TECHNOLOGY FACTSHEET

CO PRODUCTION VIA REVERSE WATER GAS SHIFT

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Sector	Industry: Chemics
ETS / Non-ETS	ETS
Type of Technology	Production
Description	In an endothermic reaction CO2 is reformed with H2 to produce CO and water, the reverse water gas shift (RWGS) reaction. We assume that all carbon is converted into CO (or recycled in the process). The reaction requires heat and runs at temperatures between 800-1000 °C and at presures up to 30 bar to favour the equilibrium to CO (instead of CO2 and CH4). Some electricity is required to run the plant, e.g. for gas compression. The RWGS plant is a net electricity and heat consumer. Both H2 and CO2 are provided in this case from external sources. Often rWGS produces mixtures of CO and H2 in the ratio required for subsequent reactions. Here we assume we produce only CO, while additional H2 can be provided from the external source. Costs and energy use (for the purification, recycle, heating, and compression steps) are often associated to total mass flow capacities and include H2 as product (which is excluded from our process). This may cause some deviations in the estimates for costs and energy. CO2 + H2 -> CO + H2O DeltaH(298) = 42 kJ/mol
TRL level 2020	TRL 7 The WGS reaction is a commercial process for many decades and typically used to increase the hydrogen concentration in the syngas mixture making use of the equilibrium reaction between CO/H2O and CO2/H2. It is applied for hydrogen production (for Haber-Bosch), methanol production, and Fischer Tropsch (FT) synthesis of hydrocarbons, starting with fossil feedstocks (typically natural gas, e.g. after steam methane reforming). The reversed process, RWGS, is endothermic (instead of exothermic) and designed to reduce CO2 with H2 to produce CO (and H2O). The RWGS process, together with additional H2 supply, would provide the syngas (CO/H2) that is required for methanol synthesis or FT synthesis. Although reactor technology is mature, the reversed process is not often used and thus needs some development before reaching TRL 9, i.e. why we estimate its TRL at 7.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	PJ		10.00								
			0.30			-			50.00		
Potential	Global	PJ	Current			2030			2050		
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Market share	Global chemicals/fuels	%	2.00			40.00			100.00		
			2.00	–	2.00	40.00	–	40.00	100.00	–	100.00

Capacity utlization factor	1.00
Full-load running hours per year	8,322.00
Unit of Activity	PJ/year
Technical lifetime (years)	25.00
Progress ratio	0.90
Hourly profile	No
Explanation	The amount of CO2 and H2 that is required as feedstocks in combination with the follow-up process will probably determine the capacity of the RWGS plant. We estimate a 10 PJ/yr capacity plantsize, which is smaller as conventional WGS plants but still would require around 400 MWe electrolyzer capacity (at full load capacity) to produce hydrogen. The potential is high but uncertain. It will depend on the demand for synthetic fuels, renewable chemicals, and the role of RWGS in comparison with alternative CO production processes (e.g. CO2 co-electrolysis). We assume a learning rate of around 10% based on the estimate from Detz et al. 2018 for FT synthesis.

COSTS

	Euro per Functional Unit	Current			2030			2050		
Year of Euro	2015									
Investment costs	mln. € / PJ	5.00			4.00			3.00		
		3.00	–	5.00	4.00	–	4.00	3.00	–	3.00
Other costs per year	mln. € / PJ	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max
Fixed operational costs per year (excl. fuel costs)	mln. € / PJ	0.15			0.12			0.09		
		0.12	–	0.15	0.12	–	0.12	0.09	–	0.09
Variable costs per year	mln. € /	-			-			-		
		Min	–	Max	Min	–	Max	Min	–	Max

Costs explanation	The investment costs are for 3 PJ/yr plants range from 14-23 Meuro (2015Euros), while economies-of-scale would reduce costs for 10 PJ/yr plants to 32-53 Meuro (based on three papers). It seems that Anicic et al. (2014) only report equipment costs, while Rezaei lists the bare module costs (direct and indirect costs). We started at the higher range for a 10 PJ/yr plant in 2020 and allow a reduction to the lower estimate in 2050. O&M costs are poorly described and we selected 3% of the investment costs (similar as estimated by Terwel et al. 2018).

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* CO	PJ	-1.00			-1.00			-1.00		
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	Hydrogen	PJ	0.86			0.86			0.86		
			0.86	–	0.86	0.86	–	0.86	0.86	–	0.86
	Heat	PJ	0.28			0.26			0.22		
			0.18	–	0.28	0.26	–	0.26	0.22	–	0.22
	Electricity	PJ	0.07			0.06			0.05		
			0.04	–	0.07	0.06	–	0.06	0.05	–	0.05

Energy in- and Outputs explanation	The reaction between hydrogen and CO2 produces CO (LHV = 10 MJ/kg) and water. 1 mol H2 + 1 mol CO2 -> 1 mol CO + 1 mol H2O. DeltaH(298) = 42 kJ/mol. Heat is provided to force the equilibrium to the CO side. Energy efficiency (LHVout/LHVin) to CO is 100% at 100% carbon conversion efficiency if 0.86 PJ H2 is used and 42 kJ/mol CO (or 0.14 PJ/PJ CO) is added. Energy efficiencies in literature vary from 64-100% (Sternberg, 2016; Terwel, 2018; Rezaei, 2019; van der Giesen et al. 2014). We selected a carbon efficiency of 100% assuming that unreacted CO2 is separated (e.g. with a monoethanolamine absorption column (MEA)) and recycled and assume 0.28 PJ heat per PJ of CO should be added. Additional electricity (0.07 PJ) for the plant is mainly for the compression of the product gas. Overall, the energy efficiency (including electr/heat) is 83% or 0.86 PJ H2, 0.28 PJ heat, and 0.07 PJ electricity to produce 1 PJ of CO. Future plants may become slightly more efficient thanks to improved methods, e.g. sorption enhanced H2O removal (TRL3), so we reduce the heat and electricity consumption slightly towards 2050.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Water	Mton	-0.06			-0.06			-0.06		
			-0.06	–	-0.06	-0.06	–	-0.06	-0.06	–	-0.06
	CO2	Mton	0.16			0.16			0.16		
			0.16	–	0.16	0.16	–	0.16	0.16	–	0.16

Material flows explanation	Water is produced in the process (1 mol for each mol of CO = 0.064 Mton H2O/PJ of CO) and CO2 is used as feedstock (1 mol for each mol of CO = 0.157 Mton CO2/PJ of CO).

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

	Substance	Unit	Current			2030			2050		
Emissions			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
			-			-			-		
			Min	–	Max	Min	–	Max	Min	–	Max
Emissions explanation											

OTHER										
Parameter	**Unit**	**Current**			**2030**			**2050**		
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Explanation										

REFERENCES AND SOURCES

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