TECHNOLOGY FACTSHEET

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

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Sector	Hydrogen
ETS / Non-ETS	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 methan reforming (SMR) (Berenschot, 2017).

TRL level 2020	TRL 8
	PEM electrolysis has been commercially available for around 10 years (E4tech, 2014), however according to De Vita et al. (2018), the technology is not yet at fully industrial scale (TRL 8).

TECHNICAL DIMENSIONS

Capacity	**Functional Unit**		**Value and Range**								
	MW-H2-LHV-output		12								
			12			-			60		
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		8,497
Unit of Activity	PJ/year	0.03
Technical lifetime (years)		20-30
Progress ratio		0.79
Hourly profile	No	

Explanation

The typical size for a large-scale PEM installation is 20 MWe (ECN, 2018). There are plans by Akzo Nobel and Gasunie to build a 20 MWe plant in the northern part of the Netherlands. A large PEM installation for hydrogen production of 100 MWe is mentioned by Hydrogenics (2016).

Stack sizes for large scale PEM installations range from 0.25 – 5 MW (ECN, 2018). The reported area requirements for a PEM installation of around 20 MW varies from 200 m2 to 1,170 m2 (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 such as 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 be 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	1.32			1.17			1.04	
		1.32	–	2.36	0.40	–	1.68	0.24	–	1.12
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	0.07			0.05			0.05		
		0.06	–	0.07	0.02	–	0.05	0.01	–	0.05
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).

According to Hydrogenics (2016), the CAPEX for a multi-MW installation is 1,000 €/kWe-input and it is expected to go down to 700 €/kWe-input by 2030 and 385 €/kWe-input. The OPEX is 40 €/kWe-input/yr and it is expected to decrease to 32 €/kWe-input/yr by 2030, and 28 €/kWe-input/yr by 2050. The unit described by Hydrogenics (2016) has a 100 MW electrical power input, producing low pressure hydrogen (20 bar). The unit has no storage and compression. The civil work cost are €5,000,000 and the connection cost to the public power grid €2,000,000. The latter cost is limited as another connection of the industrial plant is assumed to already exist. In addition, there are large overhaul costs such as the required change of the fuel cell stacks (Hydrogenics, 2016). A major component of the investment 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.

De Vita et al. (2018) assume a current CAPEX for large-scale PEM of 2,000 €/kW-H2-HHV-output or 1,411 €/kWe-input. For 2030, the expected CAPEX is 340 €/kW-H2-HHV-output (240 €/kWe-input), and for 2050, it is 200 €/kW-H2-HHV-output (141 €/kWe-input). According to De Vita et al. (2018), the current O&M cost are 36 €/kWe-input/yr, and will decrease to 11 €/kWe-input/yr in 2030, and 7 €/kWe-input/yr in 2050.

For PEM in general, NOW (2018) identifies, based on questionnaires, a current CAPEX of 1,390-1,540 €/kWe-input. For 2030, the CAPEX is expected to decrease to 490-1,120 €/kWe-input, and in 2050, to 210-800 €/kWe-input.

According to SA (2014), the CAPEX is 900 €2012/kWe-input and refers exclusively to the equipment - installation cost are excluded. The installation cost component of the CAPEX is a factor of 1.21 (SA, 2014).

The used factors to convert the CAPEX and OPEX found in the literature are the following:
- 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 carriers (per unit of main output)	**Energy carrier**	**Unit**	**Current**			**2030**			**2050**	
	Main output:	PJ	-1.00			-1.00			-1.00	
	hydrogen		-1.00	–	-1.00	-1.00	–	-1.00	-1.00	–	-1.00
	electricity	PJ	1.54			1.54			1.47	
			1.54	–	1.71	1.54	–	1.57	1.47	–	1.47
			-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
			-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation

Hydrogenics (2016) assumes an efficiency of 5 kWh/m3 (55.6 kWh/kg) in 2015, which goes down to 4.9 kWh/m3 (54.5 kWh/kg) in 2030, and 4.8 kWh/m3 (53.4 kWh/kg) in 2050. According to NOW (2018), the current efficiency is 4.8 kWh/m3-H2 (53.4 kWh/kg-H2), going to 4.7 kWh/m3-H2 (52.3 kWh/kg-H2) by 2030, and 4.4 kWh/m3-H2 (48.9 kWh/kg-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 flows	**Material**	**Unit**	**Current**			**2030**			**2050**		
	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 m3 hydrogen is required (14.5 kg-water/kg-H2)										
EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
Emissions	**Substance**	**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*
Emissions explanation											

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