

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

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Sector	Hydrogen supply
ETS / Non-ETS	ETS
Type of Technology	Steam methane reforming (SMR)
Description	<p>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:</p> $\text{CH}_4 + \text{H}_2\text{O} \rightleftharpoons \text{CO} + 3\text{H}_2.$ <p>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 CO₂ is captured from the pressure swing adsorption (PSA) tail gas using low temperature and cryogenic membrane separation technology.</p>
TRL level 2020	<p>TRL 9</p> <p>Mature technology. No more cost developments are assumed.</p>

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
	MW	NL	Min	Max	Other
Capacity	MW		300		
Potential	MW	NL	Unlimited		
Market share	%		-		
Capacity utilization 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 Nm ³ /h at 10.8 MJ/Nm ³ , this translates into a capacity of precisely 300 MW hydrogen energy output. The progress ratio is found in Thomas (2009).				

COSTS

Year of Euro	Euro per Functional Unit	Current			2030			2050		
		Min	Max	Other	Min	Max	Other	Min	Max	Other
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	<p>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 CO₂ capture are included. Sinnott (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, therefore 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.</p> <p>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).</p>									

ENERGY IN- AND OUTPUTS

Energy carriers (per unit of main output)	Energy carrier	Unit	Current			2030			2050		
			Min	Max	Other	Min	Max	Other	Min	Max	Other
Main output:	Hydrogen	PJ	-1.00			-1.00			-1.00		
			-1.00	-	-1.00	-1.00	-	-1.00	-1.00	-	-1.00
Electricity	PJ	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	PJ	1.42			1.42			1.42		
			1.04	-	1.42	1.04	-	1.42	1.04	-	1.42
		PJ	-			-			-		
		PJ	Min	-	Max	Min	-	Max	Min	-	Max
Energy in- and Outputs explanation	<p>The production of hydrogen of 10⁵ 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.</p> <p>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.</p>										

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS))											
Emissions	Substance	Unit	Current			2030			2050		
		CO2	Mton	-0.04			-0.04			-0.04	
			-0.04	-	-0.04	-0.04	-	-0.04	-0.04	-	-0.04
			-			-			-		
			<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>
			-			-			-		
			<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>
			-			-			-		
			<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>	<i>Min</i>	-	<i>Max</i>
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 (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.										
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