TECHNOLOGY FACTSHEET

LARGE-SCALE ALKALINE-ELECTROLYSIS HYDROGEN INSTALLATION

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Sector	Hydrogen
ETS / Non-ETS	
Type of Technology	Electrolysis
Description	Alkaline-electrolysis (AEL) is a known and developed technology used for production of hydrogen from water and is currently the main route used to produce electrolytic hydrogen. It is considered more developed than competing electrolysis technology Proton Exchange Membrane (PEM) (Weeda, 2018). Electrodes in AEL are made of nickel or of porous metal structures (NOW 2018). Hydrogen ions move towards the cathode and hydroxide ions move towards the anode. A diaphragm is used to separate the two electrode compartments. Gas receivers are then used to collect the formed hydrogen and oxygen gases. To ensure good conductivity the used electrolyte should consist of high-mobility ions. Potassium hydroxide (KOH) is normally preferred over sodium hydroxide (NaOH) because of higher conductivity (Santos, Sequeira, & Figueiredo, 2013). Cathodic reaction: 2 H2O + 2e- => H2 + 2 OH- Charge carrier: OH- Anodic reaction: 2OH- => 0.5 O2 + H2O + 2e- AEL operates at a temperature of around 60-70 degrees C (Weeda, 2018) and can produce hydrogen at a pressure of 30 bar (De Vita, et al., 2018), although installations that operate at atmospheric pressure also exist (ECN, 2018). This is expected to increase to 40 bar by 2030 and 70 bar by 2050 (NOW, 2018). Alkaline Electrolysis Cells have a limited ability to respond to load changes, which is essential when flexibility is required by the power system. The current start-up time is around 50 minutes (NOW, 2018). The electrolysis takes place in cells, which can be stacked (called a 'stack'). An installation can consist of multiple stacks.

Capacity	**Functional Unit**		**Value and Range**								
	MWH2;out;LHV		13.06								
			13.06			-			242.69		
Potential	NL	PJ	**Current**			**2030**			**2050**		
			-			-			-		
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Market share		%	-			-			-		
			-	–	-	*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)		20-40
Progress ratio		0.82
Hourly profile	No	
Explanation	An AEL installation stack for hydrogen production varies in size from 1 to 5 MW (Weeda, 2018). These units can be linked to form larger production plants. Installations can vary going up to 150 MW (Korner, 2015) or even 400 MW (IEA, 2017), but based on (ECN, 2018) a typical large scale electrolyser installation is defined here as 20 MW. AEL electrolysis produces hydrogen for which there are many different applications: to produce steam, electricity, high temperature heat, and to act as transport fuel. The produced hydrogen can also directly replace current hydrogen consumption mostly produced via steam methane reforming (SMR) or hydrogen in refinery waste gases separated using pressure swing adsorption (PSA). Branches that have shown interest in (sustainable) hydrogen production are the chemical, the petrochemical and the fertilizer sector (Berenschot, Matters, Delft, & Matters, 2017). An AEL installation can run 97% of the time (8497 hours per year) and is to be used to its fullest capacity (no hourly profile) according to (Hydrogenics, Colruyt, Sustesco, & WaterstofNet, 2016). This profile would change when connected to an intermittent source of electricity (for example, an offshore wind park). The total installation has a technical lifetime (including maintenance) of 20-40 years (ECN, 2018). The stacks have a lifetime of 9 to 15 years according to (Fraunhofer, 2014). The lifetime of the stacks is expected to increase according to (NOW, 2018) from the current 60,000 hours to 80,000 hours by 2030 and 110,000 by 2050. Until 2030, the main developments expected for alkaline technology are an increased size of the cell stack (from 1000 cm² to 2500 cm²) and an increased output pressure (from 10 to 60 bars) (Hydrogenics, Colruyt, Sustesco, & WaterstofNet, 2016). AEL electrolysis is still developing and its investment cost are expected to decrease over time. (Detz, Reek, & van der Zwaan, 2018) estimates a learning rate of 18%.	

COSTS

Year of Euro	2015								
Investment costs	**Euro per Functional Unit**	**Current**			**2030**			**2050**	
	mln. € / MWH2;out;LHV	1.02			0.70			0.70	
		0.94	–	1.84	0.61	–	1.43	0.36	–	1.08
Other costs per year	mln. € / MWH2;out;LHV	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / MWH2;out;LHV	0.03			0.02			0.01		
		0.03	–	0.03	0.02	–	0.02	0.01	–	0.01
Variable costs per year	mln. € / MWH2;out;LHV	-			-			-		
		Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Costs explanation	(NOW, 2018) (does not differentiate in CAPEX for large scale and small scale installations) assumes a current CAPEX of 620 – 1,220 EUR/kWel, which is expected to go to 410 – 970 EUR/kWel by 2030, and 250 – 750 EUR/kWel by 2050. (EUR/kW;H2;lhv is calculated by multiplying with energy efficiency PJel/PJh2;lhv) Internal data from ECN estimates 665 - 945 EUR/kWel for current AEL CAPEX, going to down to 460 - 750 EUR/kWel by 2030, and 460 - 660 EUR/kWel (EUR/kW;H2;lhv is calculated by multiplying with energy efficiency PJel/PJh2;lhv of 1.53) According to (De Vita, et al., 2018) the OPEX of a large scale AEL installation is currently 28 EUR/kWh2;hhv/yr and will go down to 14 EUR/kW;h2;hhv/yr by 2030 and 9 EUR/kW;h2;hhv/yr by 2050. Assuming 71.35% conversion efficiency of electricity to hydrogen (HHV), the OPEX is 20 EUR/kWinput/yr and goes down to 10 EUR/kWinput/yr in 2030 and 6 EUR/kWinput/yr in 2050. OPEX expressed in lhv H2 calculated using 1.18 MJh2;hhv/MJh2;lhv. A major component of AEL equipment is the stack (about 30% of the total equipment cost) (Hydrogenics, Colruyt, Sustesco, & WaterstofNet, 2016), which need to be replaced once during the the total installation's lifetime. Used factors to convert the CAPEX and OPEX found in the literature to the values above: 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 H2 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		1.53			1.50			1.47	
			1.53	–	1.67	1.50	–	1.50	1.47	–	1.47
		PJ		-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*
		PJ		-			-			-	
			Min	–	*Max*	*Min*	–	*Max*	*Min*	–	*Max*

Energy in- and Outputs explanation	AEL requires electricity as energy input and results in hydrogen (H2) as energy output. According to (NOW, 2018) the current energy consumption for a 10 MW AEL installation is currently (2018) around 4.6 kWh/m3_H2, by 2030 it will be 4.5 kWh/m3_H2 and by 2050 it will be 4.4 kWh/m3_H2. Assuming a density of 0.0899 kg/m3 this translates to a current energy consumption of 52.3 kWh/kg_H2. This is expected to go down to 50.1 kWh/kg_H2 by 2030 , and to 48.9 kWh/kg_H2 by 2050. Internal data from (ECN, 2018) gives a range of 51.1 to 55.6 kWhel;input per kgH2;output. (Weeda, 2018) uses 55 kWh;el per kgH2;output as efficiency for AEL. To convert kWh/kgH2 use 120.1 MJ;lhv/kg H2 as energy content. Example, the PJel;in/PJh2;lhv;out for Weeda (2018) is 55*3.6/120.1 = 1.65.

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current			2030			2050		
Material flows	Hydrogen	kg H2		-1.00			-			-	
			-1.00	–	-1.00	*Min*	–	*Max*	*Min*	–	*Max*
	Water	kg water		14.50			-			-	
			14.50	–	14.50	*Min*	–	*Max*	*Min*	–	*Max*
Material flows explanation	According to (Hydrogenics, Colruyt, Sustesco, & WaterstofNet, 2016), around 1.3 liter/Nm3_H2 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											

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										

REFERENCES AND SOURCES

Weeda (2018). Routekaart Waterstof TKI Nieuw Gas.

NOW (2018). Industrialisierung der Wasserelektrolyse in Deutschland.

De Vita et al. (2018). Sectoral integration - long term perspective.

Hydrogenics et al. (2016). Power to Gas.

DNVGL (2017). Rapport verkenning waterstofinfrastructuur.

E4tech et al. (2014). Development of water electrolysis in the European Union.

Detz, R.J., Reek, J.N. & van der Zwaan, B.C. (2018). The future of solar fuels.

Pesonen, O. & Alakunnas, T. (2017). Energy storage.

Korner, A. (2015). Technology roadmap hydrogen and fuel cells.

Fraunhofer (2014). Water electrolysis, status and potential for development.

Berenschot (2017). Electrification in the Dutch process industry.