Mobilité hydrogène

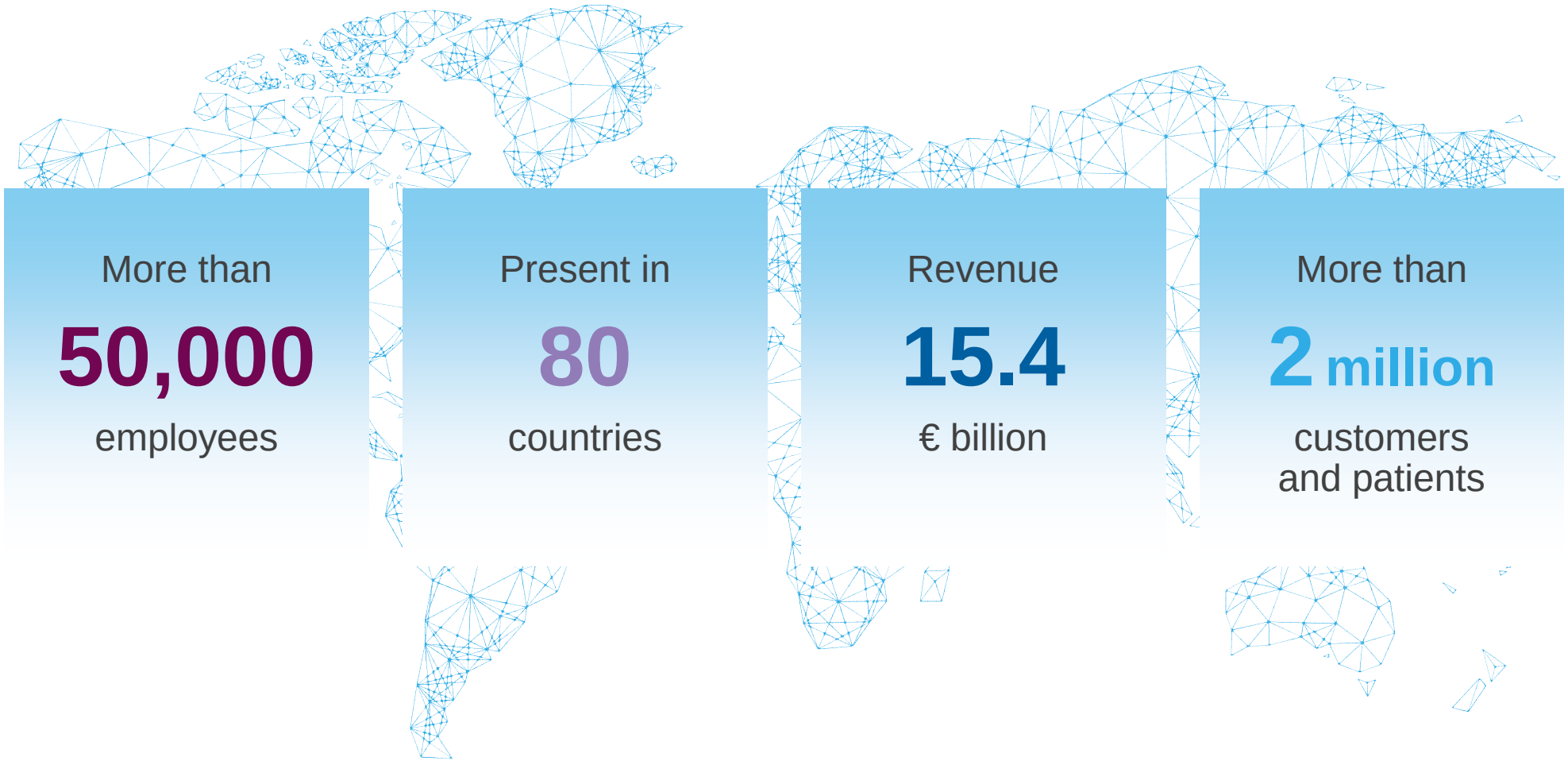
Laurent Allidieres & Caroline Le Mer
Air Liquide Advanced Business & Technologies

Art et métiers, 12 octobre 2015

An introduction to Hydrogen mobility

- Video : https://www.youtube.com/watch?v=PiIGOvRWtyo

Air Liquide … Key figures 2014



More than

50,000

employees

Present in

80

countries

Revenue

15.4

€ billion

More than

2 million

customers
and patients

Air Liquide … World leader in gases, technologies and services for …

Industry

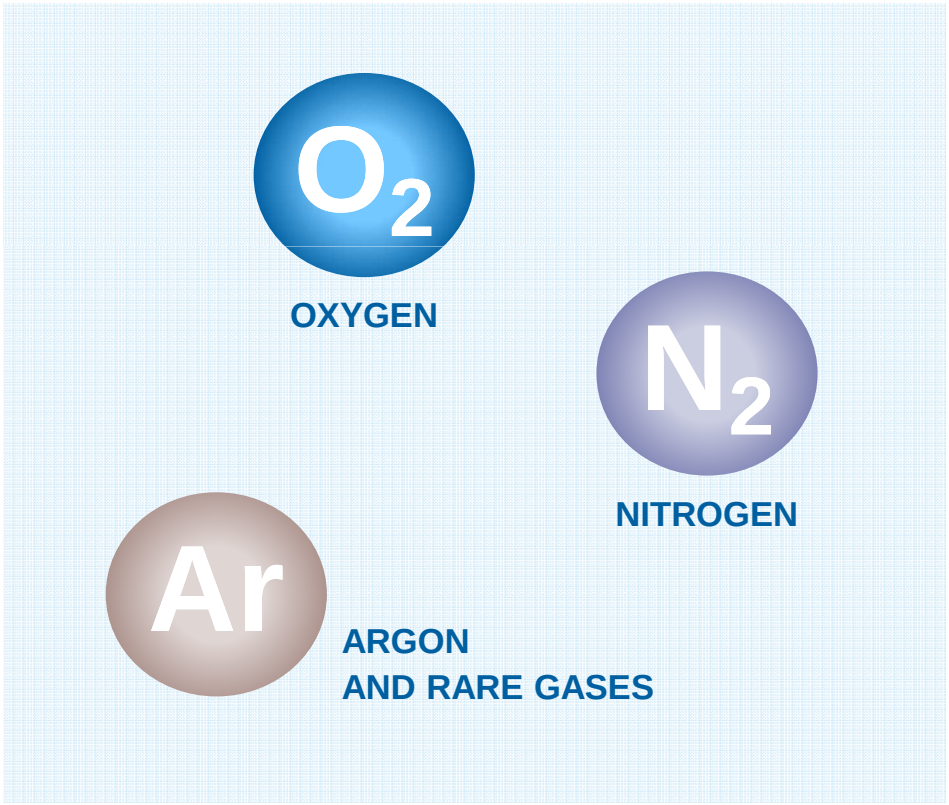
- For a wide range of industrial processes for customers:
  - energy, metals, food, chemicals, automotive, pharmaceuticals …

Health

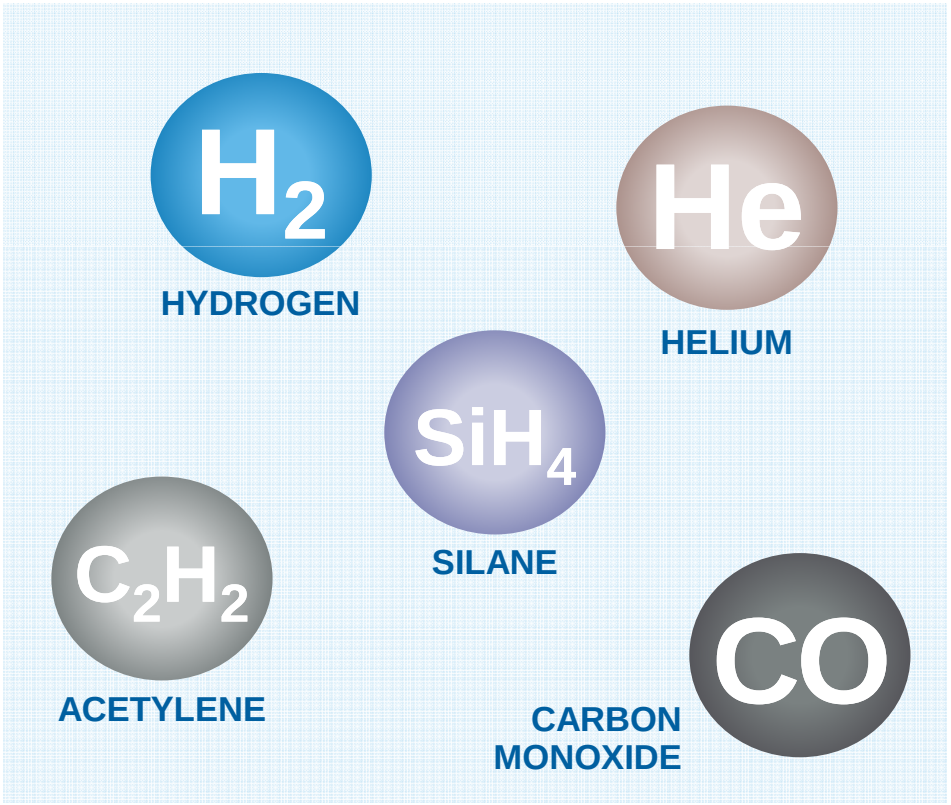
- For hospitals
- For patients at home
- For hygiene and specialty ingredients

Air Liquide … Unique expertise and skills

Separating the components of the **air** to take advantage of their properties



Producing molecules from **natural resources** of the Planet



Innovative structures

Science & Technology

R&D **Engineering & Construction** **ALTEC centers**

Entrepreneur Push New Markets

aB&T network

Venture Capital

ALIAD Venture Capital

Open Innovation

LAB

Air Liquide: 50+ years of H_2 expertise

Air Liquide's H_2 Portfolio –

About 200 plants,
€ 2B revenue

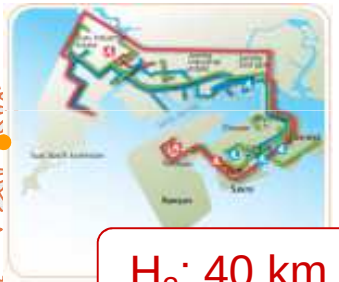
<u>Full product spectrum</u>:
- **Heat treatment**
- **Glass**
- **Electronics, photovoltaics**
- **Chemicals & refineries**
- **Ariane 5 & Ariane 6**
- **Fuel cell vehicles**

Air Liquide Worldwide Hydrogen Operations

H_2: 545 km

Key Figures:

- 200 H2 plants.
- 55 Hydrogen / CO Units
- 23 H_2 Purification Units
- 13 Billion m^3/year
- More than 1,850 km H_2 pipeline



H_2: 40 km

H_2: 950 km

OTF: Over the Fence supply, Air Liquide owns and operates plants

AL's assets for H_2 supply:

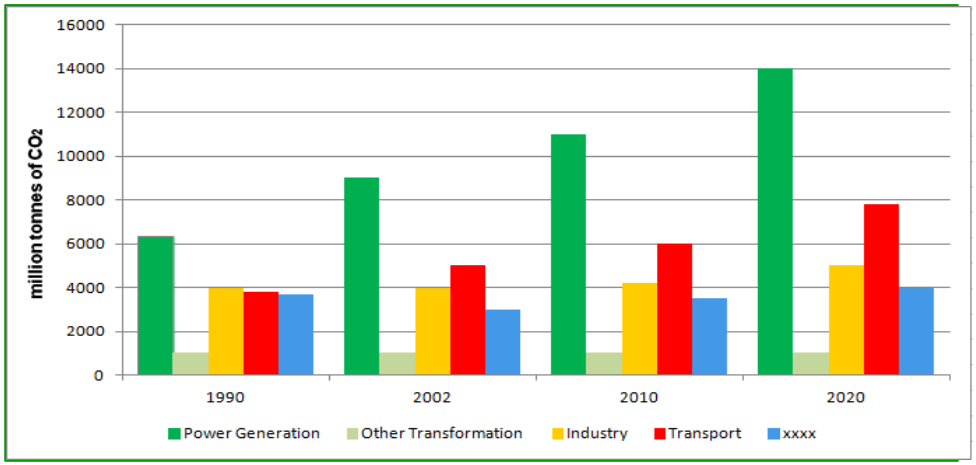
- H_2 Production Unit for OTF supply of H_2
- H_2 Purification Unit – OTF Supply of H_2
- H_2/CO Production Unit (SMR / POX)

Why is H2 energy so interesting?

- Limited oil resources
- Climate change triggering new objectives worldwide

Climate change: triggering new objectives worldwide

Greenhouse gases → T° → Reduce emissions of CO_2 & CH_4



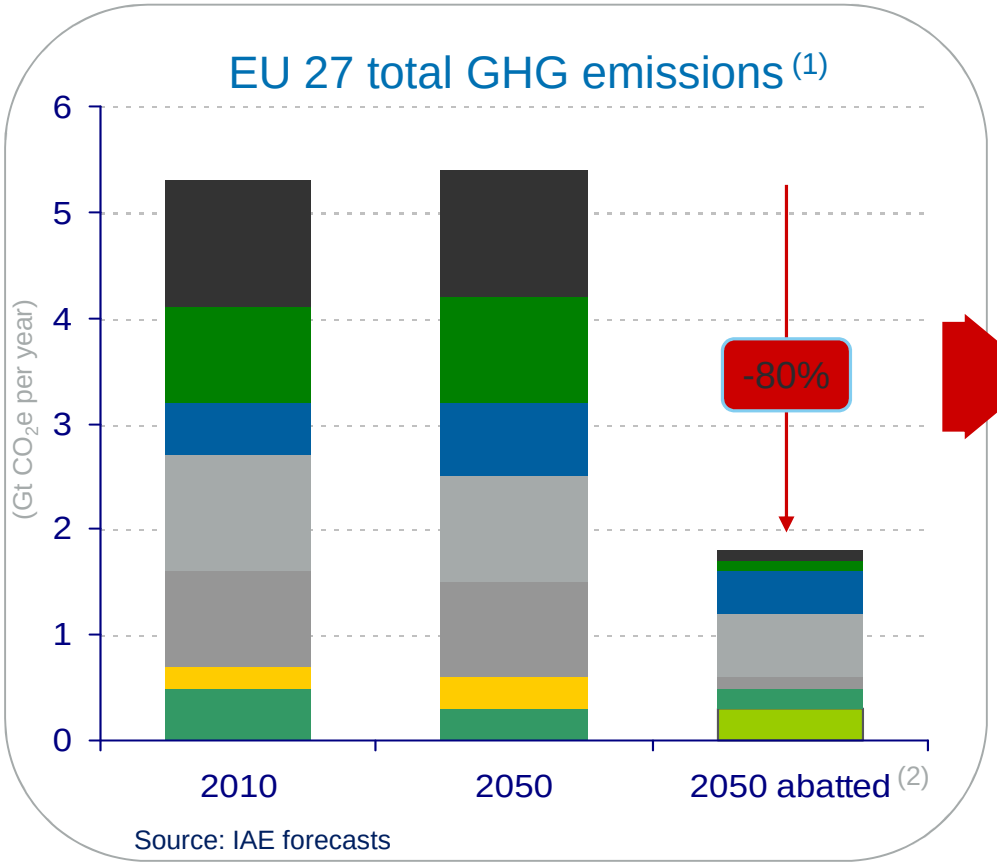
Regulation & Financing

COP21 World climate discussions:

- Europe: Europe strategy: reduce by 80% GHG emissions by 2050 (comp to 1990)
- Japan: By 2030, cut 26% emissions vs 2013, increase sustainable energy mix
- US: By 2030, cut 26-28% emissions vs 2005 via “Clean Power Plan”
- China: Emission peak by 2030, grow share of non-fossil fuel to 20%

Climate change: triggering new objectives in Europe

To reduce emission by 80% by 2050, we need to reduce emissions in transportation by 95%



Sector	Total abatement
Power	95 to 100%
Road transport	95%
Air & sea transport	50%
Industry (3)	40%
Buildings	95%
Waste	100%
Agriculture	20%
Forestry	-0.25 Gt CO_2e

(1) Large efficiency improvements are already included in the baseline based on the International Energy Agency. World Energy Outlook 2009, especially for industry.
(2) Abatement estimates within sector based on Global GHG Cost Curve.
(3) CCS applied to 50% of large industry (cement, chemistry, iron and steel, petroleum and gas, not applied to other industries).
Source: www.roadmap2050.eu

Hydrogen: a solution to energy and environmental challenges

H2 can be produced **from various energy resources**

H2 + fuel-cell = **zero emission** (CO2, particles, NOX, SOX…)

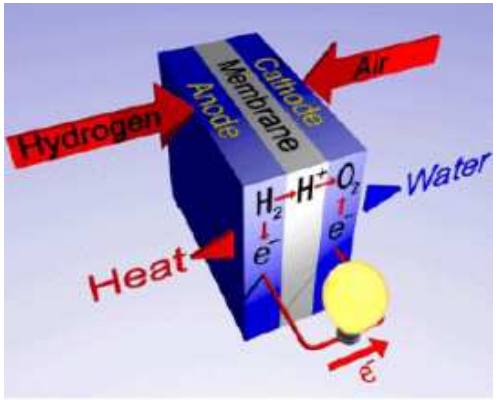
O2+2H2= 2H2O+heat → **up to 85% efficiency** (CHP)

Fuel cells can provide **power for a wide range of applications**

Hydrogen: a **medium for energy storage**

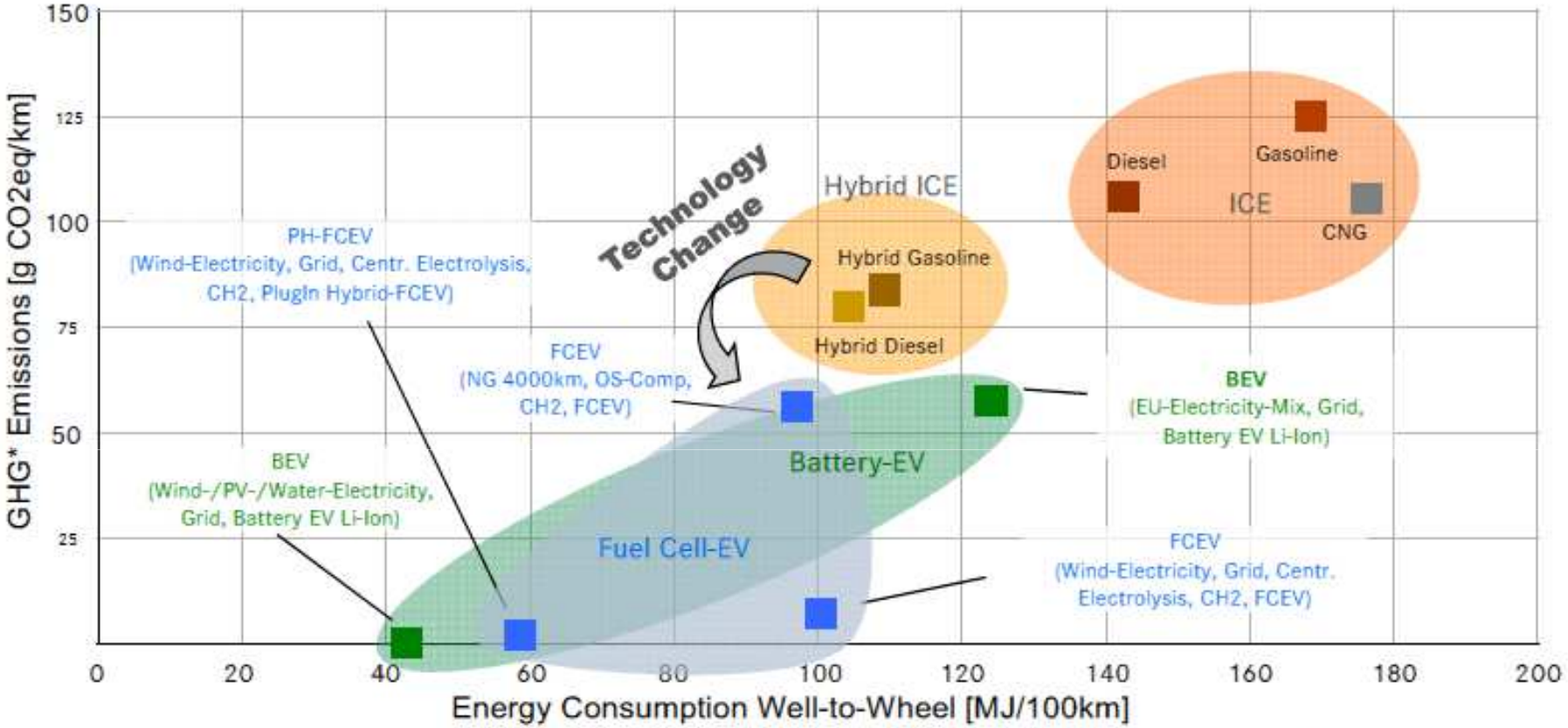
Mobility

Stationary



(1) Catalog of CHP technologies, EPA, 2015

FCEV can offer zero-emission mobility with good driving range

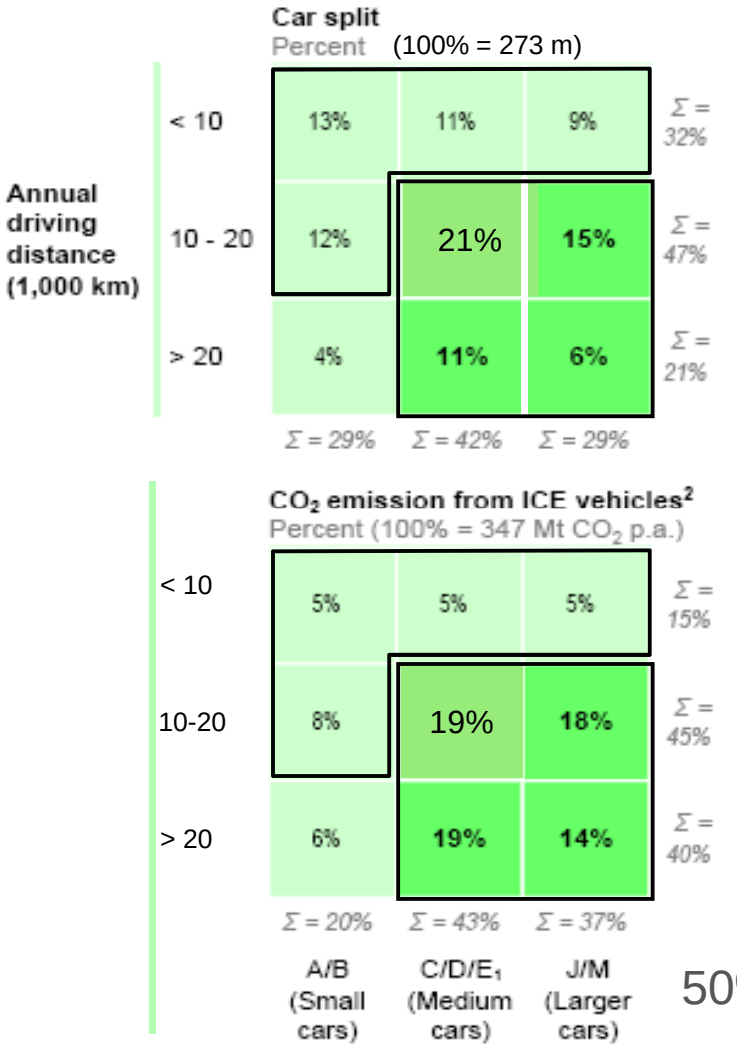


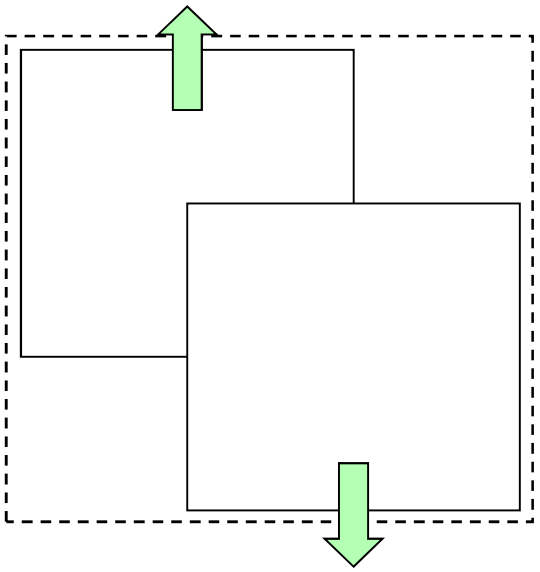
*GHG: Green House Gas

Source: JRC/EUCAR/CONCAWE (2013) WtW Report, Version 4

- Driving range:
  - Toyota Mirai : 500 km
  - Honda claims 700 km for new FCEV commercialized in 2016

Focusing on the right segment

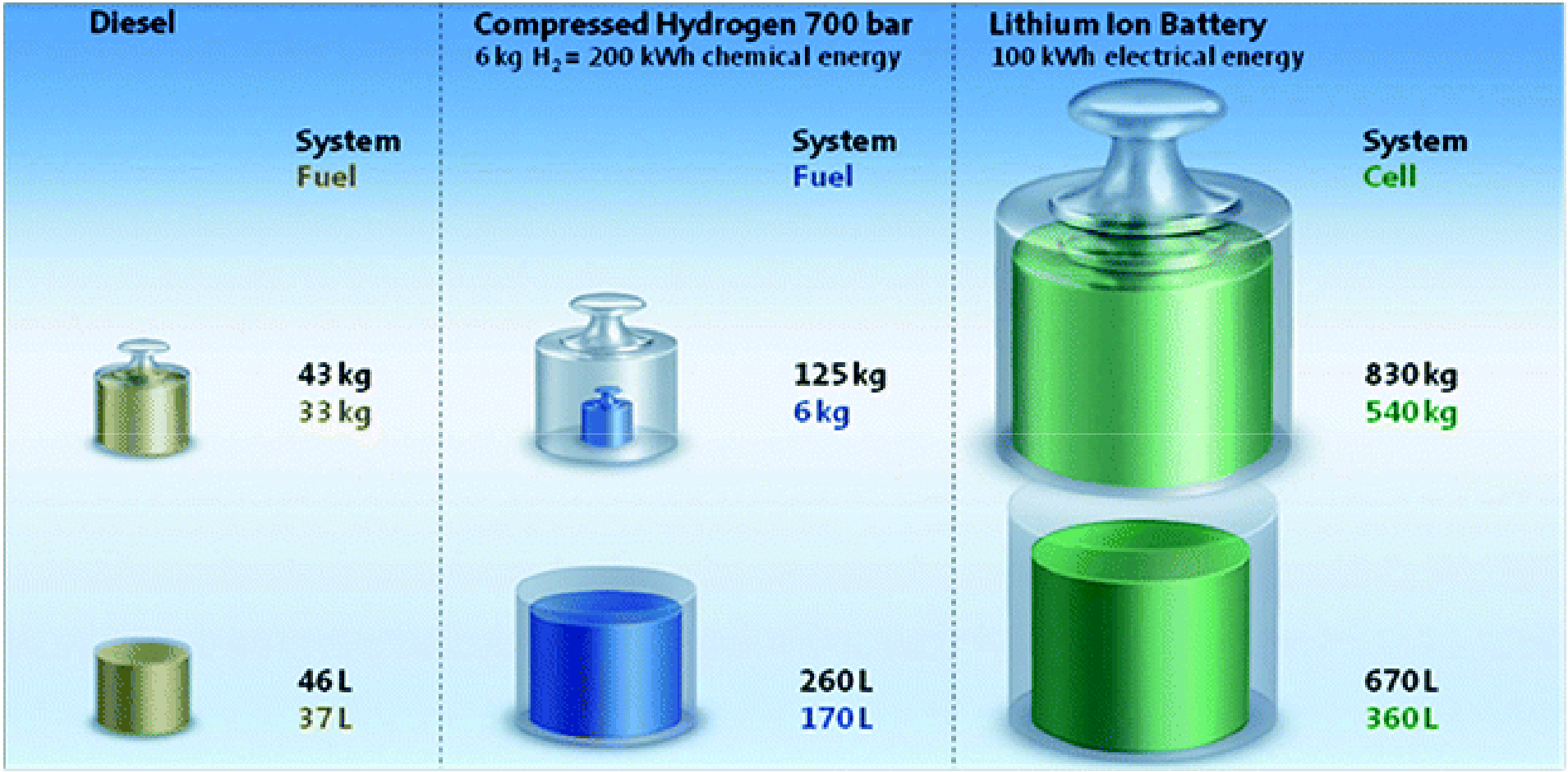




Source : A portfolio of power-trains for Europe: a fact based analysis (McKinsey, 2010)

50% of the vehicles = 70% CO2 emissions

H2 energy content



Source: Opel

Hydrogen in the Future Energy System

Natural gas

Bioressources

Wind turbines

Photovoltaics

Reformer (+CCS)

Gasification, pyrolisis…

Electrolyser

Hydrogen storage

Fuel Cell System

Electrical network

H2 refueling station

Hydrogen electric vehicles

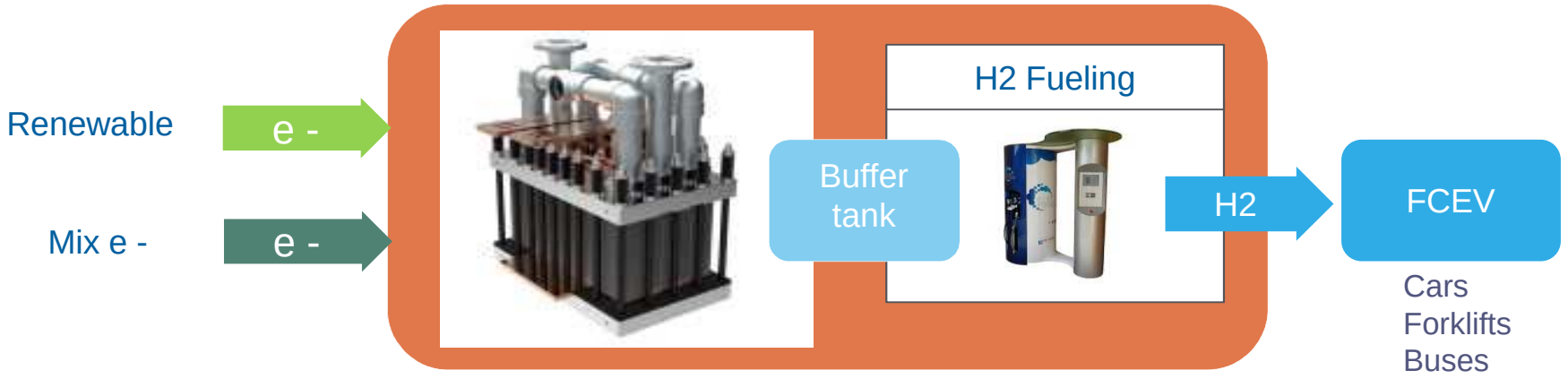
Cogenerator (heat + electricity)

NG grid or H2 grid

Hydrogen : actor of « Smart Energy Grid »

Power to H2 – distributed or semi-centralized

Distributed water electrolysis + H2 refueling station



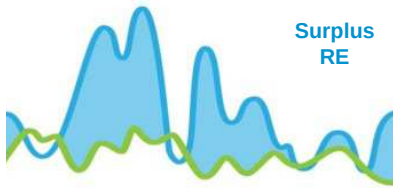
Semi-centralized electrolysis

Combined heat and power Stationary FC

Natural gas grid / 5 à 20% vol. H2

H2

Grid services spot price arbitration



e -

Electrolysis

H2

BLUE HYDROGEN

Storage and distribution

H2

FCEV

Industrial customers

AIR LIQUIDE ADVANCED BUSINESS & TECHNOLOGIES

Why is H2 energy so interesting?

- Limited oil resources
- Climate change triggering new objectives worldwide
- H2: great opportunities as energy carrier
- Technology getting ready

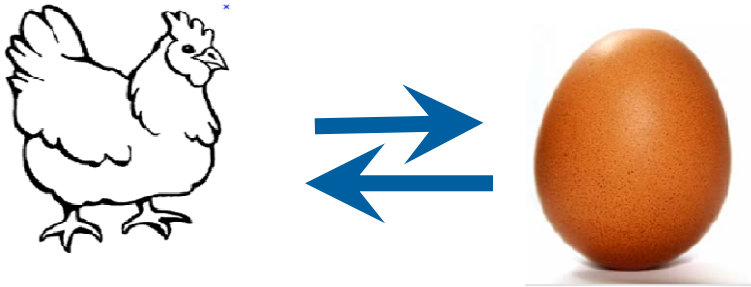
To make it happen, 2 main challenges

- The « chicken & egg » & « valley of death » challenges
- Produce decarbonized H2 at competitive cost

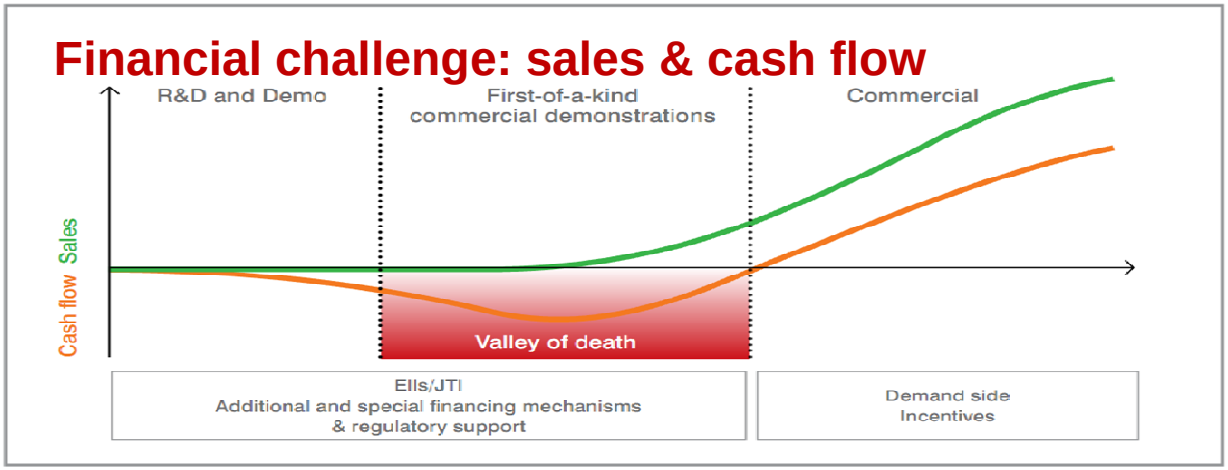
The “chicken & egg” & “valley of death” challenges

- Hydrogen technology must **compete** in:
  - **Price** (customers won’t pay more)
  - **Quality:** (safety, reliability, proximity, rapidity)

chicken or egg?

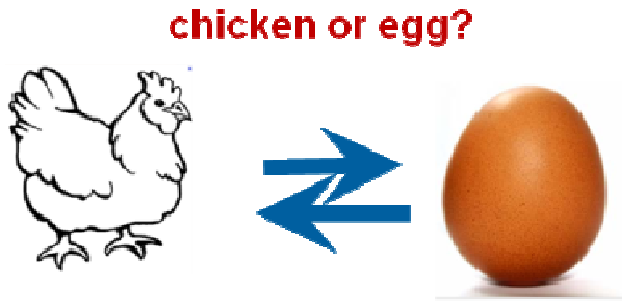


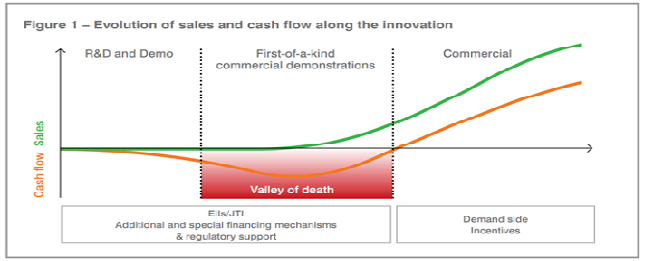
- OEM will not put FCEVs on the roads if they are no hydrogen recharging stations (HRS)
- HRS will not be fully loaded overnight, resulting in low profitability at the beginning
- Learning by doing effect



The chicken & egg & “valley of death” solutions

- Public support :
  - Through **regulations**
  - Through **subsidies**
  - Through **innovative financing**
- Partnerships
  - Ex H2 mobility Germany
- Captive fleets deployments
  - Ex Hyway
- …





Air Liquide's commitment: Blue Hydrogen

- Air Liquide's **Blue Hydrogen** initiative:

50% of H2 energy from carbon-free processes by 2020

- renewable energy sources, water electrolysis, biogas reforming
- CCS technologies with natural gas reforming

A commitment to meet both environmental requirements and social / economic constraints.

Achieving "Blue H2":

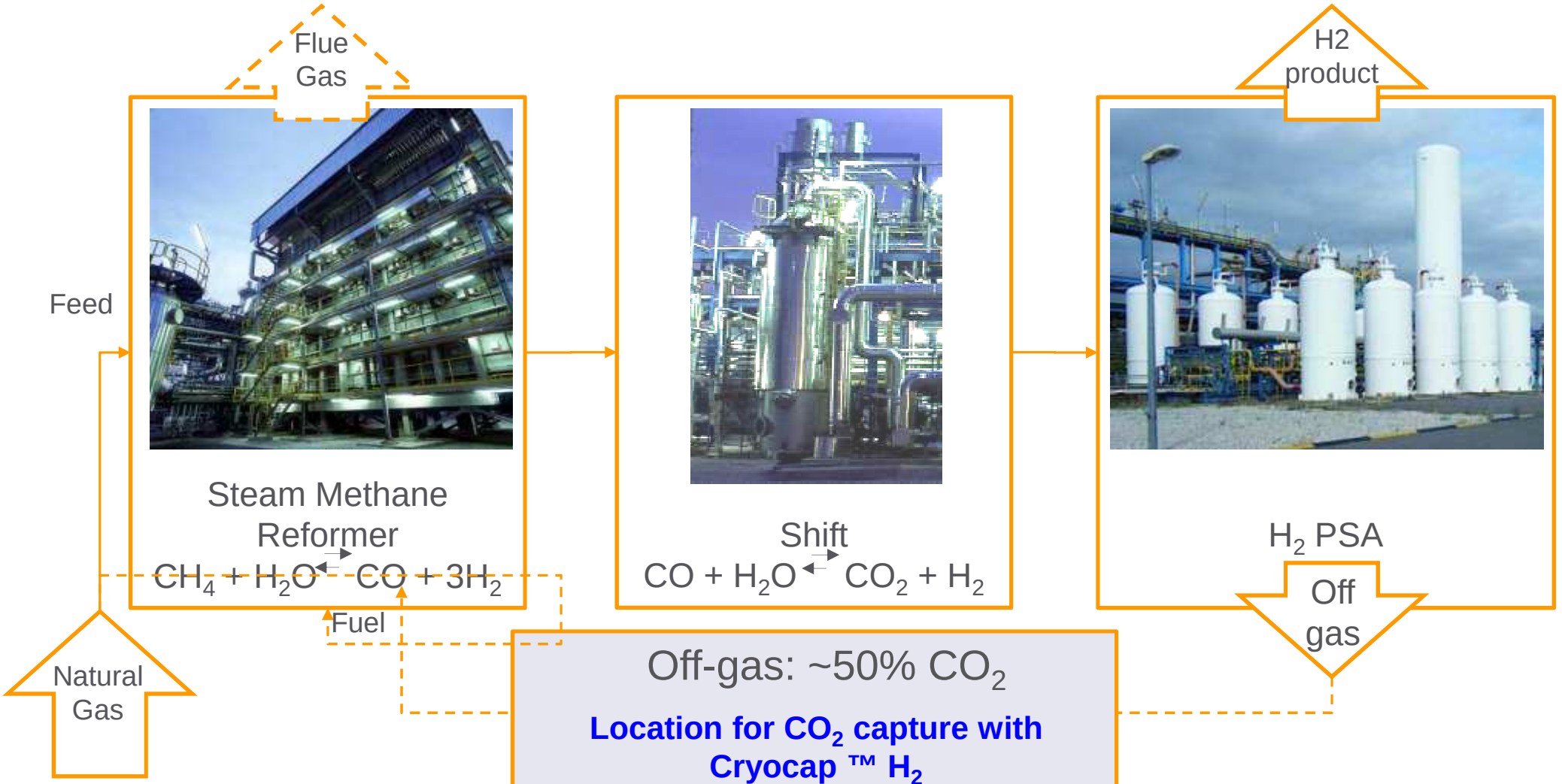
1. Natural gas reforming + CC technology = cut emissions to ISO-approved levels
2. Biomass gasification
3. Biogas reforming
4. Renewable energies during water electrolysis

Note: Even when produced from natural gas, hydrogen is a virtuous energy: for equal distances traveled, hydrogen cars allow to reduce greenhouse gas emissions by 20% vs combustion vehicles.

How is hydrogen produced ?

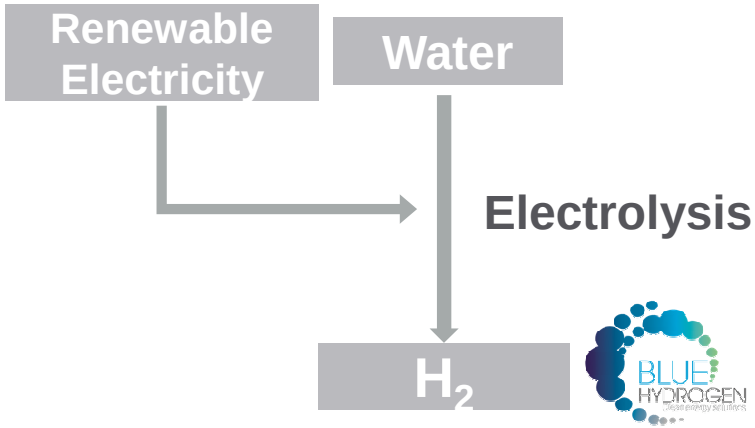
	Near-term	Mid-term	Long-term
Thermal processes	Natural gas reforming	Biogas reforming	Biomass gasification
Electrolytic processes	Low temperature water electrolysis		High temperature water electrolysis
Biological processes		Photoelectrocatalysis	Biological prod

CO2 capture from SMR plants (Cryocap™ H2)



Electrolysis (renewable electricity)

Two alternative mature technologies: Alkaline electrolysis and PEM electrolysis



HYSTAT AEL

(Source: http://www.hydrogenics.com)

AEL (Alkaline electrolysis):

- commercially proven, cheap and robust
- operation at low pressure (< 10 bar(a))
- larger scale than PEM

PEM (Polymer electrolyte membrane):

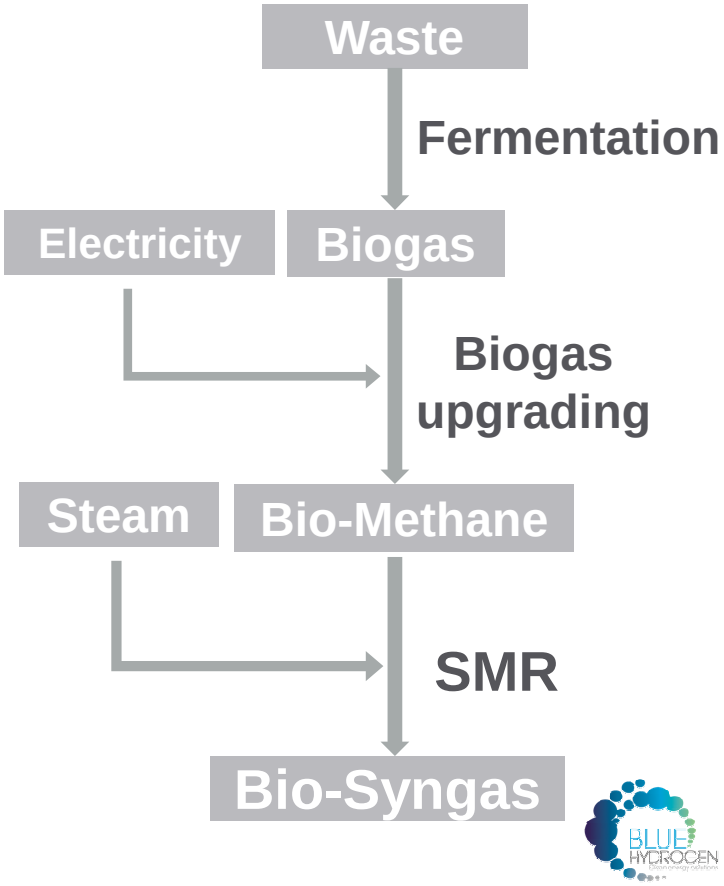
- higher investment costs
- fast response time (suitable e.g. for grid balancing)
- operation at high pressure (~50 bar(a)) ⇒ less energy needed for downstream compression

AL operating several electrolysers since decades

Ongoing tests of electrolysis for on-site H_2 supply of H_2 charging stations (ex: CEP Germany)

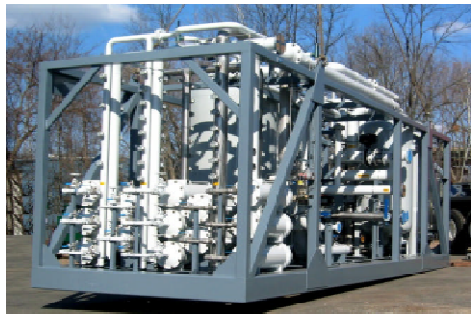
Biomethane + SMR

Biogas (CH4+CO2) upgrading to Bio-Methane and conversion in a SMR to syngas



Commercially proven and available

SMR offers optimum efficiencies and performance, also at large scale



MEDAL membrane module

Héracles SMR plant, Rozenburg (NL)

AL proprietary technology for:

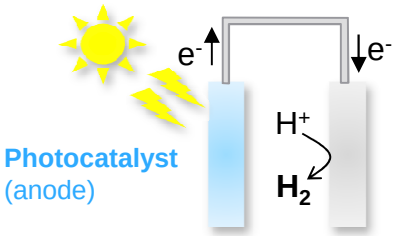
SMR (small onsite units and large commercial units >130,000 Nm^3/h H_2)

Membrane based biogas upgrading (MEDAL)

In the future ?

Solar

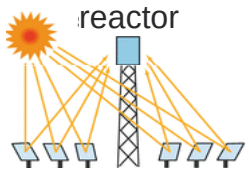
Photoelectrochemical water splitting



H2O → H2 + ½ O2

More R&D needed:
- highly efficient photocatalyst
- durability
- low cost materials
- large scale process

Thermochemical H2 production



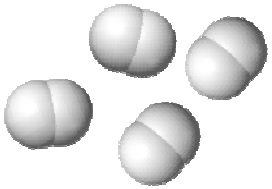
heat+ ZnO → Zn + ½ O2
Zn + H2O → ZnO + H2
(Zn cycle exemple)

More R&D needed:
- durable materials
- low cost receivers/reactors
- heat transfer for chemical cycle

Biological H2 production

cyanobacteria or microalgae + H2O + sun → H2

More R&D needed:
- efficient microorganisms
- single organism system
- high volume manufacturing process

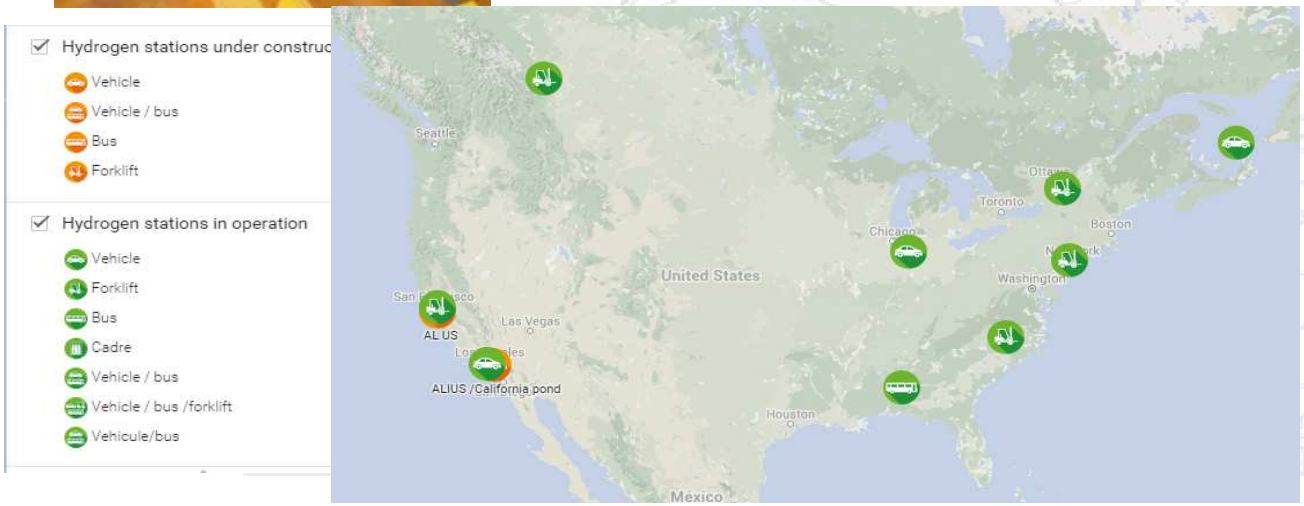


BLUE HYDROGEN
Clean energy solutions

AIR LIQUIDE
ADVANCED BUSINESS & TECHNOLOGIES

Deployment status in North America

Roadmap US: 100 public stations in California by 2020 (13 are open today)



Air Liquide:

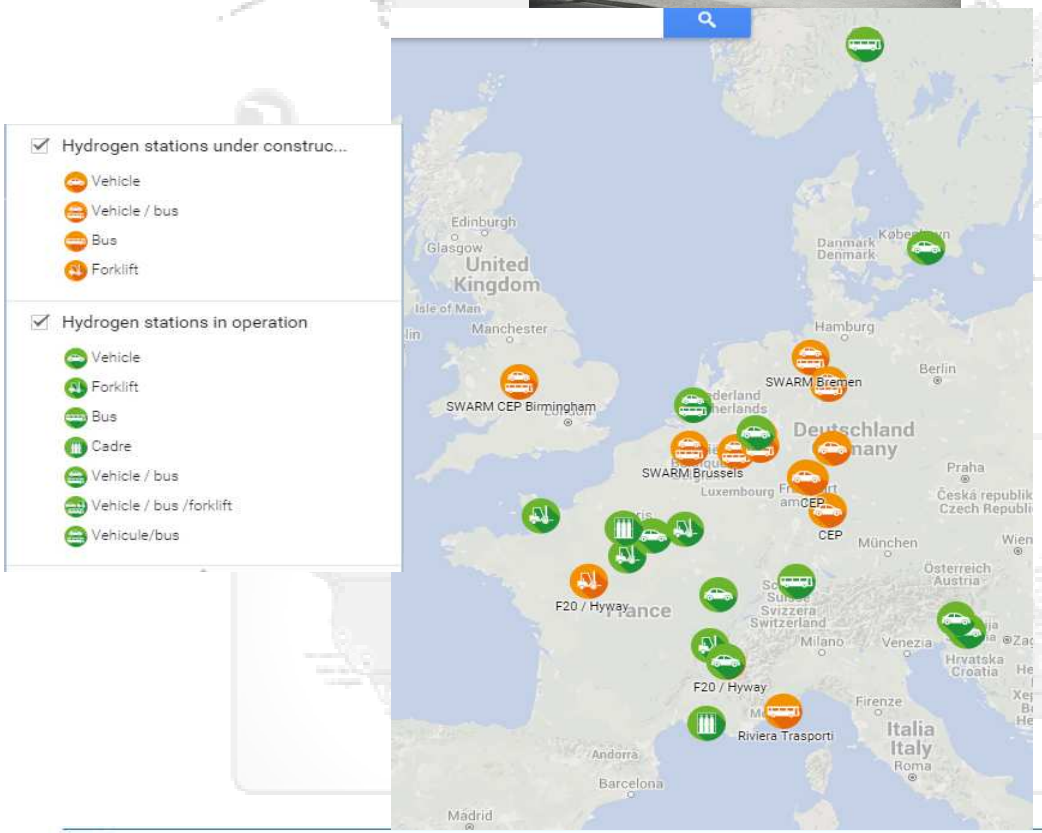
1 open station in California, 1 under construction

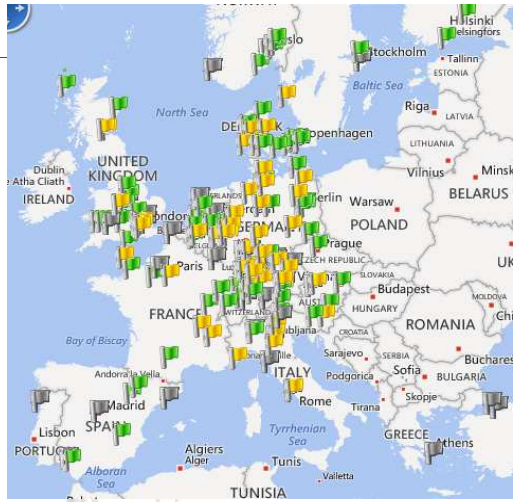
12 stations in Northeast US under construction in partnership with Toyota Motor Sales US Inc.

Largest bus station (20 buses fleet) opened for Vancouver olympics (2011)

Forklift station and H2 for **Coca-Cola** (US) and **Wallmart** (CA)

Deployment status in Europe





Main initiatives :

- **H2 Mobility Deutschland (Roadmap: 100 stations by 2018, 400 by 2023)**
- **Mobilité hydrogène France**
- **Scandinavian Hydrogen Highway Partnerships**
- **UK H2 mobility**

Air Liquide:

First H2 station for private cars in Düsseldorf **in 2012**

Plan for **9 stations in Germany (Clean Energy Program)**

2 stations opened in **France in 2015**

H2 pipeline connected station opened in 2014 in Rotterdam

5 stations in Denmark

2 stations for bus in Norway and Switzerland

Forkilft stations and H2 for **Ikea and FM Logistic's (France)**

Deployment status in Asia

Roadmap Japan: 100 stations by 2016, 1000 by 2025.
400 Mirai on the roads today, 550 by year end
South Korea: 170 HRS by 2020

Air Liquide:

Japan: 2 first H2 stations for private cars in Aichi prefecture **from Jan. 2015 (AL/Toyota Tsucho JV)**

In 2016, 4 stations built, 3 operated by AL

Korea : First 700 bar station under construction

Thank you for you attention

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- www.airliquideadvancedbusiness.com/
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Collection Manifestô - Alternatives, Gallimard
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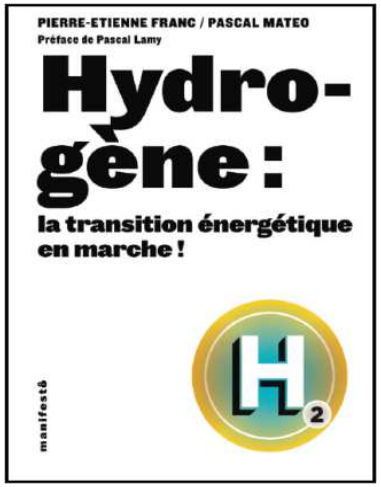
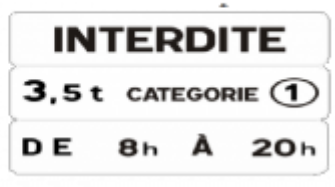


SYMBIO FCELL

Arts et Métiers - Octobre 2015

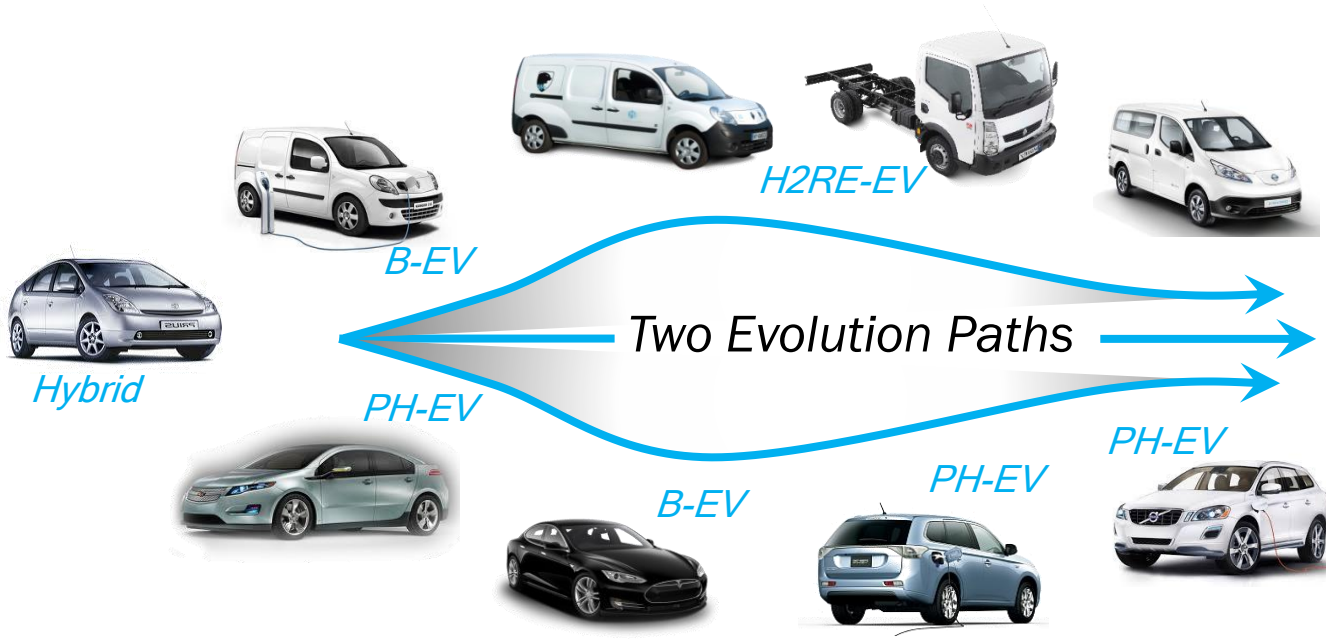
DUE TO CITIZEN PRESSURE, CITIES ARE LIMITING ACCESS FOR NOISY & POLLUTING VEHICLES



A real Headache for delivery and other services companies

WE SEE TWO MAJOR ROADMAPS, ALL LEADING TO ELECTRIC VEHICLES WITH MORE THAN 800KM RANGE

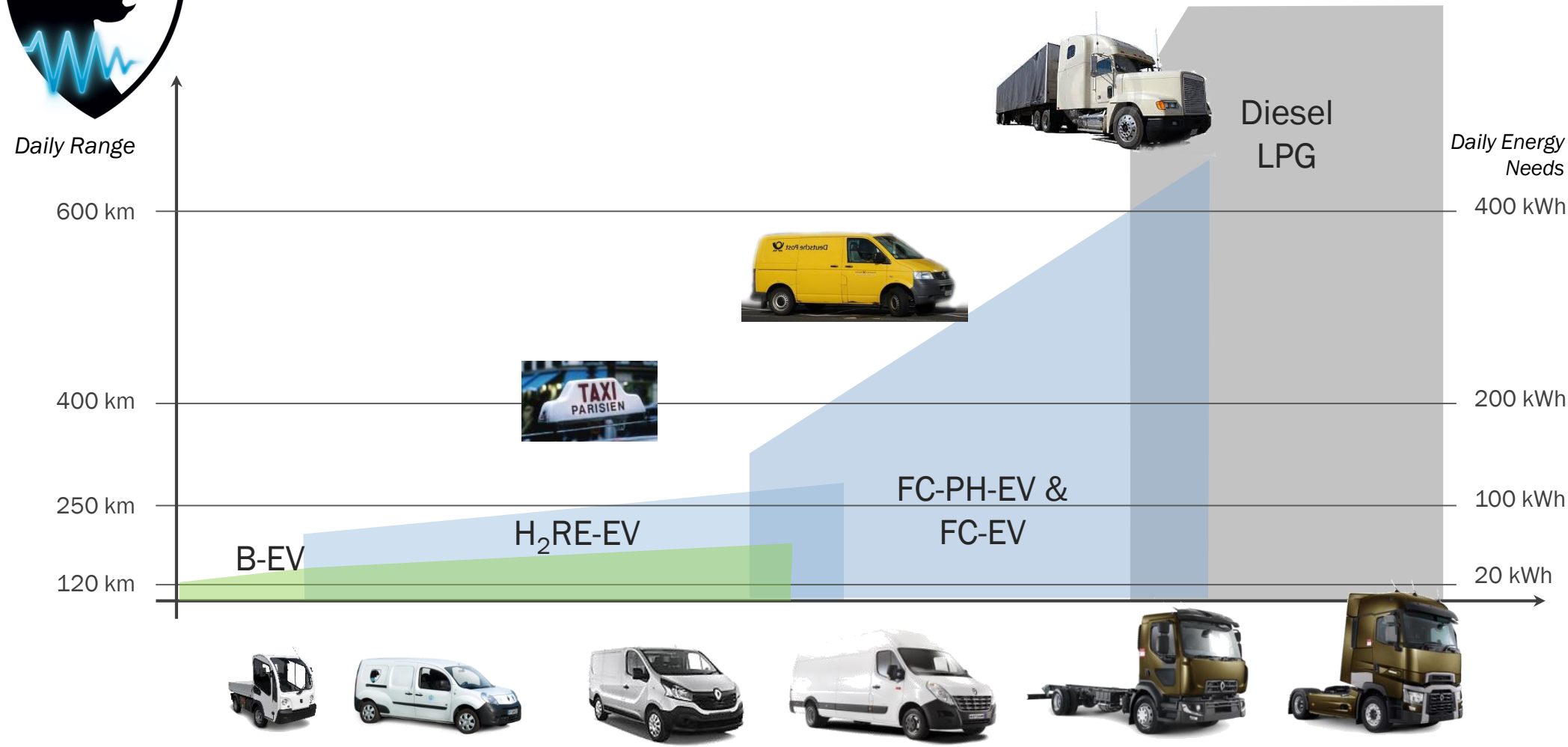
For **Commercial Vehicles** "zero CO_2" is required



For **Passenger Cars**, ICE performances are expected

PHEV: plug-in hybrid electric vehicle, ICE: Internal Combustion Engine, BEV: Battery Electric Vehicle, H2-RE-EV: Hydrogen Range Extended Electric Vehicle

FOR COMMERCIAL VEHICLES, DUTY CYCLE NEEDS WILL DRIVE CHOICE OF TECHNOLOGIES



OEM FOCUS ON FC-EV DEPLOYMENT IN 2020-2025:
THEY ARE WAITING FOR A FIRST INFRASTRUCTURE

Production of H2 vehicles

100 000

50 000

1000

HRS

100 000

100

2013

2015

2018-2020

2020-2025

GM

Ford

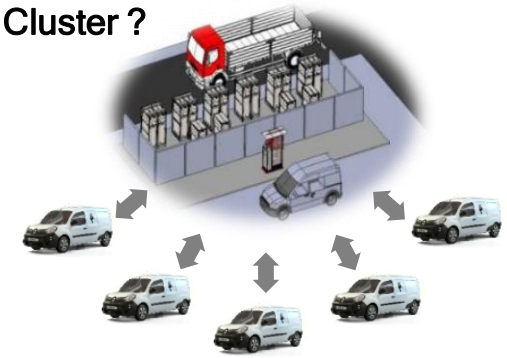
NISSAN

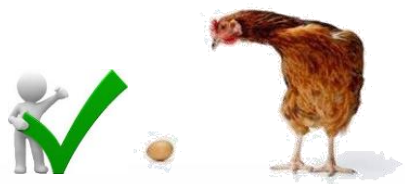
In France, H2 Mobility France industrial Consortium covers the value chain

Vehicles	Electrolyser	H_2 Prod.	HRS Supp.	HRS Op.
				
Symbio FCell Intelligent Energy Hyundai Renault Trucks PFA	McPhy energy AREVA H_2Gen ITM POWER	AIR LIQUIDE Compagnie Nationale du Rhône COFELY GDF SUEZ	McPhy energy ITM POWER AIR LIQUIDE AIC Haskel MILTON ROY H2 Logic	ENGIE idex EDF AIR LIQUIDE ADVANCED BUSINESS & TECHNOLOGIES

FRENCH H2 MOBILITY CLUSTERS APPROACH ANSWERS THE INFRASTRUCTURE DILEMMA

What is a Hydrogen Cluster ?





I – Deploy first Clusters	II – Link Clusters	III – National coverage

Clusters

- Affordable investments
- Maximizes HRS utilization rate

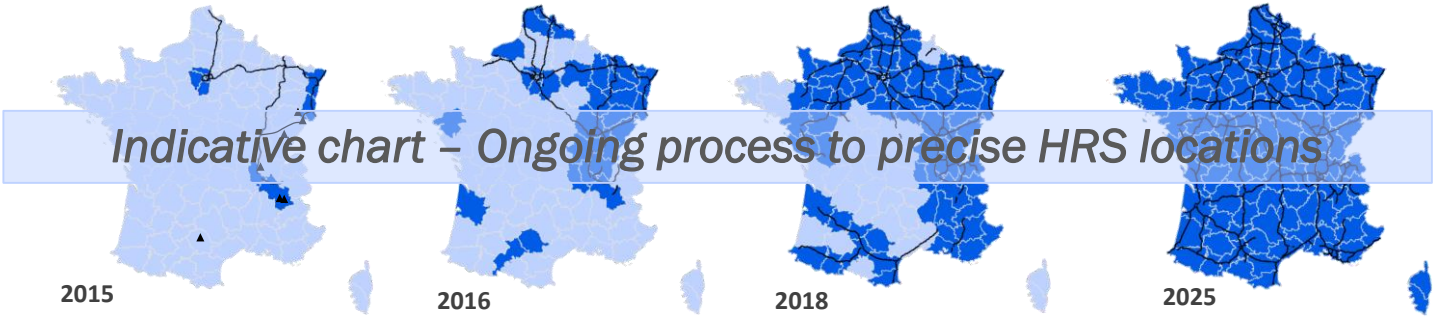
Investment TRIGGERS

Supply of series FCEVs

- 2nd generation FCEV drives cost decrease
- Policy support
- Evidence consumers will buy
- Regulation barriers addressed

National-scale deployment

- Widespread network for passenger car drivers
- Sufficient vehicles to create viable business case for refuelling stations



Indicative chart – Ongoing process to precise HRS locations

Source : Mobilité Hydrogène France

H2 Mobility France Consortium is deploying now HRS and fleets of Vehicles

Plan H2 Mobilité France: 9 stations en 2015…
25 Stations en 2016 +

- **6 Stations déjà existantes:**
  - Saint-Lô (site : services du CG 50)
  - Lyon (site : Port Edouard Herriot)
  - Grenoble (site : station GEG)
  - Dole (site : Solvay Tavaux)
  - Luxeuil (site : PPDC La Poste)
  - Albi (site : circuit d'essai)
- **3 Stations financées par le Call FCH-JU 2014 (Ouvertures 2015-2016):**
  - Rodez
  - Paris Ivry S/Seine
  - Sarreguemines
- **9 Stations présentées dans le Call FCH-JU2015 (Ouvertures 2016-2018):**
  - Lyon
  - Valence
  - Montélimar
  - Bordeaux
  - Nantes
  - Paris – Sud
  - Paris – Nord
  - Rouen
  - Nancy
- **15 Stations financées en Normandie par TEN-T (Ouvertures 2016-2017)**
  - Territoire = Basse Normandie + Départements Limitrophes
  - Principe = préfigurer un maillage dense à l'échelon régional
  - Sites d'implantation = en cours de définition
- **Autres territoires à l'étude**

Source : Mobilité Hydrogène France

SYMBIO FCELL BRINGS APPROPRIATE SOLUTIONS TO ACCELERATE ZE VEHICLES DEPLOYMENT

We developed a Zero Emission LCV solution competing with Diesel

Full package with high level of service

- Same daily range, no winter effect
- No pollutant, no CO_2
- Same availability
- Symbio service support
- Automatic Hydrogen Billing
- Predictive maintenance

With no change in Cost of Ownership

Based on a kit integrated in **standard, mass-produced electric vehicles**
starting with Renault Kangoo ZE

Inside

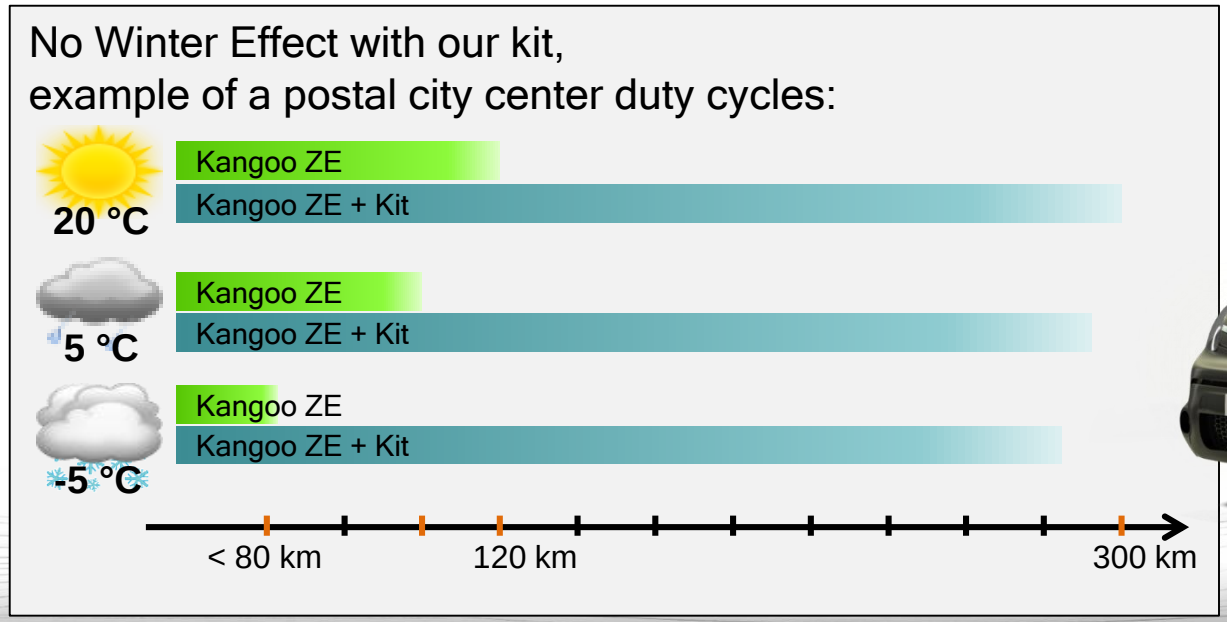
Inside

European Certification
Product available within Renault dealers

Our kit doubles the range of your Electric Vehicle and solves the "winter effect"

22 kWh from batteries + 26 kWh from hydrogen + 24 kWh of Heat

- In winter, the Fuel Cell heat is used to heat the vehicle: no Cold Weather impact on vehicle range(1)



(1) *BEV usual heating uses battery power*

AND IT WORKS IN REAL LIFE…

Export Historique 38SEGRA2 pour la journée du 28/07/2015

Synthèse globale pour la période :

Temps de conduite total : 06:47
Temps d'arrêt total : 01:39
Kilométrage total effectué : 320,9

Date : 28/07/2015

Etape	Stop	Go	Adresse	Km	Arrêts	Conduite
KANGOO H2 DM192AA-38SEGRA2 - Clé n° 46000015BFF04401						
1		08:40	CETUP			
2	08:51	09:03	22 Rue Henri Tarzé - 38000 Grenoble	5,8	00:12	00:11
3	10:57	11:03	Grand'Rue - 73220 Aiguebelle	81,4	00:06	01:54
4	12:02	12:06	26 Rue de la Curiaz - 73140 Saint-Michel-de-Maurienne	47,2	00:04	00:58
5	12:10	12:23	L'Autoroute de la Maurienne - 73140 Saint-Michel-de-Maurienne	0,7	00:13	00:04
6	13:26	13:29	D1006 - 73220 Aiton	50,7	00:03	01:02
7	13:59	14:44	Le Boisset - 73800 Francin	48,3	00:45	00:30
8	16:08	16:18	26 Rue Henri Tarzé - 38000 Grenoble	54,9	00:10	01:24
9	16:40	16:46	360 Rue Emile Romanet - 38340 Voreppe	18,2	00:06	00:22
10	17:08		CETUP	13,7		00:22

Temps de conduite total : 06:47
Temps d'arrêt total : 01:39
Kilométrage total effectué : 320,9

Around 300 kg carried on average on this day

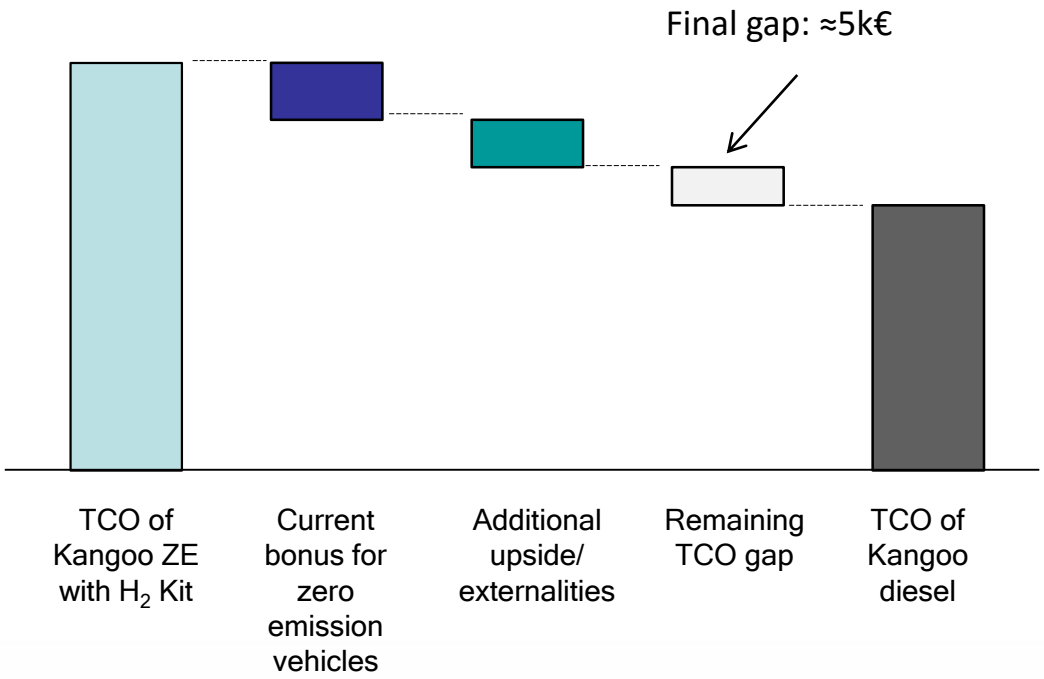
WITH BATTERIES + H2 = STAY 100% NOISE, CO_2 AND POLLUTANT FREE

A Hydrogen Fuel Cell generates only pure water

- Anode : $H_2 \rightarrow 2H^+ + 2e^-$
- Cathode : $½\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$ + Heat

Hydrogen is not a Green House Gas

With H_2RE-EVs, the TCO(1) gap vs. Diesel close to 5k€ for Captive Fleets



Significant upside/externalities(2)

- Increased number of addressable duty cycles compared with battery electric vehicles
- Better work conditions leading to reduced accident rate for electric powertrains due to lower driver fatigue
- Increased vehicle availability due to rapid vehicle fuelling
- Restrictions in urban access with diesel vehicles anticipated, increasing needs for clean vehicles
- Drivers are proud of their cars
- No fears of using the car heating in winter

Source : Mobilité Hydrogène France

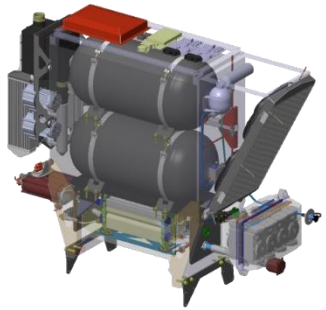
(1) TCO: Total Cost of Ownership
(2) H_2 Mobility France Workshop with 10 French fleet operators held in Feb 2014

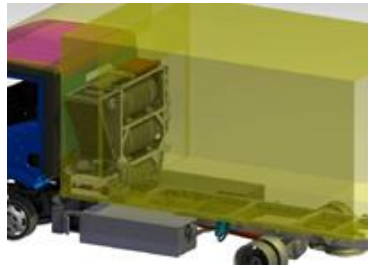
NEW PRODUCT: SMALL DELIVERY TRUCK

3,5 tons (1t payload) e-trucks with H_2FC-RE

- Close partnership with Renault Trucks to support sales and maintenance

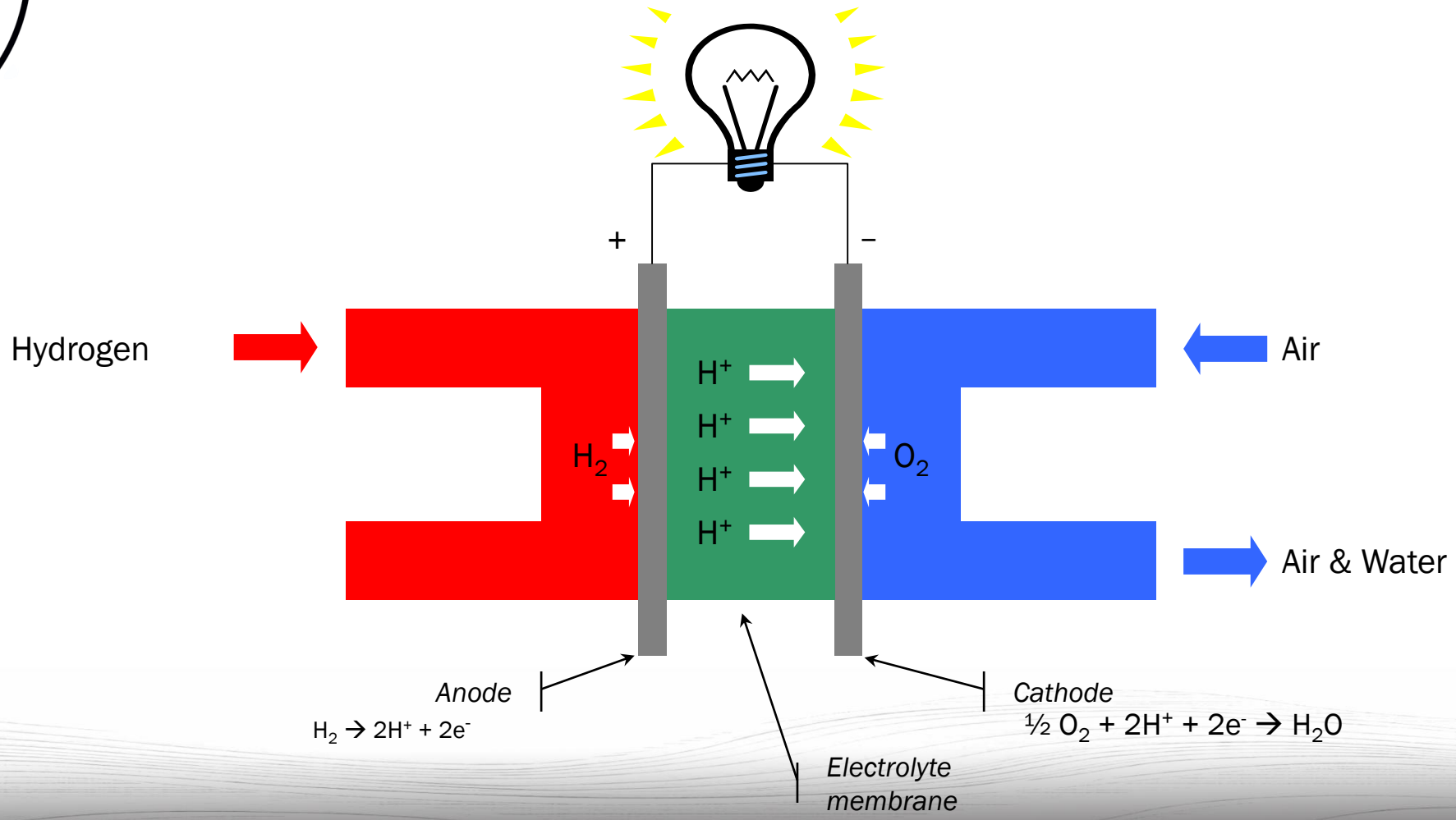
Specifications	
Technical GVW	4,5 t
Admin GVW	3,5 t
Pay load	1000 kg
Electric motor	47 kW / 350 Nm
ESS Lithium-ion	Valence 42 kWh
ESS weight	400 kg
ESS charging time	7 h
Range extender	20 kW Fuel Cell
Hydrogen Tank capacity	2X75 litres 350 b (3,6 kg)
H2 storage	42 kWh
Fuel Cell Weight	260 kg





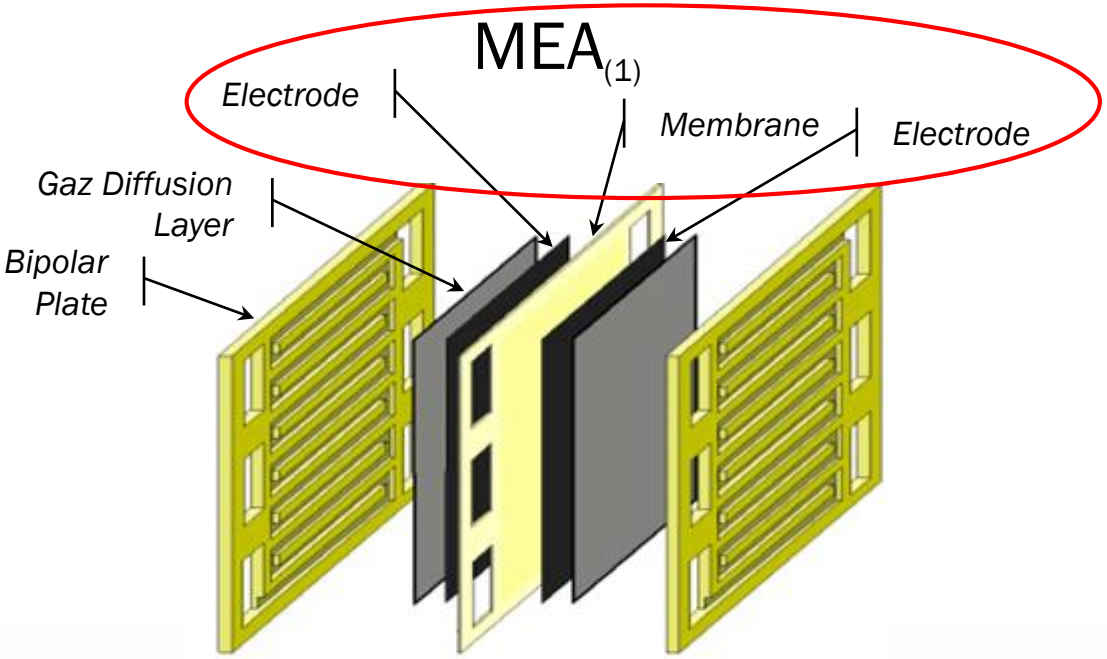
TECHNICAL SLIDES

PEMFC* Cell Principles



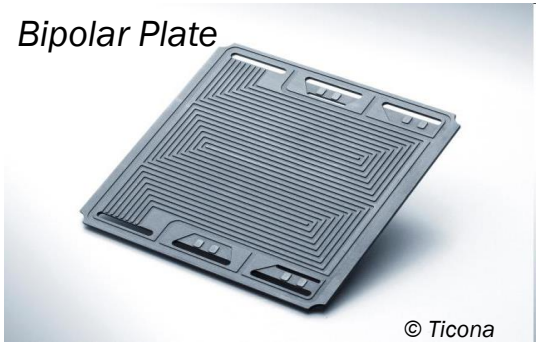
*Proton Exchange Membrane Fuel Cell

PEMFC Cell to Stack



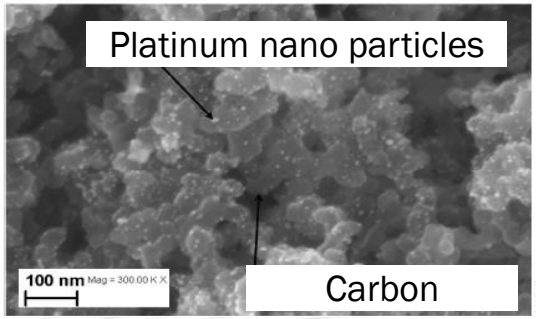
© Energy research Centre of the Netherlands (ECN)

Bipolar Plate



© Ticona

Electrode

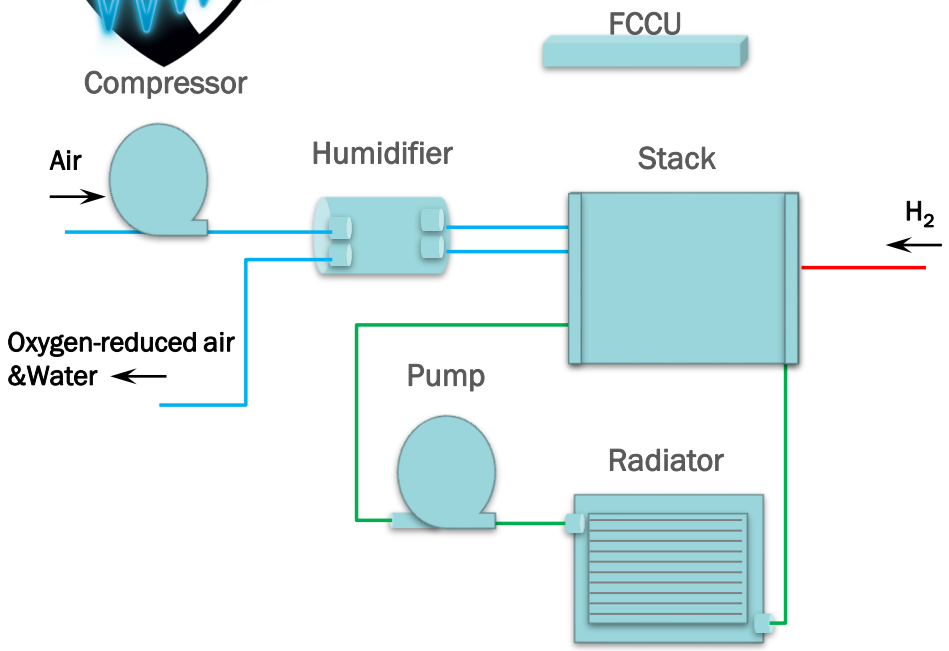


© MEB-FEG, CEA ultramicrotomy

© Symbio FCell

(1) MEA: Membrane Electrode Assembly

A Liquid Cooled System




Stack


FCCU


Humidifier

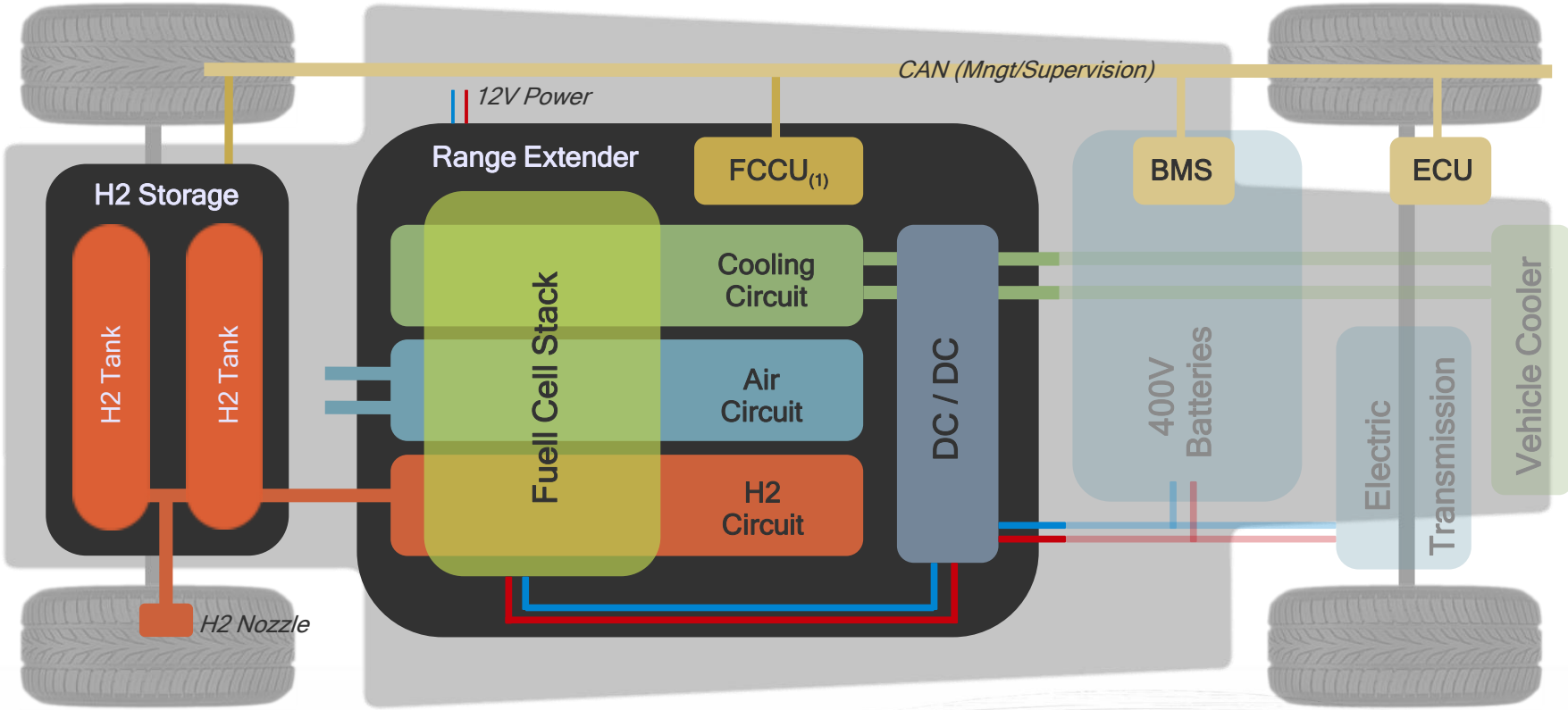

Compressor

Advantages of a Cooling Loop Architecture

- Better management of the stack hygrometry
  - Using an humidifier
- No synchronization of the air stoichiometry and stack temperature
  - Cooling circuit and air circuit: they can be managed separately
- No need for an “ultra-pure” water
  - Problems of bacteria in stored water
  - No water / air separation issue (water trap)
- Easier Cold Start management
  - The Cooling circuit uses water with glycol

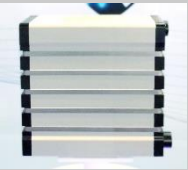
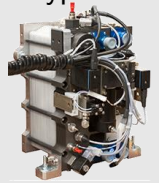
FCCU: Fuel Cell Control Unit

RANGE EXTENDER INTEGRATION



(1) FCCU: Fuel Cell Control Unit
(2) BMS: Battery Management Unit
(3) ECU: Engine Control Unit
(4) DC/DC: Converts a source of direct current (DC) from one voltage level to another

STRONG R&D PARTNERS

cea	R&D programs to develop and improve 80kW fuel cell stacks	Genepac F  Stack 80kW 
MICHELIN	R&D programs to develop and improve 10kW fuel cell stacks	Type 3 
ARMINES	R&D programs to develop advanced fuel cell system features	
FCellSys	R&D programs to improve fuel cell systems safety and validate systems in automotive conditions	

Our Best of breed Key technology partners are European

MEA	SolviCore Fuel Cell Technologies, PaxiTech
Bipolar Plates	DANA, borit, Freudenberg, elringklinger
Tanks & HP	Raigi, AD-VENTA, ullit
Vehicle Integration	Green GT, WR
Power Electronics	TRONICO ALCEN

CREATED IN 2010, SYMBIO FCELL BASED ITS DEVELOPMENTS ON KEY PLAYERS PARTNERSHIPS

COMPANY

2010-02
Creation of Symbio FCell

2010-12
1st investment round with CEA Invest. & IPSA

2013-10
Symbio as H2 Mobility France Coordinator

2014-04
2nd investment round : Michelin shareholder

2014-09
Our Kangoo at Palais de l'Elysée

2015-06
>60 Kangoos H2 delivered

2010-02 :
Licensing with CEA

2011-03
R&D Contract with Ecole des Mines - Armines

2013-05
Partnership with Renault Trucks

2014-03
Agreement with Renault

2014-11
Launch of 1st Ww H2 Cluster : HyWay

2010 | 2011 | 2012 | 2013 | 2014 | 2015

PRODUCTS

2011-02
Design of 1st 5 kW Fuel Cell

2012-06
2 Kangoo with 5kW H_2 RE delivered to Solvay

2014-02
Kangoo H2 approved

2014-07
1st open road test of Kangoo H2 with La Poste

2014-03
First batch of production, 50 Kangoo

2010-11
1st Wv Fuel Cell for race car, 100 kW

2011-07
2nd Fuel Cell for race car, 300kW

2013-11
Design of 1st Fuel Cell for Truck, 80 kW per stack

2015-02
1st Maxity H2 with 20 kW Range Extender for La Poste

2015-06
H2 Digger with Volvo CE

Symbio FCell

THANK YOU