TECHNOLOGY FACTSHEET

METHANOL PRODUCTION FROM CO2

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Sector	Industry: Chemics
ETS / Non-ETS	ETS
Type of Technology	Production
Description	In an exothermal reaction CO2 is hydrogenated with H2 to produce methanol, water, and heat. Some byproducts are formed and used as purge gas. This stream is finally combusted and emits CO2. The process runs at a typical temperature of 200-250 °C and at 30-80 bar. The conversion of CO2 in this direct methanol synthesis route is not so high (21%, Anicic, 2014; 33%, Van Dal, 2013), which allows for improvement in the future, e.g. by the development of new catalysts and technologies. After the reaction, the mixture is cooled and led through a flash separator/knock-out drum to separate the gasses from the liquid phase (crude methanol). The majority of the gasses (CO2 and CO) are recycled to the reactor. The crude methanol is purified by leading it through a fractionation column (connected to a heat exchanger) and a stripper unit. The process heat from the synthesis reactor generates steam, which is partly used in the purification process (fractionation and gas stripping) and may be used to generate electricity. Some electricity is required to run the plant, e.g. to drive the compressors for gas compression. The methanol plant is a net electricity consumer and steam producer. Both H2 and CO2 are provided in this case from external sources.
TRL level 2020	TRL 8
	Conventional commercial scale methanol plants produce methanol from natural gas or coal (e.g. Lurgi Megamethanol process) at a scale of 3000-5000 ton per day, although via a syngas production step. CRI developed a direct hydrogenation process to convert CO2 with H2 into methanol (George Olah plant in Iceland 4000 ton/yr). The process is slightly different than conventional synthesis of methanol and further scale-up of the CRI plant has to be demonstrated (Marlin, 2018). For this reason we estimate the TRL at level 8.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
Capacity	PJ		10.00		
			0.08	-	37.00

			Current			2030			2050		
Potential	Global	PJ	100.00			1,432.68			8,643.88		
			0.08	–	2,000.00	1,432.68	–	1,432.68	8,643.88	–	8,643.88
Market share	Global	%	5.00			40.00			100.00		
			5.00	–	5.00	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 potentials are based on current numbers for methanol demand. We have projected future demand for methanol by applying a linear growth factor (Detz et al., 2018) starting from the current status and steadily increased the market share of methanol produced from CO2. Methanol is currently mainly used in the chemical sector but its use as a fuel (for road transport and shipping) is growing. Total demand in the future will depend on its future role and on the development of conversion processes that use methanol as feedstock, such as methanol-to-gasoline, methanol-to-olefins, and methanol-to-aromatics. We assume that the process runs 95% of the time (based on continous supply facilities for H2 and CO2). The progress ratio is derived from Detz 2018 (methanol plant), which might be conservative as the direct hydrogenation of CO2 is a rather novel technology and may learn faster than conventional methanol production technology if for instance mass production of modular units is allowed. This ratio is not used to estimate the future costs, these are based on literature estimates.

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	mln. € / PJ	11.00			8.00			7.00		
		3.00	–	23.00	7.00	–	11.00	5.00	–	11.00
Other costs per year	mln. € / PJ	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / PJ	0.44			0.24			0.18		
		0.09	–	0.92	0.24	–	0.24	0.18	–	0.18
Variable costs per year	mln. € /	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Costs explanation										

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Hydrogen	PJ	1.22			1.20			1.18		
			1.15	–	1.25	1.20	–	1.20	1.18	–	1.18
	Methanol	PJ	-1.00			-1.00			-1.00		
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	Electricity	PJ	0.05			0.04			0.03		
			0.03	–	0.06	0.04	–	0.04	0.03	–	0.03
	Heat	PJ	-0.09			-0.09			-0.09		
			-0.27	–	0.09	-0.09	–	-0.09	-0.09	–	-0.09

Energy in- and Outputs explanation	The reaction between hydrogen and CO2 produces methanol, water, and heat. 3 mol H2 + 1 mol CO2 -> 1 mol CH3OH + 1 mol H2O + heat. The heat is used in the purification/distillation process. Max energy efficiency is 89% at 100% carbon conversion efficiency. The carbon conversion efficiency ranges typically between 90 and 99% in literature. Here we take 92% conv efficiency for 2020, which leads to an energy efficiency of 85% or 1.22 PJ H2 and 0.05 PJ electricity to produce 1 PJ of methanol and 0.09 PJ of heat. Although the conversion efficiency is high, the conversion yield is low. This leads to significant amounts of recycled gas flows. A small part of the produced gasses are used as purge gas. This share is burned and provides heat and CO2 emissions. Additional electricity for the plant ranges between 3 and 6% of which we select 0.05 PJ/PJ product (0.06 PJ electricity in and 0.01 PJ electricity produced). We assume that future plants become slightly more efficient, so we reduce hydrogen and electricity consumption (towards the lower estimates of 2020), while heat production remains similar.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	CO2	Mton/PJ product	0.07			0.07			0.07		
			0.07	–	0.07	0.07	–	0.07	0.07	–	0.07
	Water	Mton/PJ product	-0.03			-0.03			-0.03		
			-0.03	–	-0.03	-0.03	–	-0.03	-0.03	–	-0.03

Material flows explanation	The reaction between hydrogen and CO2 produces methanol and water. 3 mol H2 + 1 mol CO2 -> 1 mol CH3OH + 1 mol H2O. Although the conversion efficiency is high, we assume that some of the gaseous byproducts (or unreacted gas) are used as purge gas. This gas is used energetically and produces H2O and CO2 after combustion with oxygen from air (also pure oxygen can be used to burn the purge flows, e.g. if coupled to electrolysis). Thanks to improved process efficiency, we assume that the carbon conversion efficiency also increases from 92% to 96%.

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

	Substance	Unit	Current			2030			2050		
Emissions	CO2	Mton	0.07			0.07			0.07		
			0.07	–	0.07	0.07	–	0.07	0.07	–	0.07
	CO2	Mton	-0.01			-0.01			-0.00		
			-0.01	–	-0.01	-0.01	–	-0.01	-0.00	–	-0.00
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Emissions explanation	CO2 input is 0.074 Mton in 2020. Not all ends up in methanol as part is ending up, partly after conversion, as CO2 emissions in the flue gas.

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
CRI plant: http://www.carbonrecycling.is
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