



Study on the Import of Liquid Renewable Energy: Technology Cost Assessment

October 2020

Agenda

01 Short Introduction to DNV GL and Presenters

02 Study Objectives, Scope and Approach

03 Study Results / Key Technologies

Introduction Project Team



Maurice Vos

Senior consultant

- >10 years experience of experience in energy sector.
- Various projects for NRA's & TSO's on implementing EU regulations; specialist in gas transmission tariffs.
- Assists clients in positioning for and understanding of the development of a hydrogen economy



Jochum Douma

Consultant

- Technical and market experience in the hydrogen value chain.
- Market modelling and analysis, Techno-economic feasibility studies and system integration.
- Technical and research background and experienced in finding cost and performance figures in energy systems.



Albert van den Noort

Principal consultant

- PhD degree in respectively Chemical Engineering and Applied Physics.
- Current role focusses on the energy transition with a special focus on the role of hydrogen

Overview of DNV GL

12,000

employees

150+

years

100+

countries

100,000+

customers

5% R&D

of annual revenue

MARITIME



OIL & GAS



ENERGY



**BUSINESS
ASSURANCE**



**DIGITAL
SOLUTIONS**



Technology & Research

Global Shared Services

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Background and Study Objectives

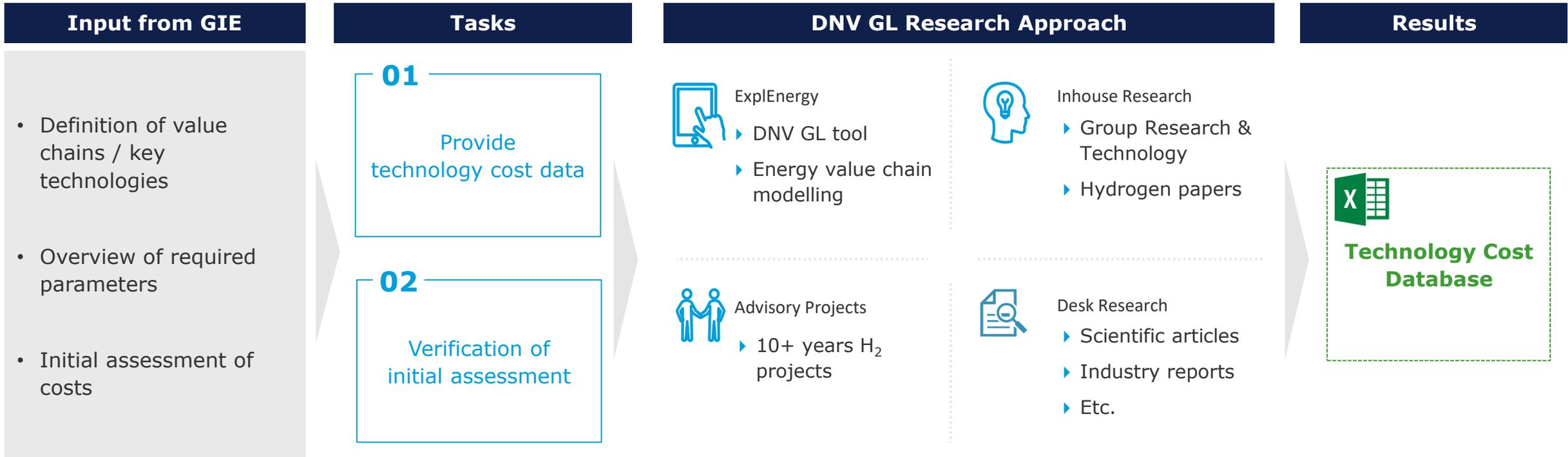
Background

- Import of natural gas and LNG is currently key to delivering -- securely, reliably and efficiently -- energy to Europe
- However, decarbonization requirements bring uncertainty to future role of natural gas in Europe and its current use is expected to decline
- Still, 'molecules' will be required in a future energy system and valuable gas infrastructures are already present.
- Infrastructure, including LNG, can support decarbonization of European energy supply

Study Objectives

- What role could LNG import infrastructure play in a net zero energy future?
- Comparison of various methods (energy carriers) for importing liquid renewable energy using existing infrastructure
- Comparison based on strengths and weaknesses and costs associated with the development of the identified routes
- DNV GL collaborate with GIE to assess costs of different technologies / energy carriers

Scope and Approach



Scope and Approach

#	Step in value chain	Technology	DNV GL role
0	Energy production	1 Biogas production (Anaerobic digestion)	Review
		2 Biogas production (Thermal gasification)	Review
		3 Offshore wind	Review
		4 Onshore wind	Review
		5 Solar PV	Review
1	Liquefaction technologies	6 Hydrogen liquefaction	Researched figures
2	Regasification technologies	7 LH2 regasification	Researched figures
3	Conversion technologies	8 Pyrolysis	Researched figures
		9 Hydrogenation and dehydrogenation of LOHC	Researched figures
		10 H ₂ conversion into ammonia	Researched figures
		11 Ammonia cracking	Researched figures
		12 Ammonia liquefaction	Researched figures
		13 H ₂ conversion into methanol	Researched figures
		14 Methanation	Review
		15 Alkaline electrolysis	Review
		16 PEM electrolysis	Review
		17 SOEC electrolysis	Review

Scope and Approach

#	Step in value chain	Technology	DNV GL role
4	Storage technologies	18 LH ₂ storage	Researched figures
		19 LOHC storage	Researched figures
		20 Methanol storage	Researched figures
		21 Ammonia storage	Review
5	Shipping technologies	22 LH ₂ shipping	Researched figures
		23 LOHC shipping	Researched figures
		24 Methanol shipping	Researched figures
		25 Ammonia shipping	Review
6	Transport technologies	26 H ₂ compression	Researched figures
		27 H ₂ pipeline	Researched figures
7	CCUS technologies	28 Carbon capture	Researched figures
		29 Carbon storage	Researched figures
		30 Carbon shipping	Researched figures
		31 Carbon transport	Researched figures

Scope and Approach

- ⇒ Costs are **unit costs**, mostly provided as a **range** (i.e. low, mid, high)
- ⇒ We assume **industrial scale** installations
- ⇒ **Comments** provide relevant additional information (such as capacity of installation) or calculation to derive unit costs
- ⇒ References to **data source**

Quantitative information per technology

01

CAPEX

- ▶ Capital expenditures / investment costs
- ▶ Dependent on capacity installed

02

OPEX

- ▶ Operating expenditures
- ▶ Fixed: % of capex
- ▶ Variable: mostly energy use (e.g. electricity)

03

Efficiency / losses

- ▶ Efficiency: Energy conversion efficiency
- ▶ Losses: loss of hydrogen (carrier)

04

TRL

- ▶ Technology Readiness Level



General observations / remarks

High TRL

- More certainty around cost figures
- Sometimes based on 'real-world' data, or closely related information (e.g. vessels)
- Research/information on established technologies (e.g. CO₂ & ammonia transport) not known
- 'New' use may differ from envisaged use (ammonia as feedstock vs. energy carrier)

Low TRL

- Larger range of cost figures
- Mostly based on (chemical engineering) modelling, assumptions, scaling of pilot plants, etc.
- Lots of research (for certain technologies such as pyrolysis)
- Mostly regarded as technology for energy sector (e.g. pyrolysis)

Please note:

- We only provide individual elements of a possible supply chain. Assessing integrated costs requires supply chain modelling.
- This may alter performance and/or costs of technologies (e.g. ammonia production connected to electrolysis providing flexibility to electricity grid)

Agenda

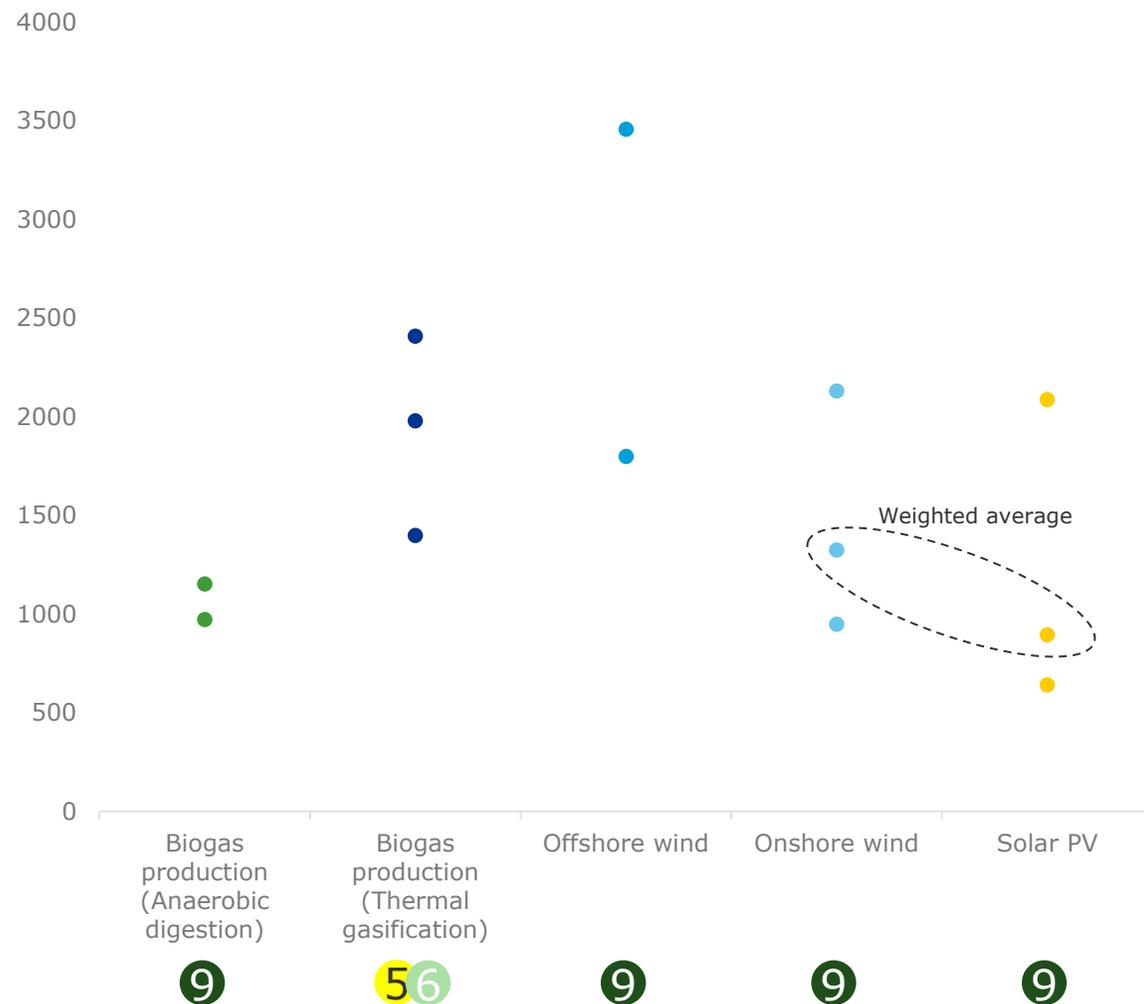
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0. Energy Production

Unit Capex [EUR/kW]



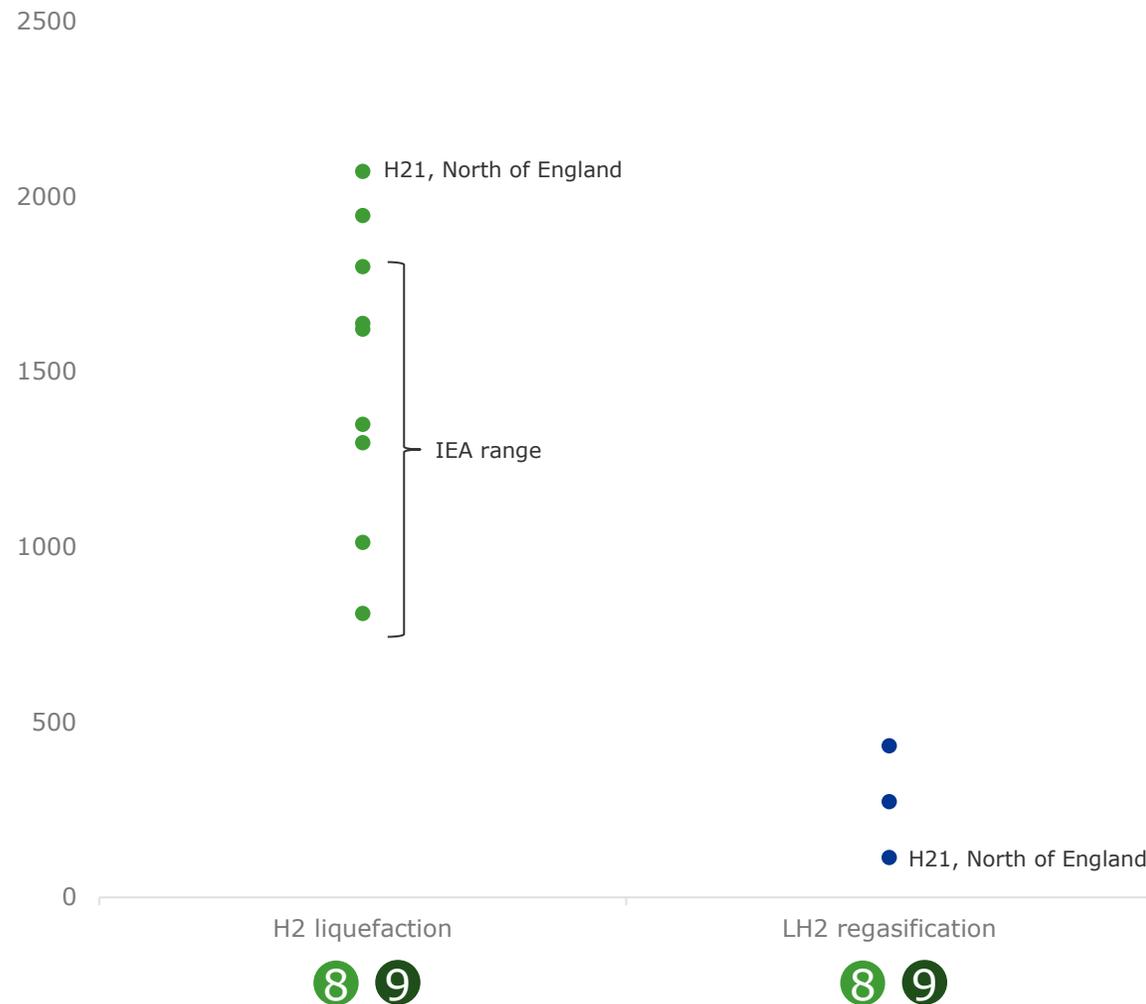
- TRL of biogas production through gasification less than anaerobic digestion.
- Low estimate for offshore wind costs represent GW-scale for 2025 → potential for cost reductions
- Range for solar very dependent on type of module
- Offshore wind range due to different country and site-specific requirements

0. Energy Production

Technology	CAPEX <i>unit</i>	VOM <i>unit</i>	FOM <i>unit</i>	Efficiency/ losses <i>unit</i>	TRL
Biogas production (Anaerobic digestion)					
	1153 EUR/kW		10 % of CAPEX p.a.	95 %	9
	973 EUR/kW		6 % of CAPEX p.a.	95 %	9
		12 EUR/MWh			
		29.4 EUR/MWh			
Biogas production (Thermal gasification)					
Small	2410 EUR/kW		0.25 MEUR/MWhth/yr	64 %	5 to 6
Medium	1980 EUR/kW		0.22 MEUR/MWhth/yr	64 %	5 to 6
Large	1400 EUR/kW		0.15 MEUR/MWhth/yr	75 %	5 to 6
Offshore wind					
	3458 EUR/kW				9
	1800 EUR/kW				9
			1.8 % of CAPEX p.a.		9
			3.4 % of CAPEX p.a.		9
			3.2 % of CAPEX p.a.		9
Onshore wind					
	950 EUR/kW		3.1 % of CAPEX p.a.		9
	1326 EUR/kW				9
	2131 EUR/kW		2.4 % of CAPEX p.a.		9
Solar PV					
	643 EUR/kW		1.3 % of CAPEX p.a.		9
	896 EUR/kW		1.0 % of CAPEX p.a.		9
	2088 EUR/kW				9

1. Liquefaction & 2. Regasification Technologies

Unit Capex [EUR/kW]



- Large range in H₂ liquefaction capex
 - Typical today: 5 TPD (SMR: 200-500 TPD)
 - Low temperature (~20K), catalytic process
- Limited number of sources for LH₂ regasification

1. Liquefaction & 2. Regasification Technologies

Technology	CAPEX <i>unit</i>	VOM <i>unit</i>	FOM <i>unit</i>	Efficiency/ losses <i>unit</i>	TRL	Year
Hydrogen liquefaction						
Low	810 EUR/kW_H2					2019
Typical	1350 EUR/kW_H2					2019
High	1800 EUR/kW_H2					2019
	1013 EUR/kW_H2		2.5 % of CAPEX p.a.			2025
	1638 EUR/kW_H2		2.5 % of CAPEX p.a.			2025
	1622 EUR/kW_H2					2019
	1946 EUR/kW_H2					2007
	1297 EUR/kW_H2					2007
	2072 EUR/kW_H2					
				0 % H2 losses		
			4 % of CAPEX p.a.			2019
					8-9	2019
Low		0.24 kWh/kWh_H2				2019
Typical		0.30 kWh/kWh_H2				
High		0.39 kWh/kWh_H2				2015

1. Liquefaction & 2. Regasification Technologies

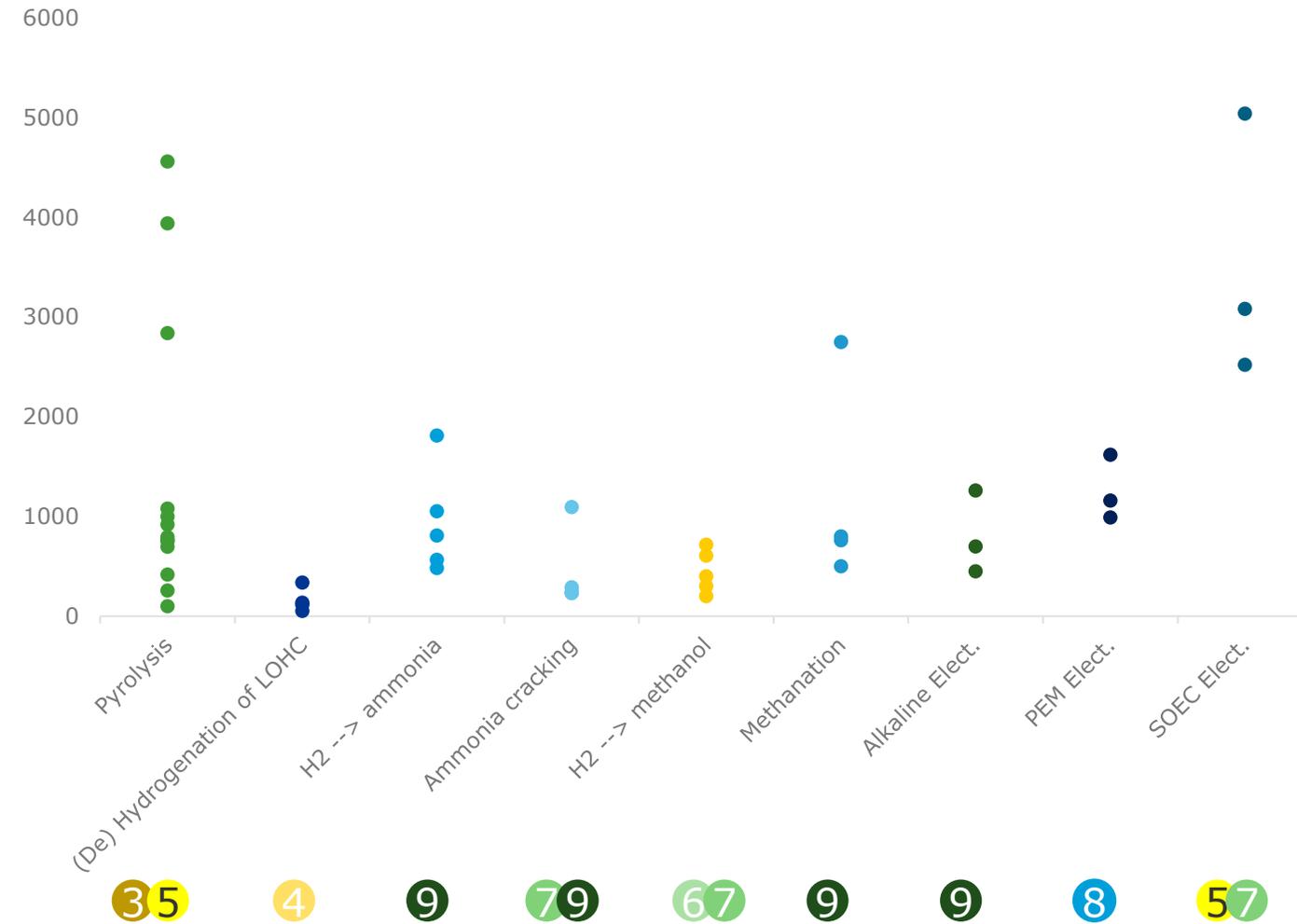
Technology	CAPEX <i>unit</i>	VOM <i>unit</i>	FOM <i>unit</i>	Efficiency/ losses <i>unit</i>	TRL	Year
Natural / Bio gas liquefaction						
Low (natural gas)	331 EUR/kW		1.9 % of CAPEX p.a.	90.5 % of gas feed	9	2018
Mid (natural gas)	717 EUR/kW		2.1 % of CAPEX p.a.	90 % of gas feed	9	2018
High (natural gas)	1269 EUR/kW		2.5 % of CAPEX p.a.	88 % of gas feed	9	2018
Low (natural gas)				5 % of gas feed		
Mid (natural gas)				10 % of gas feed		
High (natural gas)				27 % of gas feed		
	1600 EUR/kW					2014
	1814 EUR/kW					2014
		1.83 kWh/kg of bio-LNG				2018
		1.38 kWh/kg of bio-LNG				2018
Future (>2025)	1000 EUR/kW		5% of CAPEX p.a.			2025

1. Liquefaction & 2. Regasification Technologies

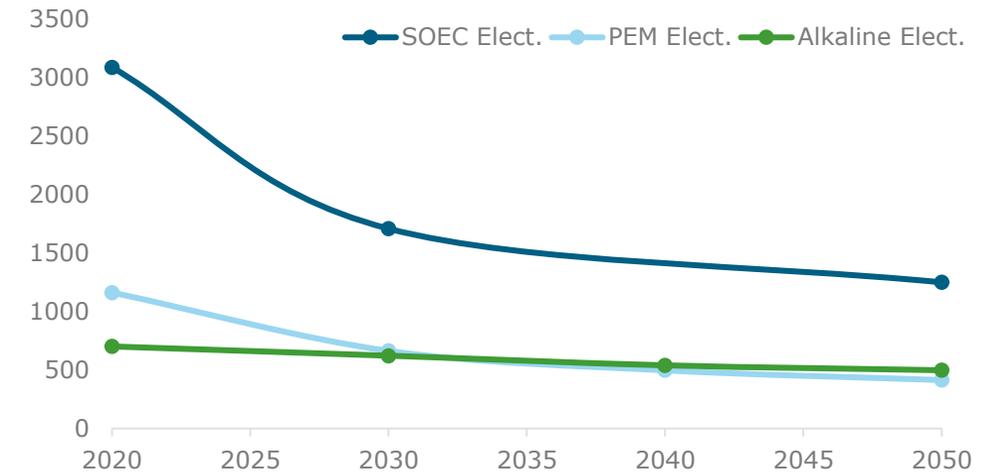
Technology	CAPEX	unit	VOM unit	FOM unit	Efficiency/ losses	unit	TRL	Year
LH2 regasification								
Low			0.002 kWh/kWh_H2					2019
Typical			0.003 kWh/kWh_H2					2019
High			0.005 kWh/kWh_H2					2019
Low	114	EUR/kW_H2						2019
Typical	273	EUR/kW_H2						2019
High	432	EUR/kW_H2						2019
Low				2.5 % of CAPEX p.a.				2019
				3 % of CAPEX p.a.				2017
					0	% H2 losses		2017
	112	EUR/kW_H2	0.01 kWh/kWh_H2					2016
							8-9	

3. Conversion Technologies

Unit Capex [EUR/kW]



- Low TRL technologies (pyrolysis, SOEC electrolysis) show larger range of cost values
- Many sources for pyrolysis
- Limited for LOHC ('only' 2), with estimates differing a factor 2
- Future outlook for electrolysis provided:



3. Conversion Technologies (1/4)

Technology	CAPEX	unit	VOM unit	FOM unit	Efficiency/ losses	unit	TRL	Year
Pyrolysis								
Plasma pyrolysis		1,000 EUR/kW_H2			13.7 % of CAPEX p.a.	47.5 %		2005
Plasma pyrolysis		3,940 EUR/kW_H2			3 % of CAPEX p.a.	53 %		2019
Plasma pyrolysis		2,839 EUR/kW_H2			5 % of CAPEX p.a.	53 %		2019
Plasma pyrolysis (Low)		100 EUR/kW_H2	0.33 kWh/kWh_H2		2 % of CAPEX p.a.	50 %		2018
Plasma pyrolysis (Typical)		760 EUR/kW_H2	0.37 kWh/kWh_H2		1 % of CAPEX p.a.	54 %		2018
Plasma pyrolysis (High)		4,559 EUR/kW_H2	0.48 kWh/kWh_H2		% of CAPEX p.a.	39 %		2018
Molten Metal		753 EUR/kW_H2			3 % of CAPEX p.a.	49 %		2016
Molten Metal (Low)		697 EUR/kW_H2	0.26 kWh/kWh_H2		% of CAPEX p.a.	54 %		2018
Molten Metal (Typical)		795 EUR/kW_H2	0.43 kWh/kWh_H2		5 % of CAPEX p.a.	54 %		2018
Molten Metal (High)		919 EUR/kW_H2	0.41 kWh/kWh_H2		2 % of CAPEX p.a.	54 %		2018
Gas reactor (Low)		255 EUR/kW_H2	0.53 kWh/kWh_H2		3 % of CAPEX p.a.	52 %		2018
Gas reactor (Typical)		417 EUR/kW_H2	0.64 kWh/kWh_H2		3 % of CAPEX p.a.	54 %		2018
Gas reactor (High)		1,079 EUR/kW_H2	0.37 kWh/kWh_H2		3 % of CAPEX p.a.	54 %		2018
Molten metal (thermal decomposition)							3 to 4	2020
Plasma pyrolysis							6 to 8	2020
Gas reactor (catalytical decomposition)							3 to 4	2020
Pyrolysis (general)							3 to 5	2020

3. Conversion Technologies (2/4)

(De) Hydrogenation of LOHC						
Hydrogenation (TOL)	52 EUR/kW H2	0.72 EUR/kg_TOL	2.5 % of CAPEX p.a.		4	>2025
Hydrogenation (DBT)	53 EUR/kW H2	3.60 EUR/kg_DBT	2.5 % of CAPEX p.a.		4	>2025
Hydrogenation (TOL)	116 EUR/kW H2		4 % of CAPEX p.a.			2019
Dehydrogenation (TOL)	136 EUR/kW H2	0.33 kWh/kWh_H2	2.5 % of CAPEX p.a.	90 % H2 recovery	4	>2025
Dehydrogenation (DBT)	136 EUR/kW H2	0.33 kWh/kWh_H2	2.5 % of CAPEX p.a.	90 % H2 recovery	4	>2025
Dehydrogenation (TOL)	337 EUR/kW H2	0.45 kWh/kWh_H2	4 % of CAPEX p.a.	90 % H2 recovery		2019
		0.41 kWh/kWh_H2				
			4 % of CAPEX p.a.			2018
H2 --> ammonia						
Low	566 EUR/kW_NH3				9	2007
Typical	808 EUR/kW_NH3	0.075 kWh/kWh_NH3			9	2007
High	1051 EUR/kW_NH3				9	2007
Large	481 EUR/kW_NH3		2.5 % of CAPEX p.a.			2025
Small	1812 EUR/kW_NH3		2.5 % of CAPEX p.a.			2025
	570 EUR/kW_NH3		4 % of CAPEX p.a.			2018
Low		0.079 kWh/kWh_NH3				
Typical		0.14 kWh/kWh_NH3				
High		0.20 kWh/kWh_NH3				
			4 % of CAPEX p.a.			

3. Conversion Technologies (3/4)

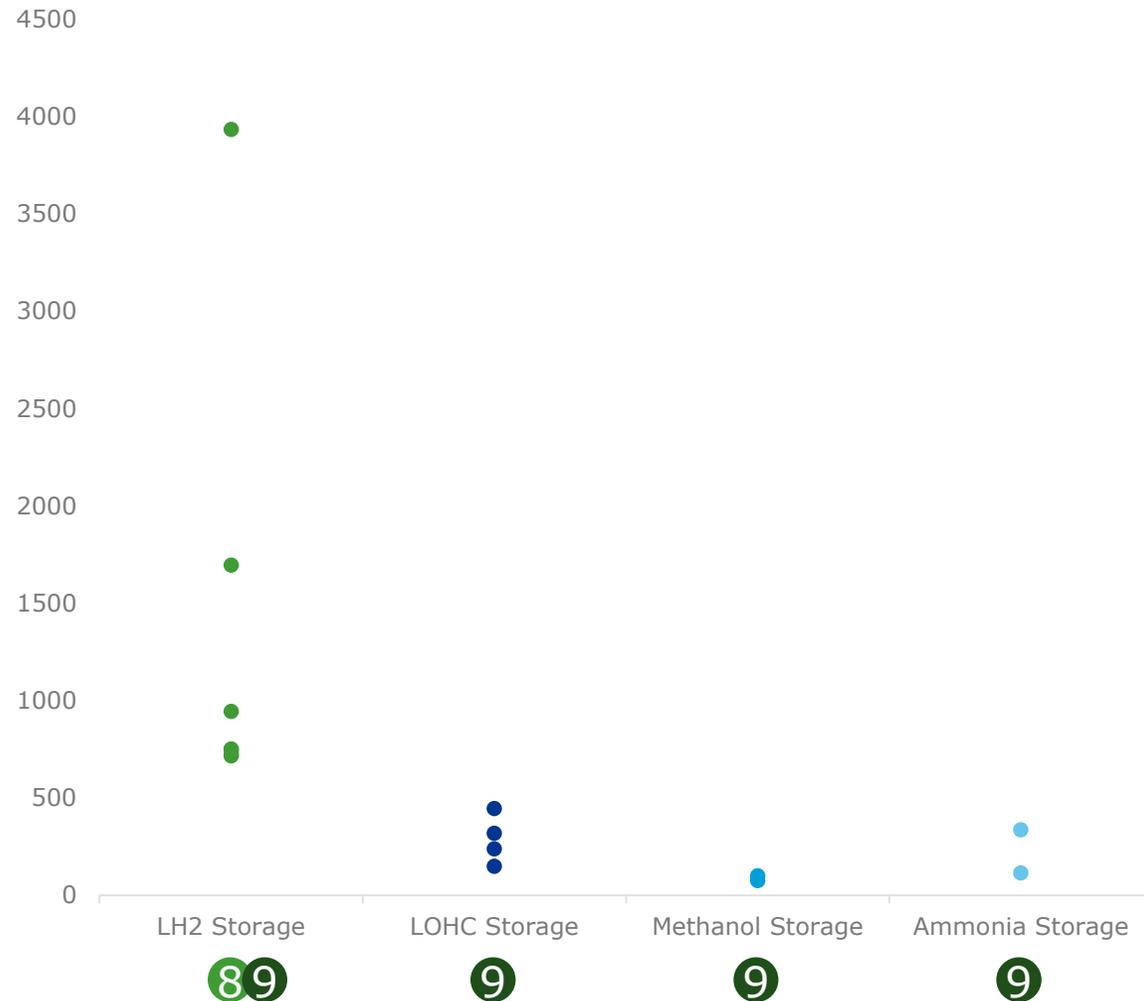
Ammonia cracking					
				7-9	
Low	229 EUR/kW_H2	0.148 kWh/kWh_H2	3 % of CAPEX p.a.		2018
Typical	235 EUR/kW_H2	0.139 kWh/kWh_H2	3 % of CAPEX p.a.		2018
High	241 EUR/kW_H2	0.131 kWh/kWh_H2	3 % of CAPEX p.a.		2018
Large	289 EUR/kW_H2	0.127 kWh/kWh_H2	2.5 % of CAPEX p.a.	90 % mZ	2025
Small	1,094 EUR/kW_H2		2.5 % of CAPEX p.a.		2025
H2 --> methanol					
	607 EUR/kW_MeOH	0.08 kWh/kWh_MeOH		96 %	6-7 2019
	718 EUR/kW_MeOH	0.07 kWh/kWh_MeOH	5.0 % of CAPEX p.a.		6-7 2014
Typical	300 EUR/kW_MeOH		4.0 % of CAPEX p.a.	79 % (LHV MeOH/LHV H2 2015)	
Low	200 EUR/kW_MeOH		4.0 % of CAPEX p.a.	89 % (LHV MeOH/LHV H2 2015)	
High	400 EUR/kW_MeOH		4.0 % of CAPEX p.a.	69 % (LHV MeOH/LHV H2 2015)	
Methanation					
Today	800 EUR/kW_CH4		3.00 % of CAPEX p.a.	80 %	9 2020
Future 2030	600 EUR/kW_CH4		3.3 % of CAPEX p.a.	80 %	9 2030
Future 2050	500 EUR/kW_CH4				2050
Typical	761 EUR/kW_CH4	0.013 kWh/kWh_CH4	4.0 % of CAPEX p.a.	77 %	9 2019
Future 2030	662 EUR/kW_CH4	0.013 kWh/kWh_CH4	4.0 % of CAPEX p.a.	77 %	2030
Future 2050	509 EUR/kW_CH4	0.013 kWh/kWh_CH4	4.0 % of CAPEX p.a.	77 %	2050
Low	500 EUR/kW_CH4		3.0 % of CAPEX p.a.	80 %	2018
High	2750 EUR/kW_CH4		3.0 % of CAPEX p.a.	80 %	2018
Direct Air Capture (today)	1800 EUR/kW_CH4	0.25 kWh/kgCO2	4.0 % of CAPEX p.a.		9 2018
Direct Air Capture (future 2050)	1278 EUR/kW_CH4	0.25 kWh/kgCO2	4.0 % of CAPEX p.a.		9 2050

3. Conversion Technologies (4/4)

Alkaline Elect.						
Low	450 EUR/kWe	52.9 kWh/kgH2		63.0 %		2019
High	1260 EUR/kWe	47.6 kWh/kgH2		70.0 %		2019
Today (2020)	700 EUR/kWe	52.0 kWh/kgH2	2.0 % of CAPEX p.a.	64.1 %	9	2020
Future (2030)	621 EUR/kWe	49.0 kWh/kgH2	2.0 % of CAPEX p.a.	68.0 %		2030
Future (2040)	539 EUR/kWe	48.0 kWh/kgH2	2.0 % of CAPEX p.a.	69.4 %		2040
Future (2050)	497 EUR/kWe	47.0 kWh/kgH2	2.0 % of CAPEX p.a.	70.9 %		2050
PEM Elect.						
Low	990 EUR/kWe	59.5 kWh/kgH2		56.0 %		2019
High	1620 EUR/kWe	55.5 kWh/kgH2		60.0 %		2019
Today (2020)	1160 EUR/kWe	55.0 kWh/kgH2	2.0 % of CAPEX p.a.	60.6 %	8	2020
Future (2030)	663 EUR/kWe	50.0 kWh/kgH2	2.0 % of CAPEX p.a.	66.6 %		2030
Future (2040)	497 EUR/kWe	48.0 kWh/kgH2	2.0 % of CAPEX p.a.	69.4 %		2040
Future (2050)	414 EUR/kWe	47.0 kWh/kgH2	2.0 % of CAPEX p.a.	70.9 %		2050
SOEC Elect.						
Low	2,520 EUR/kWe	45.0 kWh/kgH2		74.0 %		2019
High	5040 EUR/kWe	41.1 kWh/kgH2		81.0 %		2019
Today	3083 EUR/kWe	41.0 kWh/kgH2	1.0 to 2.5 % of CAPEX p.a.	81.3 %	5 to 7	2018
Future (2030)	1706 EUR/kWe	37.7 kWh/kgH2	1.0 to 2.5 % of CAPEX p.a.	88.5 %		2030
Future (2050)	1248 EUR/kWe	37.7 kWh/kgH2	1.0 to 2.5 % of CAPEX p.a.	88.5 %		2050

4. Storage Technologies

Unit Capex [EUR/MWh]



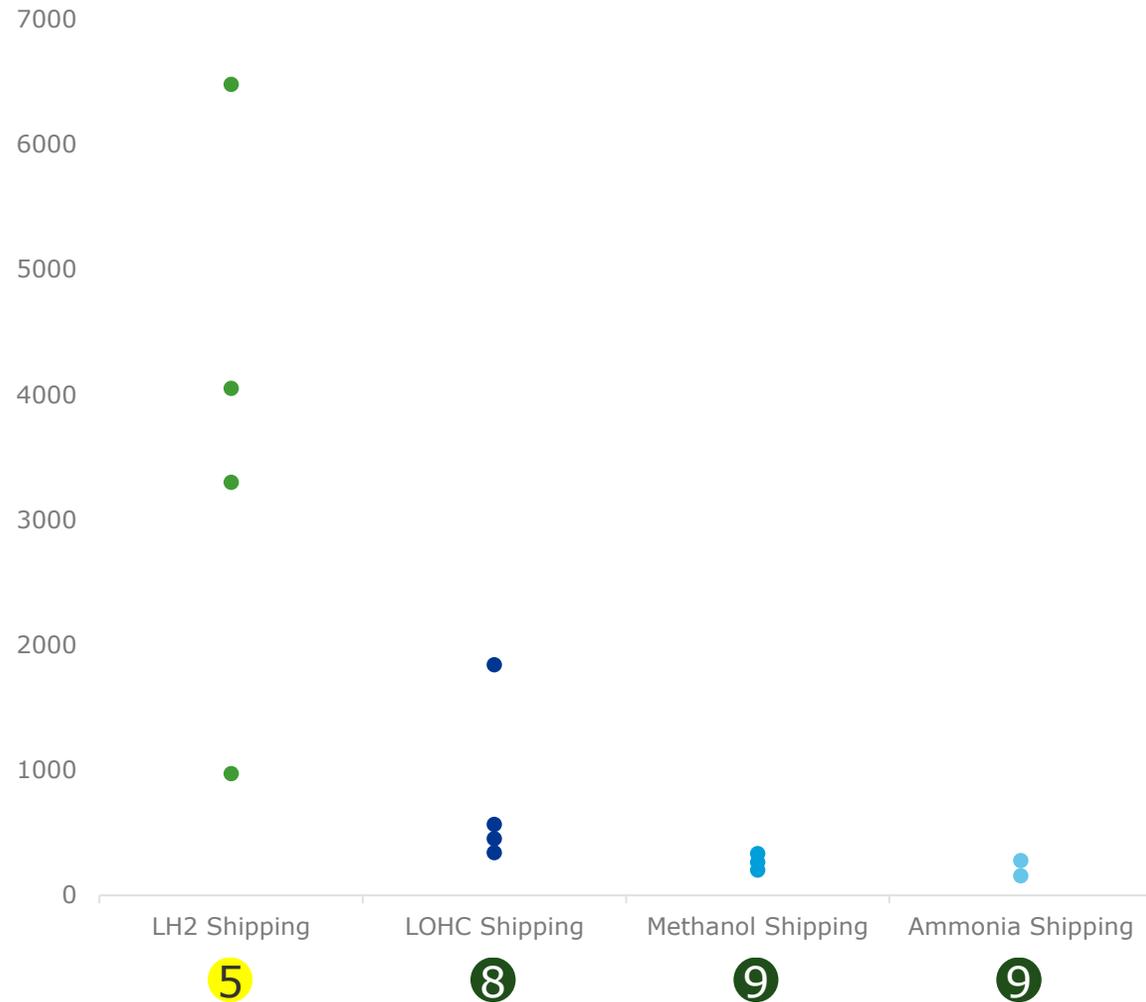
- Large LH₂ storage at lower TRL than LOHC, methanol, ammonia
 - NASA: 3800 m³, 270 ton LH₂
 - NASA (under construction): 5300 m³
 - JAXA: 540 m³, 38 tons LH₂
- Capex of LOHC, methanol and ammonia in same order of magnitude
- LOHC and Methanol can use 'standard' floating roof tanks.
- Ammonia storage at low temperatures for large storages, pressurised for smaller storages (not considered)

4. Storage Technologies

Technology	CAPEX	unit	VOM unit	FOM unit	Efficiency/ losses	unit	TRL	Year
LH2 Storage								
	717	EUR/MWh_H2					8-9	
	720	EUR/MWh_H2					8-9	
Typical	750	EUR/MWh_H2			0.03	% boil off/day	8-9	
	750	EUR/MWh_H2			0.1	% boil off/day	8-9	
	945	EUR/MWh_H2					8-9	
	1695	EUR/MWh_H2		2.0 % of CAPEX p.a.	0.04	% boil off/day	8-9	
High	3935	EUR/MWh_H2					8-9	
					0.3	% boil off/day	8-9	
LOHC Storage								
Low	150	EUR/MWh_H2		3.0 % of CAPEX p.a.	0	% H2 losses	9	
Mid	239	EUR/MWh_H2		0.7 % of CAPEX p.a.	0	% H2 losses	9	
	318	EUR/MWh_H2		0.5 % of CAPEX p.a.	0	% H2 losses	9	
High	446	EUR/MWh_H2		2.0 % of CAPEX p.a.	0	% H2 losses	9	
Methanol Storage								
Mid	75	EUR/MWh MeOH		0.7 % of CAPEX p.a.	0	% H2 losses	9	
High	100	EUR/MWh MeOH		0.5 % of CAPEX p.a.	0	% H2 losses	9	
Ammonia Storage								
High	337	EUR/MWh NH3	0.0019 kWh/kWh NH3	2.0 % of CAPEX p.a.	0.03	% boil off/day	9	2019
Low	115	EUR/MWh NH3	0.0747 kWh/kWh NH3		0.1	% boil off/day	9	2008

5. Shipping

Unit Capex [EUR/MWh]



- Similar to storage, LOHC, methanol and ammonia shipping in same order of magnitude
- LH2 shipping is currently at low TRL: Kawasaki is converting LPG ship to LH2 "Suiso Frontier"
- LH2 boil-off can contribute considerably in propelling the vessel (dependent on size and speed)

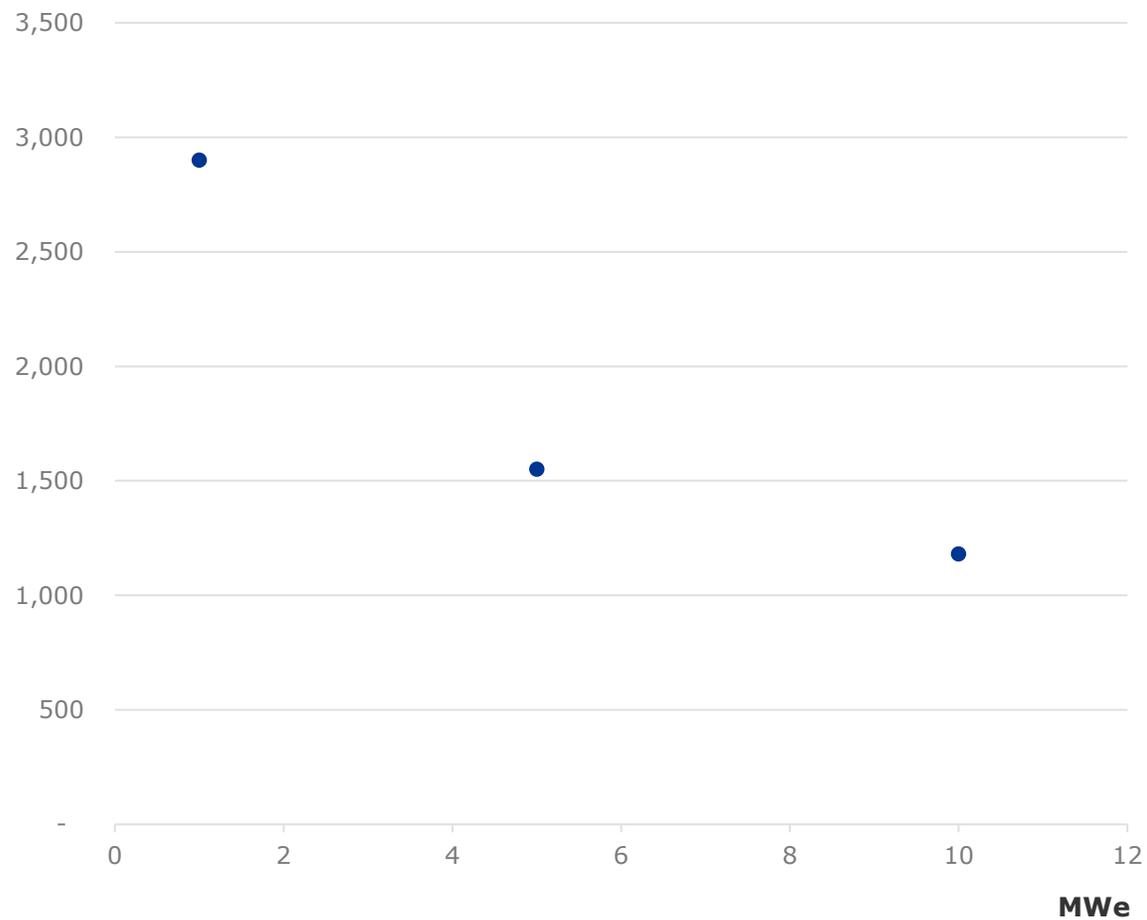
5. Shipping

Technology	CAPEX	unit	VOM unit	FOM unit	Efficiency/ losses unit	TRL	Year
LH2 Shipping							
Low	972	EUR/MWh					
Typical	4050	EUR/MWh					
High	6480	EUR/MWh					
Low			0.0004536 EUR/(MWh*km)				
Typical			0.007776 EUR/(MWh*km)				
High			0.013932 EUR/(MWh*km)				
Low					0.1 % boil off/day		
Typical					0.2 % boil off/day		
High					0.4 % boil off/day		
						5	2019
	3301	EUR/MWh		2.5 % of CAPEX p.a.			
LOHC Shipping							
Low	340	EUR/MWh	0.0010368 EUR/(MWh*km)		0.0017 %/km (losses)	9	2019
Typical	454	EUR/MWh	0.0012312 EUR/(MWh*km)		0.0023 %/km (losses)	9	2019
High	567	EUR/MWh	0.0014256 EUR/(MWh*km)		0.0029 %/km (losses)	9	2019
	1842	EUR/MWh		2.5 % of CAPEX p.a.			
Methanol Shipping							
					0 % H2 losses	9	2019
Low	201	EUR/MWh					
Typical	266	EUR/MWh					
High	334	EUR/MWh					
Low			0.0007128 EUR/(MWh*km)				
Typical			0.0010044 EUR/(MWh*km)				
High			0.001296 EUR/(MWh*km)				
Ammonia Shipping							
Typical	279	EUR/MWh		4.0 % of CAPEX p.a.		9	2019
Low	155	EUR/MWh	0.000080 EUR/(MWh*km)	4.0 % of CAPEX p.a.	0.08 % boil off/day		2020

6. Hydrogen Pipeline Transport

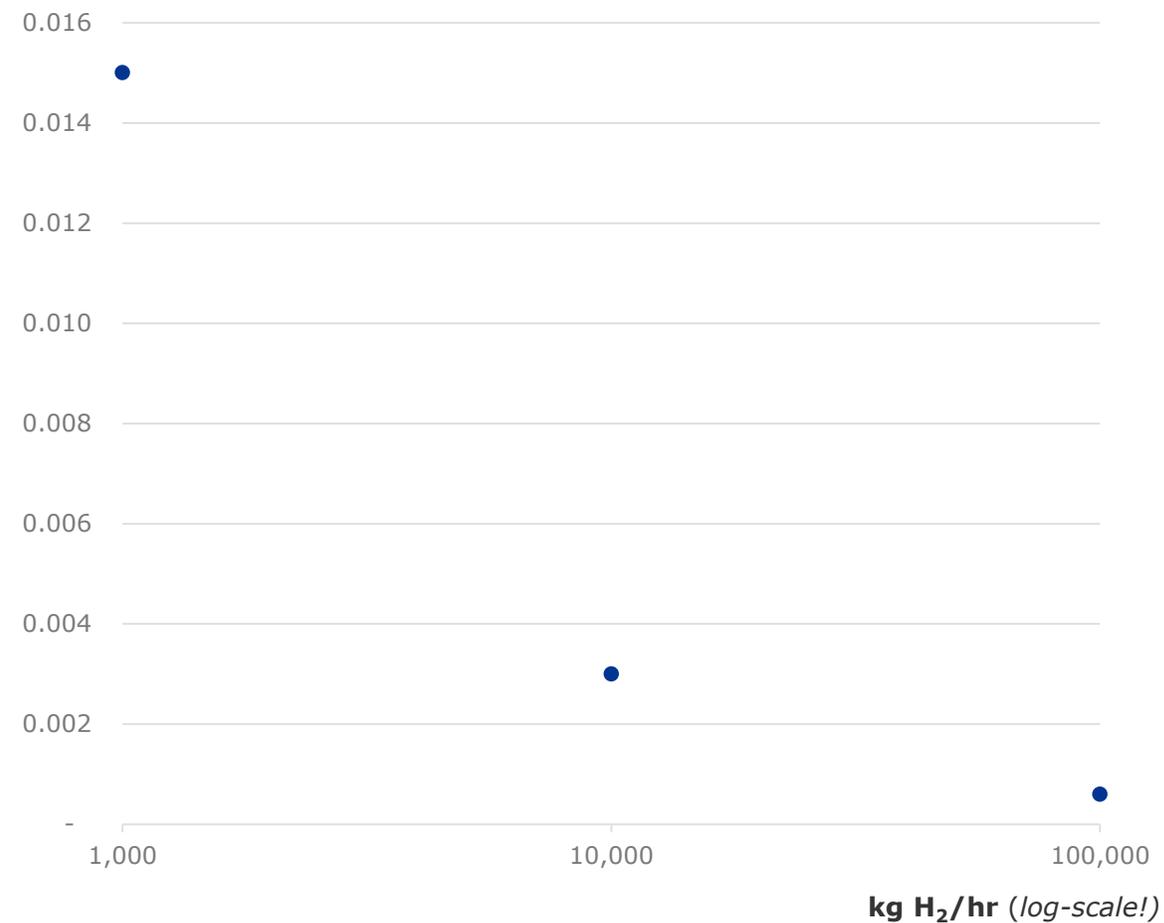
Hydrogen compression

Unit Capex [EUR/kWe]



Hydrogen pipelines

Unit Capex [EUR/kW/m]



7. CCUS

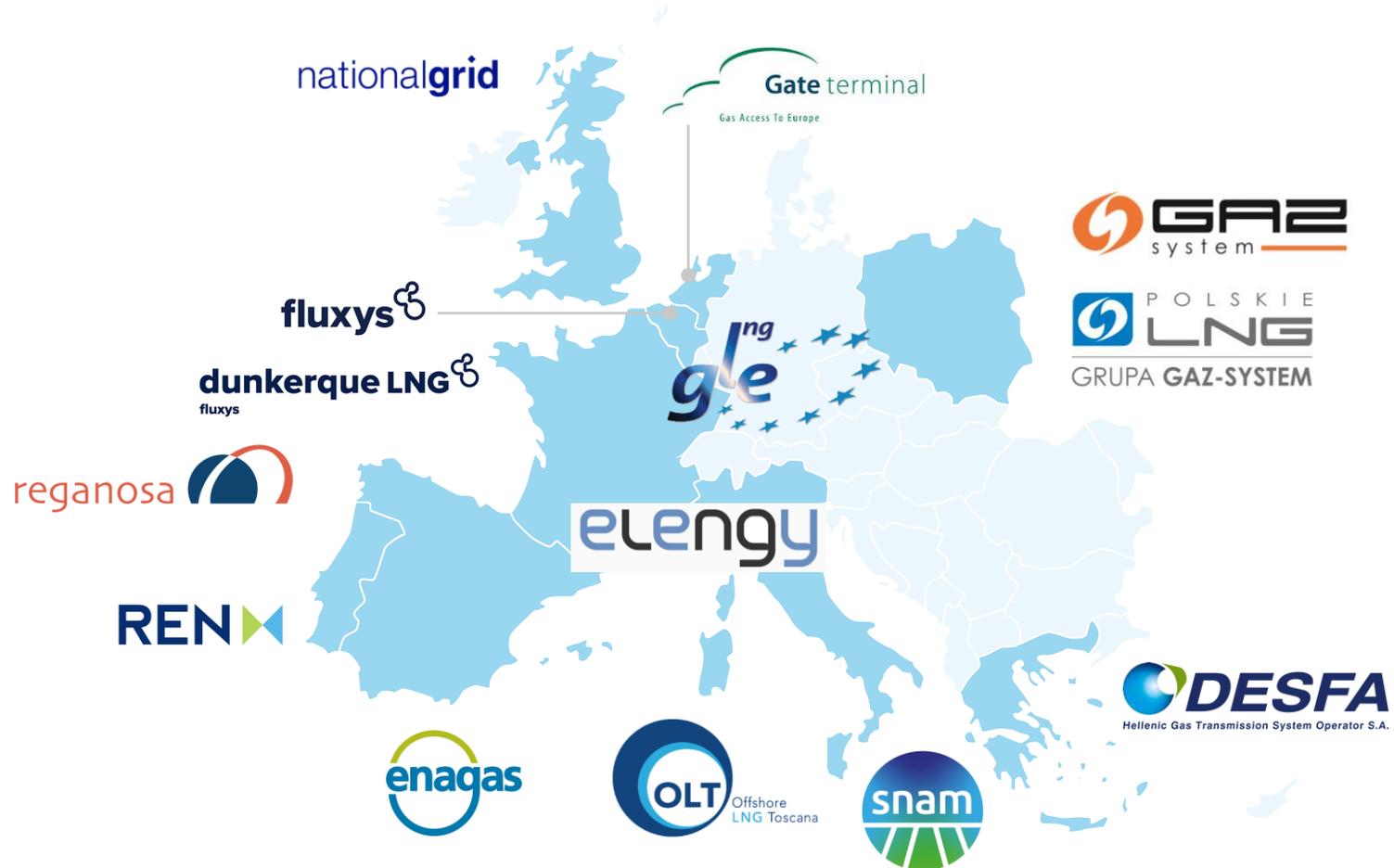
Technology	CAPEX <i>unit</i>	VOM <i>unit</i>	FOM <i>unit</i>	Efficiency/		TRL	Year
				losses	<i>unit</i>		
Carbon capture (combustion)							
ATR w/ integrated CO2 capture	952,699 EUR/MW H2 (LHV)		3.1 % of CAPEX p.a.	74.7	%	9	2018
ATR w/ integrated CO2 capture	955,182 EUR/MW H2 (LHV)		5.0 % of CAPEX p.a.	82	%		2016
SMR w/ integrated CO2 capture (low)	630,000 EUR/MW H2 (LHV)		3.2 % of CAPEX p.a.	69	%		2019
SMR w/ integrated CO2 capture (mid)	720,000 EUR/MW H2 (LHV)		3.2 % of CAPEX p.a.	69	%		2019
SMR w/ integrated CO2 capture (high)	1,350,000 EUR/MW H2 (LHV)		3.2 % of CAPEX p.a.				
SMR w/ integrated CO2 capture	1,089,147 EUR/MW H2 (LHV)		5.0 % of CAPEX p.a.	78	%		2016
Carbon storage							
Offshore UKCS, depleted field	545,101 EUR/(tCO2/hr)		9,763 EUR/year/(tCO2/hr)			9	2018
Offshore NCS, depleted field	652,087 EUR/(tCO2/hr)		8,543 EUR/year/(tCO2/hr)			9	2018
Offshore, no legacy wells	525,600 EUR/(tCO2/hr)		26,280 EUR/year/(tCO2/hr)				
Offshore, depleted field	210,240 EUR/(tCO2/hr)		26,280 EUR/year/(tCO2/hr)				
Offshore, aquifer	871,620 EUR/(tCO2/hr)		30,660 EUR/year/(tCO2/hr)				
Onshore, no legacy wells	118,260 EUR/(tCO2/hr)		13,140 EUR/year/(tCO2/hr)				
Onshore, depleted field	210,240 EUR/(tCO2/hr)		13,140 EUR/year/(tCO2/hr)				
Onshore, aquifer	306,600 EUR/(tCO2/hr)		13,140 EUR/year/(tCO2/hr)				
						9	
Carbon shipping							
Small	3220 EUR/tCO2/vessel	263 MWh/day	3 % of CAPEX p.a.	0	% losses		2018
Mid	2032 EUR/tCO2/vessel	339 MWh/day	5 % of CAPEX p.a.	0	% losses		2018
Large	1587 EUR/tCO2/vessel	415 MWh/day	5 % of CAPEX p.a.	0	% losses		2018
						9	

7. CCUS

Technology	CAPEX <i>unit</i>	VOM <i>unit</i>	FOM <i>unit</i>	Efficiency/			TRL	Year
				losses	<i>unit</i>			
Carbon transport (pipeline)								
12" 2.5 MtCO ₂ /year Onshore	236,000 EUR/km/ (MtCO ₂ /yr)							2010
16" 5.0 MtCO ₂ /year Onshore	128,000 EUR/km/ (MtCO ₂ /yr)							2010
24" 15 MtCO ₂ /year Onshore	55,333 EUR/km/ (MtCO ₂ /yr)							2010
32" 30 MtCO ₂ /year Onshore	37,000 EUR/km/ (MtCO ₂ /yr)							2010
40" 50 MtCO ₂ /year Onshore	29,800 EUR/km/ (MtCO ₂ /yr)							2010
12" 2.5 MtCO ₂ /year Offshore	472,000 EUR/km/ (MtCO ₂ /yr)							2010
16" 5.0 MtCO ₂ /year Offshore	256,000 EUR/km/ (MtCO ₂ /yr)							2010
24" 15 MtCO ₂ /year Offshore	118,667 EUR/km/ (MtCO ₂ /yr)							2010
32" 30 MtCO ₂ /year Offshore	74,000 EUR/km/ (MtCO ₂ /yr)							2010
40" 50 MtCO ₂ /year Offshore	59,600 EUR/km/ (MtCO ₂ /yr)							2010
44" 50 MtCO ₂ /year	40,000 EUR/km/ (MtCO ₂ /yr)	17.11 kWh/tCO ₂						2012
48" 50 MtCO ₂ /year	44,000 EUR/km/ (MtCO ₂ /yr)	11.82 kWh/tCO ₂						2012
52" 50 MtCO ₂ /year	48,000 EUR/km/ (MtCO ₂ /yr)	7.98 kWh/tCO ₂						2012
56" 50 MtCO ₂ /year	52,000 EUR/km/ (MtCO ₂ /yr)	6.87 kWh/tCO ₂						2012
44" 50 MtCO ₂ /year	38,000 EUR/km/ (MtCO ₂ /yr)	24.74 kWh/tCO ₂						2012
14 Mt CO ₂ /year offshore	72,997 EUR/km/ (MtCO ₂ /yr)			4 % of CAPEX p.a.				2017
20 Mt CO ₂ /year offshore	48,132 EUR/km/ (MtCO ₂ /yr)			4 % of CAPEX p.a.				2017
30 Mt CO ₂ /year offshore	33,862 EUR/km/ (MtCO ₂ /yr)			4 % of CAPEX p.a.				2017

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Thank you

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