TECHNOLOGY FACTSHEET

TNO

LIQUEFIED HYDROGEN STORAGE

Date of factsheet	26-10-2020
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Sector	Hydrogen
ETS / Non-ETS	Non-ETS
Type of Technology	Storage
Description	Storage of liquefied or cryogenic hydrogen in tanks is attractive when a high volumetric energy density is wanted. However, an essential part of this technology is the liquefaction process which is expensive and requires 25-40% of the energy content of the hydrogen stored. Hydrogen has to be cooled down below -253°C to become liquefied. Moreover, liquefied hydrogen storage requires expensive (dewar) tanks which are designed to minimize heat transfer from the outside to the liquid, and often additional insulation of the tanks and storage facilities is used. Still, losses due to boil-off of hydrogen are 0.1-0.5% per day. However, the operational pressure is low, < 10 bar, and after liquefaction the physical volumetric energy density of liquefied hydrogen is 2300-2950 kWh/m3. Tanks can therefore contain 0.1-100 GWh. Liquefied hydrogen is the preferred option when large amounts of hydrogen must be transported over long distances where no pipelines are available. Tanks can be loaded upon trucks or stored in ships. The investment costs for liquefied hydrogen storage consists of two parts, i.e. the costs of the tanks and the costs of the liquefaction process. The costs of the tanks scale with the amount of hydrogen that can be stored (expressed in in kg or GWh), the costs of the liquefaction scale with the maximum hydrogen flow (expressed in tons/day or MW_H2). Since costs of liquefaction are usually the dominant factor, here MW_H2 is used as the unit of capacity of the installation.
TRL level 2020	TRL 9
	Technology provided by Air Liquide, Linde and others.

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range		
Capacity	MW		34.70		
			34.70	-	34.70

			Current	2030	2050
Potential			-	-	-
			Min – Max	Min – Max	Min – Max
Market share		%	-	-	-
			Min – Max	Min – Max	Min – Max

Capacity utlization factor		1.00
Full-load running hours per year		8,000.00
Unit of Activity	PJ/year	
Technical lifetime (years)		25.00
Progress ratio		
Hourly profile	No	
Explanation	The capacity of 34.7 MW is equivalent to 25 tons of hydrogen/day. This is based on the Lower Heating Value of hydrogen which is 120 MJ/kg or 0.033 MWh/kg.	

COSTS

Year of Euro	2015

	Euro per Functional Unit	Current	2030	2050
Investment costs	mln. € / MW	2.25	2.25	0.98
		0.98 – 3.63	0.98 – 3.63	0.98 – 0.98
Other costs per year	mln. € / MW	-	-	-
		Min – Max	Min – Max	Min – Max
Fixed operational costs per year (excl. fuel costs)	mln. € / MW	0.07	0.07	0.03
		0.03 – 0.11	0.03 – 0.11	0.03 – 0.03
Variable costs per year	mln. € /	-	-	-
		Min – Max	Min – Max	Min – Max
Costs explanation	The costs were derived assuming a total tank capacity of 10 GWh hydrogen. For installations with different total tank capacity, corrections must be made. Kearney estimates the cost of the tanks at 800-10000 USD/MWh H2, assuming 2828 €/MWh H2. The specified cost per MW includes the liquefaction and decrease with increasing hydrogen flow. Higher costs are for a 5 tons/day liquefaction installation, lower for 50 tons/day. For 2050 it is assumed that typical operation will be at 50 tons/day. Fixed operational cost are 3% of CAPEX.			

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
	Hydrogen	PJ	1.00	1.00	1.00
			1.00 – 1.00	1.00 – 1.00	1.00 – 1.00
	Electricity	PJ	0.36	0.19	0.18
			0.25 – 0.60	0.19 – 0.19	0.18 – 0.18
		PJ	-	-	-
			Min – Max	Min – Max	Min – Max
Energy in- and Outputs explanation	The current energy use of the liquefication process is 12 kWh/kg H2. This includes use of auxiliary equipment, compression of the inlet gas and production of liquid N2 required in the cooling process. Cardella and IDEALHY foresee a reduction to 6.4 kWh/kg H2 in the near future and eventually to 6 kWh/kg H2. This will be due to changes in the refrigeration processes and to pre-compression of hydrogen gas to higher pressures. It is not clear from the data how this will affect the CAPEX.				

MATERIAL FLOWS (OPTIONAL)

	Material	Unit	Current	2030	2050
Material flows			-	-	-
			Min – Max	Min – Max	Min – Max
			-	-	-
			Min – Max	Min – Max	Min – Max
Material flows explanation					

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
Boil-off rate	% /day	0.10	-	-
		0.06 – 0.50	Min – Max	Min – Max
		-	-	-
		Min – Max	Min – Max	Min – Max
		-	-	-
		Min – Max	Min – Max	Min – Max
		-	-	-
		Min – Max	Min – Max	Min – Max
Explanation	The boil-off rate depends on the quality of the tanks, and in particular on the size of the tanks. Due to the lower surface/volume ratio, large tanks have a lower boil-off rate.			

REFERENCES AND SOURCES	
1	A.T Kearney (2014), Energy transition Institute, Hydrogen based energy conversion, 2014. https://www.kearney.com/web/home/insights/hydrogen.
2	DOE (2019), Current Status of Hydrogen Liquefaction Costs, 2019. https://www.hydrogen.energy.gov/pdfs/19001_hydrogen_liquefaction_costs.pdf
3	U. Cardella, L. Decker and H. Klein, Roadmap to economically viable hydrogen liquefaction. Int J Hydrogen Energy 42 (2017) p. 13329-38.
4	https://hydrogeneurope.eu/sites/default/files/Hydrogen%20Europe_Green%20Hydrogen%20Recovery%20Report_final.pdf
5	IDEALHY Consortium (2017). Hydrogen liquefaction report. FCH JU FP7-JTI Proj. Ref. 278177 D5.22.
6	K. Ohlig and L. Decker, The latest developments and outlook for hydrogen liquefaction technology, AIP Conf. Proc. 1573 (2014) p. 1311-7.
7	NREL (1998) - Amos WA. Costs of storing and transporting hydrogen (1998) NREL/TP-570-25106.