Hydrogen:
premium electrofuel
&
building block for all electrofuels

IEA Hydrogen - global hub for hydrogen R,D&D

Paul Lucchese, *Mary-Rose de Valladares*

IEA Electrofuels Workshop

10 September 2018

Hydrogen – why premium electrofuel?

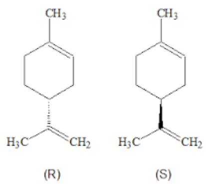
The strategic Hydrogen advantages

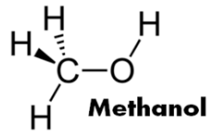
Hydrogen can play a transformative role as a highly flexible energy carrier during the clean energy transition and in an integrated future multi-sector energy system as follows:

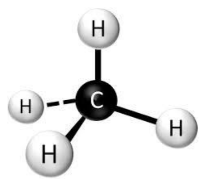
- For Sector coupling - as a bridge between different types of energies
- For Storage – utilizing electrical energy that would otherwise have been lost
- For Storage – enabling use of massive quantities of renewable energy
- For Stability - balancing grid and buffering energy system
- Decouple energy and power parameters for Recharging Infrastructure
- For feedstock – using captured carbon
- For certainty – avoiding CO2 capture from air

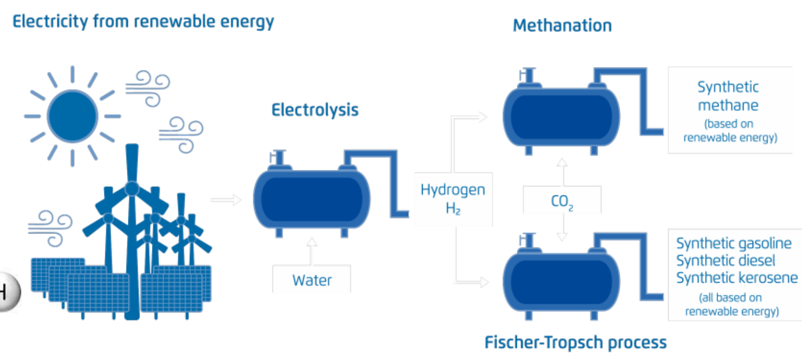
Hydrogen is a building block of all electrofuels

NH_3 ammonia



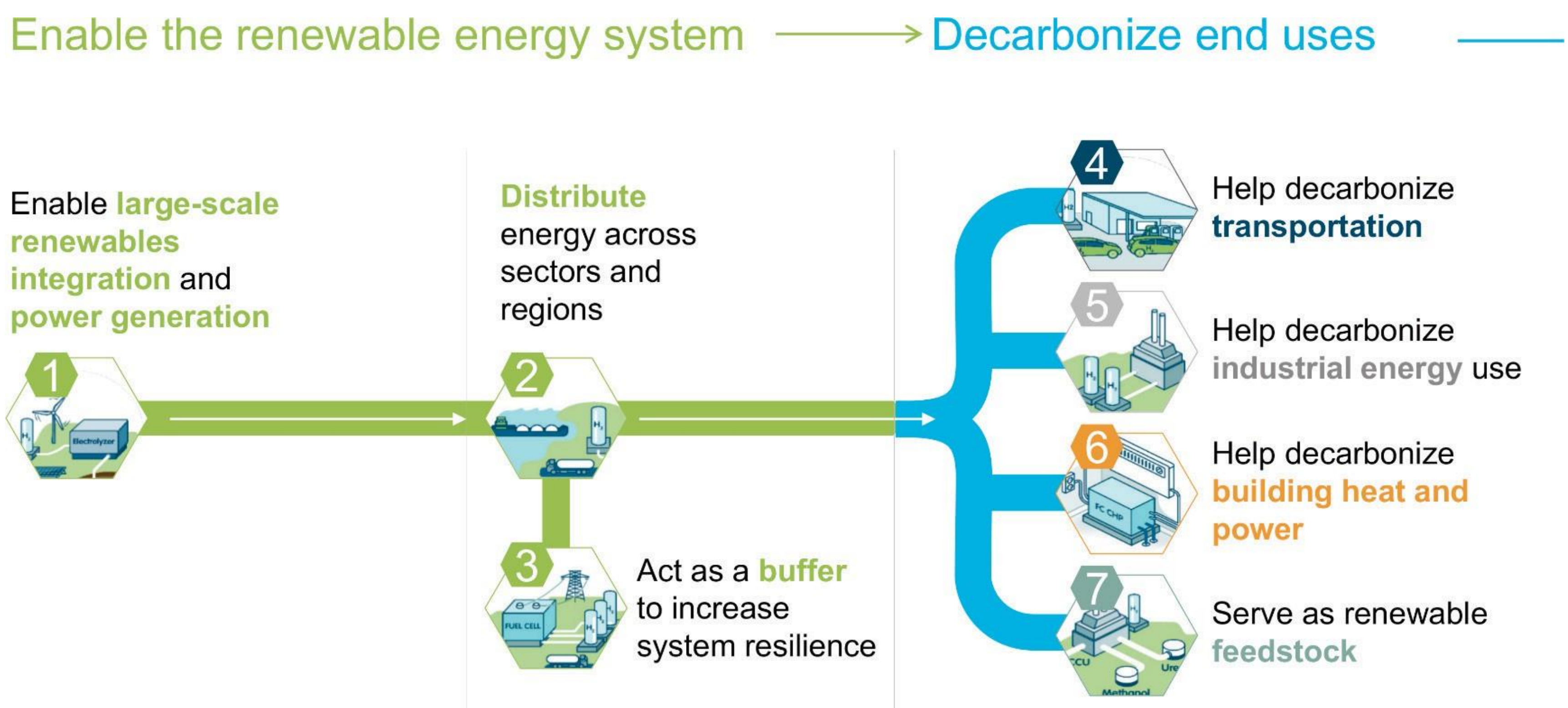






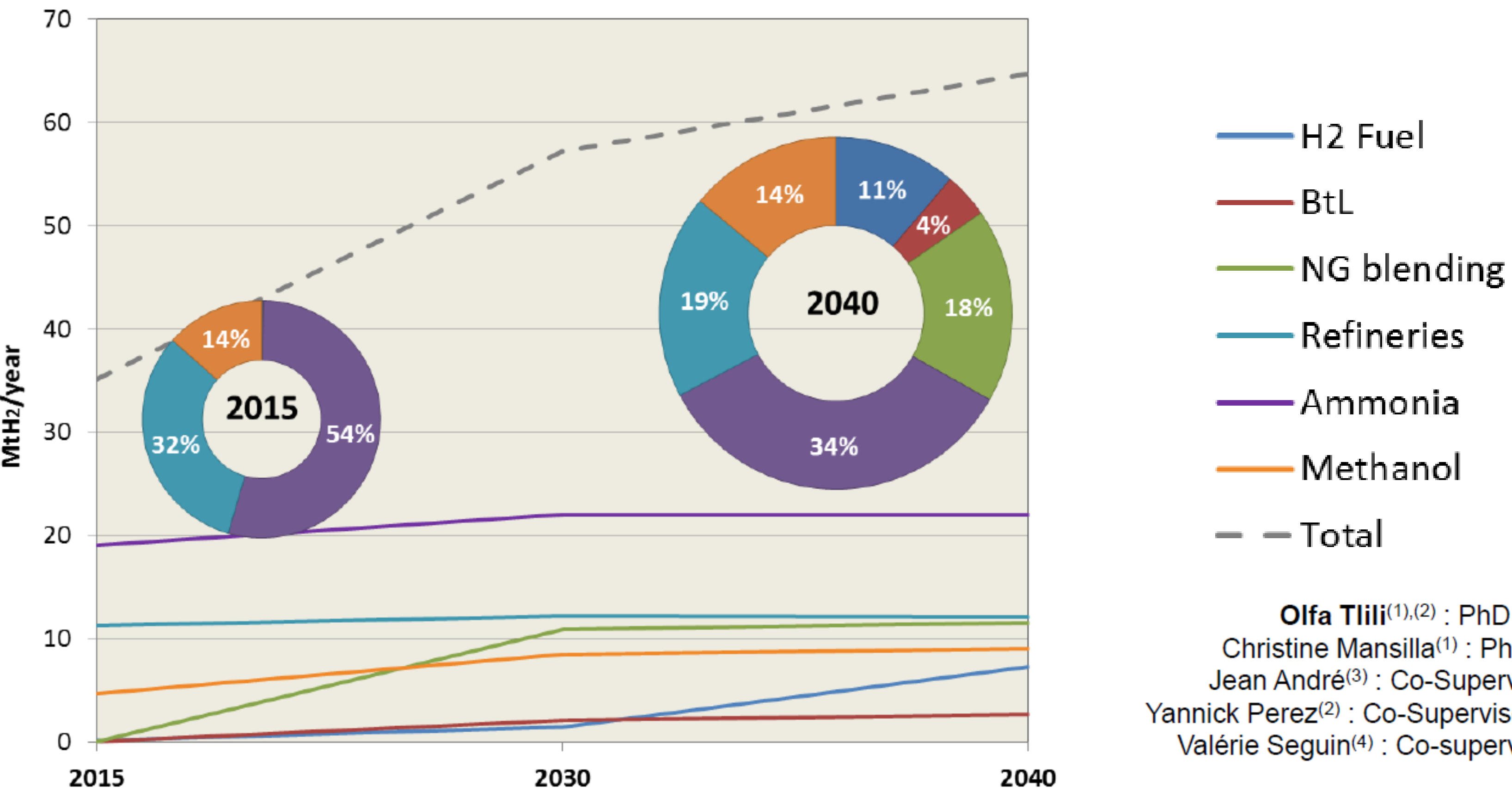
Consensus on multi-sector applications for Renewable Hydrogen
Hydrogen is a bridge between different energy sector

Hydrogen – Key to support the energy transition



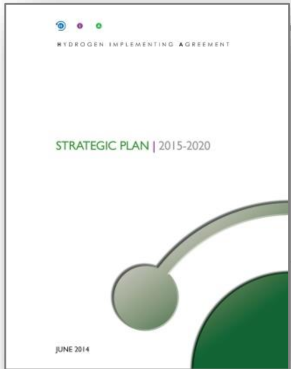
Source: Hydrogen Council

Hydrogen for industrial and chemical uses will remain predominent (Ammonia as Hydrogen carrier not taken into account)



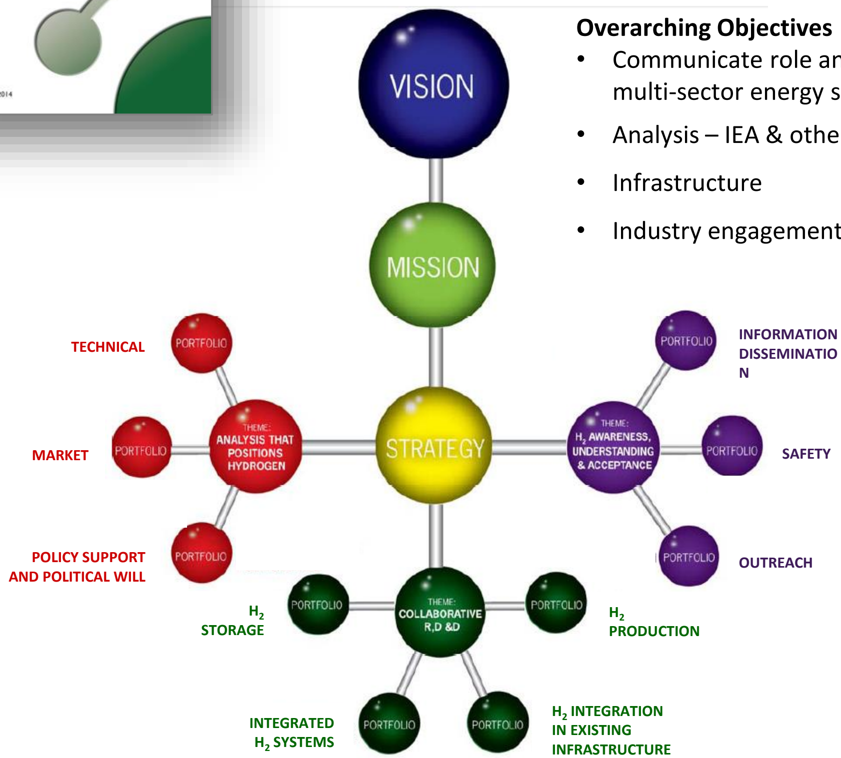
Olfa Tlili[(1),(2)] : PhD Student
Christine Mansilla[(1)] : PhD Supervisor
Jean André[(3)] : Co-Supervisor - Industry
Yannick Perez[(2)] : Co-Supervisor - Doctoral school
Valérie Seguin[(4)] : Co-supervisor – CEA Liten

IEA Hydrogen TCP – *Global Hub for hydrogen R,D&D*



Vision – a hydrogen future based on a clean, sustainable energy supply of global proportions that plays a key role in all sectors of the economy

Mission – accelerate H2 implementation and utilization to optimize environmental protection, improve energy security and economic development



Overarching Objectives

- Communicate role and value of hydrogen as flexible energy carrier in future integrated multi-sector energy system
- Analysis – IEA & other
- Infrastructure
- Industry engagement

Membership 20 Countries + EC+ UN + 4 Sponsors + 4 new members pending

THEME: COLLABORATIVE R,D &D

Collaborative R,D&D Portfolios

- Production
- Storage
- Integrated Systems
- Integrated Infrastructure

THEME: ANALYSIS THAT POSITIONS HYDROGEN

Analysis Portfolios

- Technical
- Market
- Political Decision-making

THEME: H_2 AWARENESS, UNDERSTANDING & ACCEPTANCE

Awareness, Understanding & Assessment (AUA) Portfolios

- Information Dissemination
- Safety
- Outreach

Direct Hydrogen/Fuel Cells Usage Options for transportation

Light Duty- Passenger Cars & Captive Fleets; Heavy Transport on Land - buses, heavy duty trucks, light rail trains, logistics/utility vehicles; Maritime and Air; Portables

Passenger Cars & Captive Fleets

Toyota Mirai | Honda Clarity | Hyundai Tucson | Hyundai Genesis

- Japanese vehicle production increases dramatically.
- FCEV registration is now being tracked in California.
- Norway anticipates application of FCEVs incentives similar to BEVs.

Buses

- **UC Transit in Oakland**, CA, USA - largest fleet in North America, with 12 fuel cell buses.
- Foshan and Yunfu – $17 million order for 300 fuel cell buses.
- EU Coordination a national Call for order in progress for a 1000 FC Buses
- French project for BEV/Range extender:300 vehicles with 20 HRS
- South Korea - planning to replace 27,000 CNG buses with FC buses by 2030.

Heavy Duty Trucks

Nikola Motor Company H2 powered **long range tractor trailer**

Logistics Vehicles

UPS - first hydrogen fuel cell electric class 6 delivery van. 17 vans in the U.S. by year end 2018.

Toyota a heavy duty drayage vehicle (class 8), **Amazon** buying $70 million of **fuel-cell forklifts.**

Light Rail Trains

In 2017, **Alstom** unveiled its **Coradia iLint**, which will **replace diesel trains** in the extensive, **un-electrified sections** of rail in Germany.

Airplanes & Drones

Hydrogen-powered Drone
Fuel cell technologies power drones varied applications from lightweight Hycopter to larger military based applications like the Boeing Insitu's ScanEagle drone.

HY4 Hydrogen Fuel Cell Electric Aircraft, World's first 4 seater H2 plane.

Maritime

90% of all trade is by ship. Maritime tourism is huge global industry.

The **Red and White Ferry Company** and **Sandia National Laboratory** have teamed up on a feasibility study for designing, building and operating a high-speed hydrogen fuel cell powered passenger ferry and refueling station.

Portables

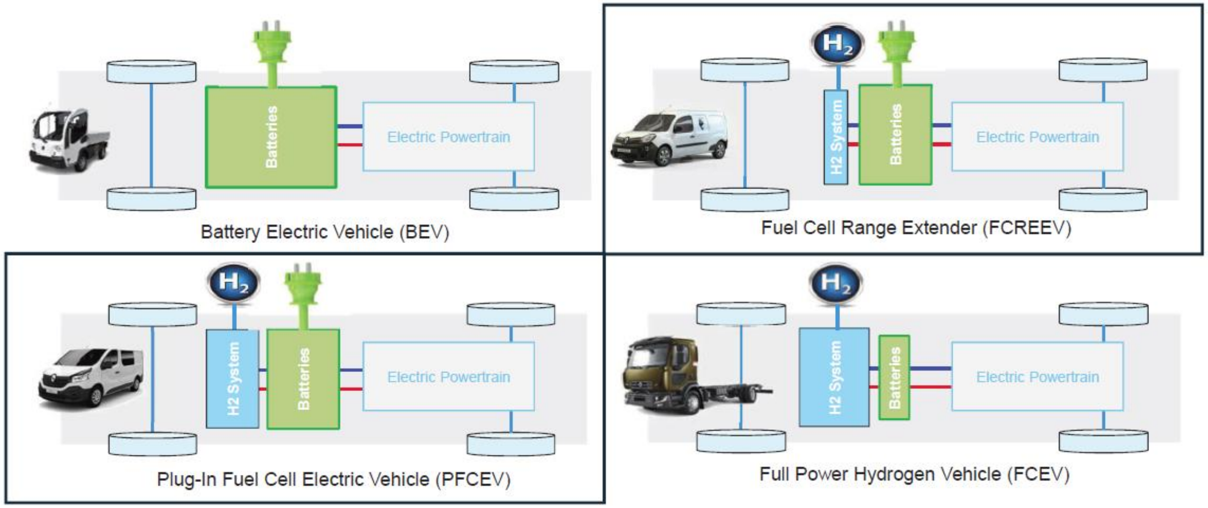
Battery and Fuel cell: a perfect technologies wedding in the electric car family

Hydrogen as a gas like others electrofuels has unique advantage to uncouple power to energy due to storage capacity
New fuels/electricity Infrastructure design will be key for massive deployment

La recharge électrique

La recharge hydrogène

Different design for power train architecture



Fonctionnement

1. Le moteur électrique assure une propulsion zéro émission.
2. La pile à hydrogène produit de l'électricité à bord.
3. La batterie et la pile hydrogène alimentent le moteur.
4. La batterie se recharge sur le secteur, l'hydrogène à la station.

Hydrogen Pathways

Hydrogen Production via Electrolysis : key technology conventional, renewable and innovative production RES technologies

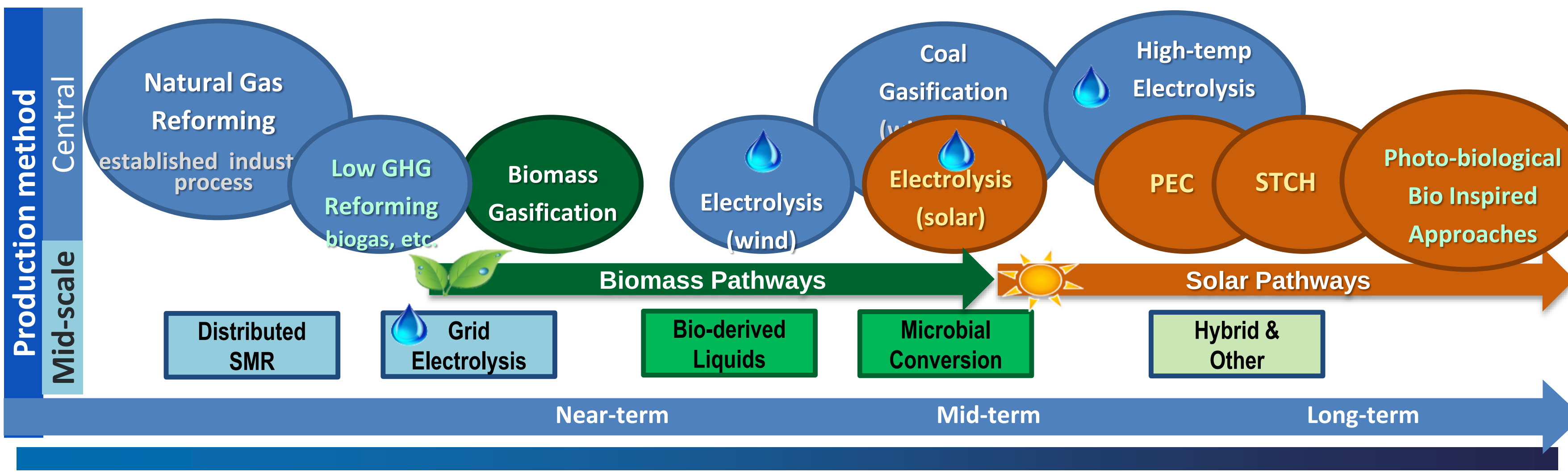
Via Electrolysis

Electrolysers available in small and large sizes (now in MWs!)

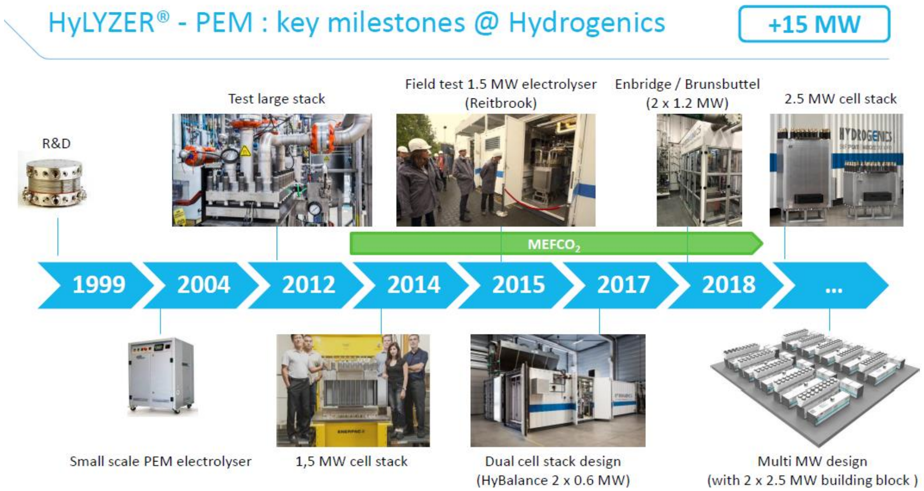
Electrolysers available in low and high temperature technologies:

Low – alkaline and polymer electrolyte membrane (PEM)
High – solid oxide electrolyser (SOEC)

Via conventional, renewable & innovative RES technologies

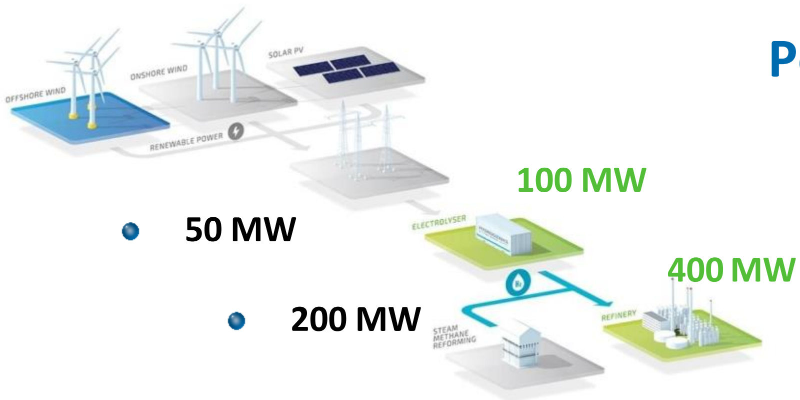


PEM Electrolyser Scaling Up



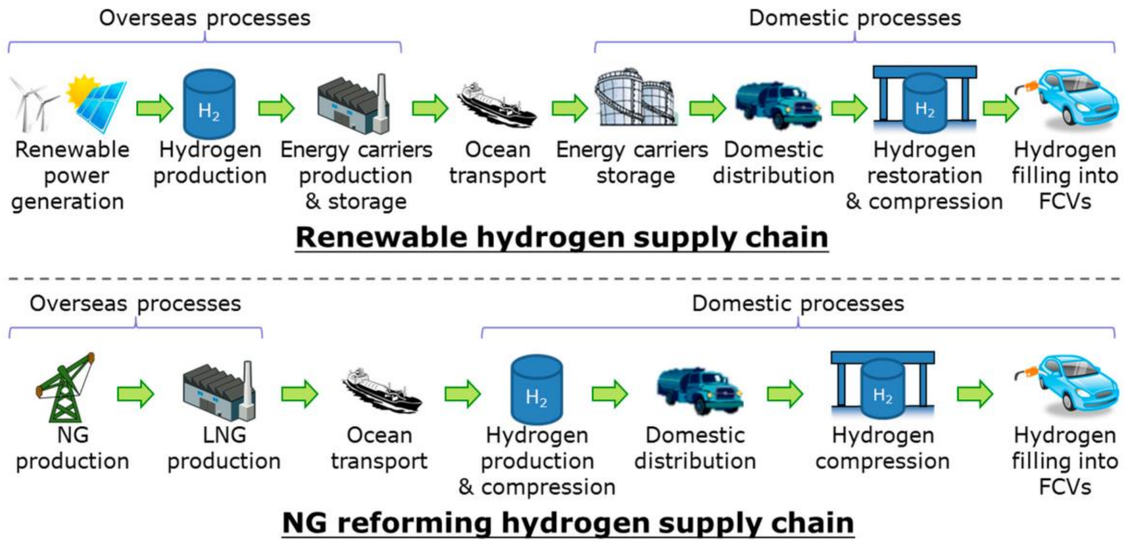
Power-to-Fuels

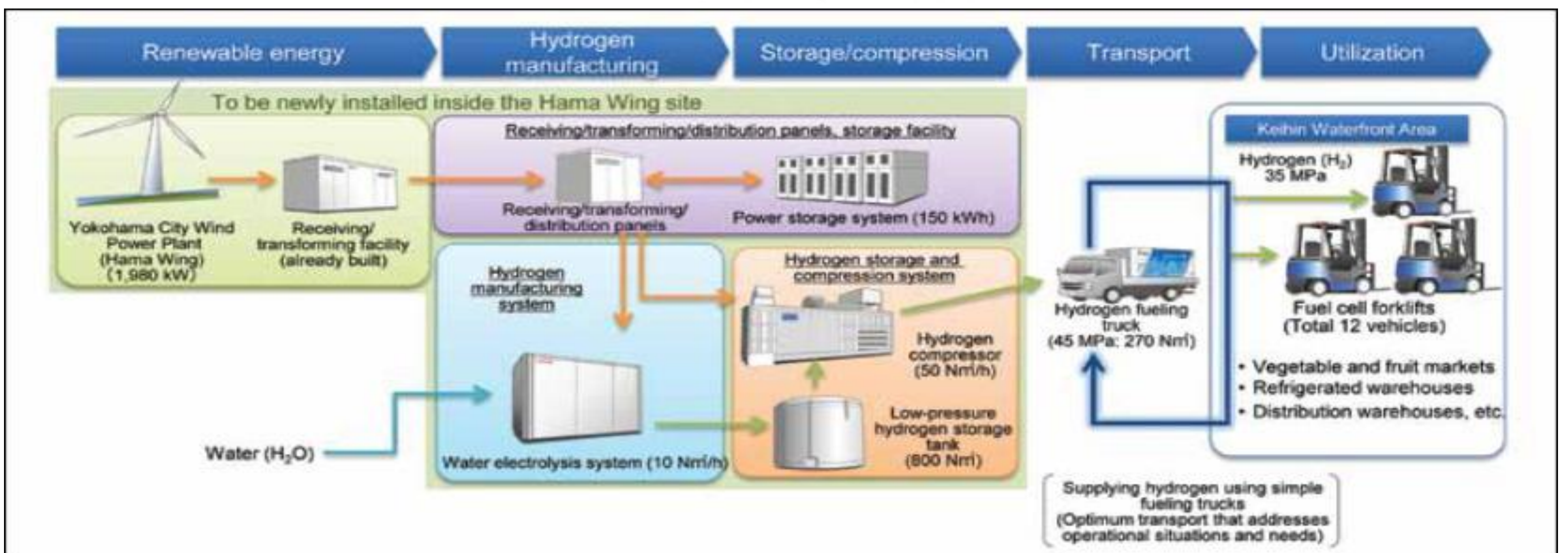
Power-to-Fuel



- Hydrogen
- Synthetic fuels / gases ($H_2 + CO_2$)
- Power-to-Refinery

Transport and Distribution – Renewable Supply Chain



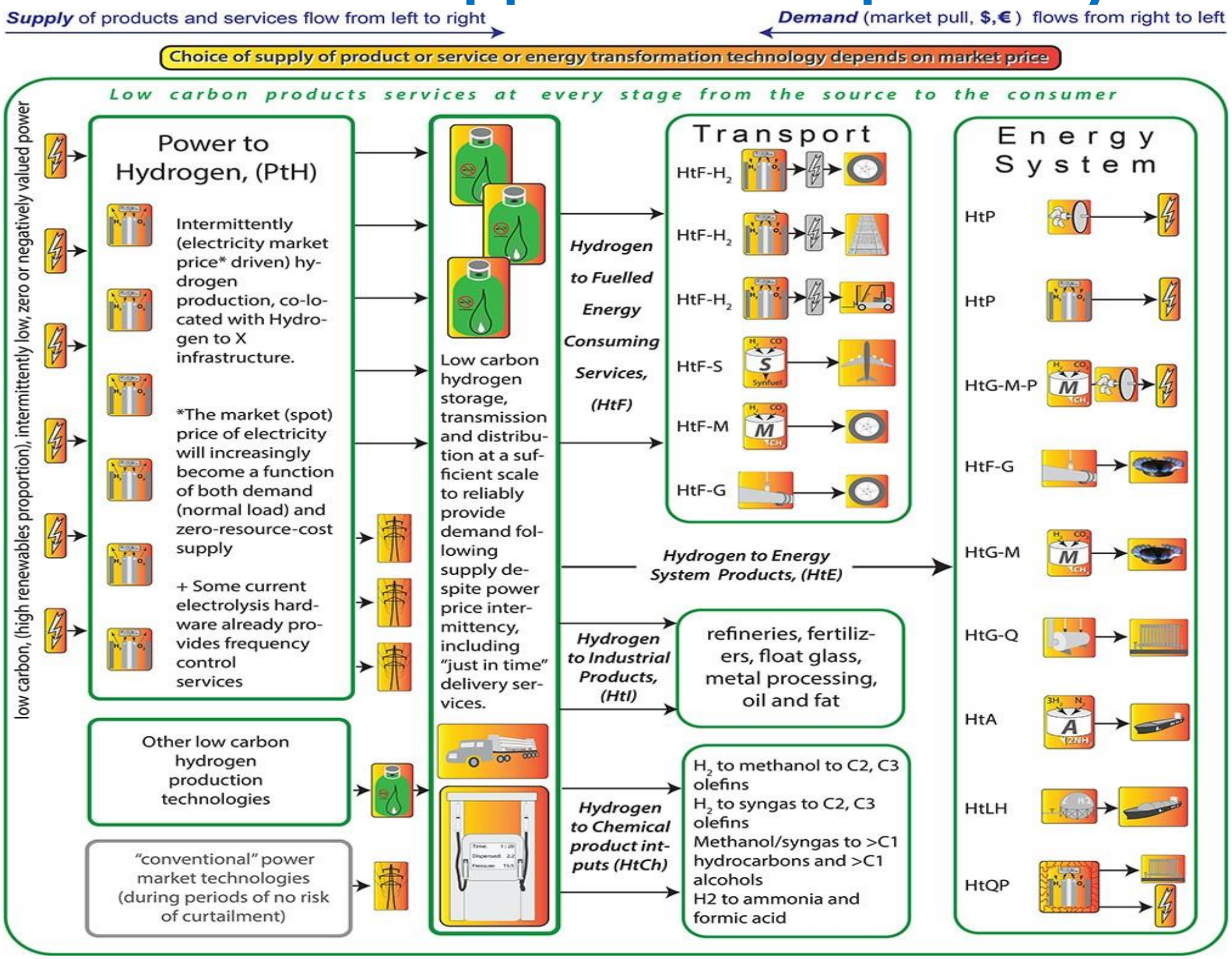


Production Pathways: Power-to-Hydrogen and Hydrogen-to-X: all sectors, applications & pathways

IEA Hydrogen Technology Collaboration Program (TCP)

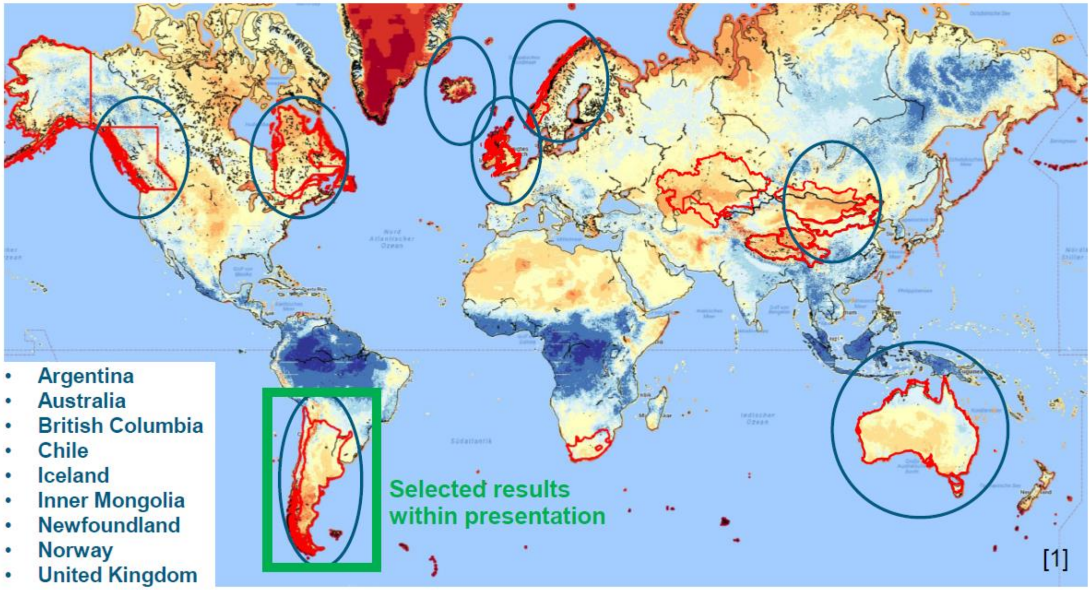
Task 38: Power-to-Hydrogen and Hydrogen-to-X: System analysis of the techno-economic, legal and regulatory conditions

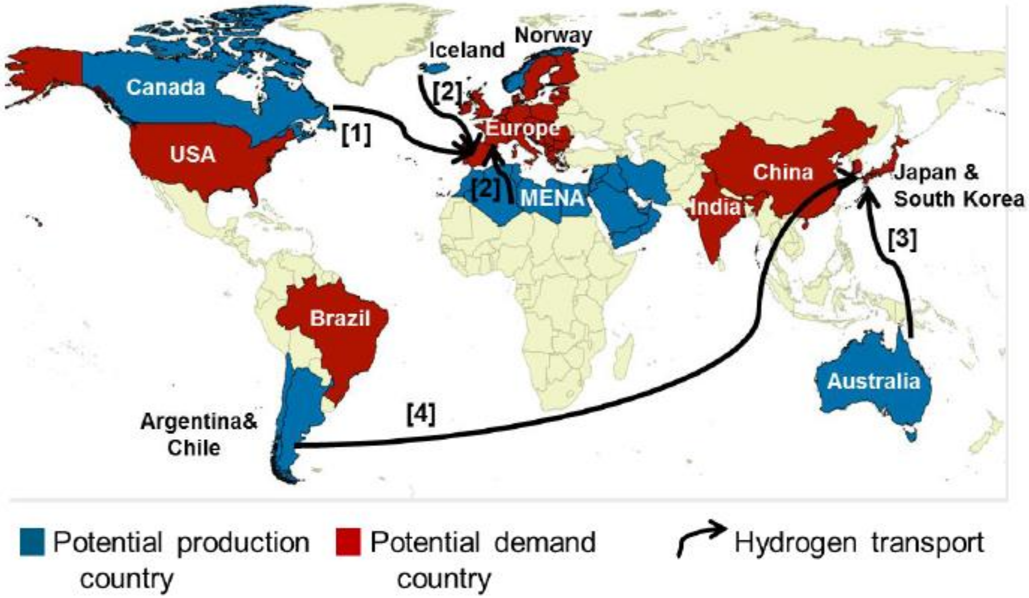
Time Frame: 2016 - 2019



The new « Hydrogen » Roads ?
Work in progress in Task 38: definition of new business cases

Wind Potential of Selected Countries





- Etude FZJ*: Possible and feasible production of possible de produire 9Mt/year from wind in Patagonia (Santa Cruz) (3cts/kWh) To Japan at a cost of 5 US $/Kg H2
- Different options for supply chain
- Renewables but also fossils+CCS
- Japanese government: ambitious goal and R&D programme
- International trade framework to be adapted

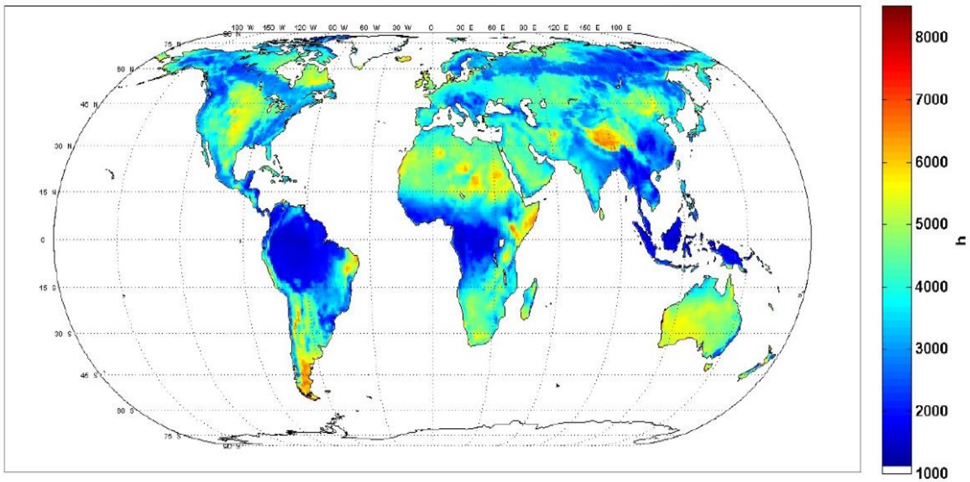
* P.Heuser, M. Reuss, T.Grube, M.Robinius, D.Stolten, FZJ, IK3 Whec 2018, Rio de Janeiro

Cost

New 2017 Study from IEA Renewable Division - Renewable Hydrogen (for industrial applications) is now an option! Scale up (competition, volume) is driving costs down

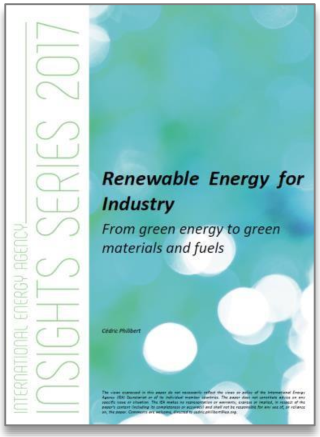
The emergence of low-cost renewable power is a game-changer

Hybrid solar and wind full load hours adjusted for overlap

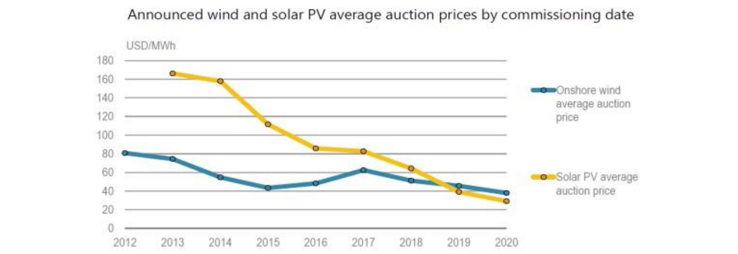


Source: Fasihi & Breyer, 2017

Capacity factors of combined wind and solar power exceeds 50% in vast areas, often remote from large consumption centers, potentially delivering huge amounts of power at less than $30MWh

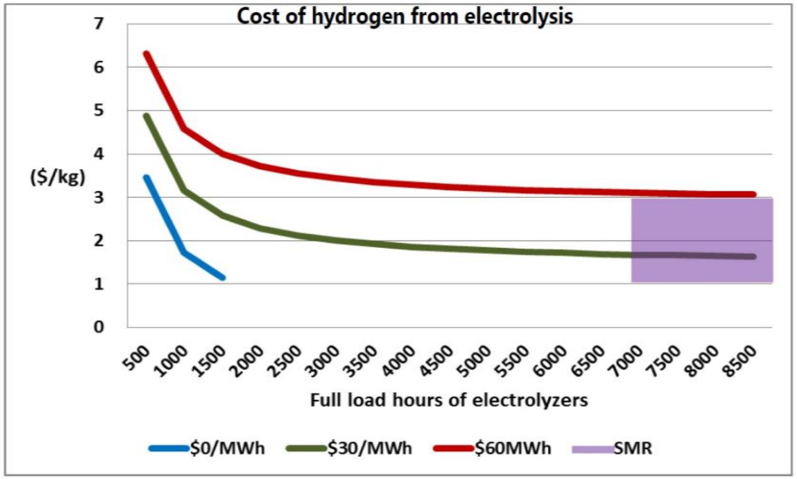


Competition driving costs down



Price discovery through competitive auctions effectively reduces costs along the entire value chain
Forthcoming expansion of auctions to more countries will accelerate cost reduction trends

Producing hydrogen from cheap solar and wind power



At USD 30/MWh or less, and with high capacity factors, solar and wind power in best resources areas can now generate hydrogen at competitive costs.

IEA Hydrogen Task 38 Electrolyser Technology Brief

KEY FINDINGS

- For alkaline systems CAPEX of 750 €/kW is reachable today for a single stack of 2 MW.
- For PEM, such CAPEX should become within reach for 5 MW systems, but currently still require the use of multi-stack systems.
- CAPEX value below 400€/kW have been projected for alkaline systems, but this will require further upscaling up to 100 MW.

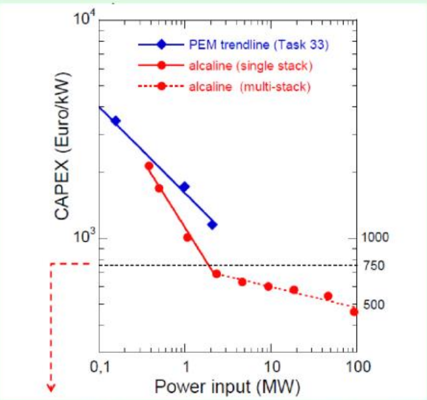


Fig. 1 CAPEX data for both PEM and alkaline electrolysers, plotted as a function of the power input. Data for alkaline systems are based on a single stack of 2.13 MW considering 230 cells, 2.6m² size. Note that change in slope for alkaline electrolysers corresponds to the use of multi-stack systems. [1]

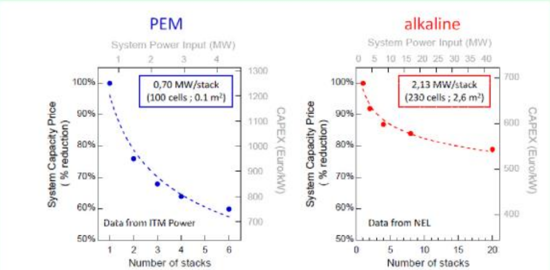
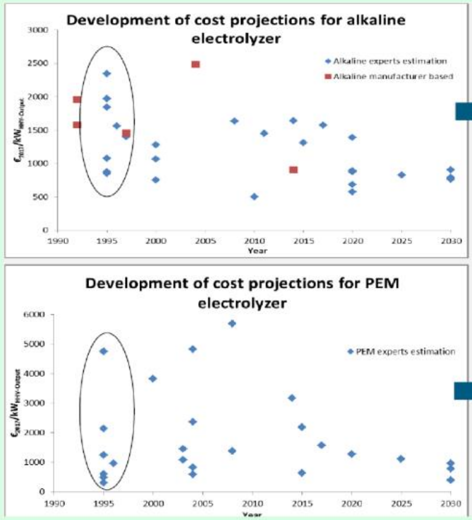


Fig. 3. Reduction in CAPEX upon use of multi-stack systems, both for PEM (left) and alkaline (right) electrolysers.

Fig. 2 Reduction in CAPEX upon use of multi-stack systems, both for PEM (left) and alkaline (right) electrolysers. [1]

KEY FINDINGS (continued)

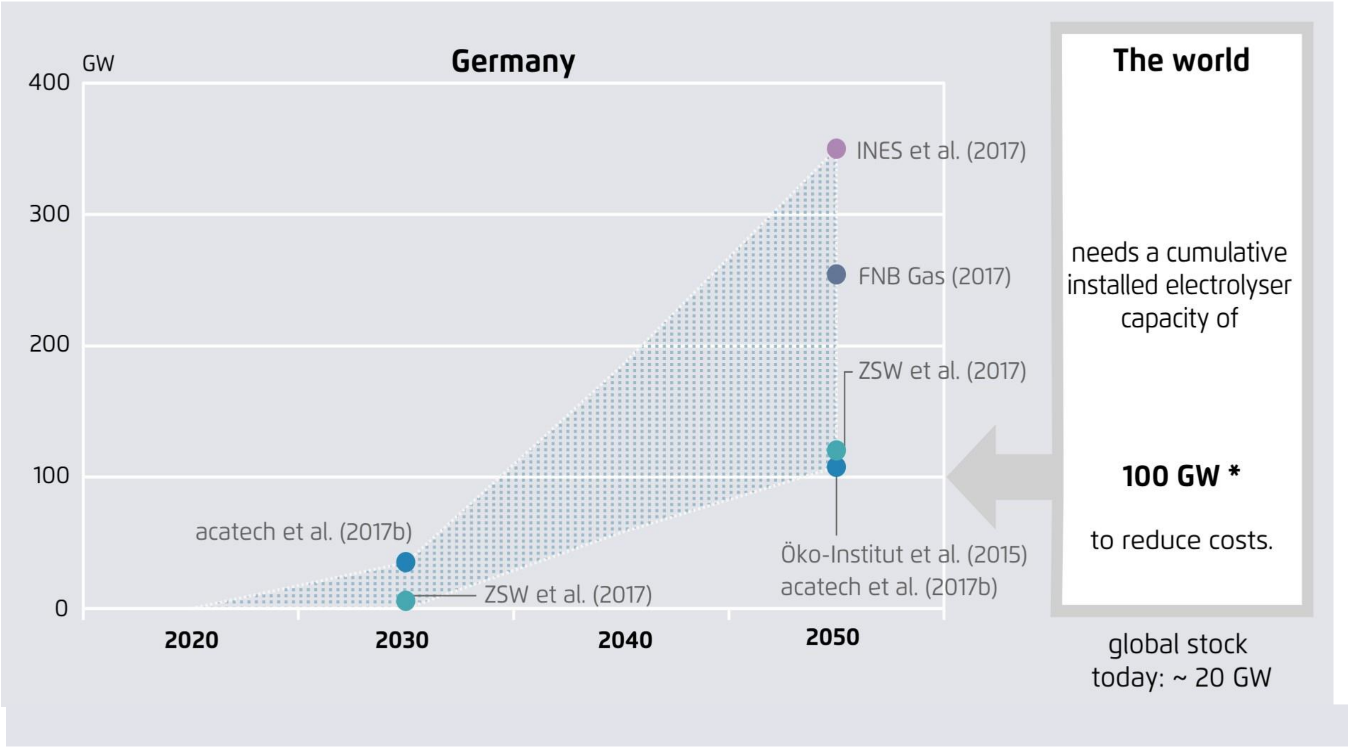


- **Range** of estimations **in 1990s for alkaline** was between **~800 and ~2500 €$_{2017}$/kW$_{HHV\text{-}Output}$**
- Today´s expectation for **2030** for alkaline droped to **~700 to ~1000 €$_{2017}$/kW$_{HHV\text{-}Output}$**.
- Alkaline: Reductions more moderate compared to PEM.
- This can be explained with the maturity of the alkaline technology
- **Range** of estimations **in 1990s for PEM** was between **~300 and ~5000 €$_{2017}$/kW$_{HHV\text{-}Output}$**
- Today´s expectation for **2030** for PEM droped to **~400 to ~1000 €$_{2017}$/kW$_{HHV\text{-}Output}$**

Fig. 3 Cost projections in the near to long term, for alkaline and PEM electrolysers [2]

Desired cost reductions require investment in electrolysers like other new energy technology PV requires more than 400GW to reduce costs as it is today

Installed electrolysis capacity for PtG/PtL in scenarios for Germany in GW



- → **Scale and learning effects** are critical for cost reduction, but uncertain (e.g. CO_2 from air).
- → International **100-gigawatts-challenge**.
- → Investments are not to be expected without **political intervention or high CO_2 price** due to high cost of synthetic fuels.

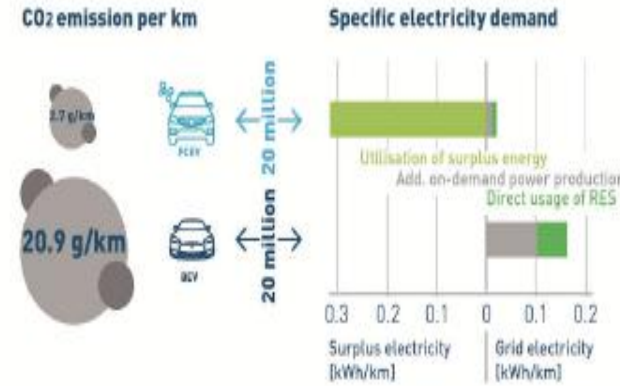
Own illustration based on Frontier Economics (2018) and others

Hydrogen Infrastructure for Mobility:
new comparative analysis dispels tale of H2 infrastructure cost barrier

Infrastructure Designs

	Ramp up	Mass market		
	0.1 million	3 million	10 million	20 million
cable length		1,800 km	28,000 km	183,000 km
transformer		6,100	55,000	187,000
slow chargers	100,000 @ 3.7 kW	2.8 million	6.5 million	11 million @ 22 kW
fast chargers	6,000 @ 150 kW	81,000	175,000	245,000 @ 350 kW
storage capacity		2 TWh	5 TWh	10 TWh
electrolysis		3 GW	10 GW	19 GW
truck trailer	42	730	1,500	3,000
pipeline		12,000 km	12,000 km	12,000 km
fueling	400	1,500	3,800	7,000

Member of the Helmholtz Association IEK-3: Institute of Electrochemical Process Engineering 15 JÜLICH Forschungszentrum

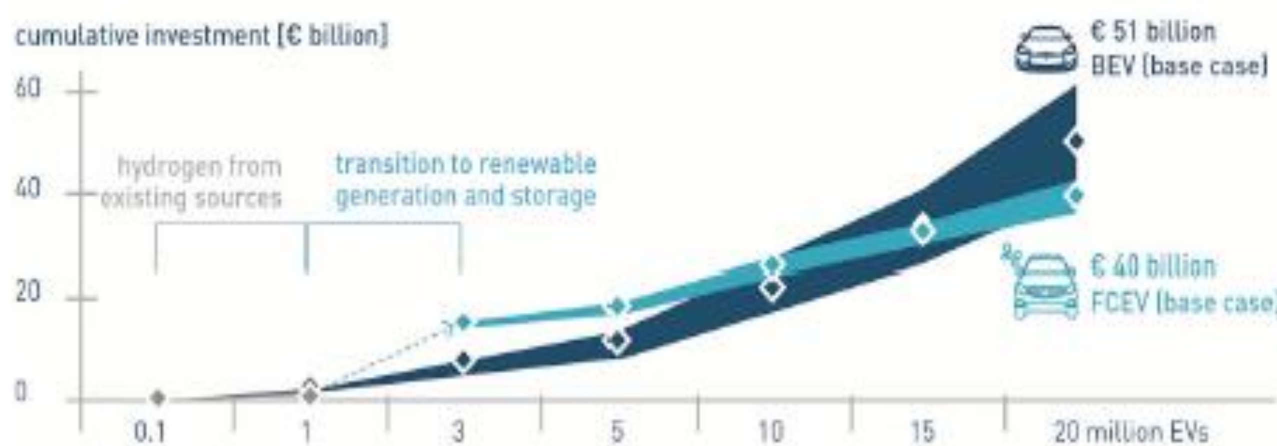


Comparative Analysis of Infrastructures: Hydrogen Fueling and Electric Charging of Vehicles

Martin Robinius, Jochen Linßen, Thomas Grube, Markus Reuß, Peter Stenze
Konstantinos Syranidis, Patrick Kuckertz and Detlef Stolten

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment Band / Volume 408
ISSN 1866-1793 ISBN 978-3-95806-295-5

« Low carbon cars in Europe: a socio-economic assesment »
« Low carbon-car in Germany »
ECF/Cambridge econometrics, february 2017

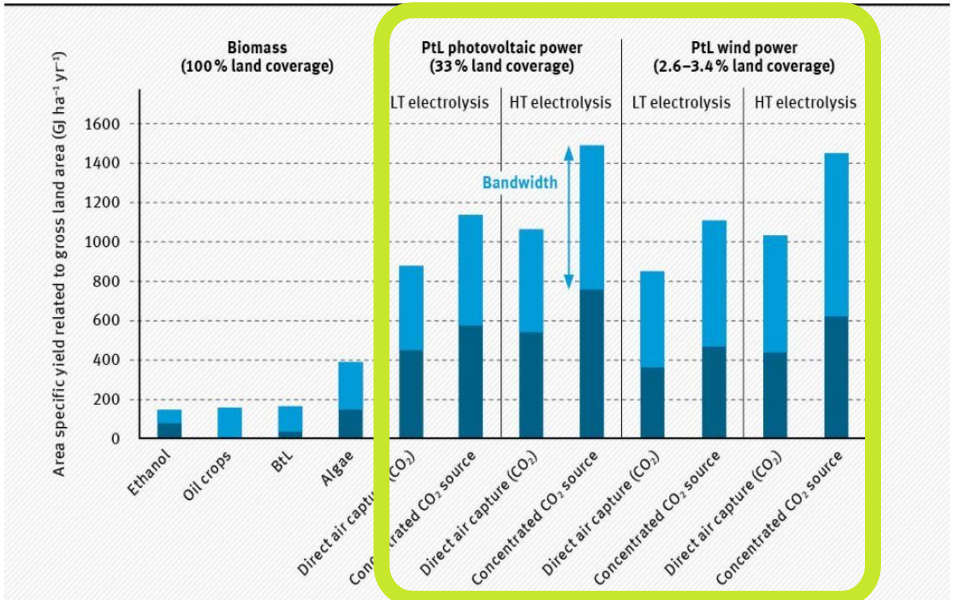


Land and water demand

Task 36 – LCSA concludes that different calculations associated with conventional LCC and LCC with externalities influences levelized cost of hydrogen. **The use of LCSA arises as a convenient methodological solution to thoroughly evaluate the performance of hydrogen energy systems.**

ludwig bölkow systemtechnik

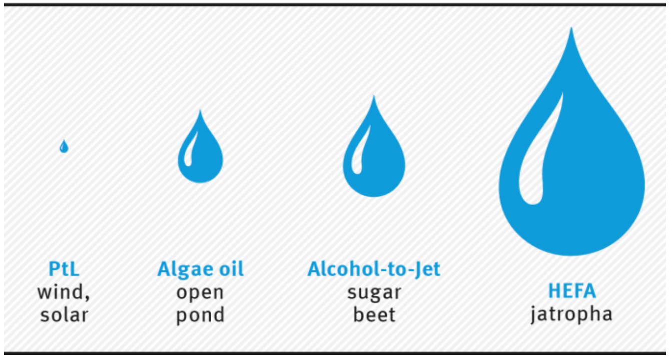
Comparison of gross area-specific yields of PtL fuels from photovoltaic and wind power and biofuels.



LT: low temperature; HT: high temperature; Algae: maximum yield depending on solar irradiation

Source: LBST

(volume representation, PtL water demand ~ 1.4 $L_{H_2O}/L_{jet fuel}$)



- Net water demand of energy crops is subject to local conditions and yield expectations.
- The water footprint of PtL fuel is by a factor of 400 to 15,000 lower than biofuels.
- Bulk PtX plants are still significant local consumers (seawater treatment, water cycling).

IEA Hydrogen Task 38
Workshop on Power to Gas
Demonstration projects analysis in the world

Towards an International PtG demo projects Road Map

20th November 2018, Aix en Provence, France
(on invitation only)

Objectives of the workshop:

IEA Hydrogen Task 38 gathers data from near 200 Power to Gas demonstration project at the world level and analyse each project through more than 25 parameters (technical, economics, projects characteristics ...).

The aim of the workshop is to present the result of this meta-analysis, to give the floor to a panel of a few demonstration projects representative of the variety of situation and to present and discuss a International PtG demo projects road map.

Conclusions and recommendations

- **Electrolysis technologies ready to scale up**
- **New promising technologies are not far behind, R&D (Mission Innovation IC#8**
- **« Green » Hydrogen markets are increasing, huge and diverse in any case**
- **… proven incentives and regulatory framework will be in place**
- **Perspectives for our TCP work:**
  - **Developping energy system analysis is key**
  - reliable database important
  - Compare different routes and pathways (Ammonia, biofuels …) and combination of routes) in different applications (heavy transport, industry…)
  - Work on financial and regulatory framework, derisking strategies for investment
- **Cooperation with others TCP, IEA analyst and other organization**

IEA Hydrogen: global hub for hydrogen R,D&D

IEA

Cooperation with IEA Headquarters

Cooperation with Sister TCPs

Center Lane

IEA Hydrogen
R,D&D
Analysis
Outreach

International

Cooperation with Organizations/Initiatives

Cooperation with Industry

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