HYDROG(E)NICS

SHIFT **POWER** | **ENERGIZE** YOUR WORLD

STATE OF PLAY AND DEVELOPMENTS OF POWER-TO-HYDROGEN TECHNOLOGIES

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Business Development & Regulatory Affairs
Renewable Hydrogen - Hydrogenics Europe N.V.

Brussels (BE), 21 February 2019

ETIP Wind workshop on Wind-to-Hydrogen

Hydrogenics in Brief

180+
dedicated employees

Our raw materials
water & renewable power are
infinite!

2000+
fuel cell sites

4 productions sites
Belgium, Canada, Germany and USA

$ 48M
2017 annual sales

1 single focus
hydrogen solutions

HYDROGENICS

Publicly traded
NASDAQ (HYGS) and
TSX (HYG) since 2000

65+ years
of experience

500+
Electrolysis plants
in operation

Global leader
in 2 main hydrogen technologies:
electrolysis and fuel cells

1,500+
Electrolysis plants
sold since 1948

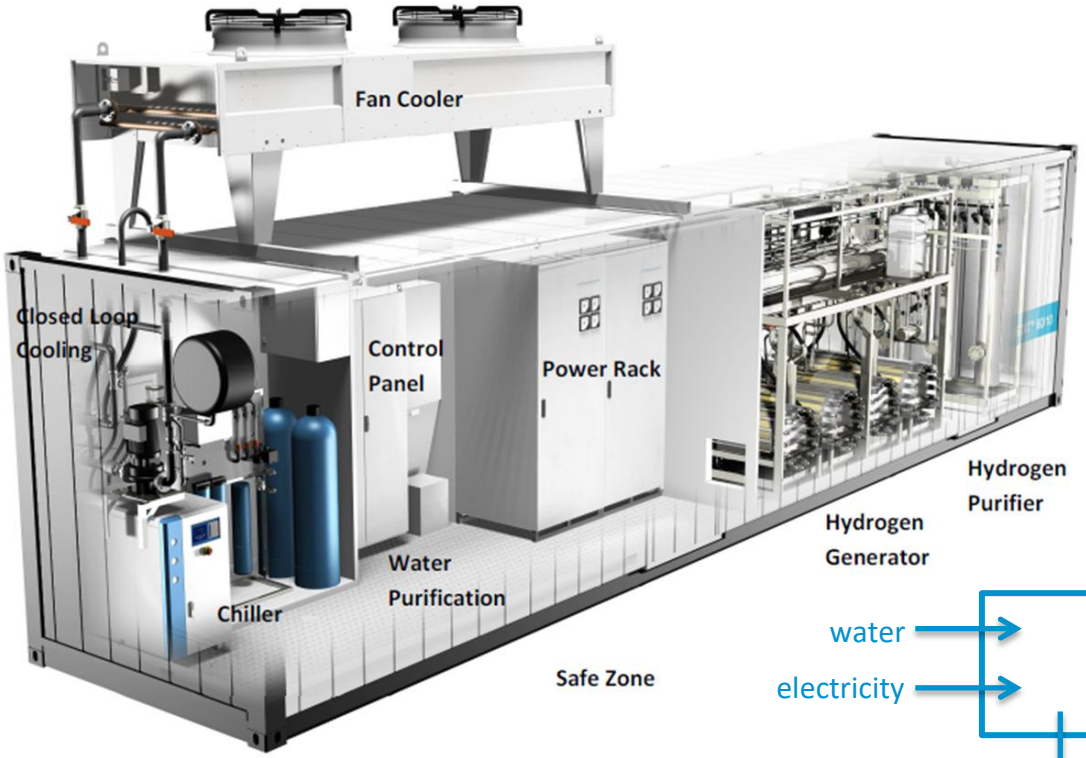
ON-SITE HYDROGEN GENERATION
Electrolyzers
Industrial Hydrogen supply

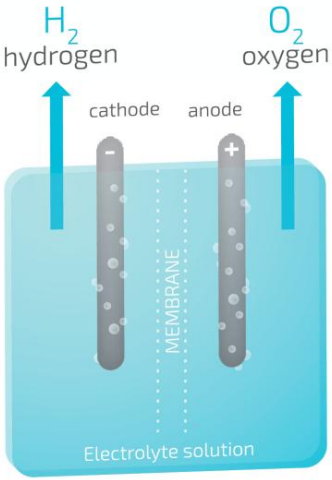
POWER SYSTEMS
Fuel cells
Stand-by Power
Mobile Power Modules
MW Power Plants

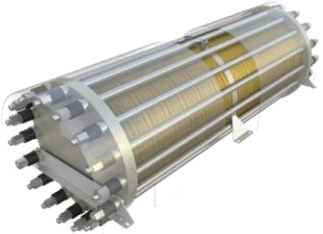
RENEWABLE HYDROGEN
Energy Storage
Hydrogen Refueling Station
Power-to-X
Grid balancing services

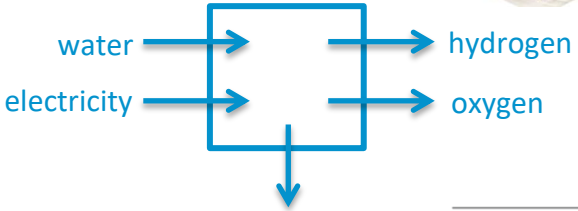
From niche…

Water electrolysis









Various water electrolyser technologies

- **Alkaline electrolysis**
  - 30wt% KOH – porous membranes
  - Been around for >60 yrs
  - Reliable proven technology
- **Proton exchange membrane**
  - ‘Polymer electrolyte membrane’
  - Compact / high currents
  - Wide working range (low-high power)
- **Solid oxide electrolyte**
  - Solid Zr_xO_y steam electrolysis
  - High temperature – high efficiency
  - Less flexible
- **Anion exchange membrane**
  - Alkaline polymer electrolyte
  - Little commercialisation

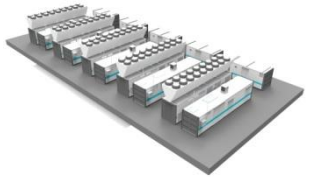
Work horse

Race stallion

Cross country horse

New colt

Alkaline & PEM electrolysis | Product's line

	Alkaline			PEM (Proton Exchange Membrane)		
						
	HySTAT®-15-10	HySTAT®-60-10	HySTAT®-100-10	HyLYZER® -300-30	HyLYZER® -1.000-30	HyLYZER® -5.000-30
Output pressure	10 barg (27 barg optional)			30 barg		
Number of cell stacks	1	4	6	1	2	10
Nominal Hydrogen Flow	15 Nm^3/h	60 Nm^3/h	100 Nm^3/h	300 Nm^3/h	1.000 Nm^3/h	5.000 Nm^3/h
Nominal input power	80 kW	300 kW	500 kW	1.5 MW	5 MW	25 MW
AC power consumption (utilities included, at nominal capacity)	5.0-5.4 kWh/Nm^3			5.0-5.4 kWh/Nm^3		
Hydrogen flow range	40-100%	10-100%	5-100%	1-100%		
Hydrogen purity	99.998% O2 < 2 ppm, N2 < 12 ppm (higher purities optional)			99.998% O2 < 2 ppm, N2 < 12 ppm (higher purities optional)		
Tap water consumption	<1.4 liters / Nm^3 H2			<1.4 liters / Nm^3 H2		
Footprint (in containers)	1 x 20 ft	1 x 40 ft	1 x 40 ft	1 x 40 ft	2 x 40 ft	10 x 40 ft
Footprint utilities (optional)	Incl.	Incl.	Incl.	1 x 20 ft	1 x 20 ft	5 x 20 ft

World hydrogen market

But most (96%) of the hydrogen produced today is not CO_2-free (from gas, oil, coal)

If produced from renewable power via electrolysis, hydrogen is fully renewable and CO_2-free.

Renewable hydrogen has the potential to decarbonize a large range of applications

Data source: The Hydrogen Economy, M. Ball 2009 & Esprit Associates 2014

Extensive experience in industry

Saint Gobain, Colombia

Elemash, Russia

Bushan, India

Camao, Brazil

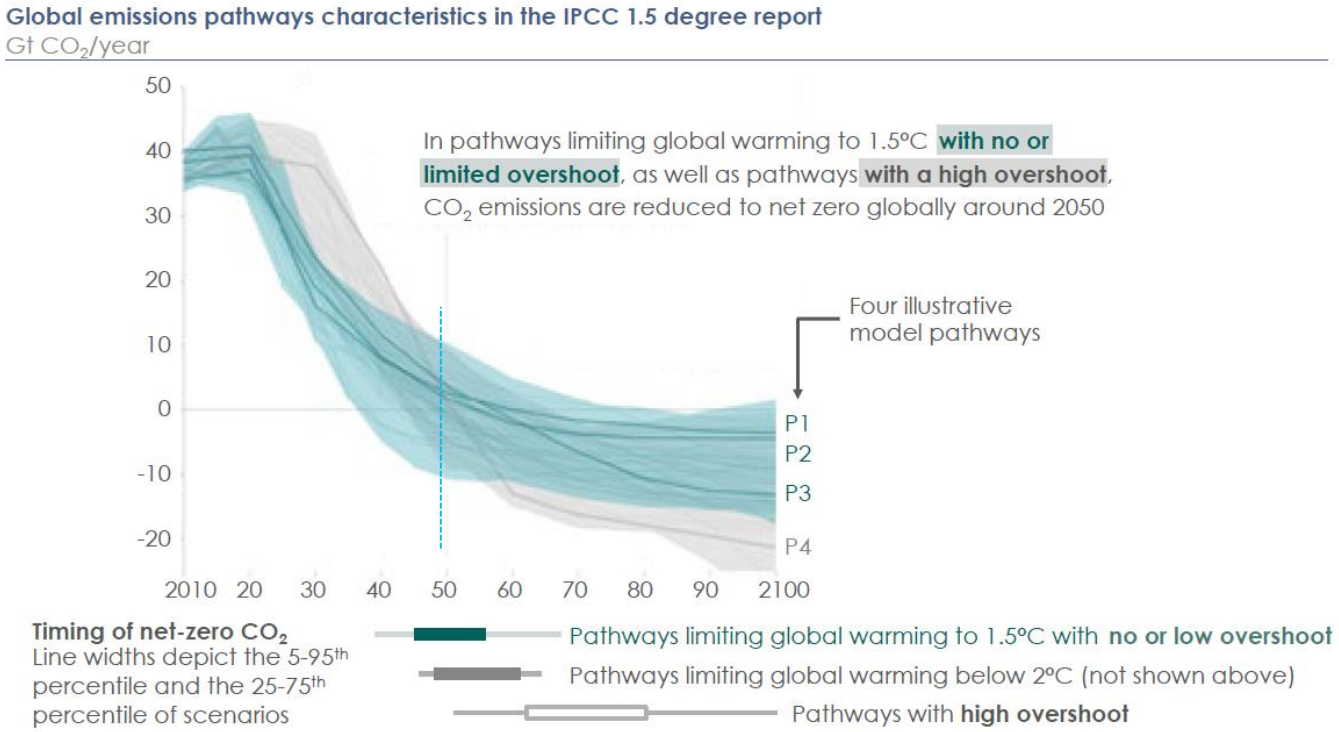
Nyagan, Russia

Kirovgrad, Russia

… to mainstream

Nations Unies
Conférence sur les Changements Climatiques 2015
COP21/CMP11
Paris, France
SECRETAIRE EXECUTIF CCNUCC
PRESIDENT
SECRETAIRE

CO2 emissions are reduced to net-zero globally by around 2050 in global emissions pathways for 1.5°C from IPCC



Source: IPCC (2018), *Global Warming of 1.5°C*

www.energy-transitions.org

All sectors need to achieve net zero emissions around 2050

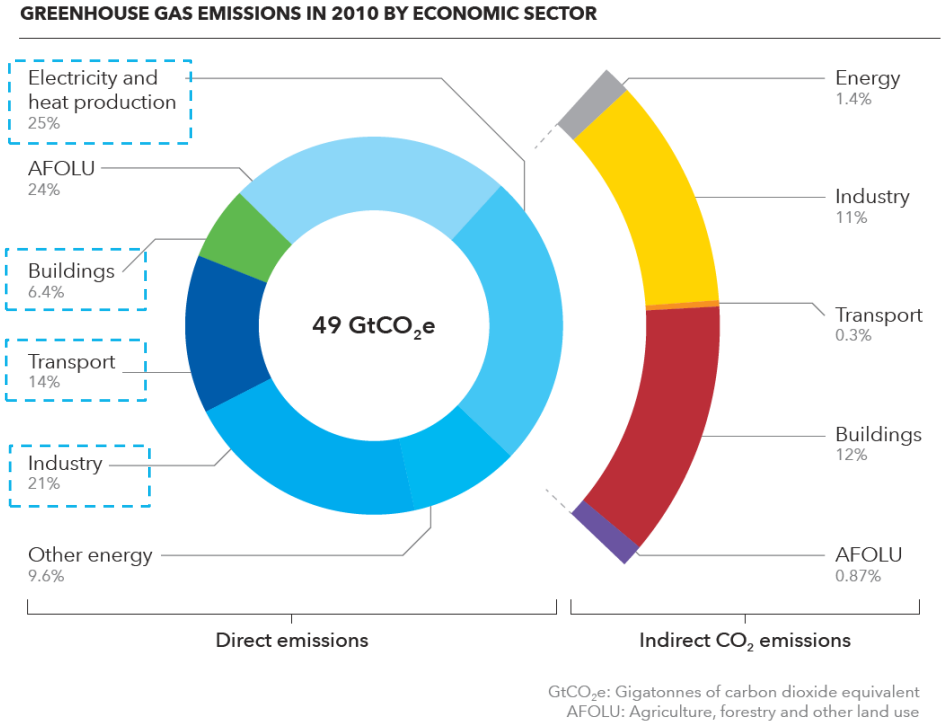
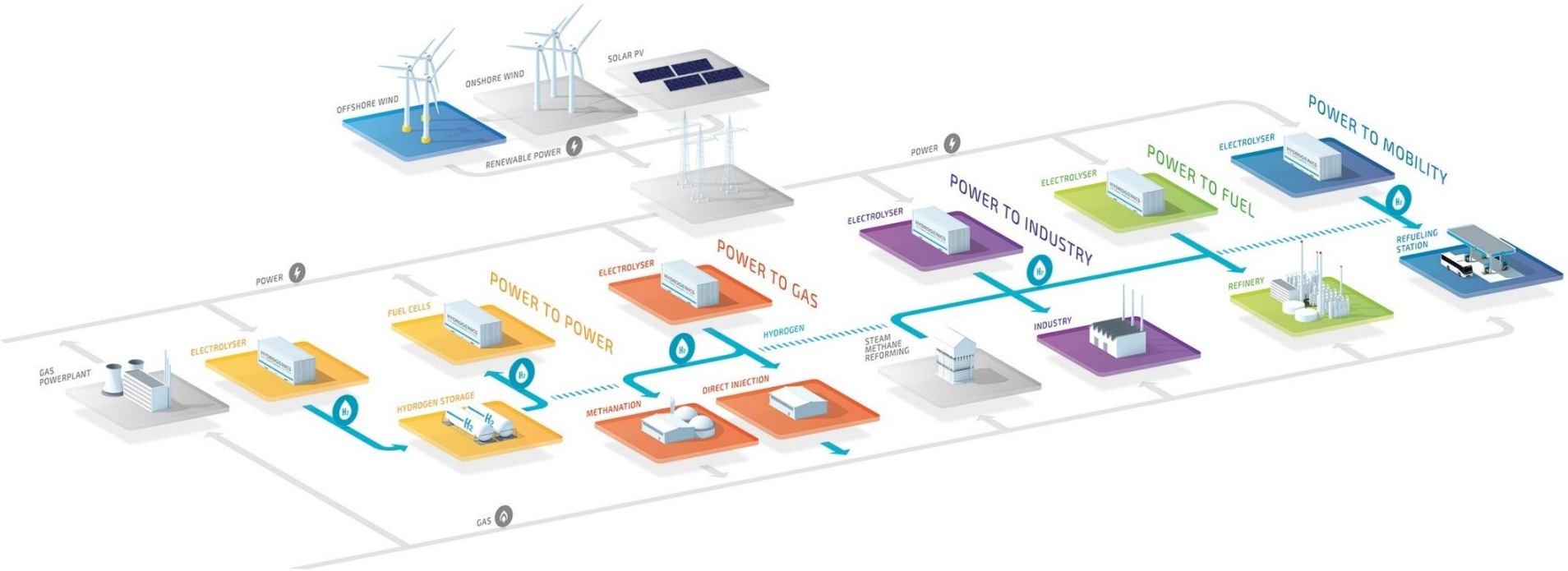


Figure 2: Greenhouse gas emissions in 2010 by economic sector. Source: IPCC[5].

Source: Hydrogen as an energy carrier, DNV-GL, 2018

Renewable Hydrogen



Selection of our key references

Electrolysis

700 bar Hydrogen Refueling Station
Aberdeen, Scotland (UK)

1,5 MW PEM P2G (direct injection), Hamburg, Germany

1 MW alkaline P2G (methanation)
BIOCAT, Copenhagen, Denmark

Fuel cells

1 MW stationary Fuel cell (H_2 repowering)
Kolon, South-Korea

Fuel cell for mobility (H_2 trains)
Alstom Coradia iLint , Germany

Fuel cell for mobility (H_2 buses), China

Power-to-Power | Power-to-Gas

Hychico, Patagonia, Argentina (2008)
Wind-to-Hydrogen, direct injection in depleted gas field & repowering

0,6 MW
Direct injection
Alkaline

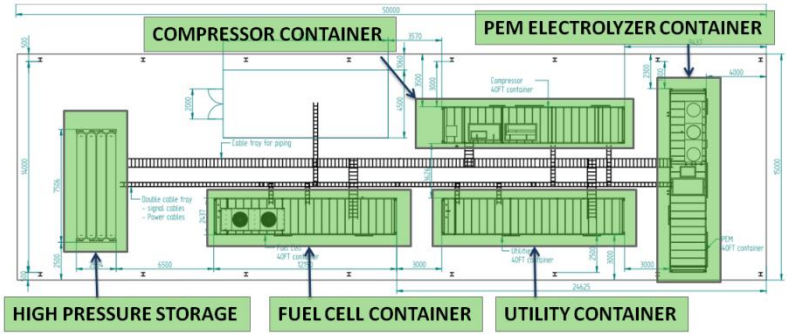
- **OBJECTIVES**
  - Demonstrate variable hydrogen production with direct connection to wind park
  - Store hydrogen in a depleted gas field
  - Re-electrification of the hydrogen blended with natural gas through a gas genset
- **SOLUTION**
  - 2 x HySTAT®-60-10 with all peripherals in 40Ft. housings to produce 120 Nm³/h hydrogen (power: 0,6 MW)
- **PARTNERS:**
  - Hychico
- **More information:** www.hychico.com.ar

Photo credits: Hychico

EGAT Lam Takhong Wind Hydrogen Hybrid Project
Thailand (2018)

1 MW electrolyser + 300 kW fuel cell

- **OBJECTIVES**
  - Use of curtailed energy from 24 MW wind farm with limited injection capacity
  - Repowering of the hydrogen through a 300 kW fuel cell to power the new energy center of EGAT
- **SOLUTION**
  - 1 MW PEM electrolyser (HyLYZER®-200-30)
  - 300 kW PEM fuel cell
  - 3 MWh (10 hours) of compressed hydrogen storage (250 bar)
- **PARTNERS:**
  - EGAT
- **More information:** www.egat.co.th/en/



Wind-to-Gas Südermarsch (Brunsbtuttel), Germany (2018)
Direct injection of hydrogen in high-pressure natural gas grid

2,4 MW
Direct injection
PEM

- **OBJECTIVES**
  - Development of 2,4 MW PEM Electrolysis System
  - Dual stack design of 1,2 MW each
  - Feed hydrogen into the medium-pressure distribution natural gas pipeline at 40-70 bar with compression
  - Optional connection to future hydrogen refueling station
- **SOLUTION**
  - 1 x HyLYZER®-400-30 PEM electrolyser with all peripherals
  - Max 400 Nm^3/h H_2 at 30 bar (Power: 2,4 MW)
  - 2x 40 ft. ISO containers
- **PARTNER:** wind2gas energy
- **More information:** www.w2g-energy.de

Photo credits: Wind to Gas Energy GmbH

Markham Energy Storage Project (Markham), Canada (2018)
Secondary Frequency Control for the IESO

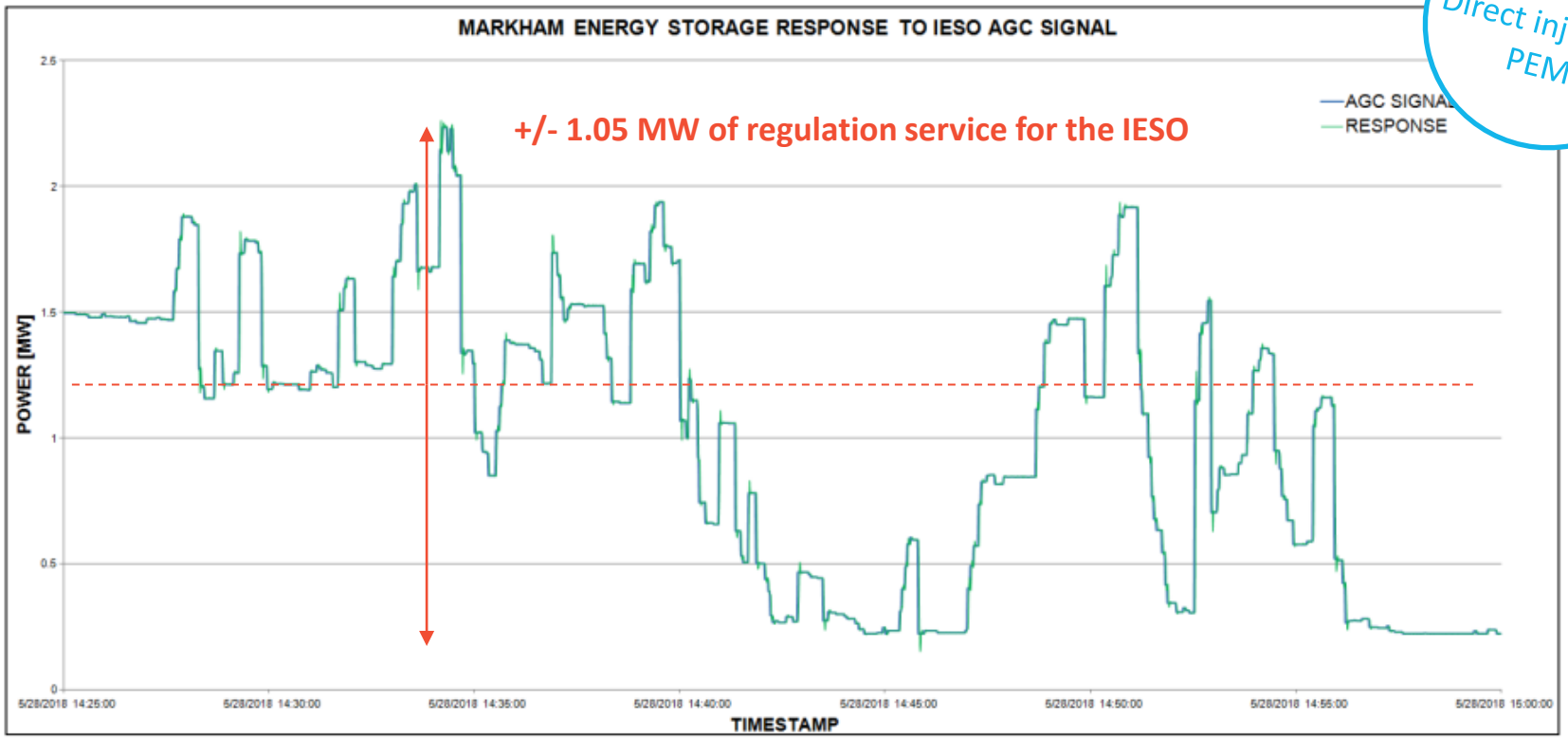
2,5 MW
Direct injection PEM

- **FEATURES**
  - Plant has been designed for 5MW (currently installed 2.5MW)
  - High purity H2 is produced by the PEMWE stacks at 30 barg
  - **Plant provides +/- 1.05 MW of regulation service for the IESO**
  - **2 second response time, 2 MW/sec ramp rate**
  - 100 kW fuel cell with 8 MWh of onsite hydrogen storage
- **SOLUTION**
  - 1 x HyLYZER®-500-30 PEM electrolyser with all peripherals
  - Max 500 Nm^3/h H_2 at 30 bar (Power: 2,5 MW)
  - Indoor design
- **PARTNER:** ENBRIDGE
- **More information:** www.enbridge.com

Markham Energy Storage Project (Markham), Canada (2018)

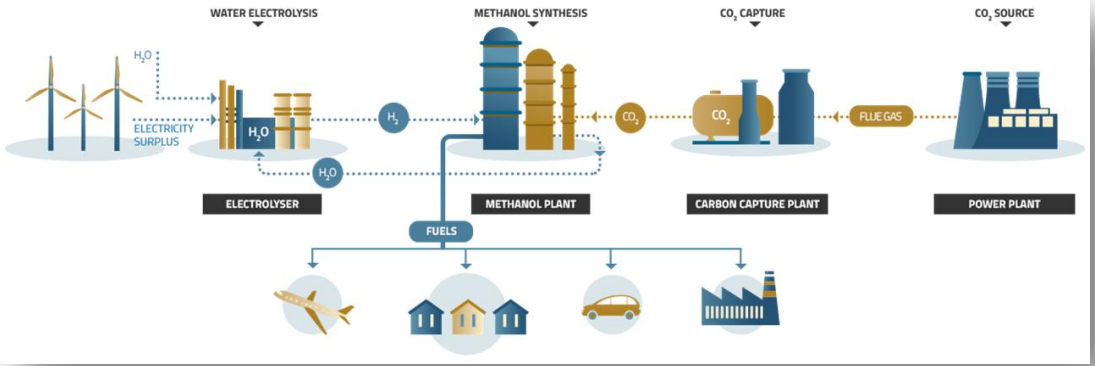
Secondary Frequency Control for the IESO

2,4 MW
Direct injection PEM



MEFCO$_2$, Niederaußem (Germany) Power-to-Methanol

- **OBJECTIVES**
  - Produce **green methanol** as energy vector from captured CO_2 and hydrogen produced using surplus renewable energy.
  - Existing post-combustion pilot CO_2 plant at coal power plant of RWE
  - Flexible operation (RES driven)



- **SOLUTION**
  - 1x HyLYZER®-200-30 (PEM, single cell stack design) with all peripherals to produce 200 Nm³/h H_2 (power: 1 MW)

- **PARTNERS:**

  - This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement (No 637016).

- **More information:** www.mefco2.eu

Power-to-Industry

HyBalance, Hobro, Denmark
Industrial hydrogen and delivery to hydrogen refueling stations

1.2 MW
PEM
Dual stack

- **OBJECTIVES**
  - Validate the highly dynamic PEM electrolysis technology in a real industrial environment and provide grid balancing services on the Danish power market
  - Validate innovative delivery processes for hydrogen fueling stations at high pressure and for industrial client (via dedicated pipeline)
- **SOLUTION**
  - 1x HyLYZER®-230-30 (PEM, dual cell stack design) with all peripherals to produce 230 Nm³/h H_2 (power: 1,2 MW)
- **PARTNERS:**
  - This project receives financial support FCH-JU (GA No 671384) and ForskEL program, administered by Energinet.dk.

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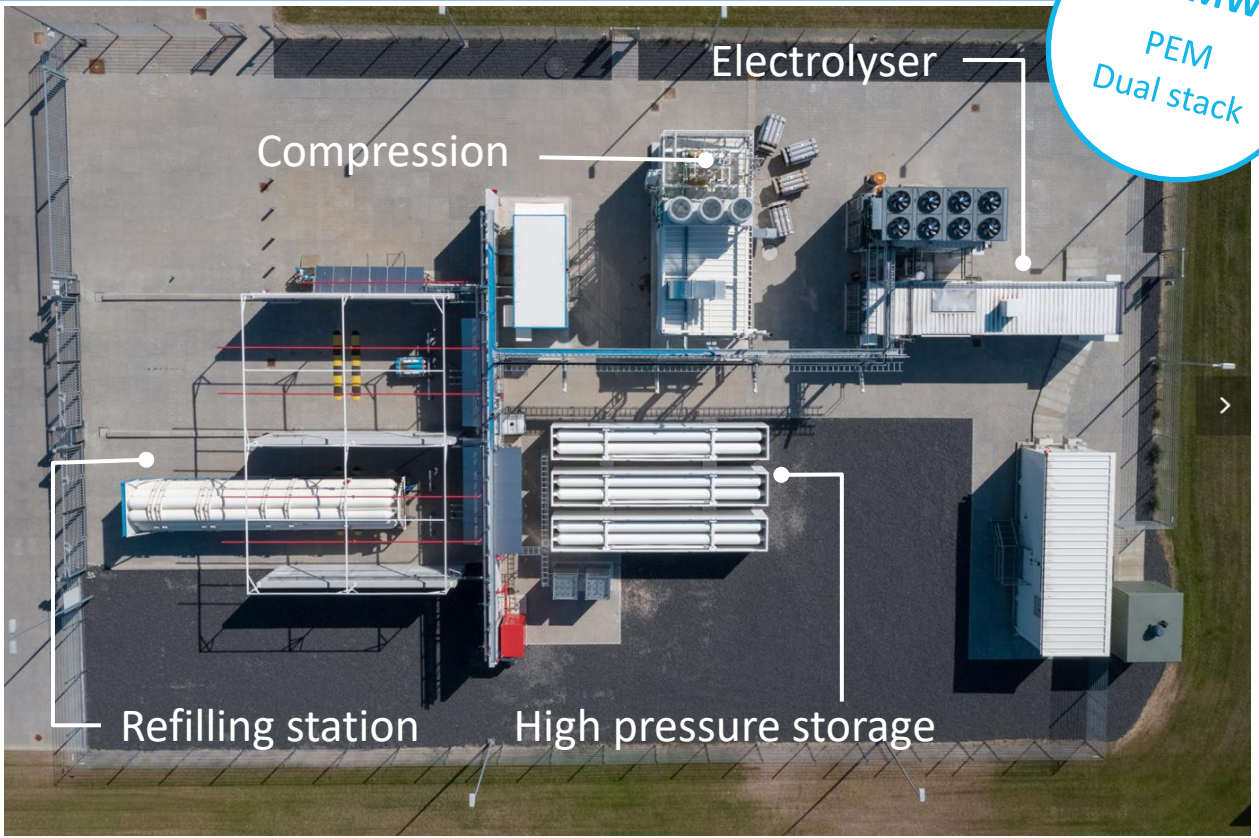
- **More information:** www.hybalance.eu

HyBalance, Hobro, Denmark
Industrial hydrogen and delivery to hydrogen refueling stations

1.2 MW
PEM
Dual stack



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HAEOLUS Berlevåg, Norway, Highly flexible electrolysers balancing the energy output inside the fence of a wind park

2,5 MW
PEM

- **OBJECTIVES**
  - Direct connection to 45 MW wind park
  - Enhanced wind integration through hydrogen
  - Demonstrate multiple control systems and applications for electricity storage, mini-grid and fuel production
  - Remote operation (difficult access)
  - Techno-economic analysis and regulatory aspects of wind-to-hydrogen
- **SOLUTION**
  - 1x HyLYZER®-500-30 (PEM) with all peripherals to produce 400 Nm³/h H_2 (power: 2,5 MW)
- **PROJECT**
  - This project receives financial support FCH-JU funding: 4,9 M€, GA No 779469, duration: 2018-2021)
- **More information:** www.haeolus.eu

- **PARTNERS**

VARANGER KRAFT
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tecnalia
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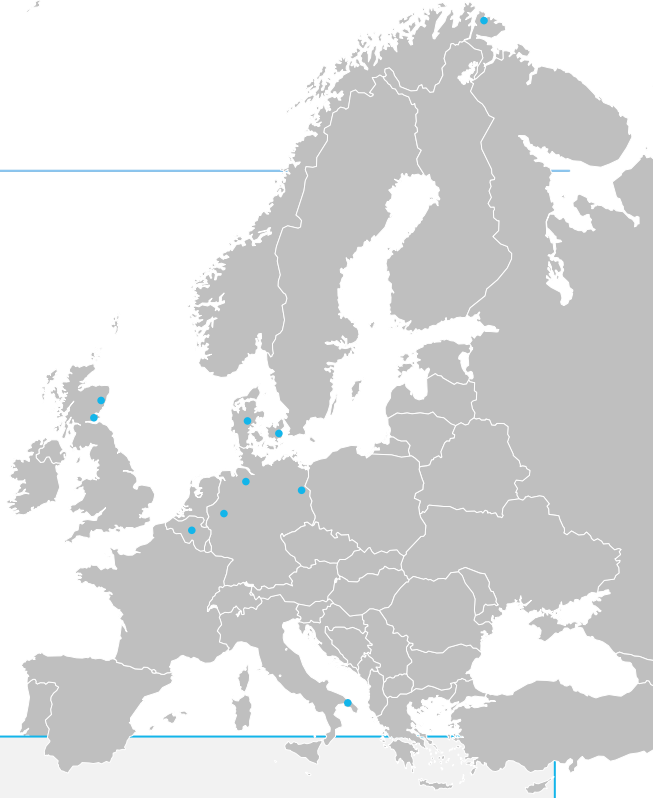
UBFC UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ

Renewable hydrogen
Selection of recent demonstration projects

	Country	Project	Size	Year	Electrolyser technology	Power	Gas	Industry	Mobility	Fuel
FCH	Norway	Haeolus	2,5 MW + 100 kW FC	2018	PEM	•				
+ CO_2	Germany	MefCO2	1 MW	2018	PEM					•
	Germany	WindGas Brunsbuttel	2.4 MW	2017	PEM		•			
	Thailand	EGAT	1 MW + 300 kW FC	2017	PEM	•				
	Canada	Embridge P2G	2.4 MW + 100 kW FC	2017	PEM		•			
FCH	Denmark	HyBalance	1.2 MW	2017	PEM			•	•	
+ CO_2	Denmark	BioCat	1 MW	2016	Alkaline		•			
+ CO_2	Italy	Ingrid	1 MW + 100 kW FC	2016	Alkaline	•	•	•		
	UK	Aberdeen	1 MW	2016	Alkaline				•	
	Germany	WindGas Reitbrook	1.5 MW	2015	PEM		•			
FCH	Belgium	DonQuichote	150 kW + 100 kW FC	2015	Alkaline + PEM	•			•	
+ CO_2	Germany	WindGas Falkenhagen	2 MW	2014	Alkaline		•			



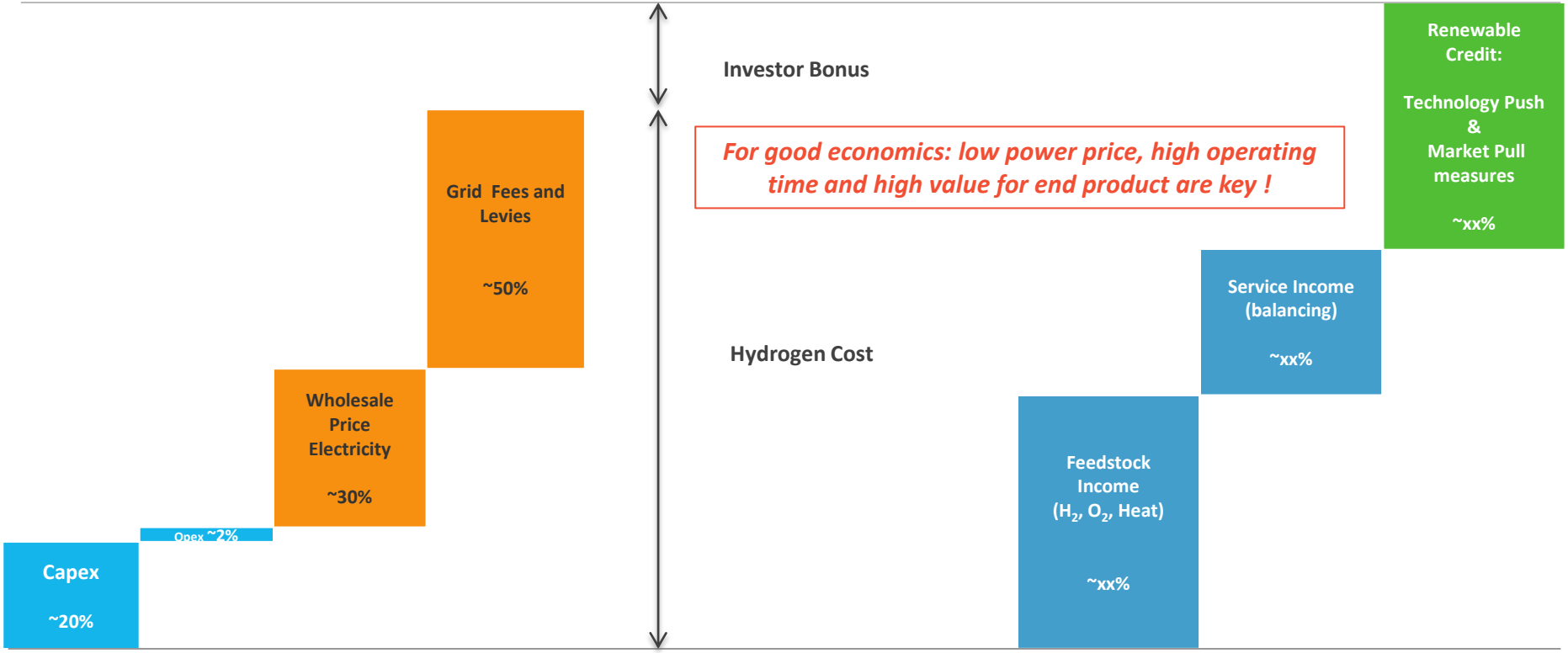
Main conclusions from these projects:

1. Hydrogen **technologies work fine** and deliver according to expectations.
2. There is still room for further technical improvement but **no technology breakthrough is expected**.
3. There is a important potential for further **cost reduction**: going from project manufacturing to product manufacturing
4. Energy **regulatory framework is no suited** for these applications and **business operation** of these projects **remains very challenging**

… the way forward !

Business Case Drivers

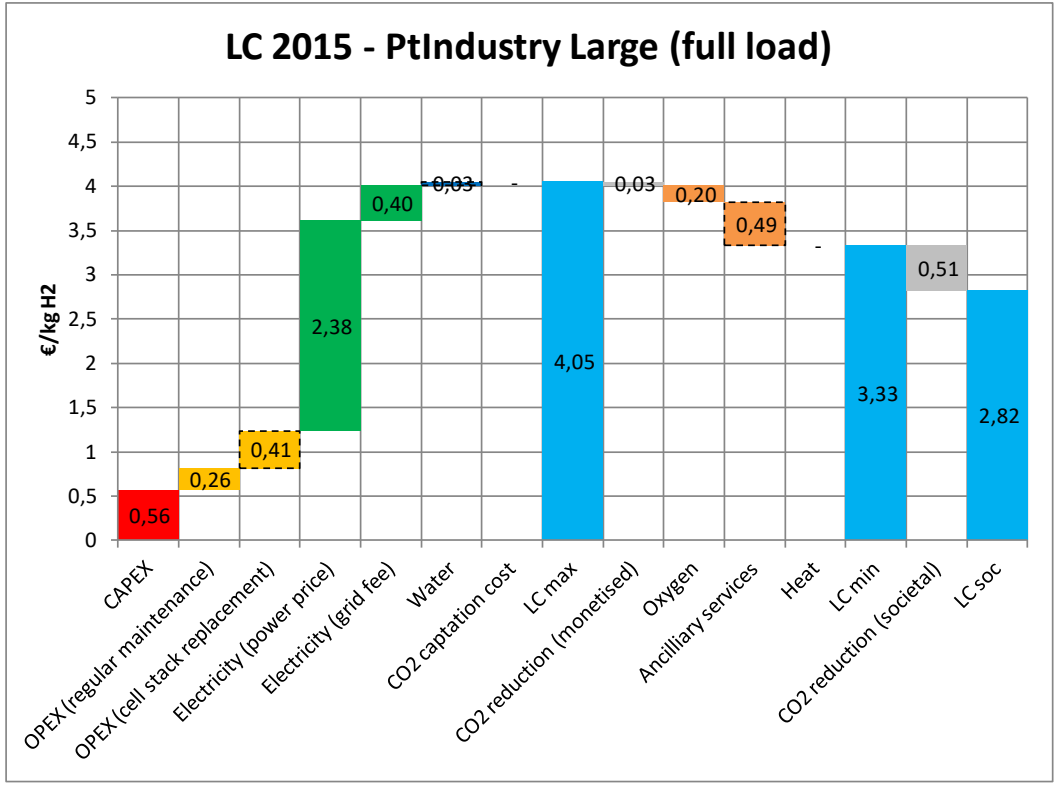
For more information on the economics, consult the Power-to-Gas Roadmap for Flanders: www.power-to-gas.be/roadmap-study



For good economics: low power price, high operating time and high value for end product are key !

Power-to-industry (large scale)

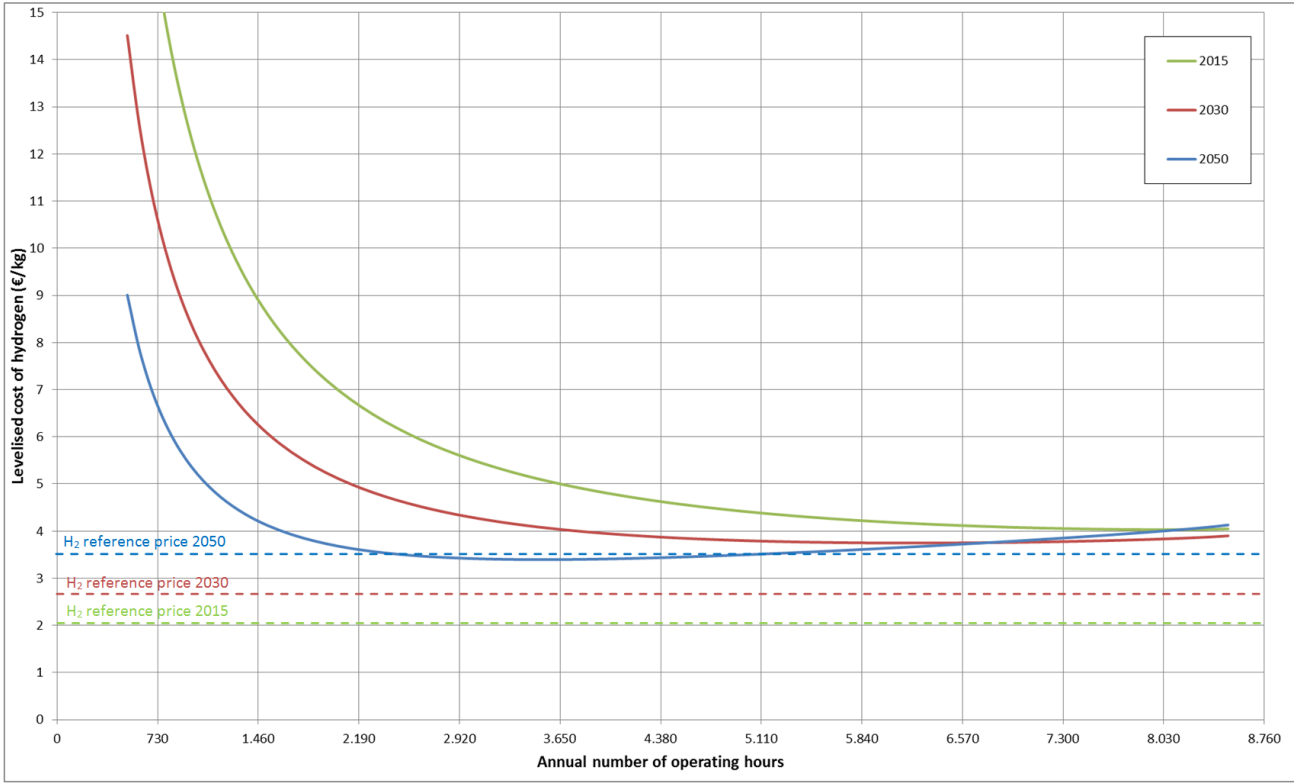
Levelized cost of hydrogen : waterfall graphs



Source: www.power-to-gas.be/roadmap-study
100 MW Electrolyser, Capex: 1000 €/kW, power price assumption ~50 €/MWh

Power-to-industry (large scale)

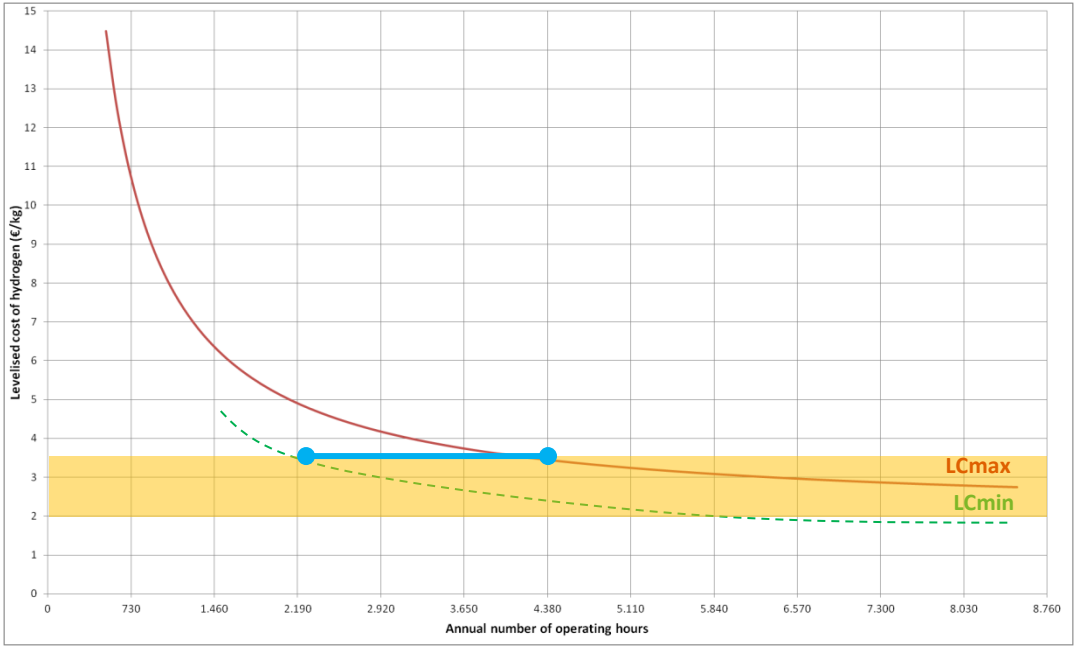
LC_{max} vs operating hours

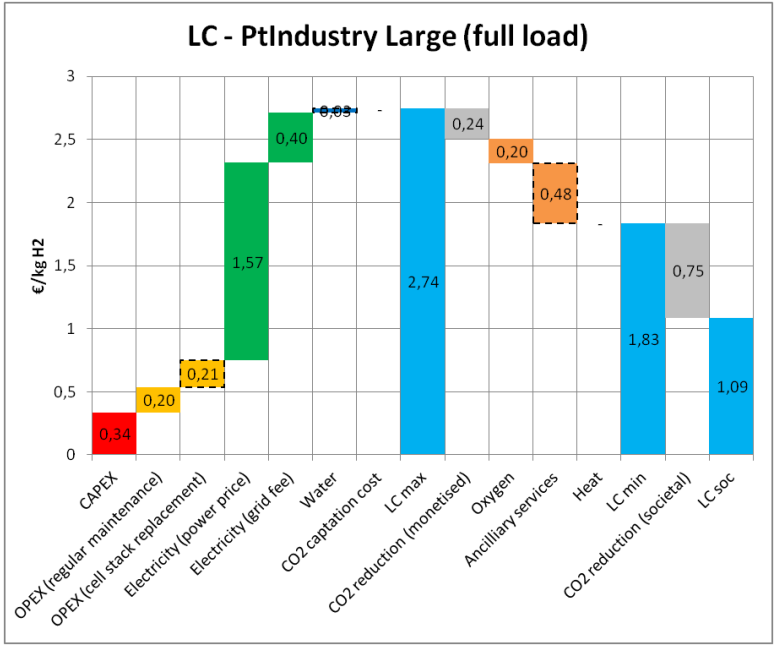


Source: www.power-to-gas.be/roadmap-study
100 MW Electrolyser, check report for all assumptions

WHAT IF

100 MW, CAPEX: 580 €/kW, power price: 36 €/MWh, grid costs: 7€/MWh





Falling cost of renewable power is improving everyday the case of renewable hydrogen

Unsubsidised clean energy world records December 2017 (EURELECTRIC Brussels)

Solar PV

Country:	Saudi Arabia
Bidder:	Masdar
Signed:	2017
Construction:	2019
Price:	**US$ 1.79 c/kWh***

Onshore wind

Country:	India
Bidder:	ReNew Power
Signed:	2017
Construction:	2019
Price:	**US$ 2.0 c/kWh**

Offshore wind

Country:	Germany
Bidder:	DONG/EnBW
Signed:	2016
Construction:	2024
Merchant Price:	**US$ 4.9 c/kWh**

** Headline figure only - may include elements of subsidy, price support or price escalation; not final*
Source: Bloomberg New Energy Finance; Images: Siemens; Wikimedia Commons; Electrek

Source: Bloomberg New Energy Finance, 6/12/17 (Eurelectric)

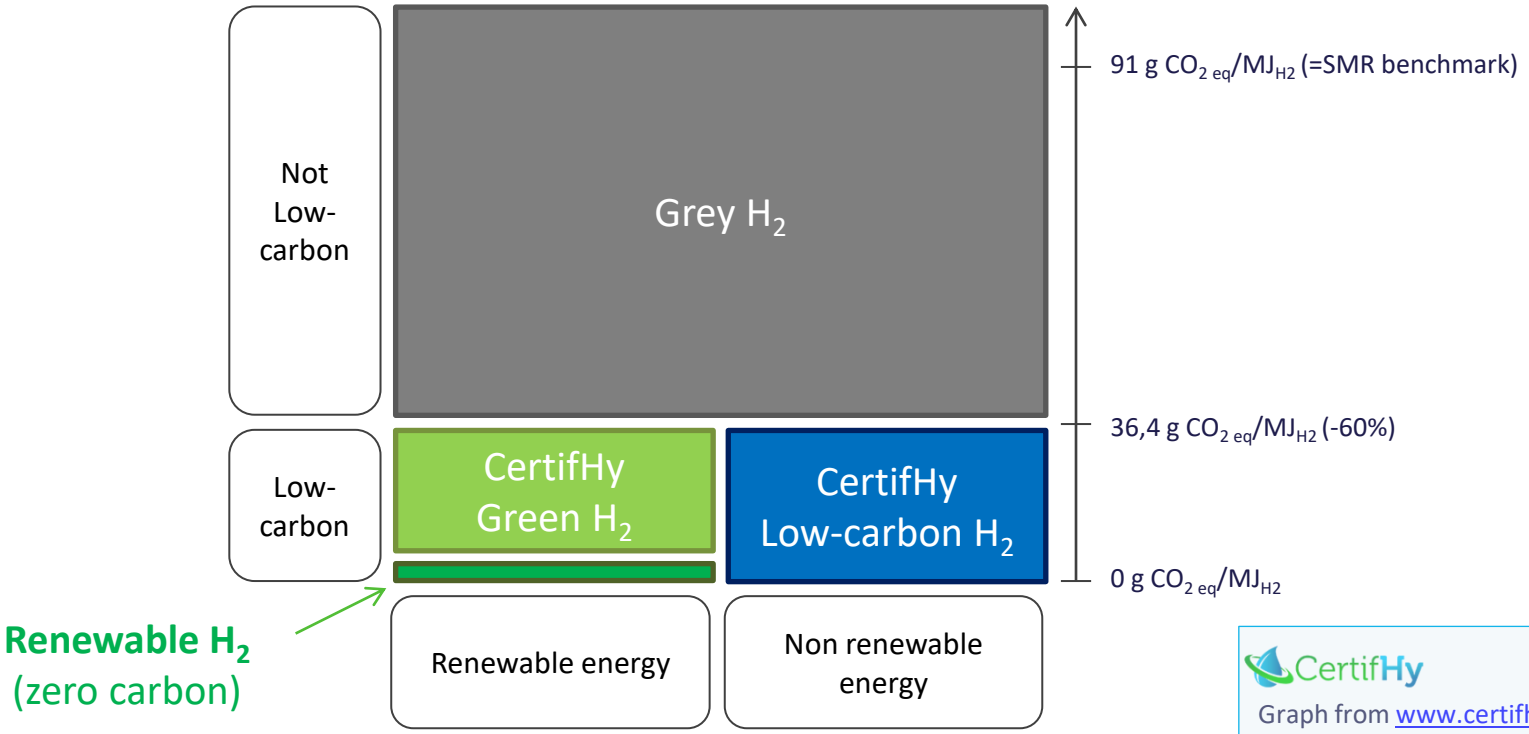
How to unlock the potential of renewable hydrogen

- Find sites with suitable conditions "connecting all the dots"
- Integrate the renewable power production in the economics and promote RES→H_2 as a way to lock-in future-proof fuel or feedstock prices
- Create market conditions for renewable hydrogen via regulation
- Reducing the cost of the hydrogen technology by going very large scale.

  NB: Only the industry can provide a sufficient market to absorb large quantities of hydrogen

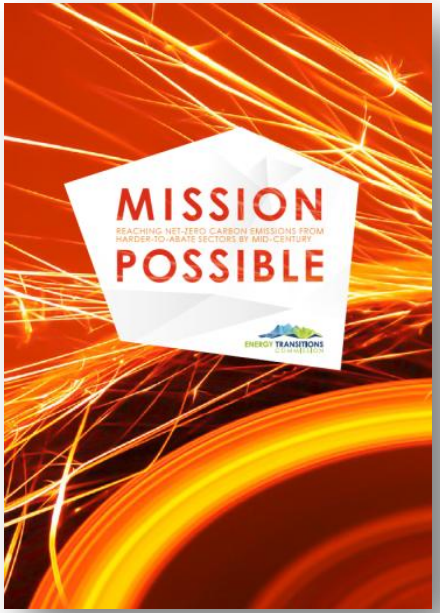
2.4 MW → **60-100 MW**

‘Clean’ hydrogen definitions & certification schemes

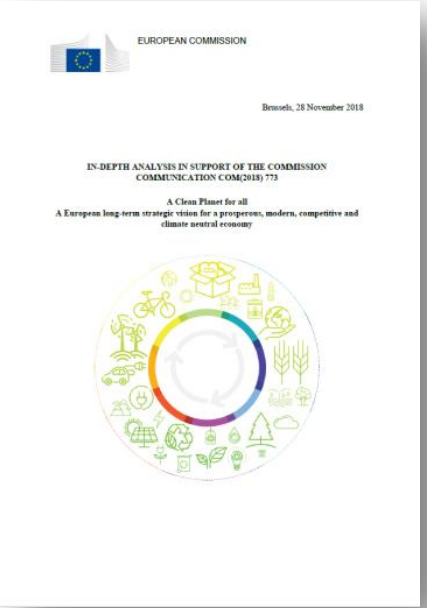


CertifHy
Graph from www.certifhy.eu modified by Hydrogenics

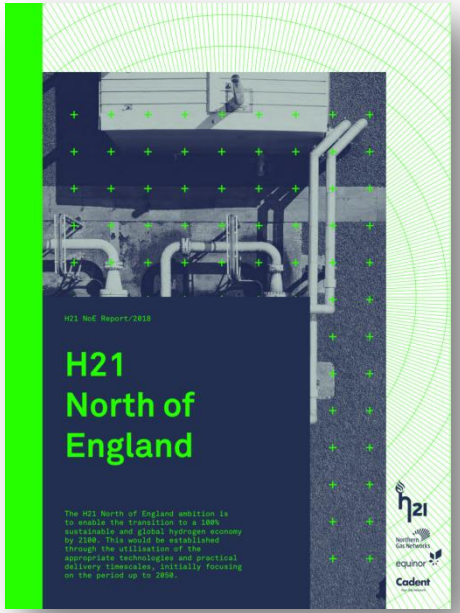
Last readings (Nov-Dec 2018)



www.energy-transitions.org

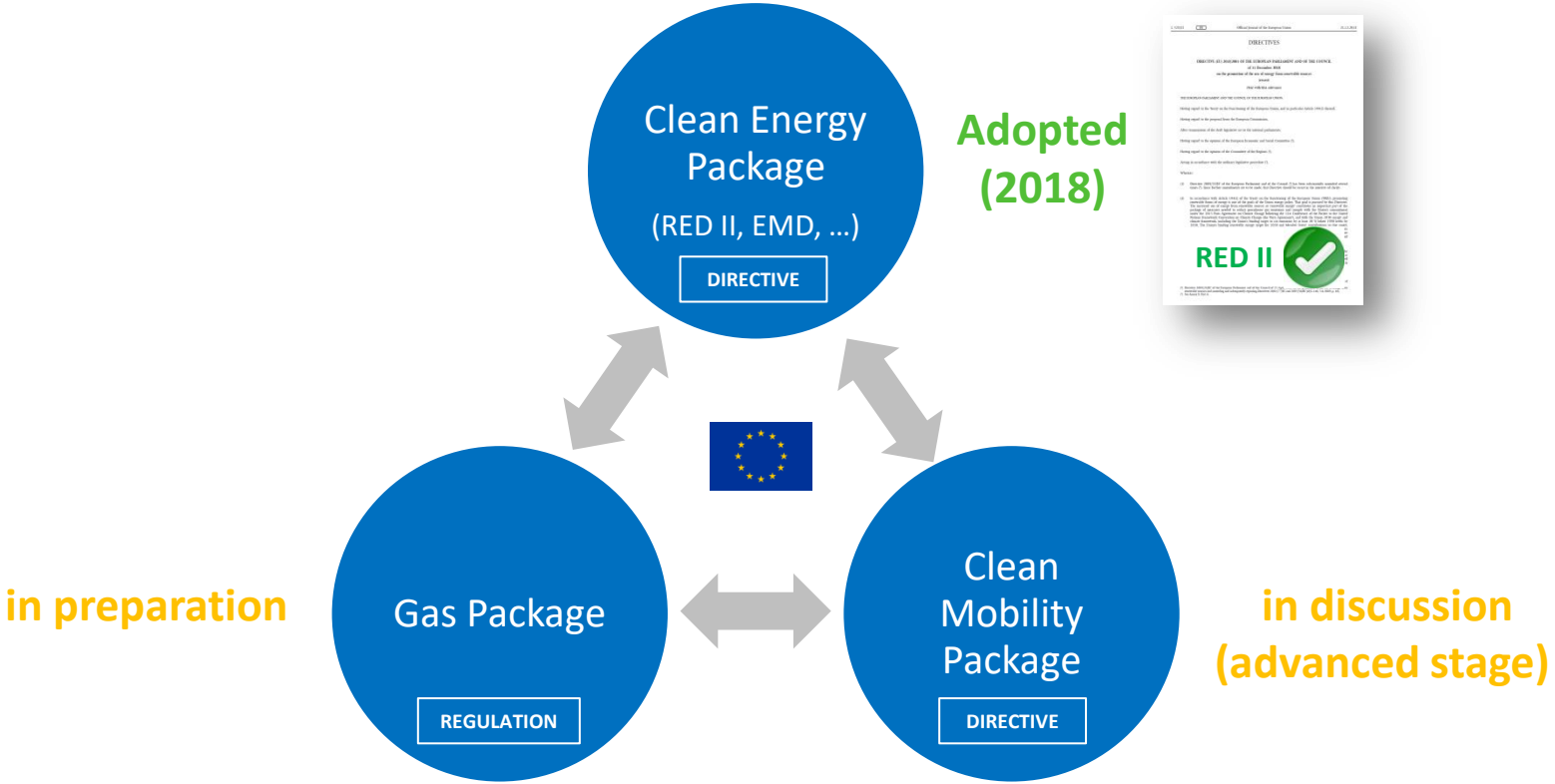


https://ec.europa.eu/clima/policies/strategies/2050_en



https://northerngasnetworks.co.uk/h21-noe/H21-NoE-23Nov18-v1.0.pdf

Main pieces of EU legislation affecting the development of hydrogen markets in Europe (2021-2030)



Conclusions

From niche

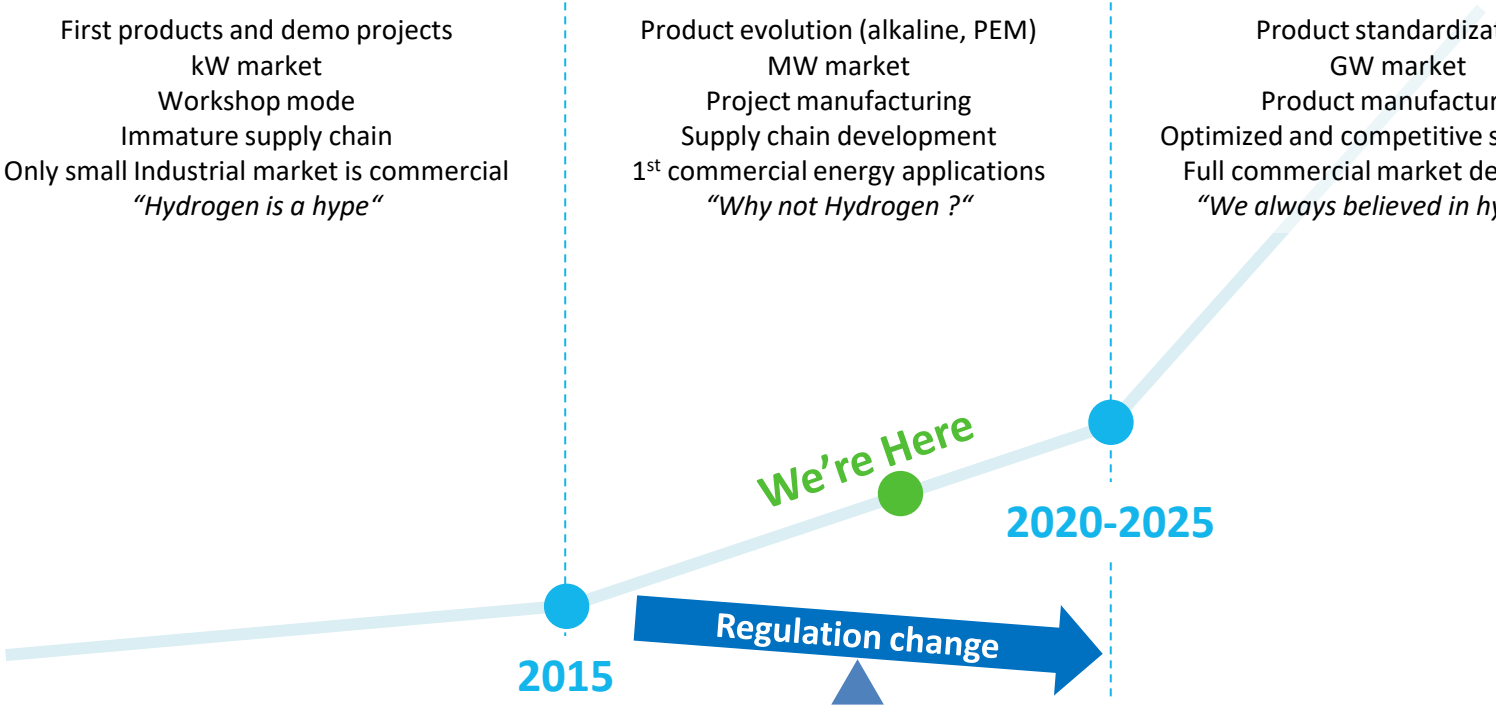
First products and demo projects
kW market
Workshop mode
Immature supply chain
Only small Industrial market is commercial
"Hydrogen is a hype"

Upscaling

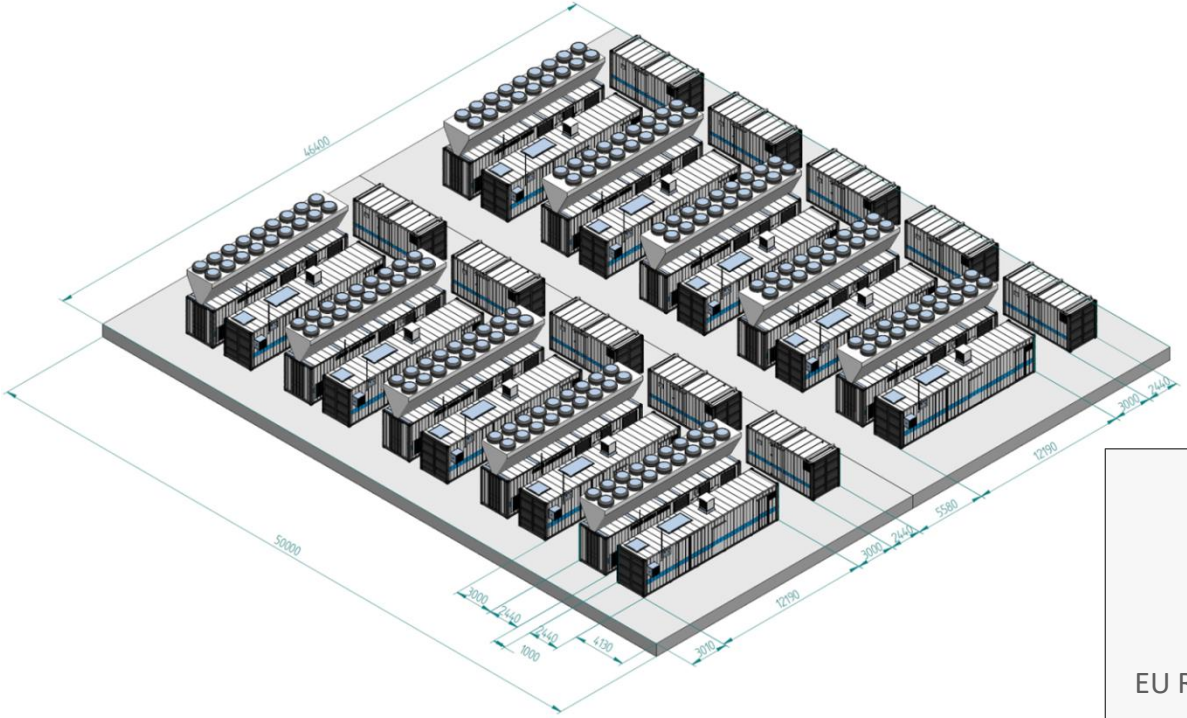
Product evolution (alkaline, PEM)
MW market
Project manufacturing
Supply chain development
1st commercial energy applications
"Why not Hydrogen ?"

To mainstream

Product standardization
GW market
Product manufacturing
Optimized and competitive supply chain
Full commercial market deployment
"We always believed in hydrogen"



We're Ready for large scale Wind-to-Hydrogen projects



We're Ready.

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Hydrogen | Basic math

Hydrogen physics

- 1 kg ↔ 11,1 Nm^3 ↔ 33,3 kWh (LHV) and 39,4 kWh (HHV)
- High mass energy density (1 kg H_2 = 3,77 l gasoline)
- Low volumetric density (1 Nm^3 H_2 = 0,34 l gasoline)

Hydrogen production from water electrolysis (~5 kWh/Nm^3 H_2)

- **Power:** 1 MW electrolyser ↔ 200 Nm^3/h H_2 ↔ ± 18 kg/h H_2
- **Energy:** +/- 55 kWh of electricity → 1 kg H_2 ↔ 11.1 Nm^3 ↔ ± 10 liters demineralized water

Power production from a hydrogen PEM fuel cell from hydrogen (+/- 50% efficiency)

- **Energy:** 1 kg H_2 → 16 kWh

Cars and buses

FCEV	H_2 tank	H_2 consumption	Driving range	Annual driving distance	Annual H_2 consumption
Car (passenger)	5 kg	1 kg/100 km	500 km	15.000 km	150 kg
Bus (12 m)	35 kg	8 kg/100 km	350 km	60.000 km	5 tons