TECHNOLOGY FACTSHEET

TNO

HIGH-TEMPERATURE MOLTEN OXIDE ELECTROLYSIS STEELMAKING (ULCOLYSIS)

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Author	Kira West
Sector	Industry: Iron and steel
	All
ETS / Non-ETS	ETS
Type of Technology	Emission reduction
Description	Molten oxide electrolysis steelmaking is an electrolytic smelting process for transforming iron oxide (ore, Fe_2O_3) into liquid metal and oxygen. Molten oxide electrolysis techniques can also be used to produce other metals from their oxides. The particular technology developed by the ULCOS (ultra-low carbon steelmaking) project is called ULCOLYSIS; researchers at MIT have developed a similar process, now spun out to a company called Boston Metal. Molten oxide electrolysis processes were originally researched in order to allow oxygen production in lunar explorations from metal oxides present on the moon, and the application as a steelmaking technology developed later. Molten oxide electrolysis, or ULCOLYSIS, does not require coke ovens or blast furnaces, and operates with electricity as its primary energy input, and therefore has a potential to reduce both cost and emissions relative to conventional steelmaking processes. Similar electrolytic processes are commercialized for other metals (aluminium, zinc, and nickel, for example). Iron ore is first dissolved in a liquid electrolyte solution at a temperature of about 1600 ℃ (above the melting point of iron). Electrical current is passed through the solution from an anode and the pool of liquid iron that acts as the cathode, and iron ore is reduced into liquid iron in an endothermic reaction. The iron then requires a carbon source to provide the carbon content of steel. This process is coupled with an electric arc furnace (EAF) with carbon input (provided by an injection of pulverized coal, scrap steel or biogenic carbon from biomass, for example) to create liquid steel (Junjie, 2018; BCG, 2013; Cavaliere, 2019; European Commission, 2016).
TRL level 2020	TRL 4
	This process is currently only at the laboratory research stage, and is not expected to be available until after 2030 (depending on the progress of research and development efforts). A key challenge of bringing this technology to market is the development of an inexpensive, inert anode material that can withstand the high temperatures and corrosive effects of the molten oxide bath. An American company, called Boston Metal, has recently raised 20 million USD to scale up molten oxide electrolysis technology to industrial scale, though the specific capacity that can be expected is still unclear. (Junjie, 2018; Cavaliere, 2019; BusinessWire, 2019).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
Capacity	Mton crude steel		-		
			Min	-	Max

			Current			2030			2050		
Potential	NL		-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Market share	Global	%	-			-			-		
			-	–	-	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)	
Progress ratio	
Hourly profile	No
Explanation	Only lab-scale tests have been done for the ULCOLYSIS process, so no typical capacity value can be shown, and no potential has been estimated. The future potential and market share will depend on the progress of the demonstration and the outlook for Dutch (and international) crude steel production. Capacity utilization is typically high in the steel sector and for high-temperature industrial processes, but before commercial demonstration no estimate can be made for ULCOLYSIS. Similarly, it is difficult to estimate the technical lifetime of equipment at the laboratory research phase of development.

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	mln. € / Mton crude steel	-			-			715.00		
		Min	–	Max	Min	–	Max	498.00	–	1,009.00
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	-			-			58.00		
		Min	–	Max	Min	–	Max	58.00	–	58.00
Variable costs per year	mln. € / Mton crude steel	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	The technology is not commercialized by 2030, so no values are given for 2020 or 2030. Early estimates of investment cost have a very wide range because the technology has not been demonstrated at scale. There is potential for further cost reductions by 2050, depending on the date of commercialization and the development and deployment of ULCOLYSIS after its commercialization. Variable costs (raw material costs, excluding energy costs) are around €175 million/Mton crude steel (European Commission 2016). European Commission (2016) provides annualized capital investment costs, without specifying a discount rate or equipment lifetime. The overnight 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.

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Electricity	PJ	-			-			13.33		
			Min	–	Max	Min	–	Max	12.38	–	14.76
	Natural gas	PJ	-			-			1.21		
			Min	–	Max	Min	–	Max	1.21	–	2.01
		PJ	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
		PJ	-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max

Energy in- and Outputs explanation	Natural gas is used in the hot rolling step, after production of liquid steel in the electrolysis step.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Iron ore	Mton	-			-			1.44		
			Min	–	Max	Min	–	Max	1.44	–	1.48
	Compressed air	million Nm^3	-			-			39.00		
			Min	–	Max	Min	–	Max	39.00	–	39.00

Material flows explanation	Compressed air inputs are given in units of normal cubic meters.

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS))											
Emissions	Substance	Unit	Current			2030			2050		
	CO2 (process)	Mton CO2-eq	-			-			-		
			Min	–	Max	Min	–	Max	-	–	-
	SO2	Mton	-			-			0.00		
			Min	–	Max	Min	–	Max	0.00	–	0.00
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Emissions explanation	SO2 emissions are given in the original source as SOx, so may include other sulfur oxides. The only direct CO2 emissions resulting from this process are from the natural gas use in hot rolling; there are no process CO2 emissions. Oxygen is produced from the electrolytic cell. Oxygen has not been considered as an "emission" as it could be captured and sold or utilized.										

OTHER										
Parameter	Unit	Current			2030			2050		
Oxygen	million Nm^3	-			-			-292.00		
		Min	–	Max	Min	–	Max	-292.00	–	-292.00
Slag	Mton	-			-			-0.05		
		Min	–	Max	Min	–	Max	-0.05	–	-0.05
Crude steel	Mton steel	-			-			-1.00		
		Min	–	Max	Min	–	Max	-1.00	–	-1.00
		-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Explanation	Oxygen is a byproduct of the electrolytic process, and is given in units of million normal cubic meters.									

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