TECHNOLOGY FACTSHEET

ECN › TNO innovation for life

STEAM METHANE REFORMING (SMR) FOR HYDROGEN PRODUCTION WITH CARBON CAPTURE FROM PRESSURE SWING ADSORPTION (PSA) TAIL GAS USING CRYOGENIC MEMBRANE SEPARATION

Date of factsheet	27-7-2018
Author	Jacob Janssen
Sector	Hydrogen supply
ETS / Non-ETS	ETS
Type of Technology	Steam methane reforming (SMR)
Description	Steam methane reforming (SMR) is a method that can be used for producing hydrogen from natural gas. This is achieved in a processing device called a reformer, which reacts steam at high temperature with the gas. SMR uses the following endothermic reaction: $CH_4 + H_2O \rightleftharpoons CO + 3H_2$. The reaction is carried out at an activation energy of 206 kJ/mol and temperatures of 500-900 degrees Celsius. In this SMR plant, a COGEN plant is running to export a relatively small fraction of the energy involved to the electricity grid. This represents a technology with high CAPEX/low OPEX. The CO_2 is captured from the pressure swing adsorption (PSA) tail gas using low temperature and cryogenic membrane separation technology.
TRL level 2020	TRL 9
	Mature technology. No more cost developments are assumed.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
Capacity	MW		300		
			Min	-	*Max*
Potential	MW	NL	Unlimited		
			Min	-	*Max*
Market share	%		-		
			Min	-	*Max*
Capacity utlization factor	1				
Unit of Activity	PJ/year				
Technical lifetime (years)	25				
Full-load running hours per year	8,322				
Progress ratio	0.95				
Hourly profile	No				
Explanation	IEA (2017) reports 100,000 Nm3/h at 10.8 MJ/Nm3, this translates into a capacity of precisely 300 MW hydrogen energy output. The progress ratio is found in Thomas (2009).				

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs per year	mln. € / MW			1.05			0.95			0.78
		1.05	-	1.16	0.95	-	1.05	0.78	-	0.95
Other costs per year	mln. € / MW			-			-			-
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / MW			0.03			0.03			0.02
		0.03	-	0.07	0.03	-	0.07	0.02	-	0.06
Variable costs per year	mln. € / MW			0.24			0.22			0.18
		0.24	-	0.24	0.22	-	0.22	0.18	-	0.18

Costs explanation	The data from NTNU (2016) is based on a different size plant, and the numbers in this factsheet are scaled to represent the same size plant as in IEA (2017). All costs exclude fuel costs and values are based on low heating value (LHV). Costs for CO_2 capture are included. Sinnot (2009) finds a higher (per kg of hydrogen output) value for investment costs, which can in part be explained by the use of data for a smaller size plant. Conventional plants (such as SMR) benefit from economy of scale, therfore a scale-up factor of 0.8 can be used (Sinnott et al., 2009) when estimating the cost of a larger scale plant. Due to lack of data, there is an implicit assumption that the same scaling factor can be applied to this plant, including its carbon capture and storage (CCS) component. In these figures, the OPEX costs amount to 3.6 % of the CAPEX costs. Variable costs included are raw water make-up, catalysts and chemicals. Cost developments are taken relative to base year, and are found in Vita (2018).

ENERGY IN- AND OUTPUTS

	Energy carrier	Unit	Current			2030			2050		
Energy carriers (per unit of main output)	*Main output:* Hydrogen	PJ			-1.00			-1.00			-1.00
			-1.00	-	-1.00	-1.00	-	-1.00	-1.00	-	-1.00
	Electricity	PJ			-0.03			-0.03			-0.03
			-0.03	-	0.00	-0.03	-	0.00	-0.03	-	0.00
	Natural gas resource (gas fields)	PJ			1.42			1.42			1.42
			1.04	-	1.42	1.04	-	1.42	1.04	-	1.42
		PJ			-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*

Energy in- and Outputs explanation	The production of hydrogen of 10^5 Nm3/h gives 8.99 PJ/y. The 0.95 factor is to account for active running hours per year. Other values are taken from IEA (2017) and NTNU (2016) and scaled accordingly. The NTNU study reports on an energy efficiency of 0.82, however based on their own reported values of in- and outlet, an energy efficiency of 0.96 is found. A plant with an average power of 300 MW (with 0.95 factor) gives 8.99 PJ/year, therefore all numbers are scaled by 8.99 to give a result per PJ. The 0.95 factor accounts for the capacity utilization rate.

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
	Substance	Unit	Current			2030			2050		
Emissions	CO2	Mton	-0.04			-0.04			-0.04		
			-0.04	-	-0.04	-0.04	-	-0.04	-0.04	-	-0.04
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
			-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Emissions explanation	IEA (2017) reports 0.8091 kg CO2/Nm3 hydrogen for the case without carbon capture and storage (CCS). This gives 0.675 Mton/year. In the OPERA model from ECN part of TNO (2018), these emissions are calculated from the fuel input. Therefore, for the purpose of this factsheet, all carbon emissions that are avoided due to CCS are specified as negative. With CCS, the number is extrapolated from that with IEA (2017) data. A plant with an average power of 300 MW (wih 0.95 factor) gives 8.99 PJ/year, therefore all numbers are scaled by 8.99 to give a result per PJ. The 0.95 factor accounts for the capacity utilization rate.										

REFERENCES AND SOURCES

IEA (2017). Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS. Accessed through https://ieaghg.org/exco_docs/2017-02.pdf

Jakobsen, D., & Åtland, V. (2016). Concepts for large scale hydrogen production. Thesis, NTNU.

Voldsund, M., Jordal, K., & Anantharaman, R. (2016). Hydrogen production with CO2 capture. International Journal of Hydrogen Energy, 41(9), 4969-4992.

Expert opinion, Jacob Moulijn

Sinnott, R.K., & Towler, G. (2009). Chemical engineering design: SI Edition. Elsevier.

Ramsden,T., Steward, D. & Zuboy, J. (2009). Analyzing the Levelized cost of Centralized and Distributed Hydrogen Production Using the H2A production Model, Version 2, National Renewable Energy Laboratory, Virginia, 2009

IEA (2015). Technology Roadmap - Hydrogen and Fuel Cells, OECD/IEA, 2015.

Whitesides, R.W. (2005). Process equipment cost estimating by ratio and proportion. Course notes, PDH Course G 127.

Vita et al (2018). Sectoral integration- long-term perspective in the EU Energy System. ASSET

Thomas (2009). Low-Cost Hydrogen Distributed Production System Development