TECHNOLOGY FACTSHEET

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HYDROGEN DIRECT REDUCTION STEELMAKING (HYBRIT) WITH ON-SITE ELECTROLYSIS

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Sector	Industry: Iron and steel
	All
ETS / Non-ETS	ETS
Type of Technology	Emission reduction
Description	Direct reduction of iron is the solid state reduction of iron oxide into iron. The principle of hydrogen direct reduction is that pre-heated iron ore is converted into direct reduced iron (DRI) in a shaft reactor, with hydrogen acting as the reducing agent and energy source. The reactor produces direct reduced iron (DRI), also called sponge iron, which is a porous, solid iron with low carbon content (below that of pig iron from a blast furnace). It can then be either compacted into hot briquetted iron (HBI, a briquette of DRI compacted at 650 degC to at least 5000kg/cubic meter to facilitate storage and transport) or fed directly into an electric arc furnace (EAF) to produce steel. The hydrogen can be supplied from any external source. In the case of electrolysis, water produced in the shaft (through the reaction of H2 and O2) can be supplied back to the electrolyser. The EAF melts and converts the iron into liquid steel, either based on 100% DRI or HBI, or in combination with steel scrap. Theoretically the process can be designed to operate with either methane or hydrogen gas as the reducing agent (or a mixture of these gases), which could allow a gradual transition towards green hydrogen as the main reducing agent for the steel sector. This factsheet looks at the case where 100% HBI and 100% hydrogen are used, and hydrogen is produced on-site via a PEM (polymer electrolyte membrane) electrolyser. Some carbon content (typically a small amount of pulverized coal, bio-methane or other biogenic carbon source is used) needs to be added to the metal in the EAF to create steel with the right composition. Natural gas-based DRI processes have been widely commercially applied worldwide. Hydrogen direct reduction steelmaking technology was first applied commercially in Trinidad in 1999 to 2001 and 2004 to 2016, under the name Circored. The project was mothballed by ArcelorMittal in 2017. That project produced direct reduced iron (DRI) from iron ore fines in fluidised bed reactors with hydrogen from steam methane reforming (SMR) as the reducing agent. The project was shut down in 2016 due to cost-cutting at ArcelorMittal, in an environment of low steel prices and potential electricity and gas price increases in Trinidad. HYBRIT is a hydrogen direct reduction process currently under development that uses iron ore pellets for steelmaking in a shaft reactor at about 800 degC, in combination with steel conversion of DRI in an electric arc furnace (EAF). The project aims to have sufficient hydrogen storage on site so that electrolysers powered by intermittent renewable energy sources can be used to produce the required hydrogen. A key benefit of this technology, according to researchers, is its flexibility of operation, with storage of H2 and of briquettes of iron (HBI, hot briquetted iron) allowing for the shaft where the reduction reaction takes place (which is designed to operate continuously) to operate independently from the EAF (which operates in batches) and the electrolyser (which is highly dependent on electricity prices). The project aims to eliminate all fossil fuels from the steelmaking process, though a carbon source is needed to give the steel the proper characteristics. The long term ambition is to use high-quality biomass to provide this carbon in the EAF, but current designs sometimes still include a small amount of pulverized coal to provide the necessary carbon content of the steel. The reference for this factsheet is the HYBRIT process, with coal as a source of carbon and on-site electrolysis for hydrogen production. (Vogl et al., 2018; Dolci, 2018; IIMA, 2020)
TRL level 2020	TRL 5
	The Circored process has been applied commercially, though ArcelorMittal noted that the process never ran on 100% hydrogen (Dolci 2018). The alternative hydrogen direct reduction option, HYBRIT, that is the reference for this factsheet, is based on existing technologies but requires demonstration and is at a lower TRL level. HYBRIT aims to have a commercial fossil-free steel option by 2035, and a pilot line is currently in development, with plans to operate from 2021-2024. The major difference with existing direct reduction options, which may require adjustments to the technology and additional experience before commercialization, is the use of 100% hydrogen as compared to natural gas or syngas. This may require changes in reactor design. In addition, carbon must be added to the EAF to reach the necessary carbon content in steel, in comparison to conventional steelmaking processes where carbon must be removed, potentially requiring changes to the furnace design. (Vogl et al., 2018; HYBRIT, 2019)

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range									
Capacity	Mton crude steel		1.50									
			1.50			-			1.50			
			Current			2030			2050			
Potential			-			-			-			
			Min	–	Max	Min	–	Max	Min	–	Max	
Market share		%	-			-			-			
			Min	–	Max	Min	–	Max	Min	–	Max	

Capacity utlization factor	1.00
Full-load running hours per year	
Unit of Activity	Mton crude steel/year
Technical lifetime (years)	20.00
Progress ratio	
Hourly profile	
Explanation	Typical capacity has been given based on existing state-of-the-art natural gas-based direct reduction plants. Potential and market share cannot be quantified at this point as there are no units currently operating commercially.

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	mln. € / Mton crude steel	-			574.00			-		
		Min	–	Max	574.00	–	932.00	Min	–	Max
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	-			17.22			-		
		Min	–	Max	17.22	–	17.22	Min	–	Max
Variable costs per year	mln. € / Mton crude steel	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	The pilot project for HYBRIT, soon to be constructed, will cost SEK 200 million (about €19 million). Documents on the HYBRIT website claim that the process will be about 20 to 30 percent more costly per tonne of crude steel than conventional processes given today's commodity and energy prices; however, with rising CO2 costs and declining green electricity prices, their fossil-free steel would be able to compete with conventional, fossil-based steel in the future (HYBRIT 2019). These CAPEX values include iron ore pelletising, the direct reduction shaft reactor, an EAF (electric arc furnace), associated lime production capacity, and the cost of an on-site electrolyzer to produce hydrogen for the process. Insufficient data has been found to quantify the variable costs for this process. Fixed operating and maintenance costs do not include the raw materials or energy described below (H2, electricity, biomass, iron ore).

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Electricity	PJ	-			12.42			-		
			Min	–	Max	12.42	–	13.10	Min	–	Max
	Biomass (high quality)	PJ	-			2.02			-		
			Min	–	Max	2.02	–	2.20	Min	–	Max
		PJ	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
		PJ	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Energy in- and Outputs explanation	This factsheet assumes that hydrogen is produced on-site via electrolysis. Biomass is used as the fuel for the iron ore pelletizing process, for the lime kiln, and in the EAF according to the HYBRIT project. Hydrogen values, when given in mass terms, were converted to energy terms considering an LHV of 120 MJ/kg.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Iron ore pellets	Mton		-			1.50			-	
			Min	–	*Max*	1.50	–	1.50	*Min*	–	*Max*
	Crude steel	Mton steel		-			-1.00			-	
			Min	–	*Max*	-1.00	–	-1.00	*Min*	–	*Max*
Material flows explanation	This factsheet assumes that the steelmaking process operates on 100% direct reduced iron. A 50% scrap input to the EAF is also technically possible, and would lower the iron ore needs to about 0.74 Mton/Mton steel.										

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

	Substance	Unit	Current			2030			2050		
Emissions	CO2 (process)	Mton		-			0.03			-	
			Min	–	*Max*	0.03	–	0.05	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
				-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Emissions explanation	The CO2 emissions shown above are process related, and exclude emissions related to fuel combustion. This CO2 is emitted in the production of lime from limestone (CaCO3 to CaO + CO2), in the degradation of electrodes, and in the EAF when some carbon is added (about half enters the steel while the other half is emitted as CO2).										

OTHER

Parameter	Unit	Current			2030			2050		
Lime (CaO) (flux)	Mton		-			0.07			-	
		Min	–	*Max*	0.05	–	0.10	*Min*	–	*Max*
Oxygen	Mton		-			-0.41			-	
		Min	–	*Max*	-0.41	–	-0.41	*Min*	–	*Max*
Slag	Mton		-			-0.09			-	
		Min	–	*Max*	-0.09	–	-0.09	*Min*	–	*Max*
Coal (or other carbon source)	PJ		-			0.15			-	
		Min	–	*Max*	0.15	–	0.15	*Min*	–	*Max*
Explanation	In this factsheet, the process is assumed to operate with 100% DRI input to the EAF, in which case no scrap is added. However, partial scrap input is also possible, which would lead to a lower need for DRI in the EAF, and no additional carbon requirement in the EAF. Coal here is used as a material (to provide the necessary carbon content to the steel) in the EAF, and is not combusted for energy purposes. It does, however, lead to process CO2 emissions (included above). Slag formation is highly dependent on the composition of the DRI, HBI, and/or scrap that is input to the EAF. This ranges from about 5% to 19% of the mass of the DRI/HBI input. The content of gangue oxides (MgO) in the metal is an important factor in determining the amount and characteristics of the slag. Oxygen production from the electrolyser assumes a PEM electrolyser with 72% efficiency.									

REFERENCES AND SOURCES

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