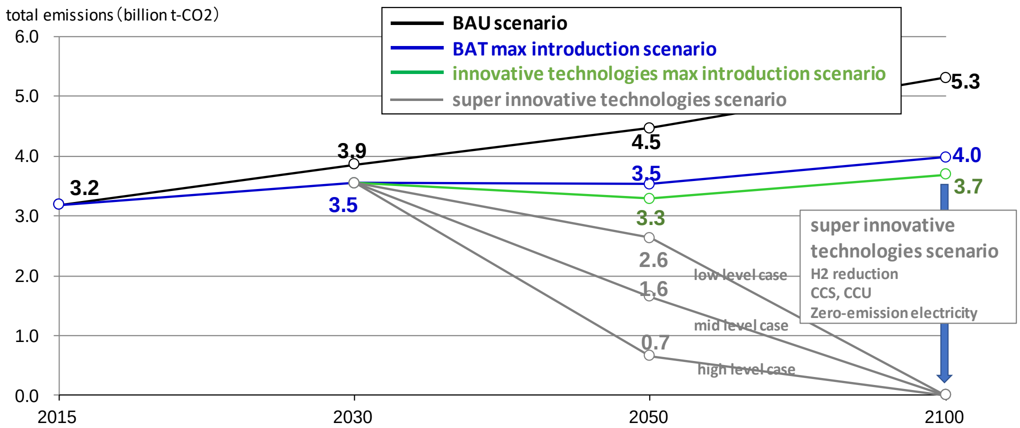


Figure 7. Transition of CO_2 emission in long-term climate change mitigation scenario

In addition, when the Super Innovative Technologies Scenario is executed only with CCS, the total storage volume in 2030-2100 can be estimated as 91.1 billion t- CO_2 in the low level case, 101.2 billion t- CO_2 in the middle level case, 111.2 billion t- CO_2 in high level case. It is also necessary to solve the issues that go beyond technical aspects, such as securing CO_2 storage sites, acceptance from society, implementing entities, and distribution of the economic burdens. Moreover, the amount of hydrogen required for producing pig iron in hydrogen-reduction in 2100 is estimated to be 1.2 trillion Nm^3, and the low cost and stable supply of large amounts of carbon-free hydrogen is a requirement for practical application.

3. Long-Term Climate Change Mitigation Measures by Japan Iron and Steel Federation

40% of the world's steel products are traded across national borders. More than 60% of the steel produced in Japan is directly and indirectly exported, catering to the global steel demand. In this way, both the supply chain and the market are globalized in the steel industry, and a global viewpoint is indispensable for effective measures against global warming in the steel sector.

Japan's steel industry has greatly contributed to the world's steel industry through excellent energy saving and environmental technologies. In addition, it has been leading the world in product functions, enhancing the international competitiveness of our country as well as the compatibility of human wellness and global environment through development of steel products contributing to improved functionality and efficiency of the final products, including weight reduction and electrification of automobiles. These facts are the basis of the current "Commitment to a Low Carbon Society" and constitute the basic idea in the long-term climate change mitigation measures after 2030.

In consideration of the long-term target (2DS target) under the Paris Agreement, development of super innovative technologies that exceed even the innovative technologies currently under development is required, in addition to the existing technologies. Figure 8 shows the basic idea of the Japan Iron and Steel Federation's long-term climate change mitigation strategy.

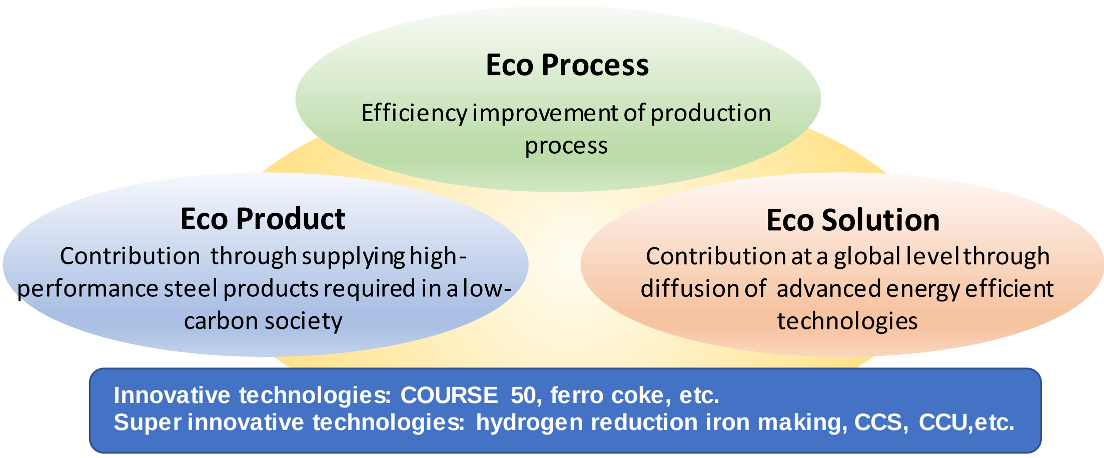


Figure 8. The Basic ideas of JISF's long term climate change mitigation measures (3 ecos and development of innovative technologies)

Approach to development of super innovation technologies

The Japanese iron and steel industry is diligently pursuing the development of innovative ironmaking technologies such as COURSE50 and ferro coke to realize practical application by 2030. When these technologies are put to practical use, they are expected to reduce CO_2 emissions of natural resource routes by 10% (excluding CCS effect). It is necessary to advance the establishment of low carbon technologies on the premise of blast furnace use, since the blast furnace method is considered to be the mainstream of the steel manufacturing method in the meantime, both technically and economically. However, these efforts alone cannot reach the long-term target level of the Paris Agreement (Maximum Introduction of Innovative Technologies Scenario in Figure 7), and "super innovation technologies" beyond them are necessary. The Japanese iron and steel industry will, using the knowledge gained from the development of COURSE50 and ferro coke as a foothold, challenge to develop technologies that will ultimately achieves zero emissions from ironmaking process, including iron reduction technologies using hydrogen, CCS (Carbon Capture and Sequestration) that would recover and store CO_2 from steel production and CCU (Carbon Capture and Utilization) that produces valuable materials using CO_2 as a raw material.

The practical application of hydrogen-reduction ironmaking process is premised that hydrogen is developed and maintained as a common energy carrier for the society, as it is widely used not only in steel production but also in various sectors such as automobiles and consumer use. Especially, an important requirement for hydrogen to be used for the production of steel, which is a basic material, is stable supply at low cost, in addition to being carbon free. Moreover, the implementation of CCS requires, in addition to the development of cheap transportation and storage technologies for large quantities of CO_2, solving issues that go beyond technical aspects, such as securing CO_2 storage sites, acceptance from society, implementing entities, and distribution of the economic burdens.

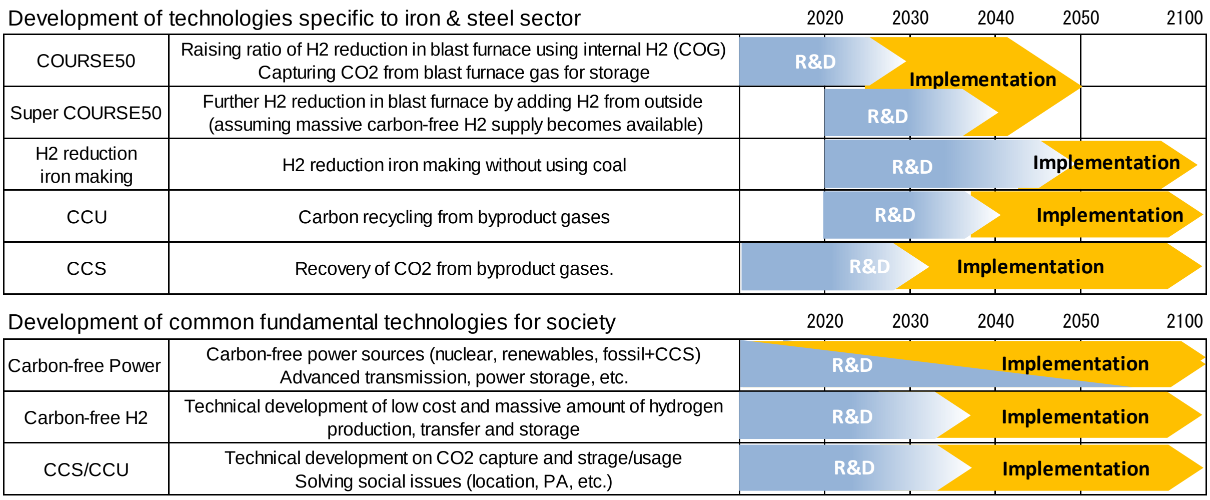


Figure 13 shows a road map for the development of super innovation technologies.

In Conclusion

The super long-term future beyond 2030 includes uncertainties that cannot be assumed at the moment, such as social situation and technology trends, and the "long-term vision for climate change mitigation" presented here is to indicate a direction towards achieving the long-term goal of the Paris Agreement, and it signifies a challenge to realize "zero-carbon steel".

Each member company of the Japan Iron and Steel Federation will, while continuing to fulfill the Commitment to a Low Carbon Society to achieve Japan's mid-term Paris Agreement target (2030), tackle the climate change mitigation measures beyond 2030 with “three ecos” and development of innovative technologies.

Appendix I: Assumptions for the calculation of the future steel demand and supply

a) Steel stock per capita

2015 : 4.0t/person (actual data)

2050 : 7.0t/person (assumed)

2100 : 10.0t/person (assumed)

		2015	2050	2100
World Population (billion)		7.38	9.77	11.18
Steel Stock	Per Capita (t/person)	4.0	7.0	10.0
	total (billion ton)	29.4	68.2	111.8

b) Population

World Population Prospects2017, UN

c) Diffusion and loss

0.1% of the total steel stock was assumed to be diffused or lost.

d) The rate of scrap generation

d-1) internal scrap: 12.5% of total crude steel production (2015 actual data)

d-2) manufacturing scrap: 9.3% of total steel products shipped out (2015 actual data)

d-3) end-of-life scrap: assumed to increase gradually from 0.8% of total steel stock in 2015 (actual data) → 1.5% in 2050→ 2.0% in 2100.

e) Yield ratio of crude steel to iron source

Yield ratio of crude steel to iron source was set as 91% (2015 actual data) for both pig iron and scrap

Table A-I Future estimates of steel supply and demand

	Production (billion t)		Scrap Generation (billion t)				Scrap Generation Rate (%)			Steel Stock		Loss rate	World Pop.
	crude steel	Pig iron DRI	total	internal	manufacturing	end-of-life	internal/ crude steel	manufacturing/ products	EoL/ steel stock	total (billion t)	per capita (t/person)	(%)	(billion)
2015	1.62	1.22	0.56	0.20	0.13	0.22	12.5	9.3	0.8	29.4	4	0.1	7.38
2020	1.85	1.35	0.68	0.23	0.15	0.3	12.5	9.3	0.9	34.8	4.5	0.1	7.8
2030	2.1	1.38	0.92	0.26	0.17	0.49	12.5	9.3	1.1	46.2	5.4	0.1	8.55
2050	2.68	1.4	1.55	0.34	0.22	0.99	12.5	9.3	1.5	68.2	7	0.1	9.77
2100	3.79	1.2	2.97	0.47	0.31	2.19	12.5	9.3	2	111.8	10	0.1	11.18

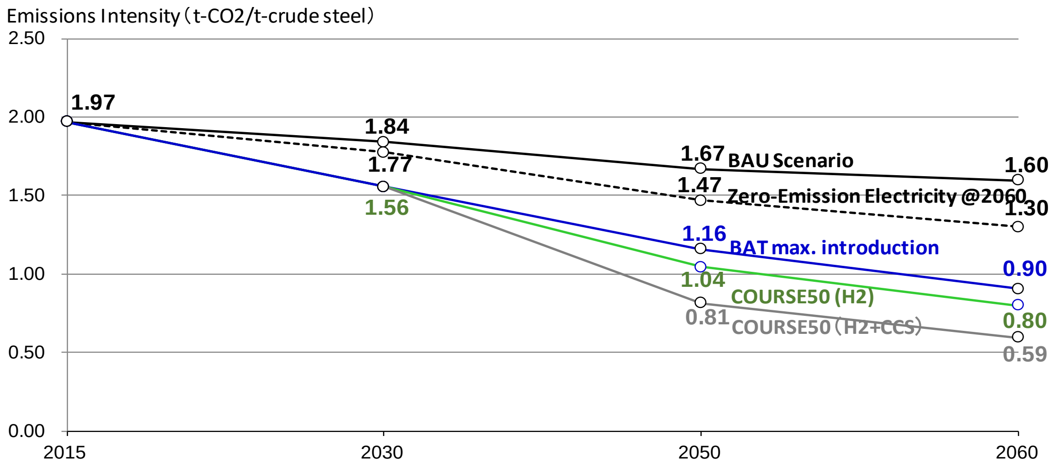
Appendix II: Consistency with IEA-ETP2017 2DS

IEA-ETP 2017 2DS assumes zero emission from the electricity sector and reduction of emission from the industry sector by 30% from present level by 2060.

When zero emission from the electricity sector is achieved, emission from grid electricity consumed in steel production process will becomes zero. Topping this with the effect of maximum implementation of BAT and the effect of COURSE50 (Hydrogen-reduction) from the Maximum Introduction of Innovative Technologies Scenario, the emission level in 2060 comes near the 30% reduction presented in the IEA-ETP 2017 2DS. Furthermore, when the CCS effect of COURSE50 is added, the scenario shows almost 50% reduction by 2060.

Calculation assumptions:

1. Emission factor from gird electricity : combined average from IGES GRID EF v10.2
2. Grid electricity intensity in BF-BOF route: 140kWH/t-s (2016 average of Japan)
3. Grid electricity intensity in EAF route: 872kWH/t-s (2016 average of Japan)
4. CO_2 emission factor in BF-BOF route: 2.4t- CO_2/t-s
5. CO_2 emission factor in EAF route: 1.0t- CO_2/t-s
6. Yield of crude steel against iron source: 0.91 (both natural resource route and scrap route)



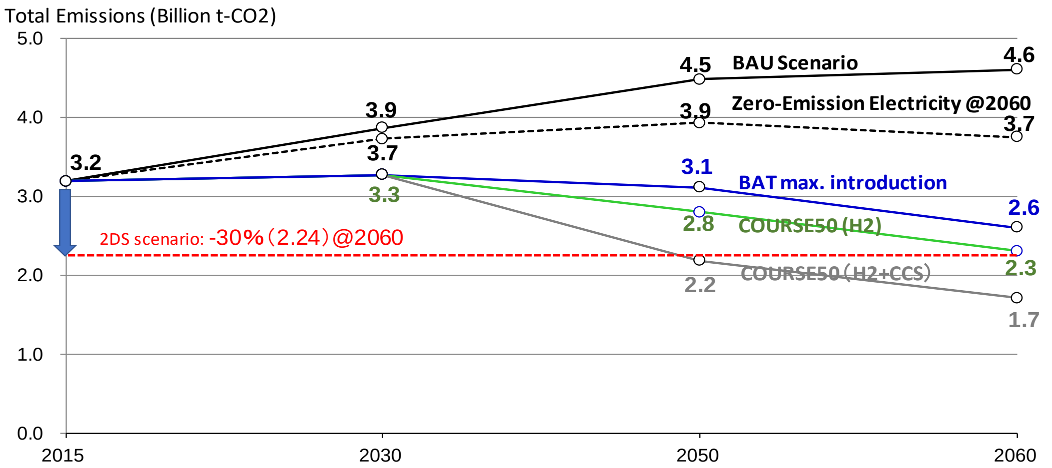


Fig A-II Relationship between IEA-ETP 2017 2DS and long-term climate change mitigation scenarios

Appendix III：Rough Estimations on Hydrogen-reduction

It is important requirement that the practical application of hydrogen-reduction ironmaking process is stable supply at low cost, in addition to being carbon free. The aspects of quantitative and economic compared with the current coal reduction were estimated as follows.

- hydrogen-reduction steel production（The chemical formula）
  $1/2Fe_2O_3 + 3/2H_2 + 48kJ \rightarrow Fe + 3/2H_2O$
- Requirement of hydrogen for 1 ton of pig-ironmaking based on the above formula
  reduction：$601Nm^3$
  ＋ compensation for endothermic reaction：$67Nm^3$
  ＋ heat to make molten iron of 1600℃：$85Nm^3$
  ＝ $753Nm^3$/ton of (theoretical) ⇒ around $1000Nm^3$/ton with assuming process efficiency of 75%

Quantitative aspects

- The amount of hydrogen required for producing pig iron in hydrogen-reduction in 2100: 1.2 trillion Nm^3/year.
- Assuming $4.5kWh/Nm^3$-H_2 production, 5.4 trillion kWh is needed for hydrogen production and more for transportation, liquefaction, storage etc.

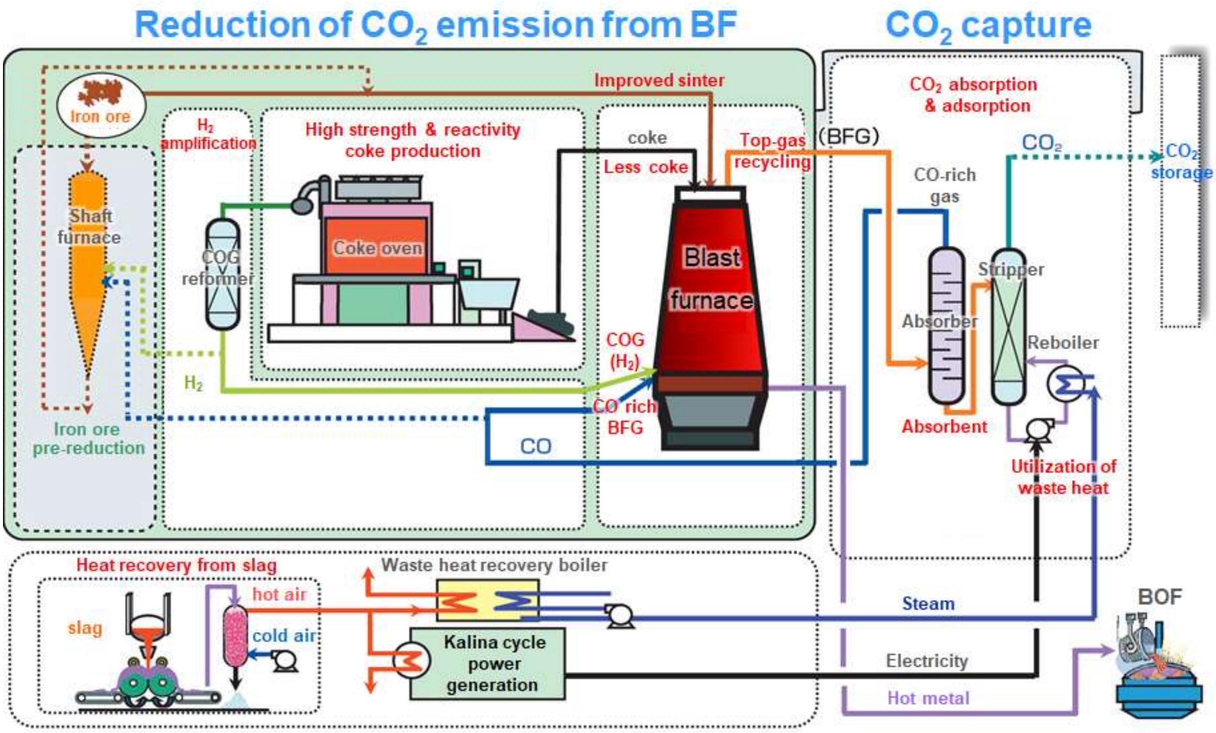
Economic aspects

- Estimation of hydrogen price equivalent for carbon reduction ironmaking; Assuming $200/t-coal and 700kg-coal/pig-iron, coal cost is $140/t-pig iron. Assuming 55% of thermic value of coal is consumed for reduction (another 45% becomes by-product gases), the cost of reducing agent is $77/t-pig iron ($140/t-pig iron x 0.55).
- The equivalent cost of hydrogen ($77/t-pig iron / $1000Nm^3$-H_2/t-pig iron) becomes 7.7 ¢ /Nm^3-H_2

Figure A-III Hydrogen price and coal price

Appendix IV : The First Step to the future (COURSE50)

COURSE50 project is the national project for drastic CO_2 reduction from ironmaking process, consisting of increasing the share of hydrogen-reduction in blast furnace and CO_2 capture from blast furnace gas.



Experimental Blast Furnace

Reducing Ratio in Blast Furnace