TECHNOLOGY FACTSHEET

METHANE PRODUCTION FROM CO2

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Sector	Industry: Chemics
ETS / Non-ETS	ETS
Type of Technology	Production
Description	After the discovery of the reaction by Sabatier and Senderens in 1902, the reaction to convert CO and CO2 to methane has now been investigated and developed for more than 100 years [Rönsch etal. 2016]. Here we focus on the process starting from CO2. In an exothermal reaction CO2 is hydrogenated with H2 to produce methane, water, and heat. Both H2 and CO2 are provided in this case from external sources. CO2 methanation is a linear combination of CO methanation and reverse water–gas shift reaction and the equilibrium of both reactions is influenced by pressure (1-100 bar) and temperature (200-550 °C). Typically, a couple (2-7) of adiabatic fixed bed reactors are coupled in series to enhance temperature controle and conversion. Intermediate recycles are used to increase carbon conversion efficiency and product yield. To regulate temperature, recycles, and pressures, several compressors and heat-exchangers are integrated in the process. The product, often called synthetic natural gas (SNG), is mainly methane but may also contain some other gases, such as H2. Depending on the required purity of the methane, additional purification may be necessary, which can increase costs and energy use. We assume here that methane is produced at sufficient purity for use in other applications. Main developments are occuring in new technologic approaches, such as isothermal, sorption enhanced, and fluidised bed methanation. The methanation process is also relevant in the context of bio-SNG production.
TRL level 2020	TRL 8 The process was developed more than 100 years ago. It has long been applied to purify gas streams (e.g. in ammonia synthesis), but during the oil crisis in the 70s also coal-to-gas concepts were developed. Recently, the CO2 hydrogenation process receives more attention in the context of power-to-gas projects, e.g. Audi's 6 MWe e-gas plant in Werlte that produces synthetic methane from CO2 and electricity. Although the technology is available on the market, further scale-up seems necessary and improvements can be made in process design and catalyst development. For these reason we estimate the TRL at level 8.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	PJ		10.00								
			0.10			-			57.00		
			Current			**2030**			**2050**		
Potential	Global	PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Market share	Global	%	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

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 capacity is based on large scale methane production, e.g. a methanation plant coupled to a large-scale electrolyzer and DAC plant. Although significantly larger as the first e-gas plant in Werlte (0.1 PJ/yr, Audi e-gas), it is smaller as existing commercial coal-to-gas plants (>50 PJ/yr). 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 methanation technology (typical starting from CO). This ratio is not used to estimate the future costs, the latter are based on projections given in literature.

COSTS

	Euro per Functional Unit	Current			2030			2050		
Year of Euro	2015									
Investment costs	mln. € / PJ	17.00			14.00			11.00		
		3.00	–	24.00	14.00	–	14.00	11.00	–	12.00
Other costs per year	mln. € / PJ	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / PJ	0.68			0.42			0.28		
		0.15	–	0.92	0.42	–	0.42	0.28	–	0.28
Variable costs per year	mln. € /	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Costs explanation	The current plant-size of the Audi e-gas plant is around 0.1 PJ/yr, while commercial coal-to-gas plants reached >50 PJ/yr scale. In the latter a slightly different methanation process is used, because the feedstock is CO/H2 instead of CO2/H2. We assume that in 2020 the capacity of a CO2 hydrogenation methanation plant can be around 3 PJ/yr, with total investment costs of 17 M€/PJ (ranging from 3 to 24 M€/PJ). These costs decline thanks to learning and economies-of-scale to 14 M€/PJ in 2030 for a 10 PJ plant (2 studies) and further to 11 M€/PJ in 2050, also for a 10 PJ/yr plant. Such as plant size is considered a commercial scale renewable methanation plant as it requires an electrolyzer of around 540 MWe running continuously. If such a plant is connected to a pipeline network, which delivers both H2 and CO2, further scale up seems possible towards the 50 PJ scale, although we do not consider such a plant-size here. O&M costs estimates range between 2 and 5 % of which we select 4% for 2020 and allow a decline to 2.5% in 2050.

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* SNG	PJ	-1.00			-1.00			-1.00		
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	Hydrogen	PJ	1.20			1.20			1.20		
			1.20	–	1.35	1.20	–	1.20	1.20	–	1.20
	Electricity	PJ	0.01			0.01			0.01		
			0.00	–	0.01	0.01	–	0.01	0.01	–	0.01
	Heat	PJ	-0.08			-0.09			-0.10		
			-0.08	–	-0.08	-0.09	–	-0.09	-0.10	–	-0.10

Energy in- and Outputs explanation	The reaction between hydrogen and CO2 produces methane, water, and heat. 4 mol H2 + 1 mol CO2 -> 1 mol CH4 + 2 mol H2O + heat. A share of the heat is used to drive a steam turbine, which produces electricity for the plant, but some heat remains to be used elsewhere (as product). Max energy efficiency to methane is 83% at 100% carbon conversion efficiency (LHVout/LHVin). The carbon conversion efficiency ranges typically between 90 and 100% in literature. Here we take 100% conv efficiency into product methane (based on Hannula 2016). The reaction is highly exothermic and efficient cooling results in the production of 0.08 PJ highgrade steam. Net electricity use for the plant ranges between 0.05 and 1.3% of which we select 0.01 PJ/PJ product. Overall, the energy efficiency (including steam) is 89% or 1.20 PJ H2 and 0.01 PJ electricity to produce 1 PJ of methane and 0.08 PJ of heat. Future plants may become slightly more efficient in recovering heat production, so we improve the heat yield to 0.1 PJ/PJ SNG in 2050.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	CO2	Mton/PJ product	0.06			0.06			0.06		
			0.06	–	0.06	0.06	–	0.06	0.06	–	0.06
	Water	Mton/PJ product	-0.05			-0.05			-0.05		
			-0.05	–	-0.05	-0.05	–	-0.05	-0.05	–	-0.05

Material flows explanation	The reaction between hydrogen and CO2 produces methane and water. 4 mol H2 + 1 mol CO2 -> 1 mol CH4 + 2 mol H2O. We assume that after several reactors and recycles, a 100% carbon conversion efficiency to methane is reached and only water and heat are generated as byproducts.

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

	Substance	Unit	Current			2030			2050		
Emissions	0	0	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
	0	0	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Emissions explanation	CO2 is used as feedstock in the process (see material flows).										

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										

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