TECHNOLOGY FACTSHEET

TNO

POLYMER ELECTROLYTE MEMBRANE (PEM) HYDROGEN INSTALLATION - SMALL-SCALE

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Sector	Hydrogen supply
ETS / Non-ETS	Non-ETS
Type of Technology	Electrolysis
Description	Proton-exchange membrane or polymer electrolyte membrane (PEM) electrolysis technology produces hydrogen from water using electricity. The electrolysis reaction takes place in cells, that are connected in series to make units (called a 'stack'). An installation generally consist of multiple stacks. Sectors that have shown interest in (sustainable) hydrogen production are the (petro) chemical sector and the fertilizer sector (Berenschot, 2017). PEM operates at a temperature of around 60-70 °C (Weeda, 2018). Electricity is used to split water (H2O) into oxygen (O2) and hydrogen (H2). The technology consists on one side of a positive terminal (anode), where water (H2O) reacts with a catalyst to form oxygen, electrons (e-) and hydrogen protons (H+). The hydrogen protons are then conducted across the polymer electrolyte membrane. At the negative terminal (cathode) of the installation, the electrons then combine with the hydrogen protons to produce hydrogen (SA, 2014). PEM uses a polymeric membrane that has a high proton conductivity when the membrane is hydrated (Feroldi & Basualdo, 2012). A PEM installation can produce hydrogen at a pressure of 5-50 bar (ECN, 2018), which can subsequently be further compressed to 80-950 bar to reduce the need for storage capacity. A pressure of 80 bar is necessary for injection in the natural gas network, whereas a pressure of 350-950 bar is necessary for using hydrogen in transport, for example in trucks and passenger vehicles (De Vita et al., 2018). Note that for almost all applications hydrogen needs to be compressed. According to NOW (2018), the pressure output of a PEM installation could potentially reach 110 bar by 2050. The potential for PEM is high, however it is currently considered not economically feasible due to, amongst others, the high CAPEX (currently estimated around four times higher than economically viable). The levelised costs of hydrogen by electrolysis is about 5 €/kg (baseload production), which compares unfavourably with the cost of hydrogen from natural gas at 1-1.5 €/kg using steam methane reforming (SMR) (Berenschot, 2017).
TRL level 2020	TRL 8 PEM electrolysis has been commercially available for about 10 years (E4tech, 2014), however according to De Vita et al. (2018), the technology is not yet at full industrial scale (TRL 8).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	MW-H2-LHV-output		2.88								
			1.27			-			2.88		
Potential	NL	PJ	Current			2030			2050		
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Market share		%	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Capacity utlization factor		0.97
Full-load running hours per year		8497.00
Unit of Activity	PJ/year	0.03
Technical lifetime (years)		20-30
Progress ratio		0.79
Hourly profile	No	
Explanation	The typical small-scale installation size is 5 MWe, with stacks of 0.25 – 1.25 MW (ECN, 2018). A 2.2 MWe installation is mentioned in Hydrogenics (2016). The required area for a small-scale PEM installation is 108-300m2 (ECN, 2018) . Hydrogen can be used to produce steam, electricity, high temperature heat, and act as transport fuel. The produced hydrogen can also directly replace current hydrogen consumption mostly produced via steam methane reforming (SMR) or by refineries using pressure swing adsorption (PSA). A PEM installation can be used as baseload production (>8000 hours per year) (Hydrogenics, 2016) or as flexible production (e.g. when connected to an intermittent source of electricity like an offshore wind park). The cell stacks have a technical lifetime of around 7 years, which is expected to increase to up to 10 years (SA, 2014). The installation itself has a technical lifetime of 20 (ECN, 2018) to 30 years (LBST 2015), which means the cell stacks need to replaced at least once within the lifetime of the installation. The investment cost of PEM electrolysis are expected to decrease. Detz et al. (2018) uses a learning rate of 21% .	

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current			2030			2050		
Investment costs	mln. € / MW-H2-LHV-output	1.85			1.43			1.26		
		1.27	–	2.60	0.61	–	1.70	0.30	–	1.26
Other costs per year	mln. € / MW-H2-LHV-output	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / MW-H2-LHV-output	0.10			0.08			0.06		
		0	–	0	0	–	0	0	–	0
Variable costs per year	mln. € / MW-H2-LHV-output	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Costs explanation

The investment costs (CAPEX) in this section refer to the equipment cost only.

PEM electrolysis investment costs are expected to decrease significantly over time. They are expected to eventually become lower than for alkaline electrolysis because of the more compact design with higher current density and relatively easier system technology (NOW, 2018).

The CAPEX for a small-scale PEM installation by Hydrogenics (2016) concerns an installation with a 2.2 MW electrical power input, a limited storage capacity for half-a-day full load production (450 kg), compression to 450 bar. Civil works costs are €100,000 and a connection cost to the public power grid is €50,000 (low-voltage connection). According to Hydrogenics (2016), the current CAPEX for a small-scale PEM unit is 1,500 €/kWe-input, and it is expected to decrease to 1,000 €/kWe-input by 2030 and to 550 €/kWe-input by 2050. A major investment cost component is the cell stack which makes up about 40% of the total equipment cost (Hydrogenics, 2016). These cell stacks have to be replaced at least once during the lifetime of the installation, due to their relatively short lifespan. The study from NOW (2018) does not differentiate CAPEX between different system sizes. For PEM, in general, the study identifies a current CAPEX of 1,390-1,540 €/kWe-input based on questionnaires. For 2030, the CAPEX is expected to lower to 490-1,120 €/kWe-input, and in 2050 to 210-800 €/kWe-input. According to SA (2014), the CAPEX for a 'forecourt' PEM installation is 940 $2012/kWe-input in 2012 and 450 $2012/kWe-input in 2030. Here, the installation cost component of the CAPEX is a factor of 1.21 (SA, 2014).

For OPEX, Hydrogenics (2016) estimates 60 €/kWe-input/yr, going down to 48 €/kWe-input/yr by 2030 and 32 €/kWe-input/yr by 2050. Assumed to be included in the OPEX are: large overhaul cost such as the required change of the fuel cell stacks (Hydrogenics, 2016). According to De Vita et al. (2018), OPEX for small-scale PEM is 70 €/kW-H2-HHV-output/yr, decreasing to 34 €/kW-H2-HHV-output/yr by 2030, and to 18 €/kW-H2-HHV-output/yr by 2030.

The used factors to convert the CAPEX and OPEX found in the literature are the following:
- Rate in 2012 $/€ 1.32. Source: https://www.poundsterlinglive.com/
- Energy content hydrogen HHV of 12.7 MJ/m3. Source: Bossel, Ulf & Eliasson, Baldur (2003) Energy and The Hydrogen Economy
- Energy content hydrogen LHV of 10.8 MJ/m3. Source: RVO (2018) The Netherlands list of fuels
- Density hydrogen at STP 0.0899 kg/m3. Source: https://encyclopedia.airliquide.com/

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	1.56			1.70			1.67		
			1.56	–	1.85	1.57	–	1.70	1.47	–	1.67
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ	-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Energy in- and Outputs explanation	The energy efficiency of the PEM system is defined as the amount of kg or m3 hydrogen that can be produced per electricity input (kWh): Hydrogenics (2016) assumes an efficiency of 5.2 kWh/m3 (57.8 kWh/kg) in 2015, which goes down to 5.1 kWh/m3 (56.7 kWh/kg) in 2030 and 5 kWh/m3 (55.6 kWh/kg) in 2050. According to NOW (2018), the current efficiency is 4.8 kWh/m3-H2, lowering to 4.7 kWh/m3-H2 by 2030 and 4.4 kWh/m3-H2 by 2050. The conversion of kWhe/kg-H2 to PJe/PJ-H2 is based on multiplying times 3.6 MJe/kWhe and dividing by 120.1 MJ-H2-LHV/kg-H2.										

MATERIAL FLOWS (OPTIONAL)											
	Material	Unit	Current			2030			2050		
Material flows	Hydrogen	kg	-1.00			-1.00			-1.00		
			-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	Water	kg	14.50			14.50			14.50		
			14.50	–	14.50	14.50	–	14.50	14.50	–	14.50
Material flows explanation	According to Hydrogenics (2016), around 1.3 liter of water per Nm3 hydrogen is required (14.5 kg-water/kg-H2)										

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											

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