TECHNOLOGY FACTSHEET

REF BOF STEELMAKING - GREENFIELD

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Sector	Industry: Iron and steel All
ETS / Non-ETS	ETS
Type of Technology	Reference
Description	The most common steelmaking route is called blast furnace-basic oxygen furnace (BF-BOF) steelmaking, which was invented in 1948 and now accounts for about 70% of global crude steel output (World Steel 2019). This process is also called basic oxygen steelmaking (BOS) or oxygen converter steelmaking (OCS). In the blast furnace, iron ore (in the form of sinter, pellets, and lump ore) and coal (in the form of coke and pulverized coal), and flux (alkaline or "basic" materials, typically burnt lime or dolomite, which react with impurities to form slag that can be separated) are injected into the top of the blast furnace, flowing downward into contact with upward-moving, hot, CO-rich gases at about 900 to 1300 degrees C. Through this process, the iron ore (Fe2O3) is reduced into elemental iron, and the iron is mixed with carbon monoxide (CO) from the flue gas. Carbon (supplied by coal and coke) acts as a reducing agent. The molten, carbon-rich (4-5%) pig iron (also referred to as hot metal) that is produced in the blast furnace 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. Coke (a high carbon content fuel, with most impurities present in coal removed) can be made onsite by heating coal in a coke oven to a high temperature (typically around 1000 degC) in vacuum conditions, or can be purchased from an offsite coke oven. The slag (by-product) 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 several off-gases from the coke ovens, blast furnace, and basic oxygen furnace with energy content that can be used. Their composition and calorific value is shown below. They can be reinjected at various points during the process (in the coke oven, pellet plant, and blast furnace), used to produce heat and power, and/or used as a feedstock for chemical production. In the case of Tata Steel in IJmuiden, the only BOF steelmaking process in the Netherlands, these excess gases arising from production are either combusted for preheating of furnaces, reinjected to the blast furnace, or used to generate electricity at nearby power plants (one owned by Tata Steel, and 3 others owned by other enterprises). The values shown as outputs in this factsheet are the net production after re-use on-site (only the part that is exported to other sites or used for power generation). For a detailed view of on-site use of these gases, see Keys, van Hout and Daniëls, 2019 and IEAGHG 2019. Typical composition of gases: -Coke oven gas: 60% H2, 23% CH4, 6% N2, 4% H2O, 4% CO, 1% CO2, <0.5% O2, 3% other; 17.3 MJ/normal cubic meter (LHV) -Blast furnace gas: 49% N2, 22% CO, 22% CO2, 4% H2, 3% H2O; 3.2 MJ/normal cubic meter (LHV) -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 9 This is the dominant primary steelmaking process and has been operating commercially for nearly 70 years.

TECHNICAL DIMENSIONS

Capacity	**Functional Unit**		**Value and Range**								
	Mton crude steel		7.80								
			7.80			-			7.80		
Potential	NL	Mton steel	**Current**			**2030**			**2050**		
			6.81			-			-		
			6.81	–	6.81	*Min*	–	*Max*	*Min*	–	*Max*
Market share	NL	%	100.00			-			-		
			100.00	–	100.00	*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)	25.00										
Progress ratio											
Hourly profile	No										
Explanation	Capacity is equal to the total nominal crude steelmaking capacity in the Netherlands in 2018. Potential is given as total production of crude steel in the Netherlands as of 2018. Capacity utilization factor is derived from 2018 data.										

COSTS

Year of Euro	2015								
Investment costs	**Euro per Functional Unit**	**Current**			**2030**			**2050**	
	mln. € / Mton crude steel	527.90			-			-	
		480.00	–	789.00	*Min*	–	*Max*	*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	33.18			-			-	
		33.18	–	112.00	*Min*	–	*Max*	*Min*	–	*Max*
Variable costs per year	mln. € / Mton crude steel	9.00			-			-	
		9.00	–	9.00	*Min*	–	*Max*	*Min*	–	*Max*
Costs explanation	CAPEX is specified for greenfield construction. No future cost reductions are projected as this is a mature technology. Variable costs are given as mln € per Mt steel produced, and fixed OPEX is given as mln € per Mt/yr steel capacity. Variable costs shown above include water, refractories, electrodes, casting powder, and sludge/slag disposal fees. Variable costs exclude purchased scrap, ferroalloys, and fluxes (this can be calculated from the material flows below; assumed costs are provided in comments). Fuel costs are also excluded. European Commission (2016) provides annualized capital investment costs, without specifying a discount rate or equipment lifetime. The overnight capital costs based on 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 carriers (per unit of main output)	**Energy carrier**	**Unit**	**Current**			**2030**			**2050**	
	Main output: Coal	PJ	18.55			-			-	
			16.36	–	19.39	*Min*	–	*Max*	*Min*	–	*Max*
	Natural gas	PJ	1.68			-			-	
			-	–	1.68	*Min*	–	*Max*	*Min*	–	*Max*
	Coke oven gas	PJ	-0.25			-			-	
			-0.31	–	-	*Min*	–	*Max*	*Min*	–	*Max*
	Blast furnace gas	PJ	-3.67			-			-	
			-3.72	–	-3.31	*Min*	–	*Max*	*Min*	–	*Max*
Energy in- and Outputs explanation	The energy flows above are net energy inputs to the steelmaking process with boundaries (as specified above) from coking and sintering to tapping liquid crude steel from the basic oxygen furnace; intermediate energy flows are not shown. Additional energy flows are shown in the section below. Coal is processed into coke in a coking plant, which is injected into the blast furnace. Energy-rich off-gases from both the blast furnace and the basic oxygen furnace are typically recycled (combusted) as energy sources in the process. The negative values represent surplus energy carriers beyond what is needed to produce crude steel. These can be utilised in various ways either within the steel sector or in other nearby industrial sites. When CBS data is used, the values refer to 2017. Additional energy flows are included in "Other" below. Note that "blast furnace gas" here refers to process gases from both the blast furnace and the basic oxygen furnace, following the CBS definition. Values from Keys, van Hout and Daniels have been aggregated. European Commission (2016) also does not specify outputs of energy-rich processes gases. IEAGHG (2013) assumes a balanced supply and demand of electricity within the plant boundaries, based on an on-site sub-critical gas boiler power plant, using blast furnace gas and basic oxygen furnace gas as the primary fuels, with supplementary natural gas use for electricity generation, and all coke oven gas used to supply heat within the process. This case is thus not directly comparable with the values of CBS and Keys, van Hout and Daniels. Here values have been adjusted to account for BOFG/BFG exported to the power plant, to exclude natural gas imported for the power plant, and to include electricity generated. European Commission (2016) has rounded the values for energy consumption to the nearest GJ, and includes energy consumption of natural gas and electricity of less than 1 GJ/t HRC.									

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Iron ore	Mt	1.24			-			-		
			1.24	–	1.24	*Min*	–	*Max*	*Min*	–	*Max*
	Crude steel	Mt	-1.00			-			-		
			-1.00	–	-1.00	*Min*	–	*Max*	*Min*	–	*Max*

Material flows explanation	Iron ore refers to lump ore, fines, and pellets purchased; fines are further processed into sinter on-site. Other materials (flux, metal scrap) are shown below in the section "Other." Assumed iron ore prices are as follows (IEAGHG, 2013): Lump ore EUR 100/t Fines EUR 78-83/t Pellets EUR 107/t

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

	Substance	Unit	Current			2030			2050		
Emissions	CO2 (process)	Mton	0.52			-			-		
			0.52	–	0.52	*Min*	–	*Max*	*Min*	–	*Max*
	NOx	kton	0.81			-			-		
			0.81	–	0.81	*Min*	–	*Max*	*Min*	–	*Max*
	SO2	kton	0.46			-			-		
			0.46	–	0.46	*Min*	–	*Max*	*Min*	–	*Max*
	Fijn stof PM10	kton	0.27			-			-		
			0.27	–	0.27	*Min*	–	*Max*	*Min*	–	*Max*

Emissions explanation	CO2 emissions shown above include only process-related CO2 emissions (excluding emissions from fuel combustion in utilities and from fuel combustion in the process). This has been estimated on the basis of carbon inputs of coke, coal, flux, and iron ore compared to carbon contained in crude steel and off gases (PBL 2009). The total CO2 emissions including energy consumption are about 1,85-1,9 MtCO2/Mton steel. PM emissions (dust) are not specified as 2.5 or 10 in Tata Steel's sustainability reporting.

OTHER

Parameter	Unit	Current			2030			2050		
Electricity	PJ	1.34			-			-		
		1.30	–	1.34	*Min*	–	*Max*	*Min*	–	*Max*
Oil	PJ	0.03			-			-		
		0.03	–	0.03	*Min*	–	*Max*	*Min*	–	*Max*
Fluxes	Mton	0.32			-			-		
		0.13	–	0.32	*Min*	–	*Max*	*Min*	–	*Max*
Scrap and ferroalloys	Mton	0.13			-			-		
		0.13	–	0.18	*Min*	–	*Max*	*Min*	–	*Max*

Explanation	In and outputs are given for the full steelmaking process, from iron ore to hot rolled coil. A total of about 110-130 normal cubic meters of oxygen are needed per tonne of crude steel (IEAGHG 2013; Keys, van Hout and Daniels, 2019), considering oxygen injection to the basic oxygen furnace and an oxygen-enriched air blast in the blast furnace. Oxygen is produced on-site with an air separation unit, and associated energy use is included above. Flux and scrap consumption can vary significantly depending on the final product specifications. Flux is an alkaline material that reacts with impurities to form a slag that can be easily separated from liquid crude steel. Typically burnt lime, limestone, olivine and/or dolomite are used. Only purchased scrap material is included here; internal scrap is excluded from this value. Assumed costs (IEAGHG, 2013): Flux EUR 31/t (average of several products) Purchased scrap EUR 222/t Ferroalloys EUR 1365-2150/t MEA solvent (make-up) EUR 1638/t

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