TECHNOLOGY FACTSHEET

HISARNA WITH CCS

Date of factsheet	7-9-2020
Author	Kira West
Sector	Industry: Iron and steel
ETS / Non-ETS	ETS
Type of Technology	CCS
Description	HIsarna is an ironmaking technology based on a smelting reduction process, which reduces energy use and CO2 emissions by eliminating several pre-processing steps which are applied in the conventional primary steelmaking process. The name is based on a mix of "Hismelt" (the name of the melting vessel) and "Isarna" (the ancient celtic word for iron). Smelting reduction combines elements of the smelting process (extraction of metal from its ore using heat and a reductant) and direct reduction. Iron ore is input without pelletizing or sintering, and is smelted into liquid pig iron within the same reactor. At the top of the reactor (called the CCF cyclone), iron ore is injected directly as a powder. The temperature is increased by the addition of oxygen which reacts with carbon monoxide. The turbulent environment in the cyclone allows greater contact time between the hot gases and the iron ore. This leads to melting and partial reduction of iron ore in the cyclone, typically in the range of 10-20% (Junjie, 2018). The molten and partially reduced iron ore then falls to the bottom of the vessel (the smelting bath) and comes into contact with coal powder which is injected at the bottom of the reactor. The reaction of carbon from the powder coal with the molten iron ore completes the reduction and creates liquid iron (and CO2 emissions). The resulting CO2 emissions are a relatively pure stream (~85-95% CO2), which facilitates capture. The temperature in the smelter is around 1400-1450 °C (Junjie, 2018; Tata Steel 2013). The partially combusted gases leave the smelter section of the reactor and circulate upwards to provide hot fuel gas to the cyclone. The liquid iron (also called hot metal or pig iron) is then tapped off at the bottom for further processing (Tata Steel, 2018). The resulting CO2 emissions from the reactor are a relatively pure stream (~85-95% CO2), which facilitates capture. The CO2-rich top gases from the reactor are sent to a CO2 processing unit where the CO2 is separated via cryogenic separation, and compressed before its injection into a pipeline (Tata Steel 2013; Junjie 2018). The molten, carbon-rich (4-5%) pig iron (also referred to as hot metal) that is produced in the HIsarna reactor is then oxidized in a basic oxygen furnace, in an exothermic oxidation reaction as pure, hot oxygen is blown over the metal, to reduce the carbon content to below 2% (often less than 1%, depending on final product specifications). Liquid crude steel is then tapped from the furnace, and slag (a byproduct, a mixture of metal oxides) removed. Slag can be used as an additive to cement, creating concrete mixtures with advantageous properties and reducing the amount of Portland cement needed, or can be sold for liming purposes to the agricultural sector. The process also produces off-gases from the basic oxygen furnace with energy content that can be used. Their composition and calorific value is shown below. They can be used to produce heat and power, and/or used as a feedstock for chemical production. Basic oxygen furnace gas: 57% CO, 14% CO2, 14% N2, 12% H2O, 3% H2; 7.5 MJ/normal cubic meter (LHV)
TRL level 2020	TRL 6
	For the HIsarna process, TRL 6 was achieved after the endurance campaign conducted from 2017 to 2018. The existing pilot plant at IJmuiden has been shut down until February 2020 (as of August 2019) due to cost cuts at Tata Steel. Campaign F, including the implementation of CO2 capture at the pilot plant, had been planned to begin in 2019, but has been postponed. There are also reports that the demonstration plant will eventually be constructed in Jamshedspur, India, rather than at IJmuiden as expected. The technology is expected to be commercially available (reaching TRL 8-9) around 2030. While no pilot of HIsarna plus CO2 capture and storage has occurred, the relevant CO2 separation, compression, and storage technologies have been demonstrated elsewhere. As of October 2019, 18 large-scale CCS facilities were in commercial operation globally, with 5 more under construction and 20 in earlier stages of development. In Abu Dhabi, a 0.8 MtCO2/year capacity capture project is operating at an Emirates Steel Industries DRI plant, capturing high purity CO2 emissions from that process, which are then transported by pipeline and used for enhanced oil recovery (EOR) (Global CCS Institute, 2019).

TECHNICAL DIMENSIONS

Capacity	Functional Unit		Value and Range								
	Mton crude steel		-								
			-			-			-		
Potential	NL	Mton steel	Current			2030			2050		
			-			6.81			-		
			Min	–	Max	6.81	–	6.81	Min	–	Max
Market share	0	%	-			-			-		
			-	–	-	Min	–	Max	Min	–	Max
Capacity utlization factor	0.87										
Full-load running hours per year											
Unit of Activity	Mton crude steel/year										
Technical lifetime (years)	20.00										
Progress ratio											
Hourly profile	No										
Explanation	High capacity factor expected, but not yet demonstrated. The capacity factor for the existing plant at IJmuiden (without CCS) has been used. The future potential and market share will depend on the progress of the demonstration and the outlook for Dutch (and international) crude steel production. As technically all blast furnace-based steel production could be replaced with the HISarna process, here the potential for 2030 is set equal to total 2018 Dutch steel production, assuming no additional growth by 2030. All HIsarna facilities can technically be equipped with carbon capture equipment. Tata Steel, along with partners in the Athos project (EBN, Gasunie, Port of Amsterdam), published a report in 2018 confirming the technical potential to build a transport network in the North Sea Canal area (near the IJmuiden plant) and geological storage site for captured CO2 in the North Sea (Tata Steel 2019).										

COSTS

Year of Euro	2015									
	Euro per Functional Unit	Current			2030			2050		
Investment costs	mln. € / Mton crude steel	-			520.00			355.00		
		Min	–	Max	299.00	–	910.00	290.00	–	419.00
Other costs per year	mln. € / Mton crude steel	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	mln. € / Mton crude steel	-			82.75			65.50		
		Min	–	Max	54.00	–	109.00	54.00	–	77.00
Variable costs per year	mln. € / Mton crude steel	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Costs explanation	This technology is considered to be available only after 2030, as the HIsarna reactor is not technologically advanced enough for commercial deployment in 2020, and will be demonstrated without integrated carbon capture and storage before it is deployed with CCS. Values also include costs for the BOF to produce crude steel from pig iron. Because Hisarna does not require sintering or pelletizing of iron ore, nor coke ovens to produce coking coal, there will likely be significant reductions in CAPEX. However, at this stage it is difficult to predict costs for a full-scale, commercial plant, and there is a large range of estimates with considerable uncertainty. One estimate claims it will reduce CAPEX by 25% compared to a conventional blast furnace (CE Delft, 2010). Here costs include the full cost of steelmaking equipment from iron ore to crude steel (including the cost of separation and compression of CO2, but not transport and storage). 2050 values assume that the technology will reach the range of the lowest 2030 estimate for CAPEX or the current level of CAPEX for commercialized smelting reduction technologies such as Finex and Corex. Similarly, the costs of CCS remain uncertain as well, but best estimates from literature and based on other existing projects have been used. Tata Steel estimated in 2018 an additional 20 to 25 M€ of investment needed for the installation of a CO2 capture facility at the existing pilot plant in IJmuiden. European Commission (2016) provides annualized capital investment costs, without specifying a discount rate or equipment lifetime. The capital costs from this source given in this factsheet were derived from the annualized costs assuming a range of discount rates of 5%-10% and equipment economic lifetimes of 10-20 years. Material and energy costs are not included above. However, there could be additional potential cost reductions relative to conventional basic oxygen steelmaking related to the use of less costly material and energy inputs (iron ore fines, rather than pellets or sinter - potentially of lower quality - and coal rather than coke).									

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Coal	PJ	-			12.70			-		
			Min	–	*Max*	11.44	–	15.24	*Min*	–	*Max*
	Natural gas	PJ	-			0.95			-		
			Min	–	*Max*	0.95	–	2.01	*Min*	–	*Max*
	Electricity	PJ	-			1.77			-		
			Min	–	*Max*	1.77	–	1.92	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Energy in- and Outputs explanation	No prospective future values for specific energy consumption were found. Potential future energy consumption reductions will depend on operational experience. Values are given in terms of tonnes of crude steel (assuming a conventional basic oxygen furnace). Electricity consumption assumes that oxygen is purchased (no electricity use for an air separation unit is included).The main values above assume cryogenic distillation carbon capture (Keys, van Hout and Daniels 2019).										

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Iron ore	Mton	-			1.42			-		
			Min	–	*Max*	1.32	–	1.42	*Min*	–	*Max*
	Oxygen	m3	-			764.00			-		
			Min	–	*Max*	764.00	–	764.00	*Min*	–	*Max*
Material flows explanation	The HIsarna process does not require sintering or pelletizing like a conventional blast furnace, but rather allows direct injection of iron ore fines (a powder of iron ore). Here it has been assumed that the quantity of iron ore fines used will be similar to the quantity of sinter, pellets and lump ore used in a blast furnace. The Hisarna process also allows the use of lower quality ores without processing (i.e. those with higher concentrations of P, Zn, S and alkalis) (Burns 2018). Oxygen is also used in the HIsarna process, injected both at the top of the smelting vessel in the cyclone converter furnace phase and closer to the bottom, just above the bath smelting phase. The injected oxygen facilitates combustion of off-gases moving upwards from the bath, creating heat that melts iron ore fines (iron oxide), which is also injected at the top in the cyclone converter furnace, and creating the necessary temperature conditions for reduction of iron oxide into pure iron and CO2 in the smelting bath below. Oxygen injection rates are not available in the literature, so we have assumed a similar oxygen injection rate as in other oxygen-enriched blast furnace or alternative processes (top gas recycling blast furnace process, COREX process). Oxygen could potentially be produced on-site with an air separation unit, but this factsheet assumes oxygen will be purchased. Future evolution of material flows in the HIsarna process, like energy inputs, will depend on operational experience. Values are given in terms of tonnes of crude steel (assuming a conventional basic oxygen furnace), but include only material flows in the HIsarna process.										

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)

	Substance	Unit	Current			2030			2050		
Emissions	CO2 (captured)	Mton CO2-eq	-			0.95			-		
			Min	–	*Max*	0.87	–	1.11	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Emissions explanation	CO2 emissions are more concentrated than with the traditional BF-BOF steelmaking route, which facilitates the deployment of carbon capture along with the Hisarna ironmaking process, which further reduces CO2 emissions compared to conventional steelmaking. This requires additional electricity consumption. The total CO2 emissions from HISarna without CCS are estimated between 1.1-1.5 tCO2/t crude steel. CO2 emissions are more concentrated than with the traditional BF-BOF steelmaking route, which facilitates the deployment of carbon capture along with the Hisarna ironmaking process, which would further reduce CO2 emissions compared to conventional steelmaking. Total CO2 emissions from the reactor are reduced by about 80% compared to the traditional blast furnace (to about 0.3-0.4 tCO2/t crude steel)(Tata Steel 2015) (Junjie 2018)(CE Delft 2010)(Keys, van Hout and Daniels 2019). Data on the split between energy-related and process CO2 emissions were unavailable. No data was available regarding NOx and SO2 emissions from this process.										

OTHER

Parameter	Unit	Current			2030			2050		
Flux	Mt	-			0.32			-		
		Min	–	*Max*	0.32	–	0.32	*Min*	–	*Max*
Crude steel	Mton	-			-1.00			-		
		Min	–	*Max*	-1.00	–	-1.00	*Min*	–	*Max*
Slag	Mton	-			-0.31			-		
		Min	–	*Max*	-0.31	–	-0.31	*Min*	–	*Max*
		-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Explanation	No data on HISarna flux consumption was available, so it is assumed that the value is similar to that of BF-BOF steelmaking.									

REFERENCES AND SOURCES

European Commission (2016), "Iron production by electrochemical reduction of its oxide for high CO2 mitigation" (IERO), https://publications.europa.eu/en/publication-detail/-/publication/4255cd56-9a96-11e6-9bca-01aa75ed71a1.

A. Keys, M. van Hout, and B. Daniëls (2019), "Decarbonisation Options for the Dutch Steel Industry," MIDDEN report, https://www.pbl.nl/sites/default/files/downloads/pbl-2019-decarbonisation-options-for-the-dutch-steel-industry_3723.pdf.

Tata Steel (2015), "Innovative ironmaking technology for a - low Carbon - and Resource Efficient - future of the European Steel Sector." Workshop on Raw materials in the Juncker Plan, 20 May 2015. https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/system/files/ged/7.%202015%2005%2020%20%20HIsarna%20-%20Workshop%20Raw%20materials.pdf

Koen Meijer (2014), "Innovative Revolutionary Ironmaking Technology for a Low Carbon Economy." Tata Steel, 2014. https://ec.europa.eu/clima/sites/clima/files/docs/0095/tata_steel_en.pdf.

Tim Peeters (2013). "HIsarna, a Revolution in Steelmaking."

N. Pardo, J. Moya and K. Vatopoulos (2012), "Prospective Scenarios on Energy Efficiency and CO2 Emissions in the EU Iron & Steel Industry." JRC. http://publications.europa.eu/resource/cellar/69893c31-b50a-11e5-8d3c-01aa75ed71a1.0001.03/DOC_1.

R. Burns (2018), "The Hisarna process for ironmaking." Steel 360, https://www.steel-360.com/technology-next/hisarna-process-for-ironmaking.

Worrell et al. (2008), "World Best Practice Energy Intensity Values for Selected Industrial Sectors," https://www.researchgate.net/publication/267944050_World_Best_Practice_Energy_Intensity_Values_for_Selected_Industrial_Sectors.

Arens (2017), "Technological change and industrial energy efficiency : Exploring the low-carbon transformation of the German iron and steel industry", https://dspace.library.uu.nl/handle/1874/344174.

Yan Junjie (2018), "Progress and Future of Breakthrough Low-carbon Steelmaking Technology (ULCOS) of EU", http://www.sciencepublishinggroup.com/journal/paperinfo?journalid=371&doi=10.11648/j.ijmpem.20180302.11.

Boston Consulting Group (2013), "Steel's Contribution to a Low-Carbon Europe 2050," https://www.bcg.com/publications/2013/metals-mining-environment-steels-contribution-low-carbon-europe-2050.aspx.
CE Delft (2010), "A long term view of CO2 efficient manufacturing in the European region," https://www.cedelft.eu/publicatie/technological_developments_in_europe%3Cbr%3Ea_long-term_view_of_co2_efficient_manufacturing_in_the_european_region/1098.
ETSAP (2010), "Technology Brief I02: Iron and Steel", https://iea-etsap.org/E-TechDS/PDF/I02-Iron&Steel-GS-AD-gct.pdf;
Tata Steel (2017), "Hisarna: Game changer in the steel industry." Hisarna factsheet. https://www.tatasteeleurope.com/static_files/Downloads/Corporate/About%20us/hisarna%20factsheet.pdf;
Vaclav Smil (2016), Still in the Iron Age: Iron and Steel in the Modern World, https://www.elsevier.com/books/still-the-iron-age/smil/978-0-12-804233-5.
World Steel (2019), "Steel Statistical Yearbook 2019 Concise version", downloaded from: https://www.worldsteel.org/en/dam/jcr:7aa2a95d-448d-4c56-b62b-b2457f067cd9/SSY19%2520concise%2520version.pdf.Global CCS Institute (2019), Global Status Report, https://www.globalccsinstitute.com/resources/global-status-report/.
Global CCS Institute (2019), CO2RE Database, https://co2re.co/FacilityData.
Tata Steel (2019), "Tata Steel and partners explore potential carbon capture project to reduce CO2 emissions from steelmaking," https://www.tatasteeleurope.com/en/news/news/tata-steel-and-partners-explore-potential-carbon-capture-project-to-reduce-co2-emissions-from-steelmaking.
OECD (2019), OECD.Stat Database, "Steelmaking capacity," https://stats.oecd.org/Index.aspx?datasetcode=STI_STEEL_MAKINGCAPACITY.
Tata Steel (2013), "Update to the Developments of an ULCOS alternative ironmaking process," https://ieaghg.org/docs/General_Docs/Iron%20and%20Steel%202%20Secured%20presentations/2_1330%20Jan%20van%20der%20Stel.pdf.
IEAGHG (2013), "Iron and Steel CCS Study (Techno-Economics Integrated Steel Mill," https://ieaghg.org/docs/General_Docs/Reports/2013-04.pdf.
Siemens VAI (2013), "Corex: an ideal concept for economic and environmental friendly steel production," https://www.metalbulletin.com/events/download.ashx/document/speaker/7185/a0ID000000X0jwnMAB/Presentation.
Netherlands Environmental Assessment Agency (2009), "Greenhouse Gas Emissions in the Netherlands 1990-2007."