Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities

Power-to hydrogen/ Green hydrogen

Brussels, Fall 2017

This compilation of application-specific information forms part of the study ***"Development of Business Cases for Fuel Cells and Hydrogen Applications for European Regions and Cities"*** commissioned by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2 JU), N° FCH/OP/contract 180, Reference Number FCH JU 2017 D4259 .

The study aims to **support a coalition of currently more than 90 European regions and cities** in their assessment of fuel cells and hydrogen applications to support project development. Roland Berger GmbH coordinated the study work of the coalition and provided analytical support.

All information provided within this document **is based on publically available sources** and reflects the **state of knowledge as of August 2017**.

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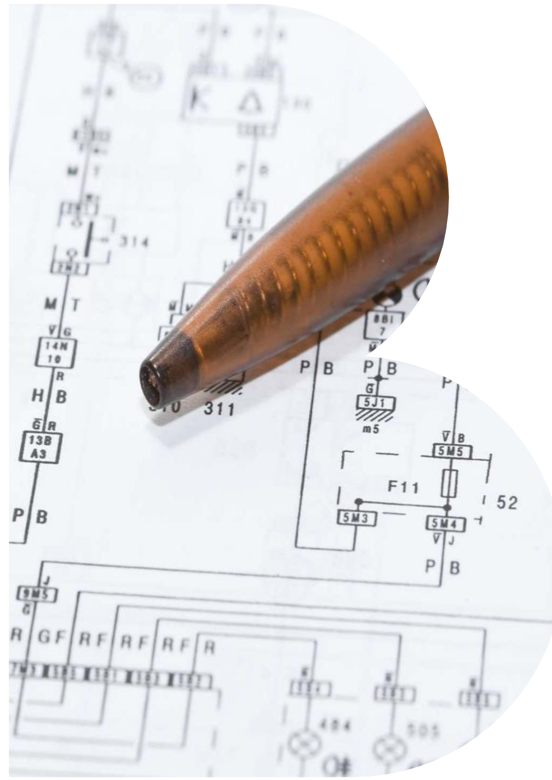
A. Technology Introduction



Electrolysers produce hydrogen from renewable energy electricity with significantly less emissions than conventional technologies

Power-to-Hydrogen / "green hydrogen"

Brief description: "Green hydrogen" production technologies produce hydrogen via an electrolyser using electricity from renewable energy sources and are therefore more sustainable than conventional hydrogen production technologies

Use cases: Cities and regions can use/promote green hydrogen production to provide a wide spectrum of services ranging from various grid services or energy storage to hydrogen refuelling stations or industrial use

Power-to-Hydrogen / production of "green hydrogen"[1]

Key components	Connection to electricity grid, electrolyser, storage facility, offtake interface, fuel cell if applicable
Electrolysis type / principle	Alkaline, Proton Exchange Membrane, (Solid Oxide)
Power consumption (1-20 MW)	51-63 kWh/kg
Tap water requirement	15 L/kg
CAPEX (1-20 MW plant size)	750 – 1,500 EUR/kW
OPEX (1-20 MW plant size)	2-4% of CAPEX
Original Equipment Manufacturers	Areva, H2B2, H2 Nitidor, Hydrogenics, Hygear, ITM Power, NEL Hydrogen, McPhy, Siemens, Sunfire, EPS, Fronius
Typical customers	Dependent on H_2 use/offtake, e.g. HRS operators, industry, TSOs, DSOs[2], natural gas network
Competing technologies	SMR, Biogas SMR, Industrial by-product hydrogen

1) Technology details based on FCH 2 JU study: "Study on early business cases for H2 in energy storage and more broadly power to H2 applications"; June 2017
2) Transmission System Operator / Distribution System Operator

Source: FCH 2 JU, Roland Berger

A

Alkaline (ALK) and Proton Exchange Membrane (PEM) are the most common electrolyser technologies in the market

Key figures of Power-2-Hydrogen technologies (as of 2017)

1b/4

	Units	Alkaline electrolysis (ALK)						Polymer electrolyte membrane electrolysis (PEM)					
		2017 @ P atm			2025 @ 15 bar			2017 @ 30 bar			2025 @ 60 bar		
		1 MW	5 MW	20 MW	1 MW	5 MW	20 MW	1 MW	5 MW	20 MW	1 MW	5 MW	20 MW
Minimum power	% Pnom	15%			10%			5%			0%		
Peak power – for 10 min	% Pnom	100%			100%			160%			200%		
Pressure output	Bar	0 bar			15 bar			30 bar			60 bar		
Power consumption @ P nom	kWhe/kg	58	52	51	55	50	49	63	61	58	54	53	52
Water consumption	L/kg	15 L/kg											
Lifetime – system	Years	20 years											
Lifetime – stack @ full charge	hr	80,000 h			90,000 h			40,000 h			50,000 h		
Degradation – system	%/1000 h	0.13%/1,000 h			0.11%/1,000 h			0.25%/1,000 h			0.20%/1,000 h		
Availability	%/year	>98%											
CAPEX – total system equipment	EUR/kW	1,200	830	750	900	600	480	1,500	1,300	1,200	1,000	900	700
OPEX – electrolyser system	% CAPEX	4%	3%	2%	4%	3%	2%	4%	3%	2%	4%	3%	2%
CAPEX – stack replacement	EUR/kW	420	415	338	315	300	216	525	455	420	300	270	210

Source: FCH2 JU

Numerous demonstration projects have already been deployed all over Europe using various electrolyser technologies

Power-to-Hydrogen / "green hydrogen"

Overall technological readiness: Depending on technology used, system in prototype phase or at pre-commercial / commercial stage; given the significant interest from industry and policy makers alike, there are significant efforts in demonstration projects and deployment initiatives all over Europe

TRL*

1	2	3	4	5	6	7	8	9
Idea	Tech. formulation				Prototype		Fully commercial	

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project budget
H2Future		2017	One of the biggest green hydrogen production sites worldwide; 6 MW PEM electrolyser, funded by FCH 2 JU with EUR 12m. Hydrogen used for industrial use and for balancing the power reserve market	EUR 18 m
Ingrid		2016	1.2 MW Alkaline electrolyser for renewable energy electricity with a solid hydrogen storage system and a fuel cell for re-electrification and other use cases	n.a.
GrInHy		2016	Production of green hydrogen for a Steel Company. Solid oxide electrolyser cell (SOEC) with 80% efficiency, 40 Nm^3 H_2/h output	EUR 4.5 m
European Marine Energy Centre (EMEC)		2015	Storage capacity of 500 kg compressed hydrogen; 0.5 MW PEM electrolyser with integrated compression absorbs excess energy from tidal turbines	n.a.
Mainz Energy Farm		2014	6 MW, high-pressure PEM electrolyser with targeted output of 200t H_2/year; Power from windfarms	n.a.
Jupiter1000		2014	Demonstration project of renewable energy electricity storage in a transmission gas grid via Alkaline and PEM electrolysers of 0.5 MW each. Commissioning and start-up in 2018	n.a.
WindGas Falkenhagen		2013	Production of 360 Nm^3 H_2/h green hydrogen from wind energy via 2 MW electrolysers in Falkenhagen. Injection of hydrogen into gas grid	n.a.

*) Technology Readiness Level ≤ 5 6-7 8-9

Source: Roland Berger

Power-to-hydrogen enables use of excess electricity and presents environmental friendly way of producing hydrogen

Power-to-Hydrogen / "green hydrogen"

Use case characteristics

Stakeholders involved

- Energy supplier, TSO, DSO
- Operator of electrolyser and ancillary infrastructure (if applicable)
- Public authority (e.g. regulator, etc.)
- H_2 consumer (if applicable)

Demand and user profile

Various options depending on the subsequent use of the hydrogen:

- use of base-load electricity
- use of peak load electricity
- use during times of low electricity prices

Deployment requirements

- Intermittent renewable energy sources nearby
- Adequate downstream infrastructure (e.g. satisfactory storage facility or connection to the gas grid or H_2 consumer)

Key other aspects

- n/a

Benefit potential for regions and cities

Environmental

- Optimal use of generated excess electricity that would otherwise be wasted
- Depending on the subsequent use of hydrogen significant reduction in emissions as green hydrogen is produced and used

Social

- Reduced retail electricity prices as cost for re-dispatch reduce with large-scale deployment. Therefore positive effects for especially low income households that are increasingly affected by rising electricity prices
- Increased stability of power supply if hydrogen is also used for grid services

Economic

- Price arbitrage opportunity based on production during low energy price periods and re-electrification during higher price periods
- Depending on regulatory framework, opportunity for additional revenues if green hydrogen is used for power-to-power grid services, for example frequency restoration reserve

Other

- Depending on the country and its regulation, feed-in tariffs exist for the re-electrification of green hydrogen

Source: Roland Berger

Total electricity cost and hydrogen prices as critical issues for the development of the green hydrogen market

Power-to-Hydrogen / "green hydrogen"

Hot topics / critical issues / key challenges:

> Cost competitiveness (cost of electrolysers not yet competitive with conventional hydrogen production like SMR or hydrogen as industrial by-product because of high production cost)

> Increasing technical performance (higher efficiencies will enable significantly lower OPEX and thus, higher allowable electricity prices, making the case even with higher initial CAPEX)

> Regulation (highly regulated electricity market which is not harmonised within the European Union; various regulatory measures and challenges for grid services supply; access regulation to curtailed electricity unclear)

> Total electricity cost as key input factor (rising electricity cost reduce competitiveness; business case highly dependent on electricity prices)

> System size (influences the project CAPEX and equipment related OPEX)

> Development of hydrogen prices (influences the potential revenue a green hydrogen production plant can generate)

> Potential levelling of feed-in tariffs for injecting into the gas grid for hydrogen compared to biogas

Further recommended reading:

> FCH 2 JU: "Study on early business cases for H2 in energy storage and more broadly power to H2 applications"; June 2017
http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf

> FCH 2 JU: "Commercialisation of Energy Storage in Europe"; March 2015
http://www.fch.europa.eu/sites/default/files/CommercialisationofEnergyStorageFinal_3.pdf

Key contacts in the coalition:

Please refer to working group clustering in stakeholder list on the share folder

https://sharefolder.rolandberger.com/project/P005

Source: Roland Berger

B. Preliminary Business Case

B

Production cost of hydrogen critically depend *inter alia* on full load hours, installed capacity and effective power input cost

Approximation of cost of green H_2 – 2017 Scenario

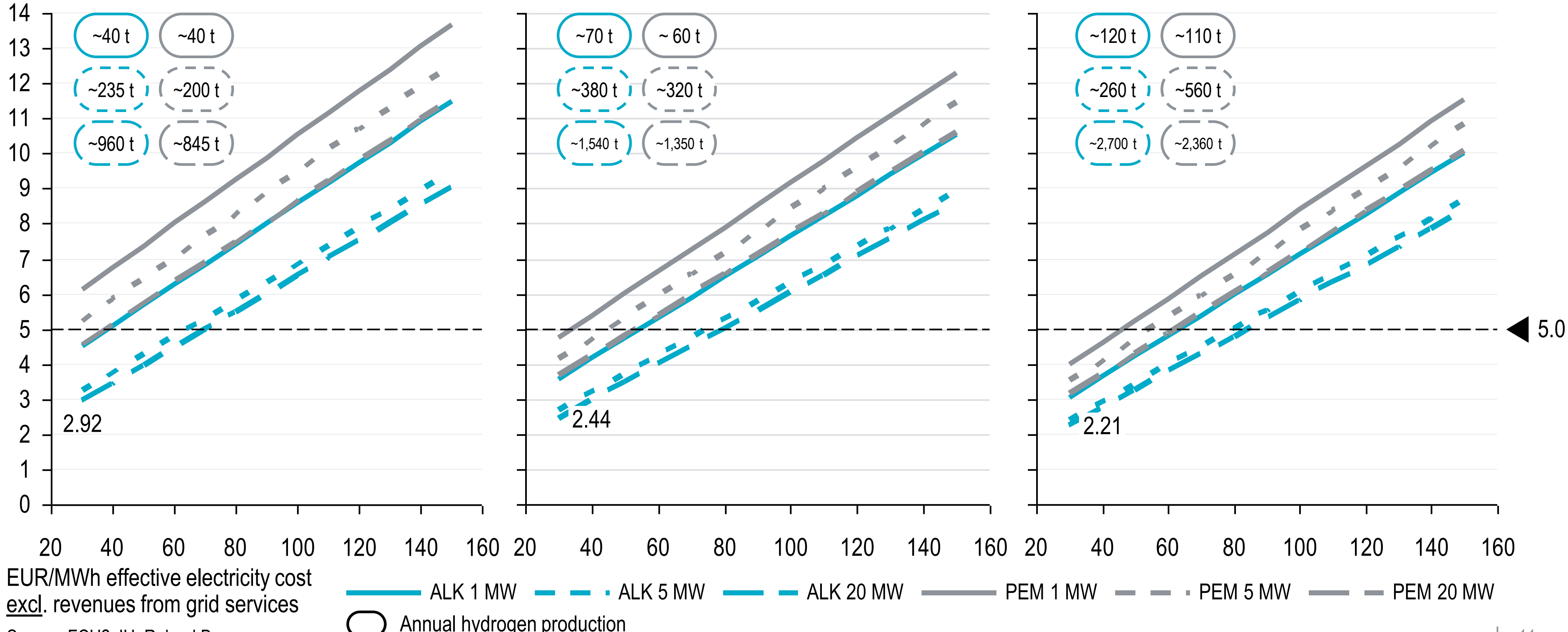
Indicative/Simplified

@ 2,500 hrs FTE p.a. … e.g. onshore wind central EU

@ 4,000 hrs FTE p.a. … offshore wind northern EU

@ 7,000 hrs FTE p.a. … baseload hydropower central/northern EU

EUR/kg



EUR/MWh effective electricity cost excl. revenues from grid services

Source: FCH2 JU, Roland Berger

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With lower cost and higher efficiencies, green hydrogen production cost are expected to decrease further in the long run

Approximation of cost of green H_2 – 2025 Scenario

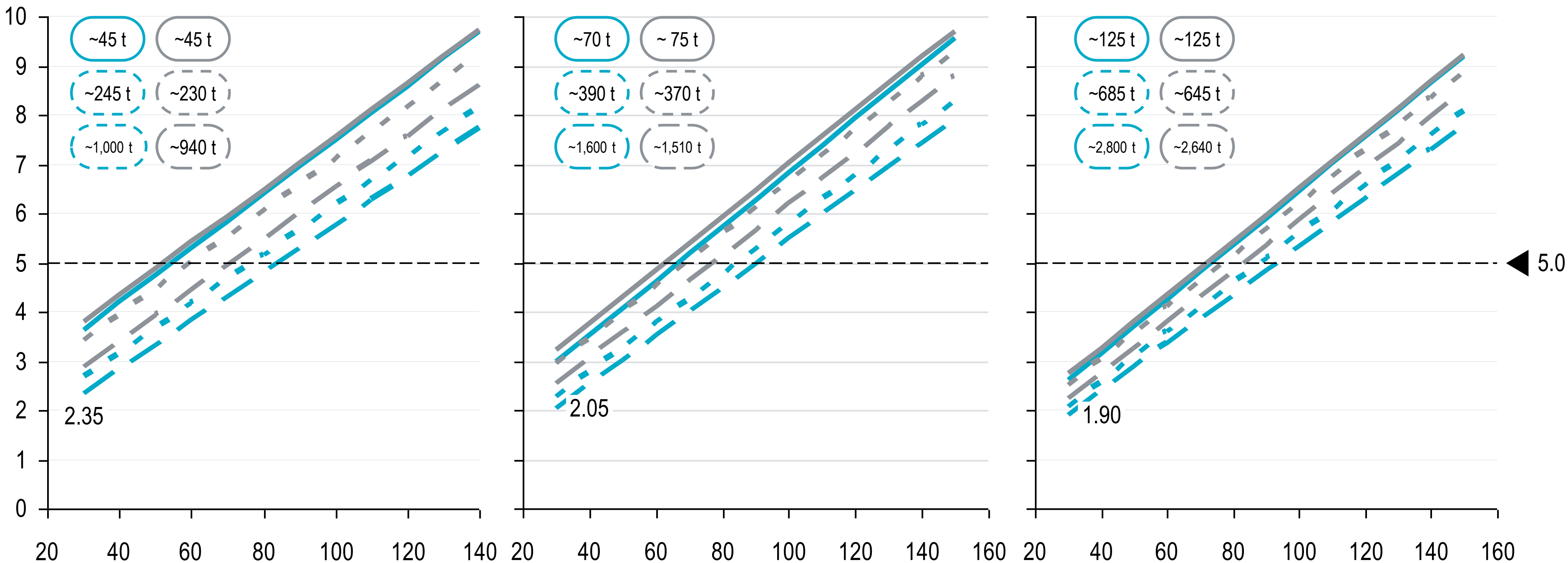
Indicative/Simplified

@ 2,500 hrs FTE p.a.
… e.g. onshore wind central EU

@ 4,000 hrs FTE p.a.
… offshore wind northern EU

@ 7,000 hrs FTE p.a.
… baseload hydropower central/northern EU

EUR/kg



EUR/MWh effective electricity cost excl. revenues from grid services

ALK 1 MW ALK 5 MW ALK 20 MW PEM 1 MW PEM 5 MW PEM 20 MW

Annual hydrogen production

Source: FCH2 JU, Roland Berger

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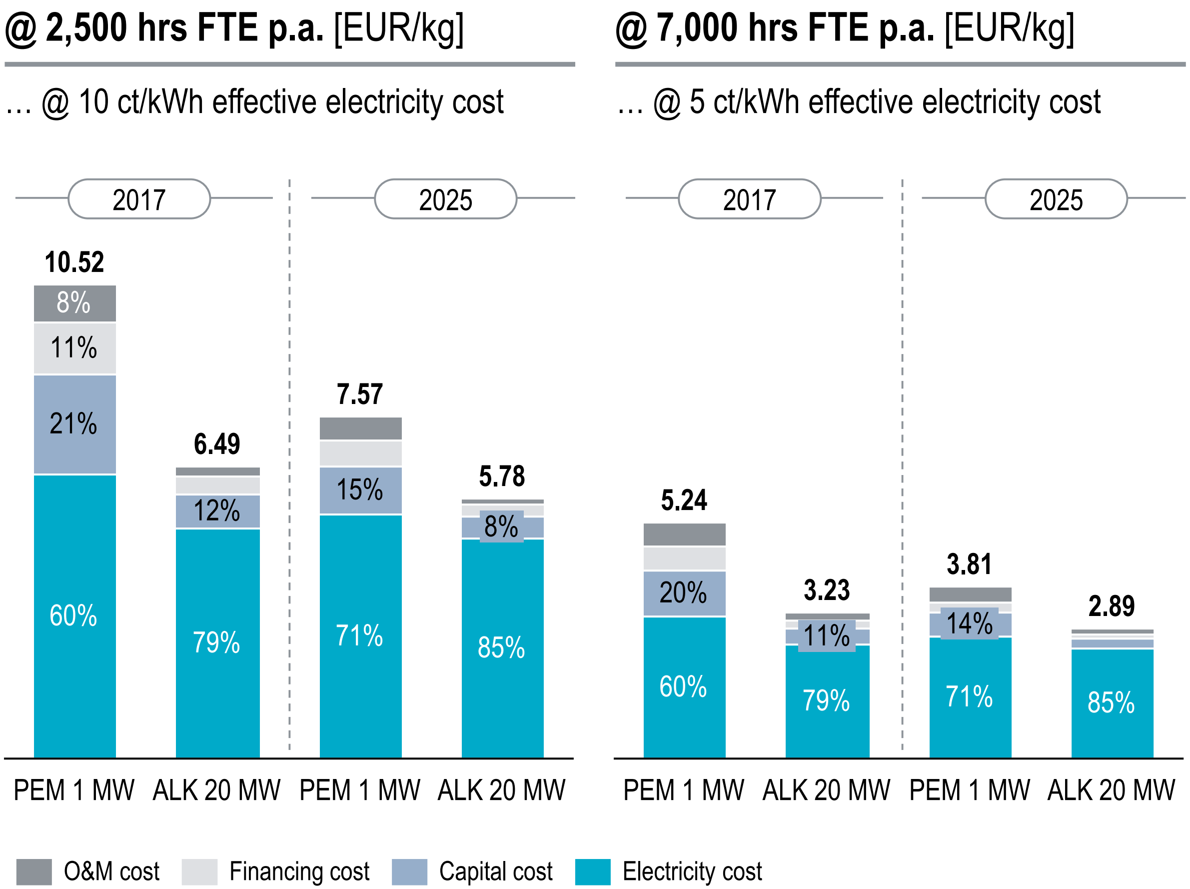
The cost of electricity is the largest cost component of the cost of green hydrogen production

Indicative cost break-down

Indicative/Simplified



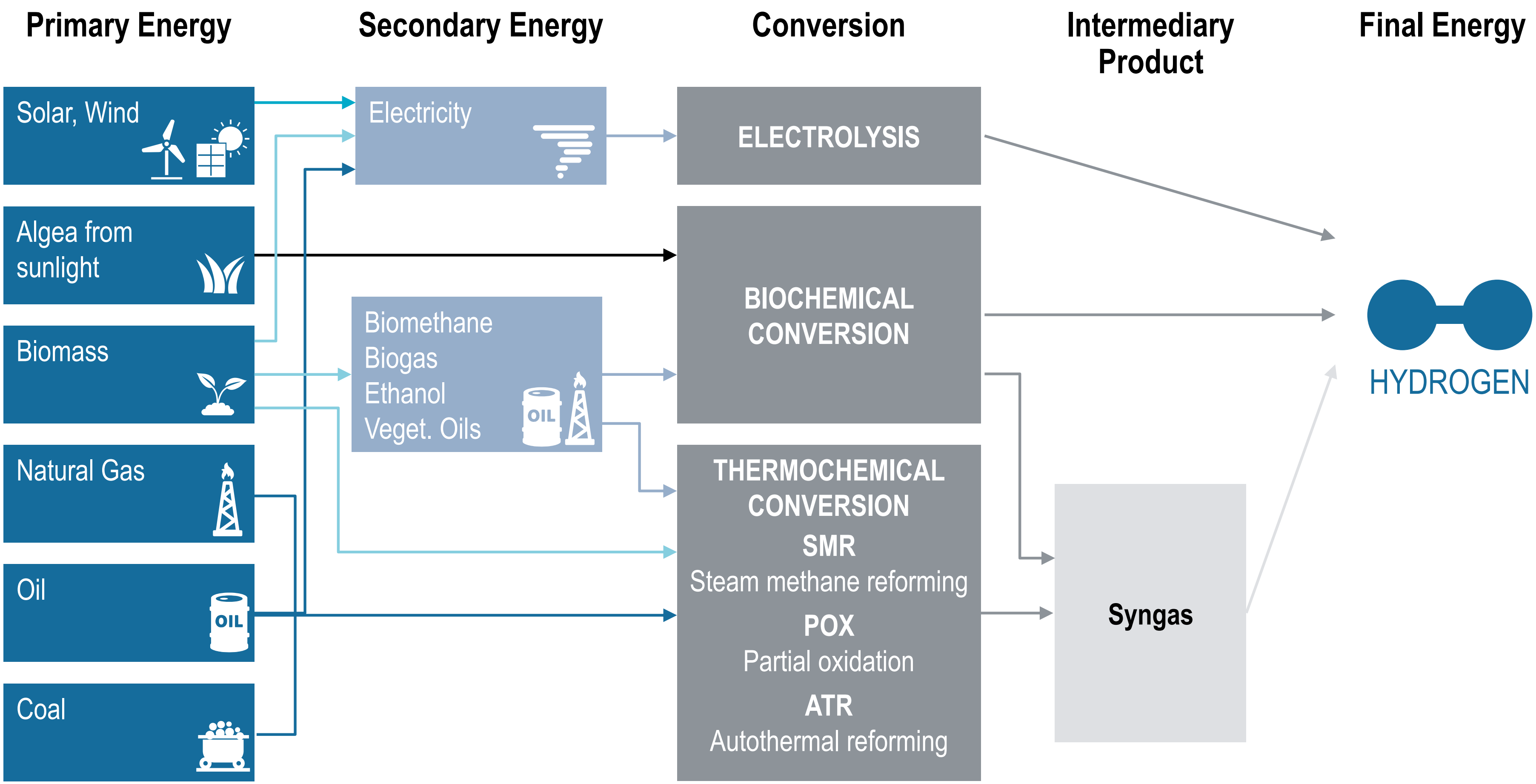
- > Cost of electricity makes up the largest part of the cost of production, followed by capital cost
- > Hence, the effective price of electricity is the key driver of any green hydrogen business case (on the cost side) – dep. on marginal cost of electricity, taxes, levies, surcharges, etc.
- > Structural cost reductions come from lower CAPEX, higher efficiencies and longer stack lifetimes
- > Please note: cost reductions through the provisions of grid services are not included yet

Source: FCH2 JU, Roland Berger

Recap: in principle, hydrogen can be produced by three major conversion methods

Different hydrogen production methods

Schematic/Simplified



Source: Shell, FCH2 JU, Roland Berger

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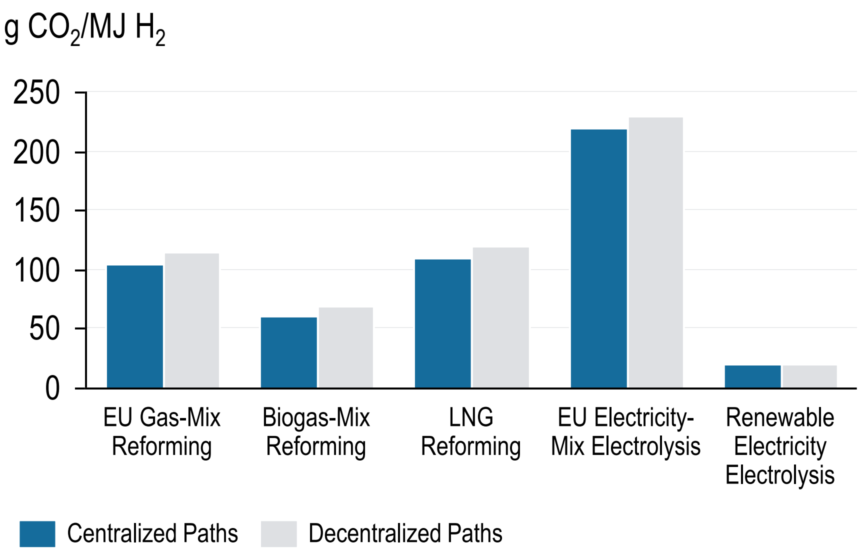
Green hydrogen might be comparatively more expensive in the short term – Fossil-fuel based H_2 causes higher CO_2 emissions

Comparison of key production methods

Indicative

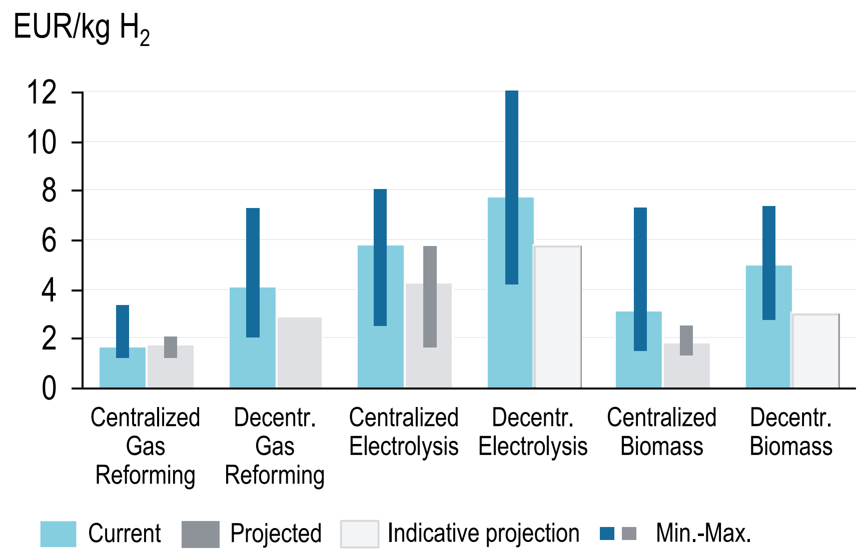
CO_2 emissions of hydrogen production



> Attributable CO_2 emissions depend on carbon intensity of underlying fuel mix (natural gas, biogas, electricity)

> Significant regional or supply-chain-related differences within each production method

Cost of hydrogen production[1]



> Production cost differ depending on plant size, capacity utilisation, raw material costs, etc.

> Decentralised gas reforming, centralised electrolysis and centralised biomass pathways in particular are expected to offer further cost-saving potential (esp. dep. on fuel prices, sustainability requirements)

1) Excl. cost of CO_2 abatement

Source: Shell, FCH2 JU, Roland Berger

CCS could be an alternative technology to "decarbonise" grey hydrogen from SMR, at higher total production cost

Excursus: SMR with Carbon Capture and Storage (CCS)

> SMR is the leading technology for hydrogen production from natural gas or light hydrocarbons. Reductions of CO_2 emissions beyond the efficiency-based minimum would only be possible by the integration of Carbon Capture and Storage (CCS)

> Several technical options exist for capturing CO_2 from an SMR-based hydrogen plant; the current standard is the is the capture of CO_2 from the shifted syngas using MDEA solvent

> CCS from hydrogen production can actually be a commercial operation, e.g. as supply of industrial and food grade CO_2 to various offtakers

> Adding CCS technology increases both capital cost and operating expenditure of the hydrogen plant (e.g. due to increasing natural gas consumption)

> Recent studies estimate that the Levelised Cost of Hydrogen from an SMR-based hydrogen plant would increase by 18-48% when including CCS technology (i.e. vs. a base case without CCS)

> Please refer to the following recent (and rather technical) study by the IEA's Greenhouse Gas R&D Programme for further information: "Techno-Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS" (IEAGHG Technical Report 2017-02, February 2017)

Source: IEAGHG, FCH2 JU, Roland Berger

Please do not hesitate to get in touch with us

Contact information

Carlos Navas
FCH2 JU

Strategy and Market Development Officer

carlos.navas@fch.europa.eu

+32 2 221 81 37

Source: FCH2 JU, Roland Berger