ALPS International Symposium
JISF, Energy Technology Committee, Chair
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JISF Long-term vision for climate change mitigation

A challenge towards Zero-carbon STEEL

September, 2019 revised

Japan Iron and Steel Federation

Part 1:
Forecast of Future Steel Demand and Supply

SDGs and Paris Agreement

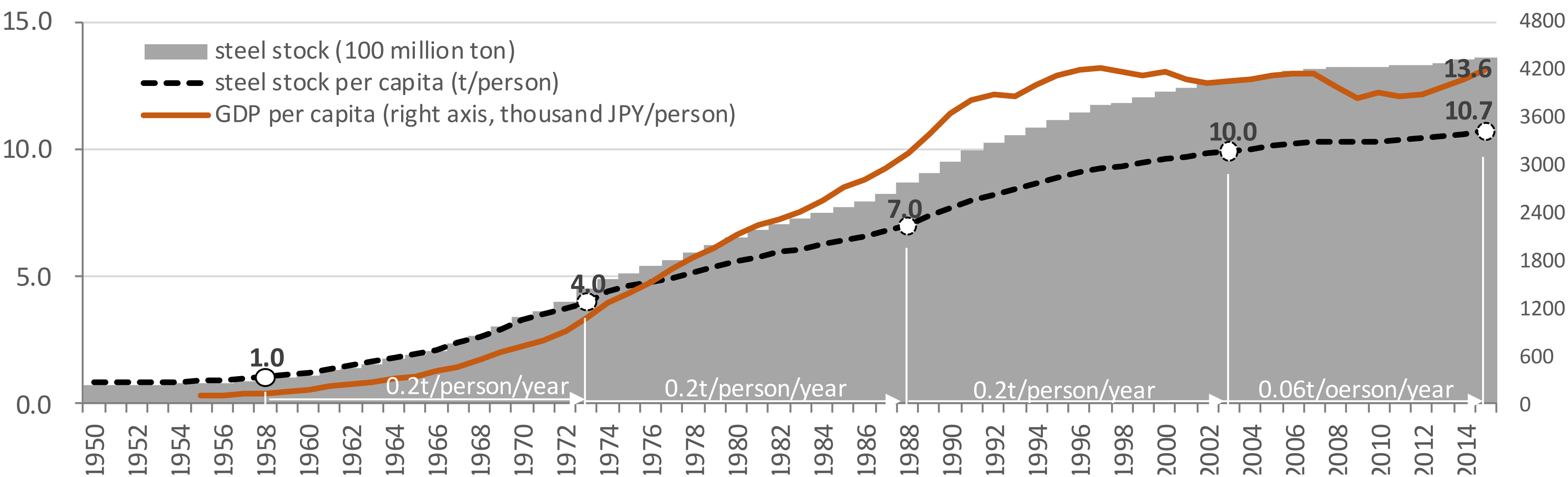
Paris Agreement

Factors promoting steel demand

Performance Trend of Steel Stock in Japan

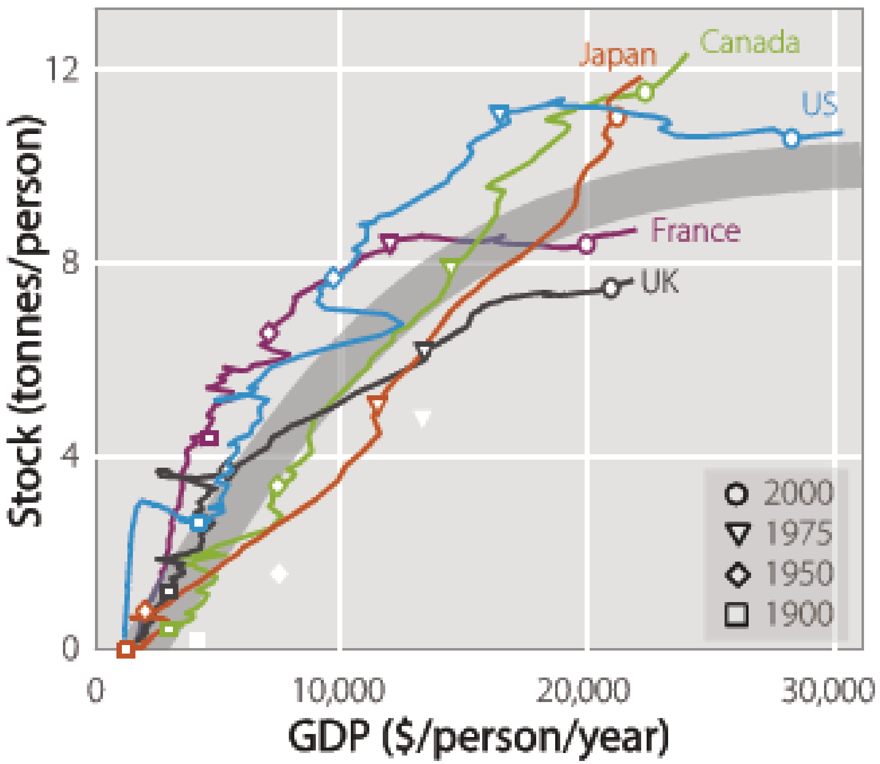
The future supply and demand of steel was estimated from the relationship between past economic growth and steel stock at a macro level. For this purpose, we analyzed the past trend of Japan's performance, which is backed by reliable data, and aligned the results with those from overseas researches.

The per capita steel stock in 1958 was only 1 t/person, but after going through the high economic growth period in the 1960's, it reached 4 t/person in 1973. 15 years later (1988) it reached 7t/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 t/person.



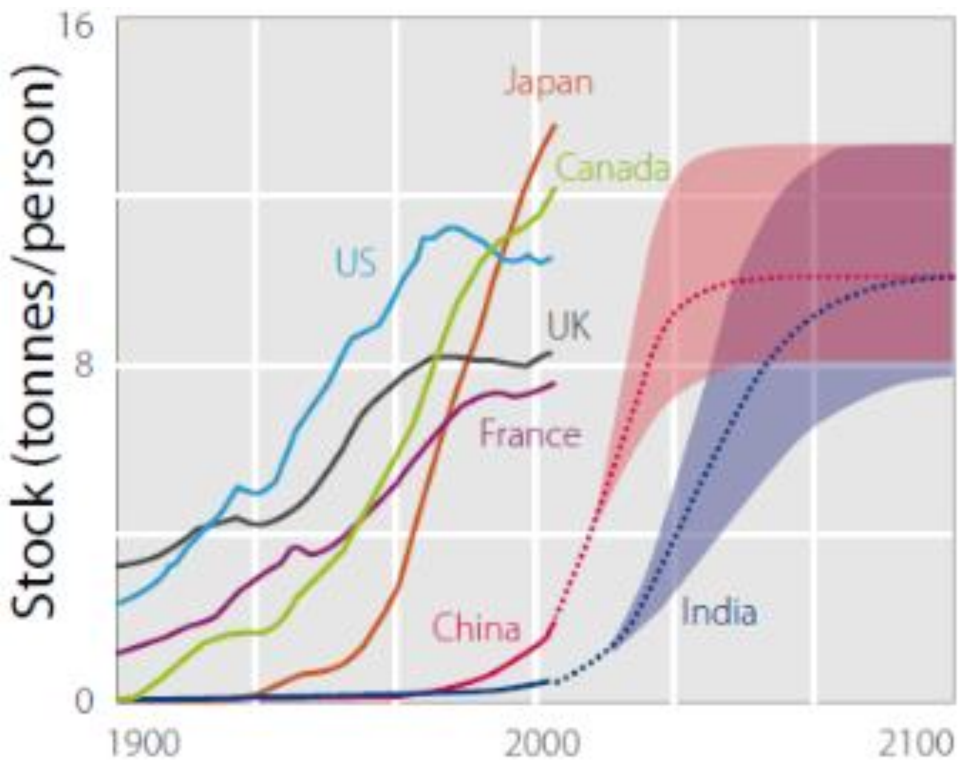
Performance Trend of Steel Stock in the World

There is a certain correlation between economic growth and the amount of steel stock per capita, and as the population increases, the total stock amount expands. The steel stocks in developed countries are estimated to be in the range of 8 to 12 t/person, and it is estimated that the steel stock will reach 10 tons per person in China in the first half of this century and in India during this century.



Relationship between GDP per capita and steel stock

Muller, et.al, "Patterns of Iron Use in Societal Evolution", Environ. Sci. Technol. 2011, 45



Transition of steel stock per capita

"Sustainable steel: at the core of a green economy", World Steel Association, 2012

Assumptions for Steel Stock Estimation

[Calculation assumptions]

a) Steel stock per capita
   2015 : 4.0t/person (actual data)
   2050 : 7.0t/person (assumed)
   2100 : 10.0t/person (assumed)

b) Population
   World Population Prospects2017, UN

		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

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

	production (billion ton)		scrap generation (billion ton)				scrap generation rate（%）			steel stock		loss rate	world pop.
	crude steel	pig iron DRI	total	internal	prompt	end-of-life	internal/ crude steel	prompt/ products	EoL/ steel stock	total (billion ton)	per capita (t/person)	（%）	(billion)
2015	1.62	1.22	0.56	0.2	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

Steel Demand and Supply in the Future

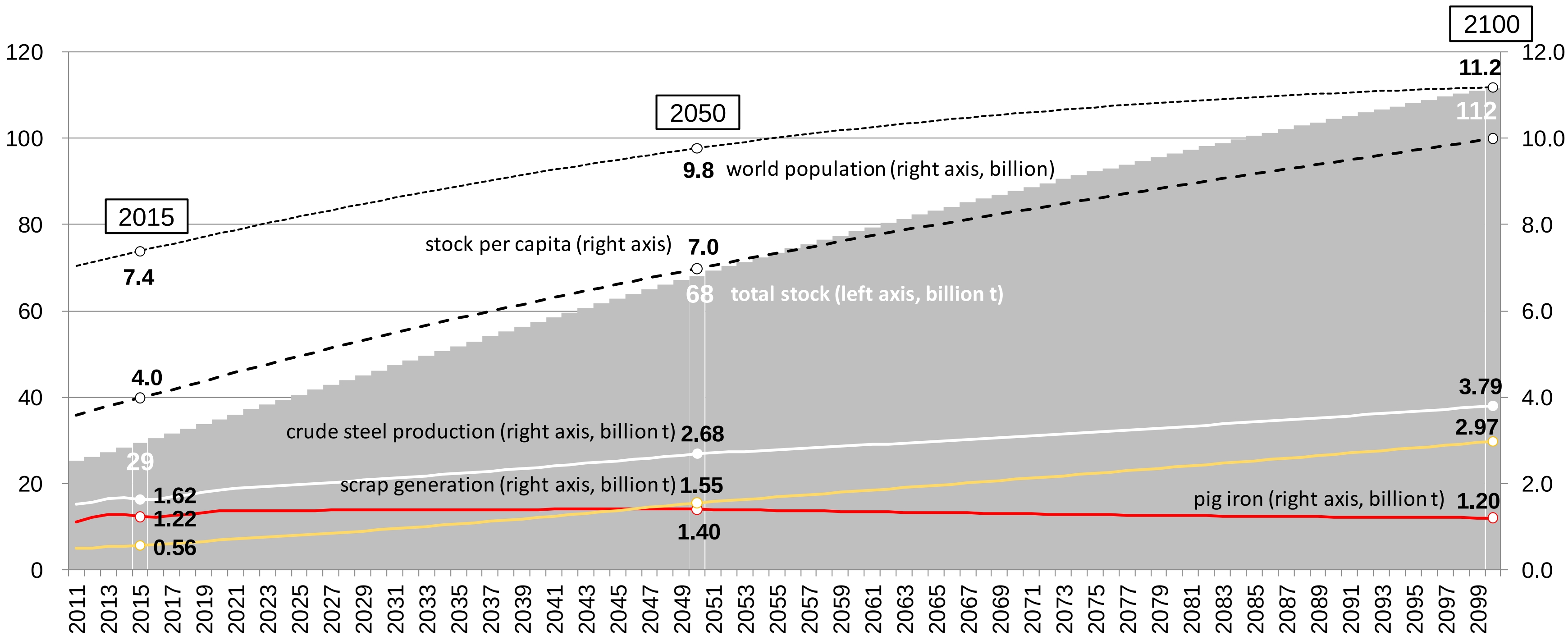
[crude steel production] increase as the steel demand increases

[scrap] its use increases mainly as a result of increased generation of end-of-life scrap due to expansion of the amount of total steel stock.

[pig iron production] As scrap alone can not meet steel demand and production from the natural resource route is essential for the expansion of steel stock, almost the same level of pig iron production as currently required will be required at the end of this century

(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



Part 2:
Long-term Climate Change Mitigation Scenarios for Steel Industry

Scenarios

BAU (Business as Usual) scenario

Only Scrap ratio in iron source increases due to increase in scrap generation while technical level stays at the current status.

BAT (Best Available Technologies) maximum introduction scenario

Maximize the diffusion of existing advanced energy saving technologies (CDQ,TRT etc.) to the world by 2050. IEA ETP 2014 assumes that the reduction potential by international diffusion of BAT is 21%.

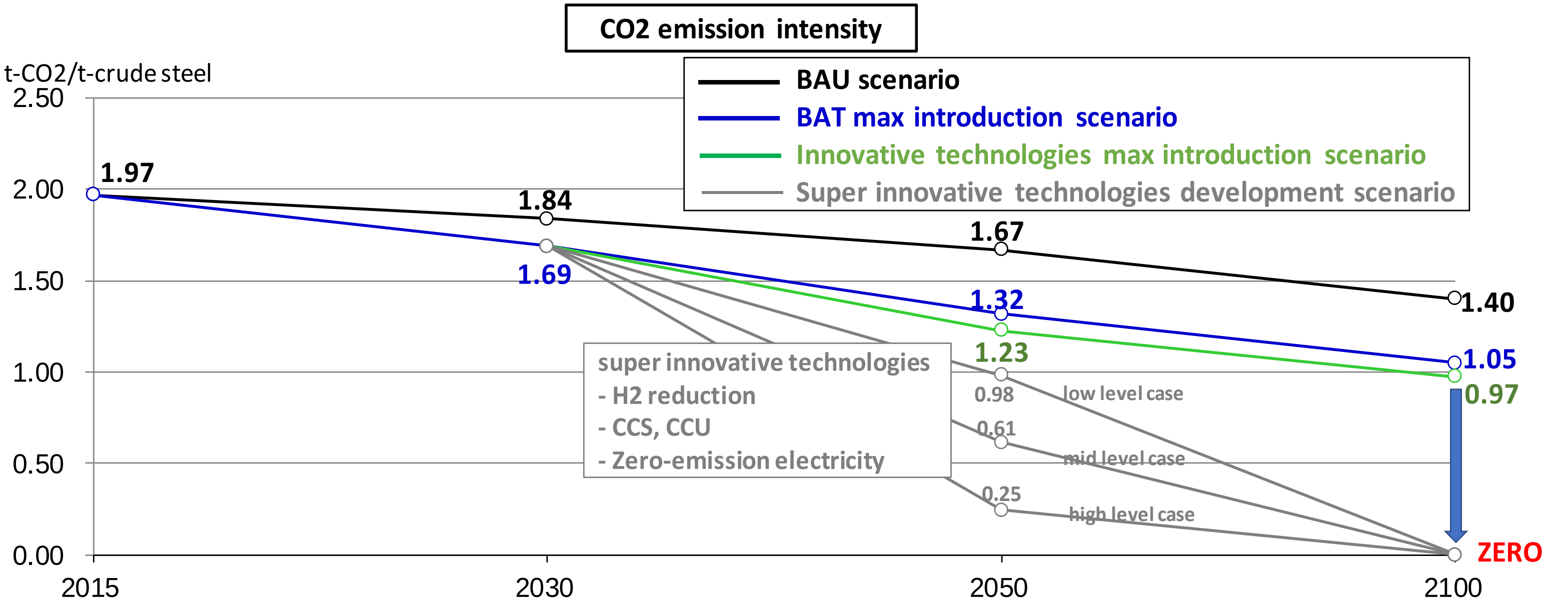
Innovative technologies maximum Introduction scenario

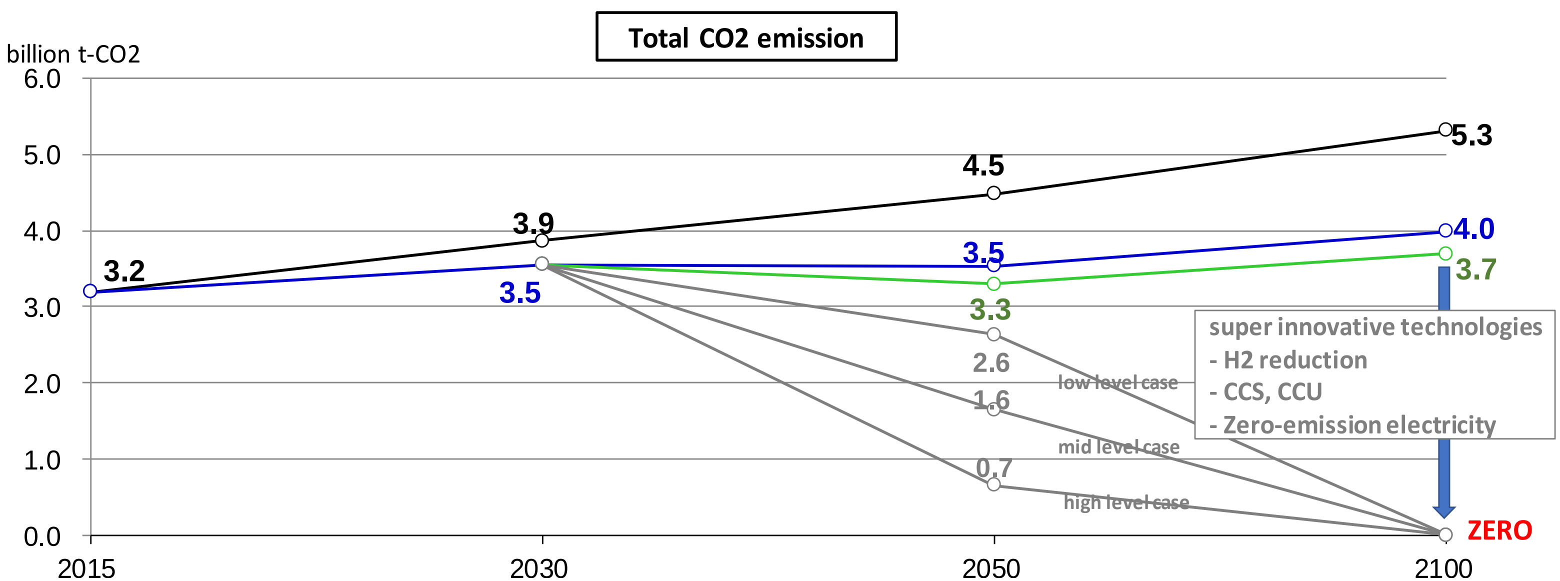
The innovative technologies currently being developed (COURSE50: hydrogen-reduction portion, ferro coke, etc) will be introduced at the maximum level from 2030 to 2050.

Super innovative technologies development scenario

With the introduction of super innovation technologies (hydrogen-reduction, 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.

CO_2 Emissions





Rough Estimations on hydrogen-reduction

$1/2Fe_2O_3 + 3/2H_2 + 48kJ \rightarrow Fe + 3/2H_2O$

Requirement of hydrogen for 1 ton of pig-ironmaking

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.

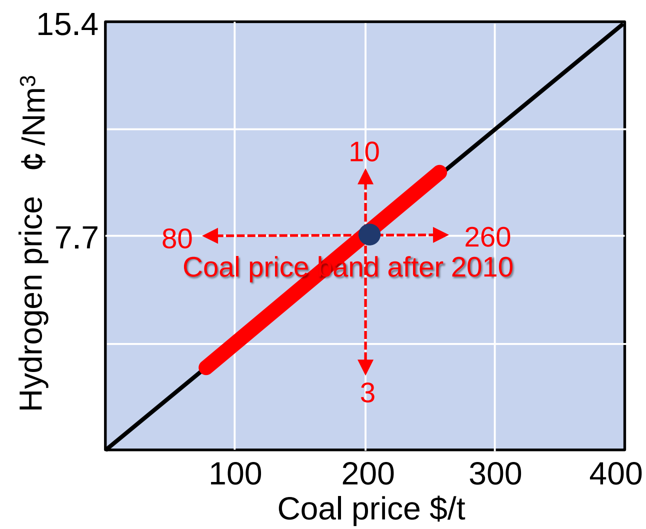
Economic aspects

Estimation of hydrogen price equivalent for carbon reduction iron-making;

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 .



Roadmap for Zero-carbon STEEL

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, 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 and CCU.

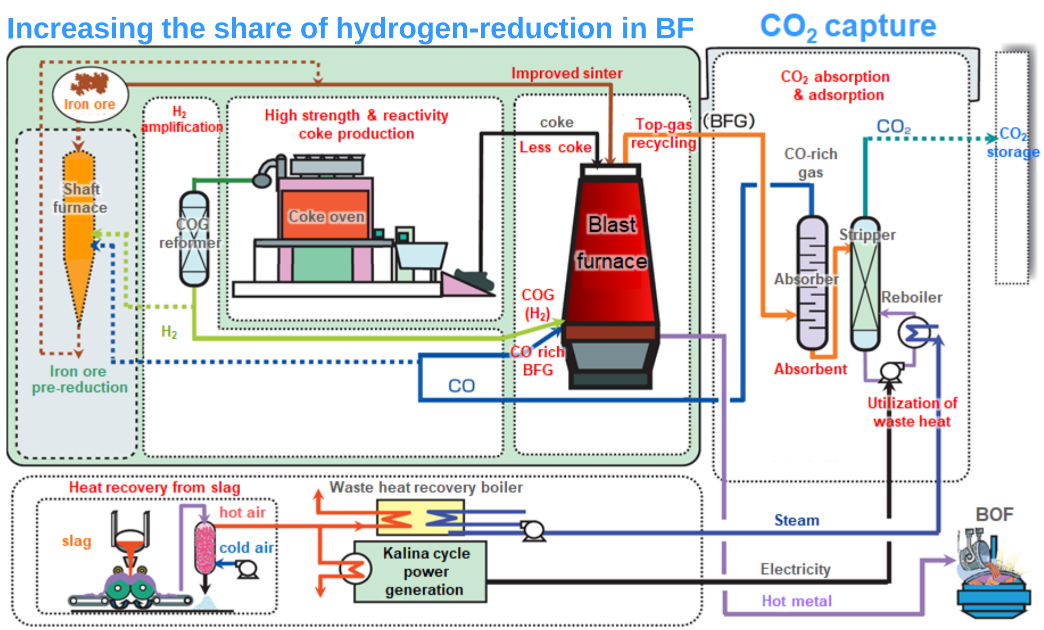
The practical application of hydrogen-reduction ironmaking process is premised that hydrogen is developed and maintained as a common energy carrier for the society, as it is widely used not only in steel production but also in various sectors such as automobiles and consumer use. Especially, an important 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 beyond technical aspects, such as securing CO_2 storage sites, acceptance from society, implementing entities, and distribution of the economic burdens.

Development of technologies specific to iron & steel sector		2020 / 2030 / 2040 / 2050 / 2100
COURSE50	Raising ratio of H2 reduction in blast furnace using internal H2 (COG) Capturing CO2 from blast furnace gas for storage	R&D → Implementation
Super COURSE50	Further H2 reduction in blast furnace by adding H2 from outside (assuming massive carbon-free H2 supply becomes available)	Stepping up → R&D
H2 reduction iron making	H2 reduction iron making without using coal	Stepping up → R&D → Implementation
CCS	Recovery of CO2 from byproduct gases.	R&D → Implementation
CCU	Carbon recycling from byproduct gases	R&D → Implementation

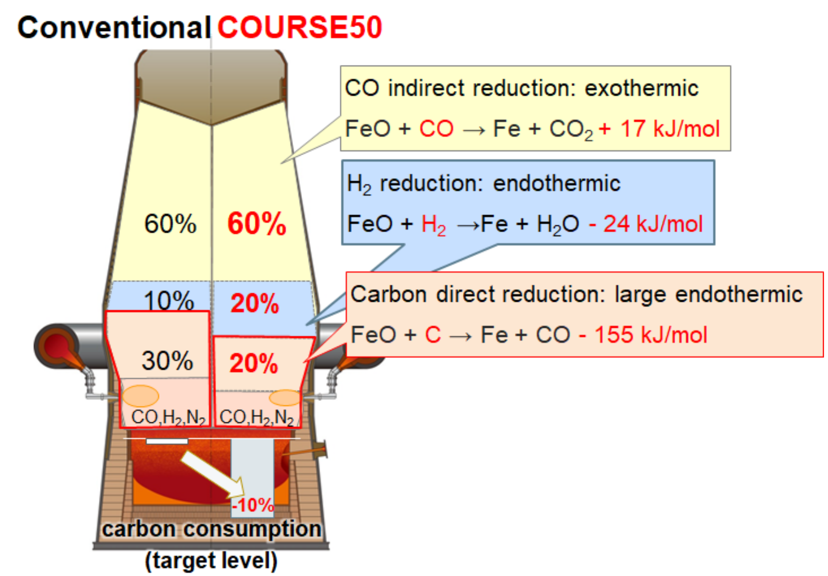
Development of common fundamental technologies for society		2020 / 2030 / 2040 / 2050 / 2100
Carbon-free Power	Carbon-free power sources (nuclear, renewables, fossil+CCS) Advanced transmission, power storage, etc.	R&D → Implementation
Carbon-free H2	Technical development of low cost and massive amount of hydrogen production, transfer and storage	R&D → Implementation
CCS/CCU	Technical development on CO2 capture and strage/usage Solving social issues (location, PA, etc.)	R&D → Implementation

The First Step to the future; COURSE50

COURSE50 project is the national project for drastic CO_2 reduction from iron-making process, consisting of increasing the share of hydrogen-reduction in blast furnace and CO_2 capture from BFG



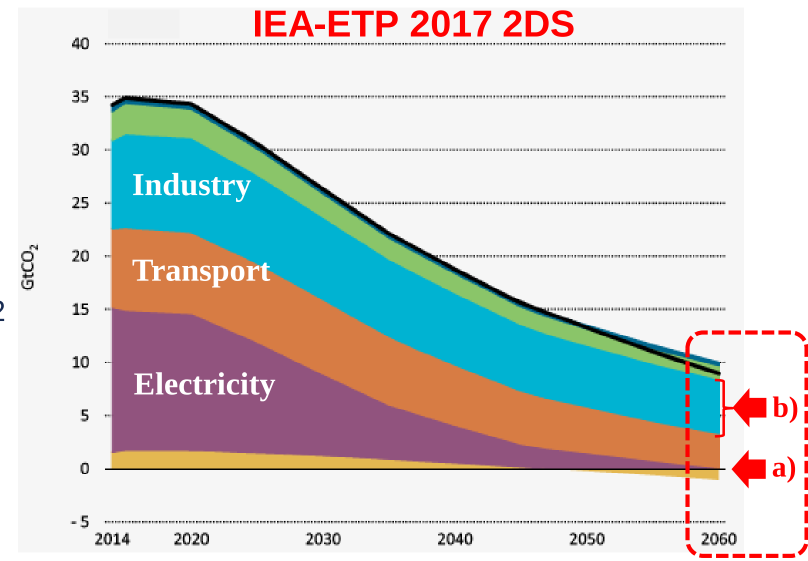
COURSE50 test blast furnace



Consistency with IEA-ETP2017 2DS

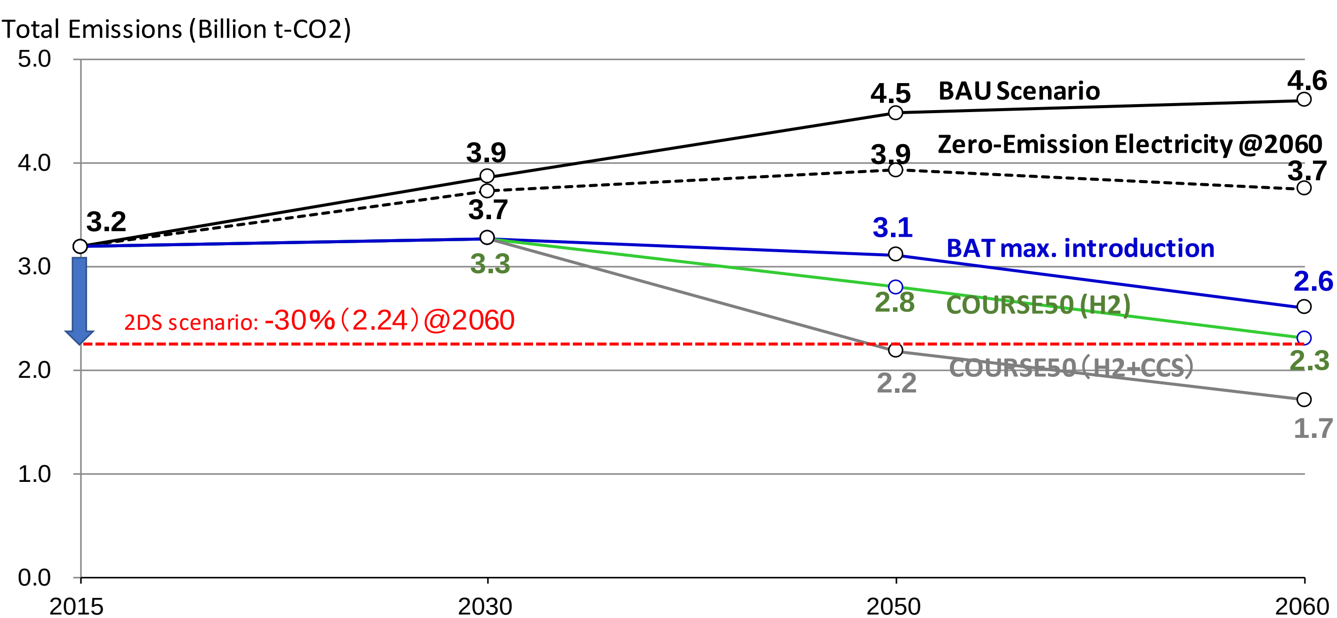
IEA-ETP 2017 2DS assumes:

By 2060,
a) zero emission from the electricity sector
b) 30% emission reduction from the industry sector



Calculation Assumptions

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



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.