L'hydrogène et les piles à combustible PEM : Une solution pour relever les défis de la transition énergétique.

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Responsable Service Recherche & Technologie
Maison de la Chimie, Paris – 13 Juin 2019

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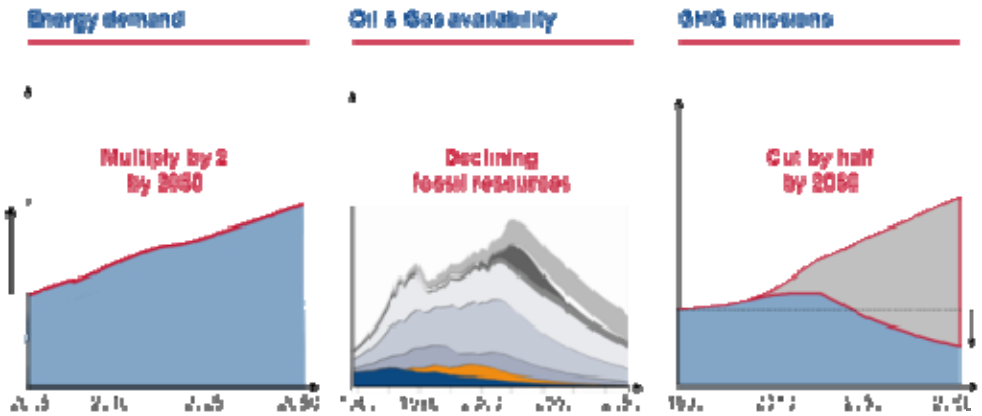
World Energetic Context
Current Status

- **Sharply rising energy demand worldwide**
- **Limited fossil resources**
- **Consensus on climate change and on the need for greenhouse gas reduction**
- **Legitimate aspirations towards development by people in many emerging countries**



Today, the world needs twice as much energy and half as much CO_2

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World energetic context
Two main challenges

Energetic Challenge:
Provide energy for the planet

Environmental Challenge:
Control the GHG emission

An alternative to the “fossils energy only”
need to be found and an energetic mix must to be set up

Energy Transition: New model with high level of renewable energies

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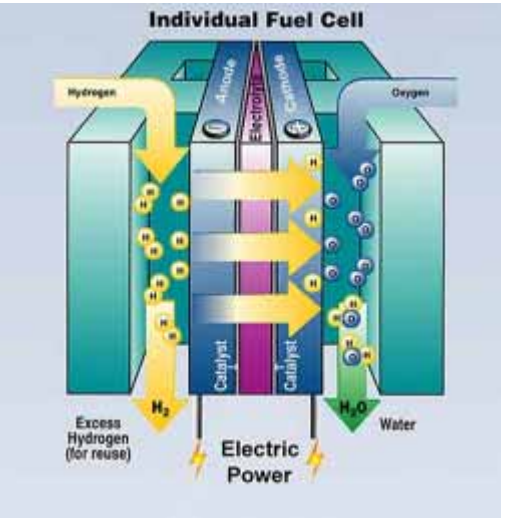
Hydrogen Energy and Fuel Cells

Why this technology could play a role in the energy transition?

Definition

- Electrochemical generator that converts chemical energy of a fuel into electricity and heat
- Two electrodes separated by an electrolyte: the negative (anode) is fed by a fuel (H_2 or CH_3OH or C_nH_m), the positive (cathode) is fed by an oxidant (O_2)
- The electrolyte allows the migration of the ion (from the combustible oxidation reaction), the electron is conducted to the external to be used as an electrical product
- Only water is produced as a by product…



Main Advantages

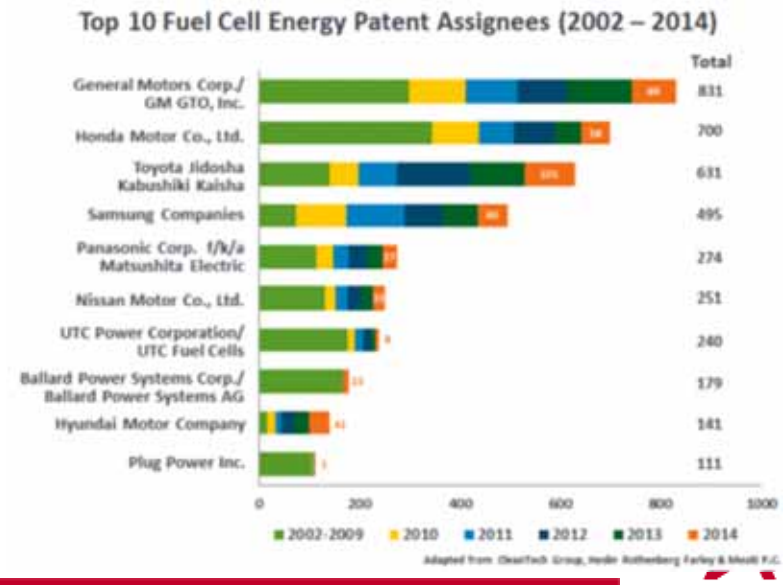
- Fuel cells can reach high energetic efficiencies such as 60% electrical efficiency and up to 85% total efficiency in cogeneration over a large scale of utilization,
- Pollution free (when feed by pure hydrogen), clean and quiet,
- Fuel cells generate high quality DC current,
- With fuel cells technology it is possible to separate and optimize the level of power generated (stack sizing) and energy available (autonomy being link to gas storage size)
- Fuel cells assets are : efficiency, autonomy, quiet and environmentally friendly technology.

The Fuel Cell:
An old and proven Technology

- First realization in laboratory in 1840 by William Robert Grove
- Renewal of interest in the 60's: the GEMINI mission astronauts use the PEM fuel cell technology to produce water and on-board energy
- Today big actors develop, test and exploit this technology:

AREVA, ENGIE, MICHELIN, SIEMENS, TOYOTA, Ford, Air Liquide, EDF, Google, Coca-Cola, HYUNDAI, NISSAN, HONDA, BMW, Mercedes-Benz, ALSTOM, Walmart

- Over 1000 patents are deposited every year in the world, in particular for mobile appications
  - France is the 5th country in term of FC patents numbers in the world



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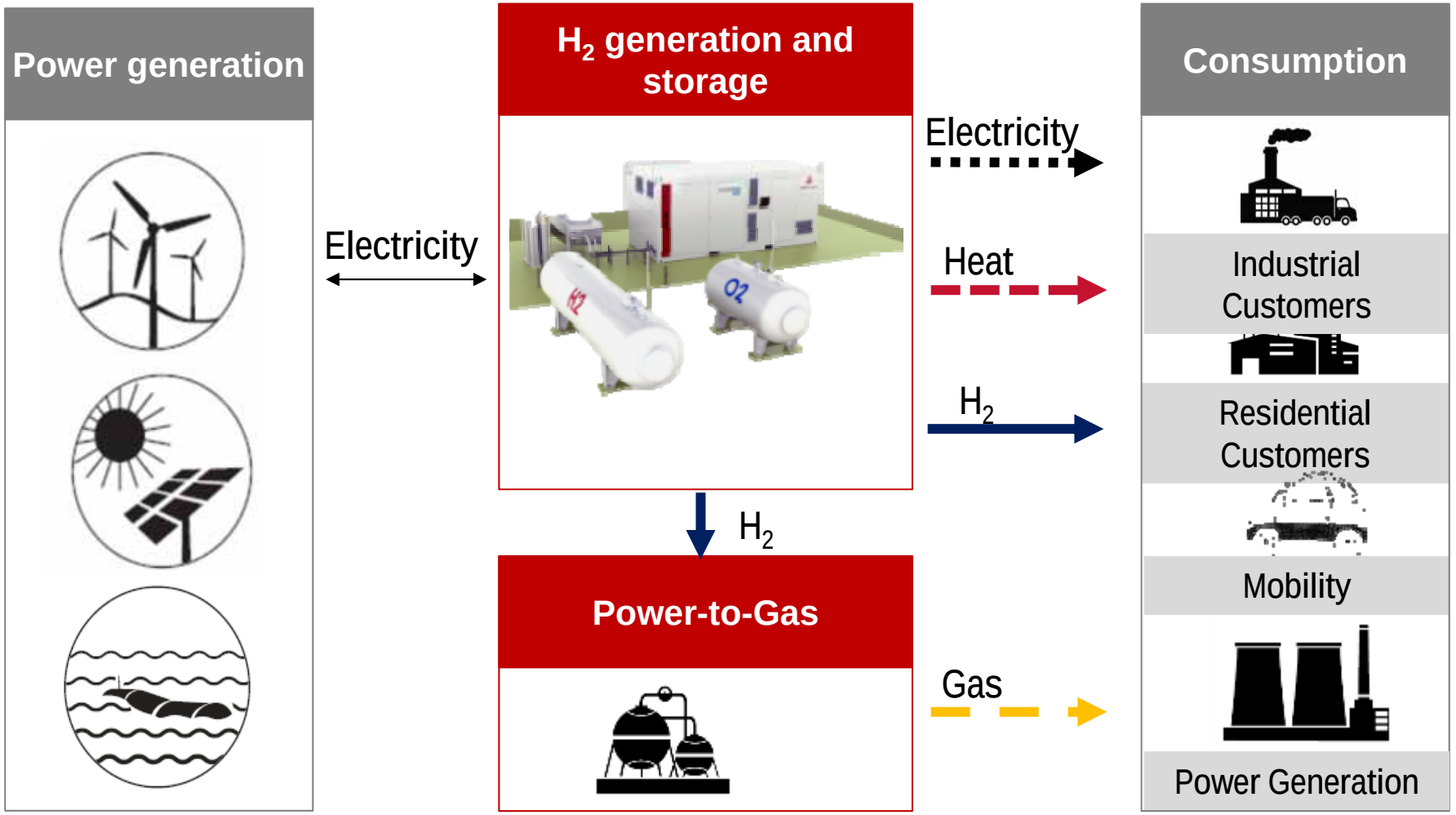
Hydrogen multi-uses model will enable to combine ROI, end-user challenges and energy transition stakes



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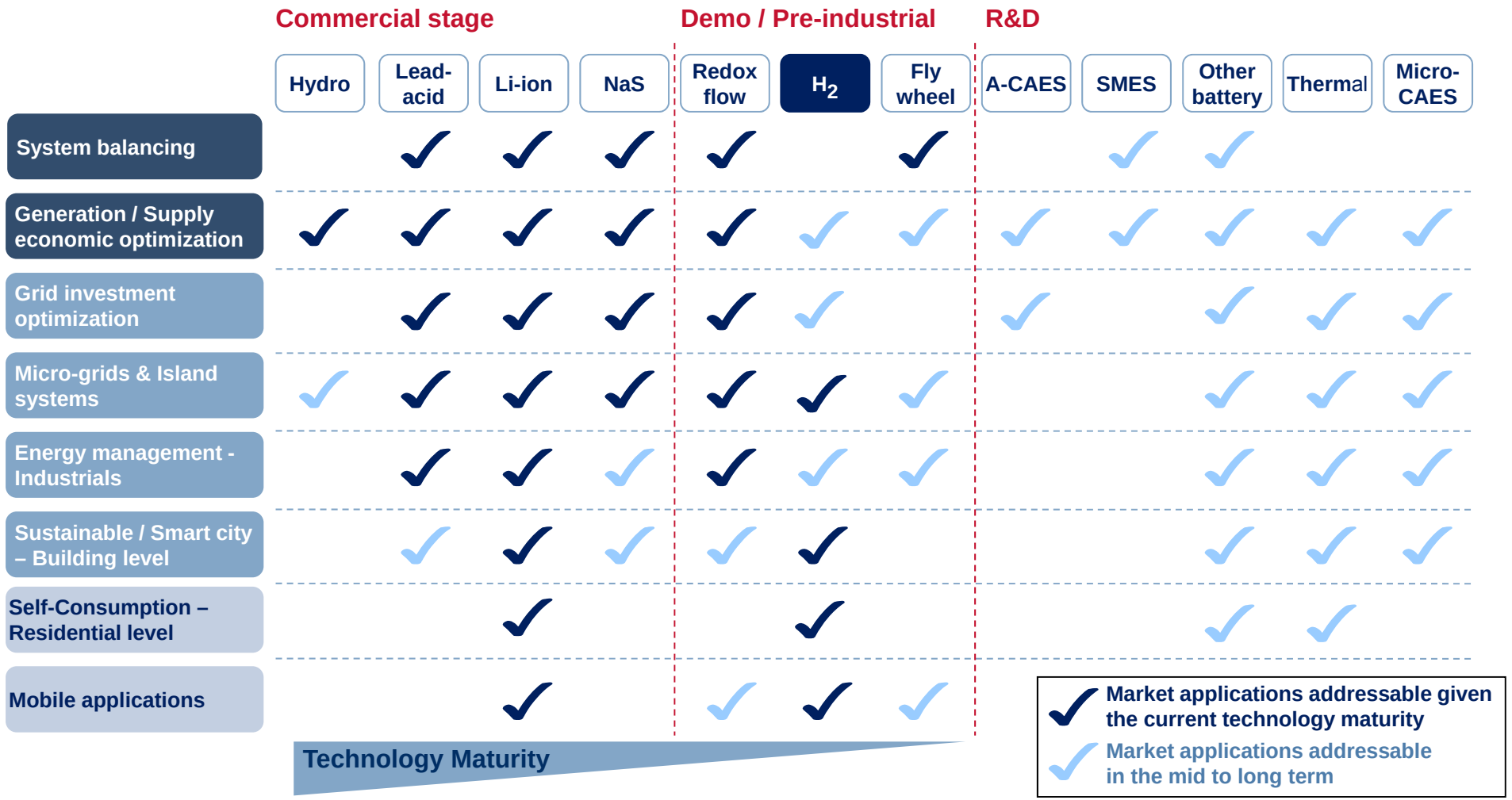
However hydrogen have to compete against more mature technologies



Source: AREVA analysis

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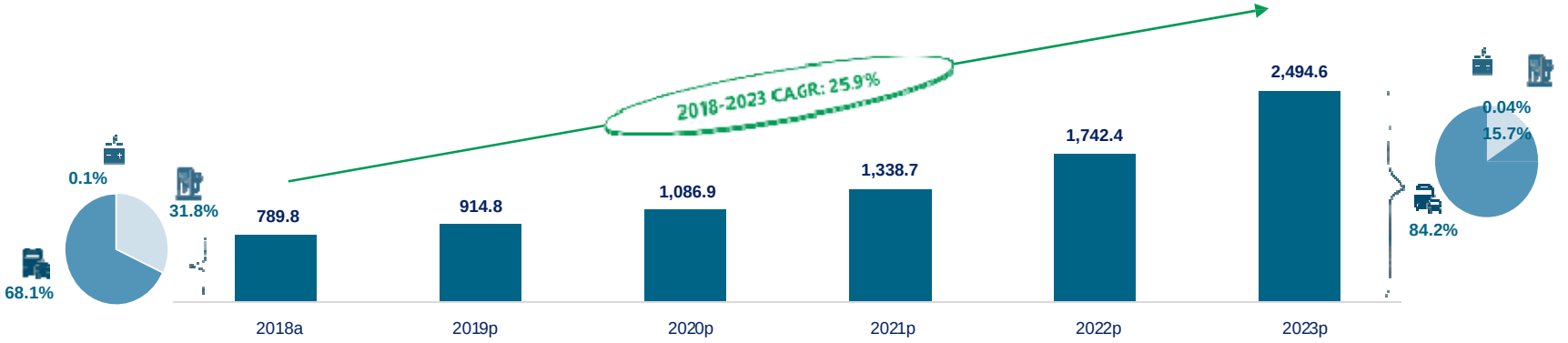
Focus on the global fuel cell market

The global fuel cell market growth is expected to accelerate to reach 2,494.6 MW by 2023p being mostly focused on transport and stationary applications

GLOBAL FUEL CELL MARKET SIZE AND FORECASTS 2018A-2023P (MW)



TRANSPORT

- *Units that provide propulsion power or range extension to a vehicle*
- **Typical power range**: 1 kW - 300 kW
- **Typical technology**: PEMFC and DMFC
- **Example of applications:**
  - Materials handling vehicles
  - Fuel cell electric vehicles
  - Truck and buses
  - Rail vehicles
  - Autonomous vehicles (air, land or water)

STATIONARY

- *Units that provide electricity and sometimes heat, but are not designed to be moved*
- **Typical power range**: 0.5 kW - 2 MW
- **Typical technology**: PEMFC, MCFC, AFC, SOFC, PAFC
- **Example of applications:**
  - Large stationary prime power and CHP(1)
  - Small stationary micro-CHP(1)
  - Uninterruptible power supplies
  - Larger permanent APUs(2) (e.g. trucks and ships)

PORTABLE

- *Units that are built into or charge up, products that designed to be moved, including small APUs*
- **Typical power range**: 1 W - 20 kW
- **Typical technology**: PEMFC, DMFC
- **Example of applications:**
  - Small movable APUs(2) (campervans, boats, lighting)
  - Military applications (portable solider-borne power, skid-mounted generators)
  - Portable products (torches, battery chargers), small personal electronics (mp3 players, cameras, etc.)

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Notes: (1) **Combined Heat and Power |** (2) **Auxiliary Power Units**

Sources: Areva, Goetz Partners, E4Tech, Technavio

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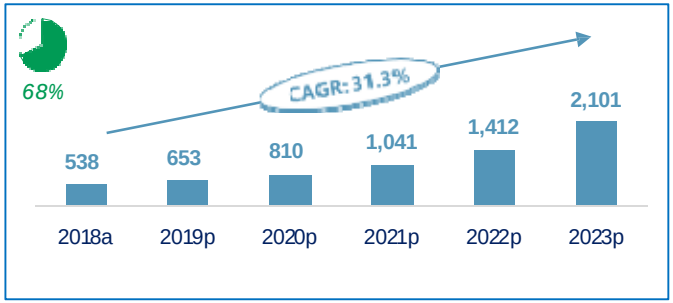
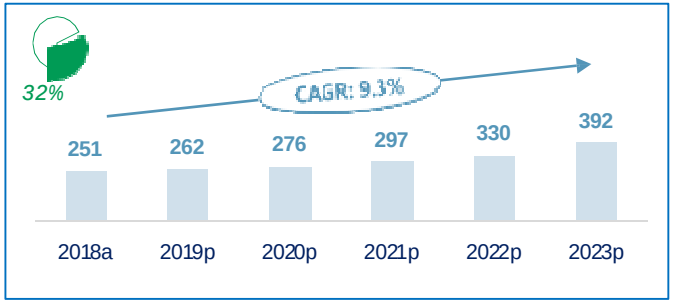
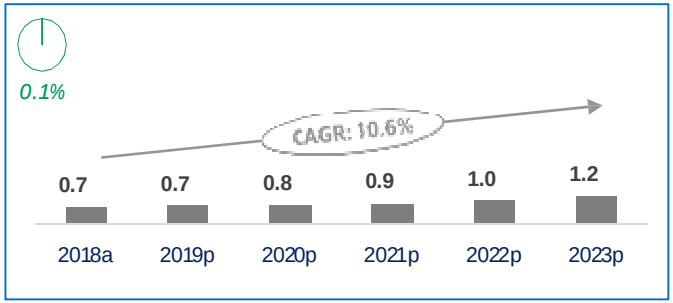
Focus on each market segment

The transport segment accounted for 68% of the total fuel cell market in 2018 and will remain the fastest-growing segment on the 2018a-2023p period

	Market size and forecasts 2018a-2023p (MW)	Market drivers
TRANSPORT		▪ Due to the extensive use of petroleum products and increasing primary energy demand from developing countries, the transport sector was responsible for 24% of direct CO2 emissions in 2017 ▪ As a result, there has been a rising demand for environmental sustainable technologies to fulfill the energy requirements from the transport sector which has been driving the adoption of fuel cells in the transport sector ▪ Fuel cells are being developed to be installed in unmanned aerial vehicles as well as for marine and train applications ▪ Various government incentives to boost the decarbonization of transport sector
STATIONARY		▪ Rapid adoption of residential micro-CHP systems in some countries such as Japan or Germany with the significant growth and commercialization of micro-CHP systems employing fuel cells in the residential sector ▪ Cost reduction of fuel cell-micro CHP technologies ▪ Various government incentives and regulation such as the resurrection of the US federal investment tax credit for stationary fuel cell systems ▪ Increase in the use of fuel cells for providing UPS backup from several critical applications such as commercial and industrial, emergency, first responders and defense and telecommunications
PORTABLE		▪ Growth in the use of electronical equipment (e.g. night vision goggles, global positioning systems, communication devices, computers and sensors, etc.) for soldiers on the field has increased the requirements for lightweight, dependable and portable electrical power supply (away from the main electrical grid) in the military sector ▪ Competitive advantages of fuel cells technologies present for portable applications vs. batteries that need to be replaced or recharged complicating the logistics process ▪ Increasing use of fuel cells in UAVs to provide a better endurance and flexibility in monitoring and surveying applications (longer operational lives, reduced GHG emissions and thermal noise signature) ▪ Increasing use in domestic devices replace batteries to power phones, cameras, etc.

Legend: 2018 capacity in MW as % of total fuel cell market **Source: Areva,Goetz Partners,Technavio**

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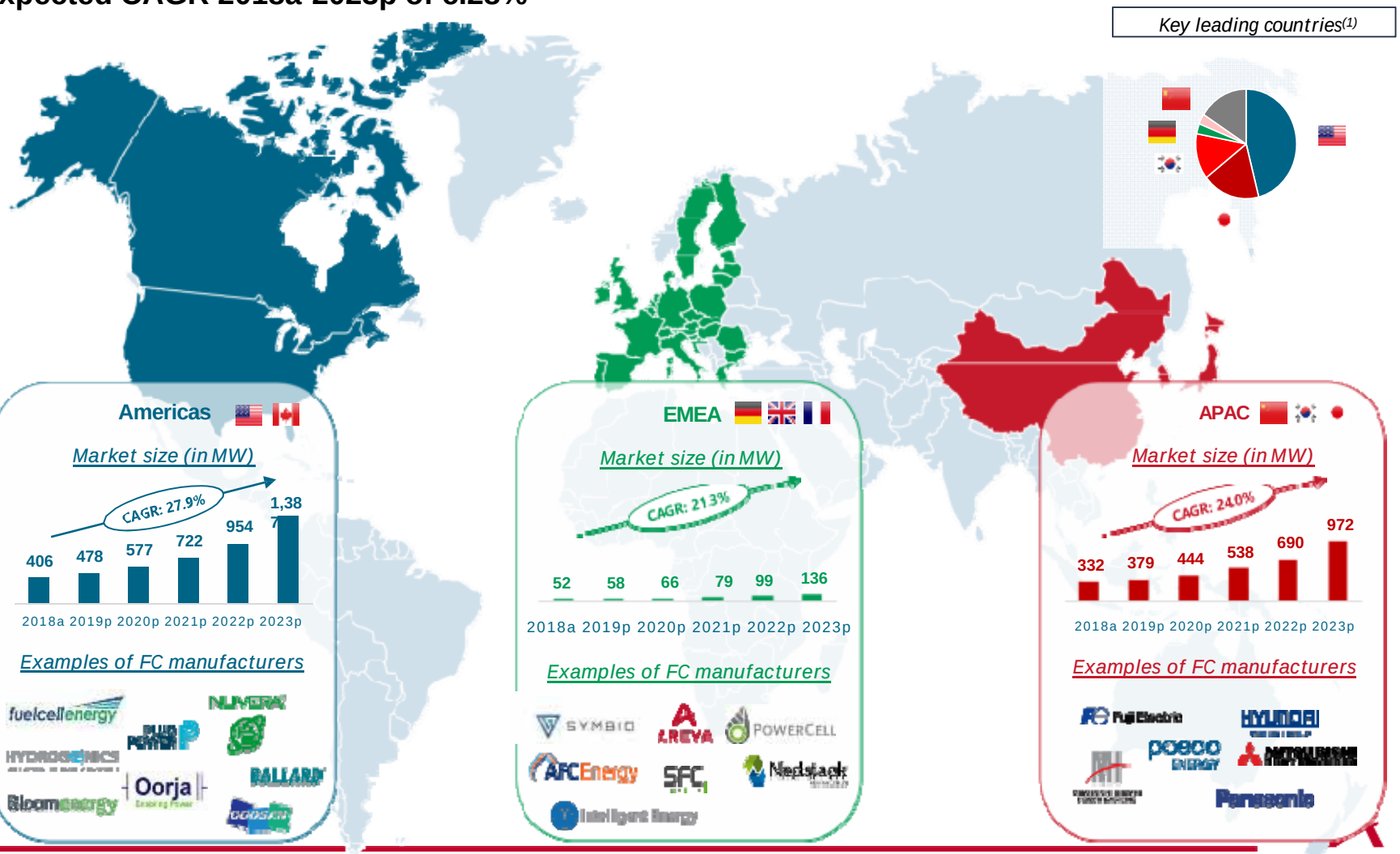
Market size by geography

In 2018, the US, Japan, South Korea, Germany and China accounted for c. 84% of global fuel market and Americas will still represent the main fast-growing region with an expected CAGR 2018a-2023p of c.28%



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Note: (1) 2018 market shares (% of global market), approximated

Source: Goetz Partners,Technavio

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Since 2017 AREVA SE proposed and set up a strategic action plan to transform the rising interest in hydrogen and fuel cells technologies into market opportunities

Leveraging Strategic Partnerships

- Validate our positioning on targeted markets
- Fine tune technical specification of our products to fit exactly the market requirements
- Locate several products within early adopters facilities to gain customers' acceptance and operational feedback

Minimizing and Sharing Risks

- Cost reduction strategy on stack and system
- Continuous effort on modularity studies to develop common denominator to our range of products in order to:
  - Minimize specific developments to seek cost reduction
  - Reduce our time to market to be able to cope with innovative nature of the markets
- Define industrial organization and partners to determine investments required, reduce ramp-up risks...

Testing and qualifying

- Qualification of stack platform, heart of our future products
- Collect sufficient REX to enhance durability, reliability,… while mitigating technology risks
- Consolidate product credibility by collecting, analyzing, integrating and valorizing our operational feedback

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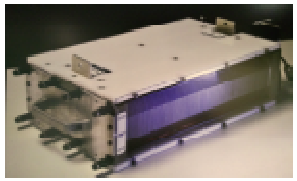
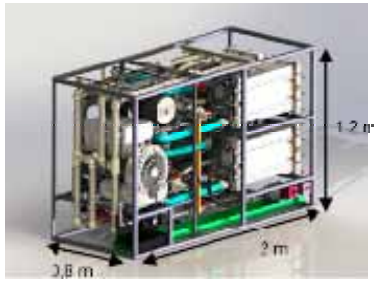
HELION / AREVA SE 2019 product portfolio

- **FC stack**
  - Small stack: from 5 to 15 kW
  - Large stack: from 20 to 50 kW



- **FC RACKS for heavy duty mobility**
  - Train, ship, boat, barge
  - From 85 to 200 kW brut



- **Mobile Genset**
  - Events, on shore power supply, temporary energy station
  - from 5 kW to 2 MW net

- **H_2 Backup (UPS)**
  - Industry, datacenters, mining, petrochemistry
  - from 5 kW to 2 MW
- **Hydrogen battery (FC+Electrolyser)**
  - For smart buildings and H2 village, off-grid communities, mining,
  - From 5 to 400 kW FC / 1 to 100 Nm3/h electrolyser

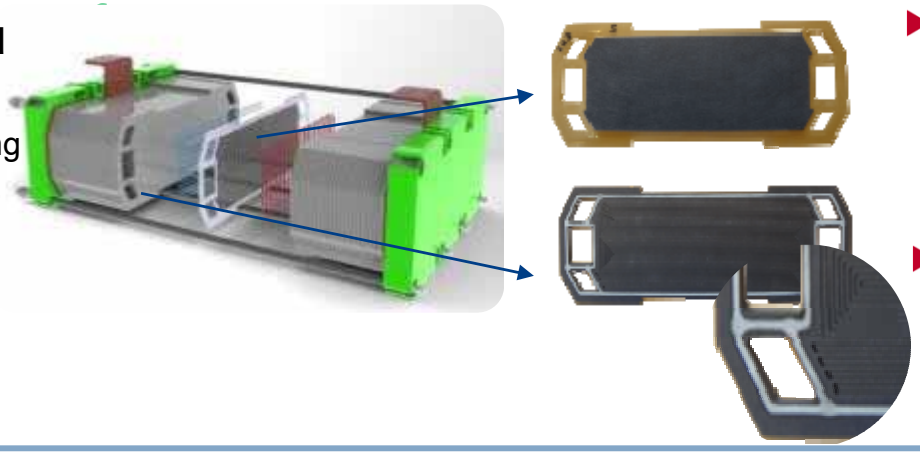
Main technology challenges
FC Stack Development

Stack Design & Manufacturing improvements for H_2/Air

- **Performance – Durability – Cost Objectives**
  - Nominal Electrochemical Performance: 0.84 A/cm² - 0.68 V/cell (0.57 W/cm²)
  - Durability > 20 000 operating hours
  - Up to 2500 Start and Stop
  - Voltage Decay < - 5 µV/H; < -0.7 % Pnom/1000 hours
  - Stack Cost < 500 €/ kW

…only a good cell design will allow a good stack

- **Stack design and manufacturing**
  - Ease manufacturing
  - Low pressure drop
  - Improved Sealing



- **MEAs**
  - Commercially available
  - Low Catalysts loading
  - Durable membrane
- **Bipolar plates**
  - Low pressure drop
  - Ease Manufacturing: molded plates

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Main technology challenges
Ongoing FC Stack Development main actions

Stack Manufacturing: 2 Platforms

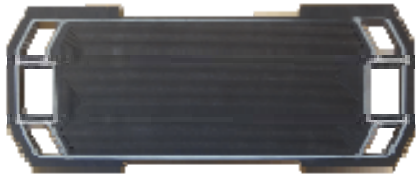
Low Power: 5 to 15 kW

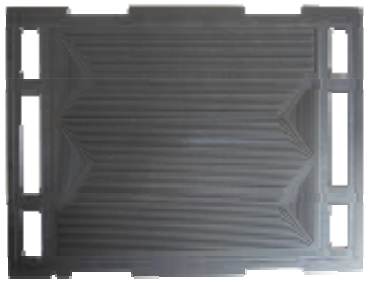
<60-160> cells

High Power: 20 to 50 kW

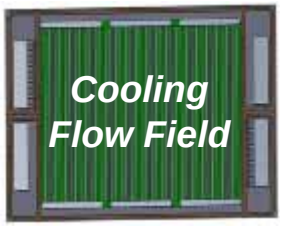
<100-160> cells

Serpentine Gas Flow Field

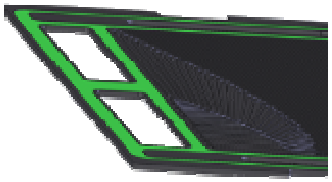




Parallel Gas Flow Field



- **Air Flow Field Design with Low Pressure Drop < 300 mbar**
  - Comparative Study on Serpentine vs Parallel GFF Design
  - Comparative Study on Low vs High Operating Pressure
    - Air Blower vs Air Compressor
- **Fuel Cell Stack Sealing Technology**
  - Seal Gasket deposited on Bipolar Plates
  - MEA integrating molded seal gasket
- **Plates & Bipolar Plates Manufacturing: molded plates development**
  - Machined BPP -> Molded BPP: Validated design full scale stack
  - Partnership with industrial manufacturers to develop a mold



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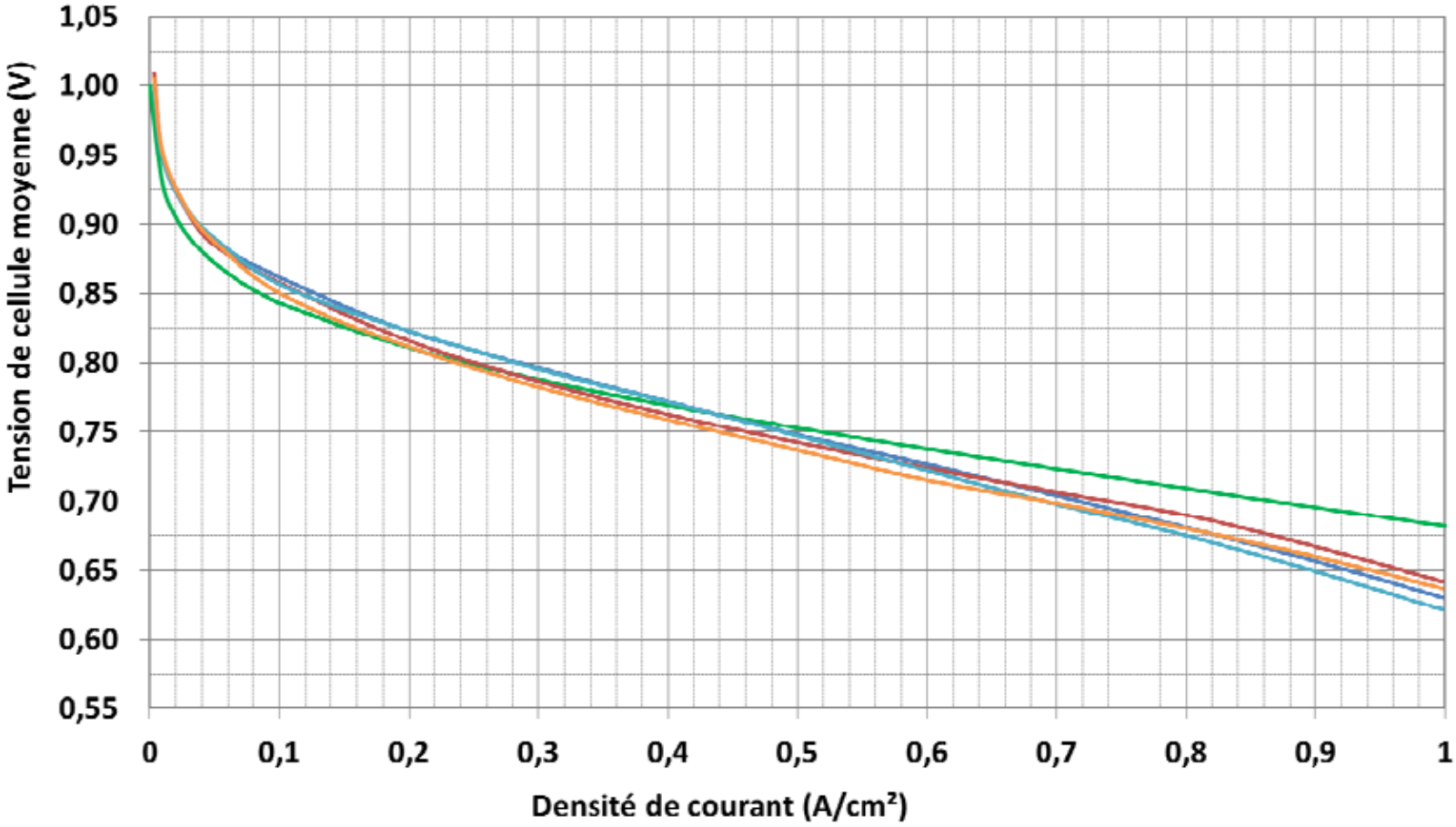
HP Fuel Cell Stack – Electrical performances

Operating conditions:

- Atmospheric pressure (0.25 barg) Temperature ~ 60-65°C
- Dry hydrogen / Air : RH 50% Stoechiometry H2 : < 1.1 Air : 2.5



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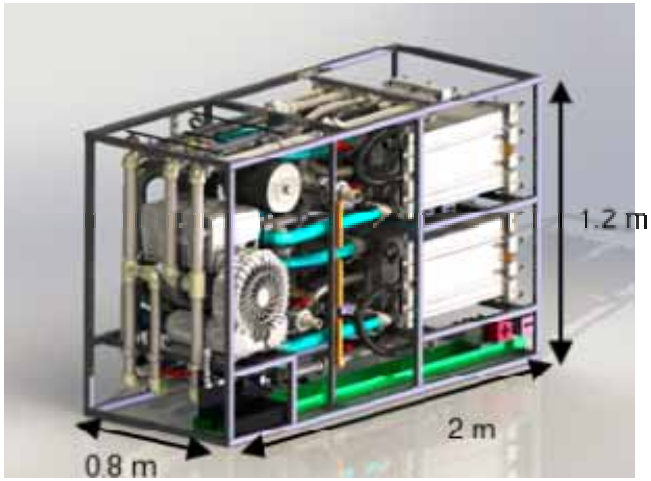
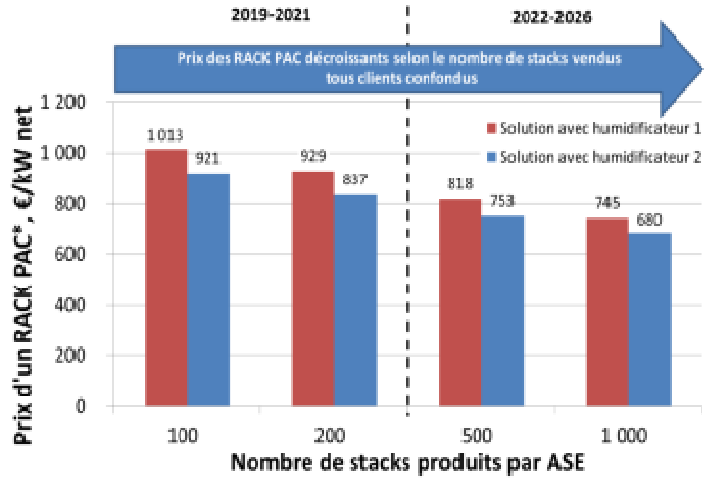
HELION / AREVA state of the art Fuel Cell RACK

- **FC RACK:**
  - Stacks + BOP (excluding cooling), Low voltage converter, Control Electronics
  - FC Rack mass: 900 kg (excluding cooling)
  - Environmental constraints: T_{min}: -5°C / T_{max}: 35°C
- **FC RACK electrical characteristics**
  - Vmin = 330 Vdc / Vmax = 670 Vdc, from BOL to EOL
  - Nominal Permanent Power: ~ 150 kW
  - Min Permanent Power : ≤ 37,5 kW
  - Net efficiency:
    - Min point > 49 % BOL; > 47 % EOL
    - Max point > 40 % BOL; > 33 % EOL
- **Performances characteristics**
  - Min Power : 15 kW, ≤ 5 min max 2 times/h
  - Pmin -⟶ Pmax: ≤ 10s ; / Pmax -⟶ Pmin: ≤ 1s
  - > 20 000 h for stacks lifetime





* Stacks équipés d'AME Lifetime > 20 000 h

Cost evolution perspective of RackPac

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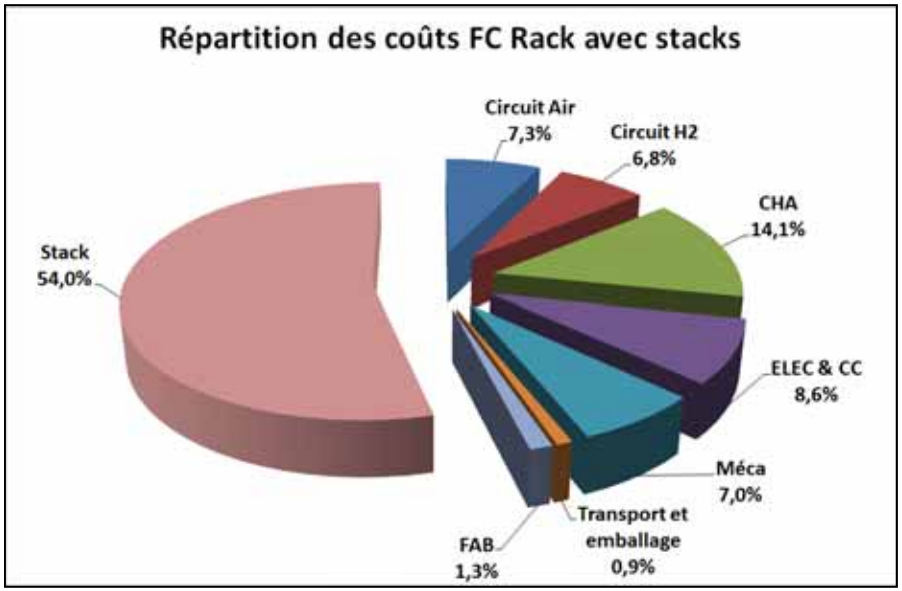
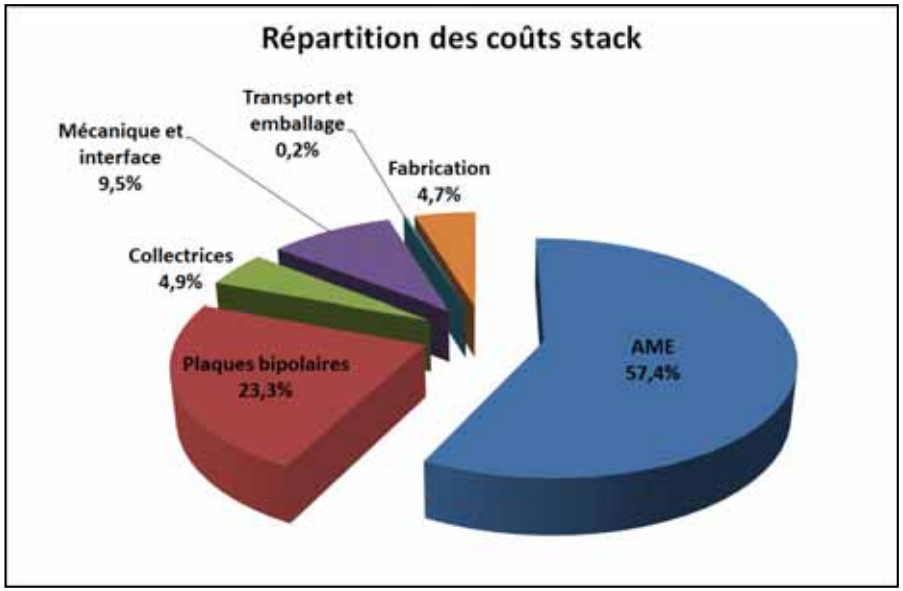
Fuel Cell RACK cost analysis





- **FC RACK:**
  - Stack weighs for more than 50 % total cost
  - Heat management is about 1/3 of BoP
- **STACK**
  - MEA weights for 57% of the total cost
  - Agreement with supplier to find optimization in term of performance and cost

Typical application projects
On-shore & on-board clean power supply

Ports located into cities need to reduce their pollution impacts.
Hydrogen PEM fuel cell power generator is an alternative to the use of diesel Gensets.

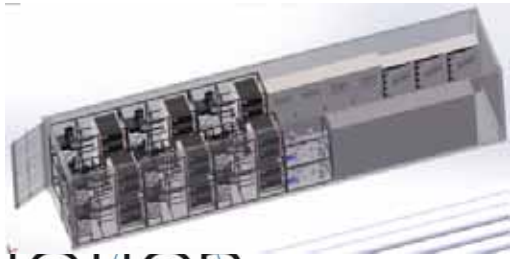
Technical solution

2 MW transportable Fuel Cell

Connexion cable

On-shore installation example

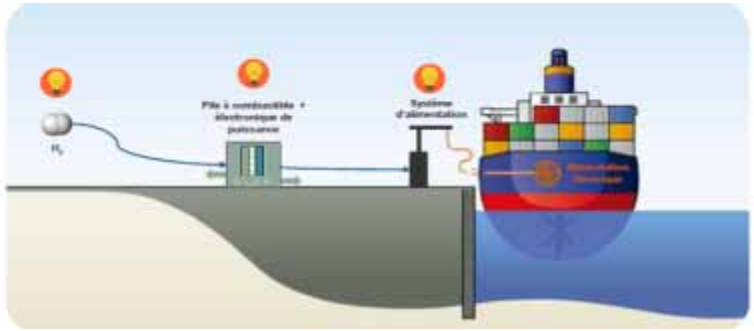
Frequency (50 & 60 Hz) and voltage (11 kV – 6,3 kV) regulation



ValHydate project
(certified AAP H2 dans les Territoires)

Objective	Supplying clean power to cruise ships in Marseille port
Date	2019
Main partners	ENGIE, KEM ONE, LINDE

The concept



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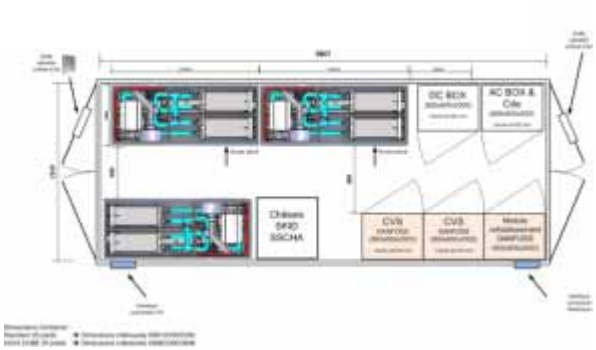
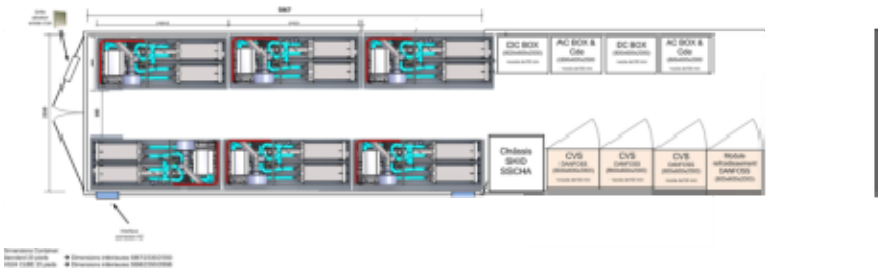
On-shore power supply solution: 1 & 2 MW mobile Fuel Cell

FC 1 MW Net Power in a 20’



FC 2 MW Net Power in a 40’



	HC 20’ container	HC 40’ container	Trailer
Pressure, bar	300	300	300
H2 stored, kg	411	823	1000
Autonomy at 800 kW net nominal power, h	7,9	15,9	17,8
Autonomy at 1 MW net max power, h	5,9	11,1	12,5

	HC 40’ container	Trailer
Pressure, bar	300	300
H2 stored, kg	823	1000
Autonomy at 1 590 kW net nominal power, h	7,9	8,9
Autonomy at 2,09 MW net max power, h	5,6	6,2

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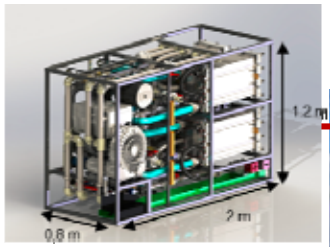
Typical application projects
Heavy mobility: fuel cell train propulsion

While governments and territories are committed to reduce greenhouse gas emissions in the transport sector, hydrogen PEM fuel cell technology is considered as a green alternative to diesel engines.

Our solution

Design and manufacture of fuel cell modules for rail applications, which can be used either for auxiliary or propulsion power



Customers

Train & tram manufacturers

Reference project: SPACT80

Power output	~ 80 kW
Date	2009
Main partners	SNCF, DGA
Objective	Integration of an AREVA's fuel cell power system in a locomotive for train propulsion.

New project: *under construction*

Power output	> 800 kW
Date	2019
Main partners	--
Objective	Integration of an AREVA's fuel cell power system in a locomotive for train propulsion.

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Typical application projects

For Smart Grid: self-sufficient renewable power plant

Armoire électrique et contrôle commande

Conversion de puissance batterie et PV

Conversion de puissance GreEnergy Box™

GreEnergy Box™ 10 kW PAC et 1 Nm3/h électrolyseur

Stockage tampon eau chaude sanitaire

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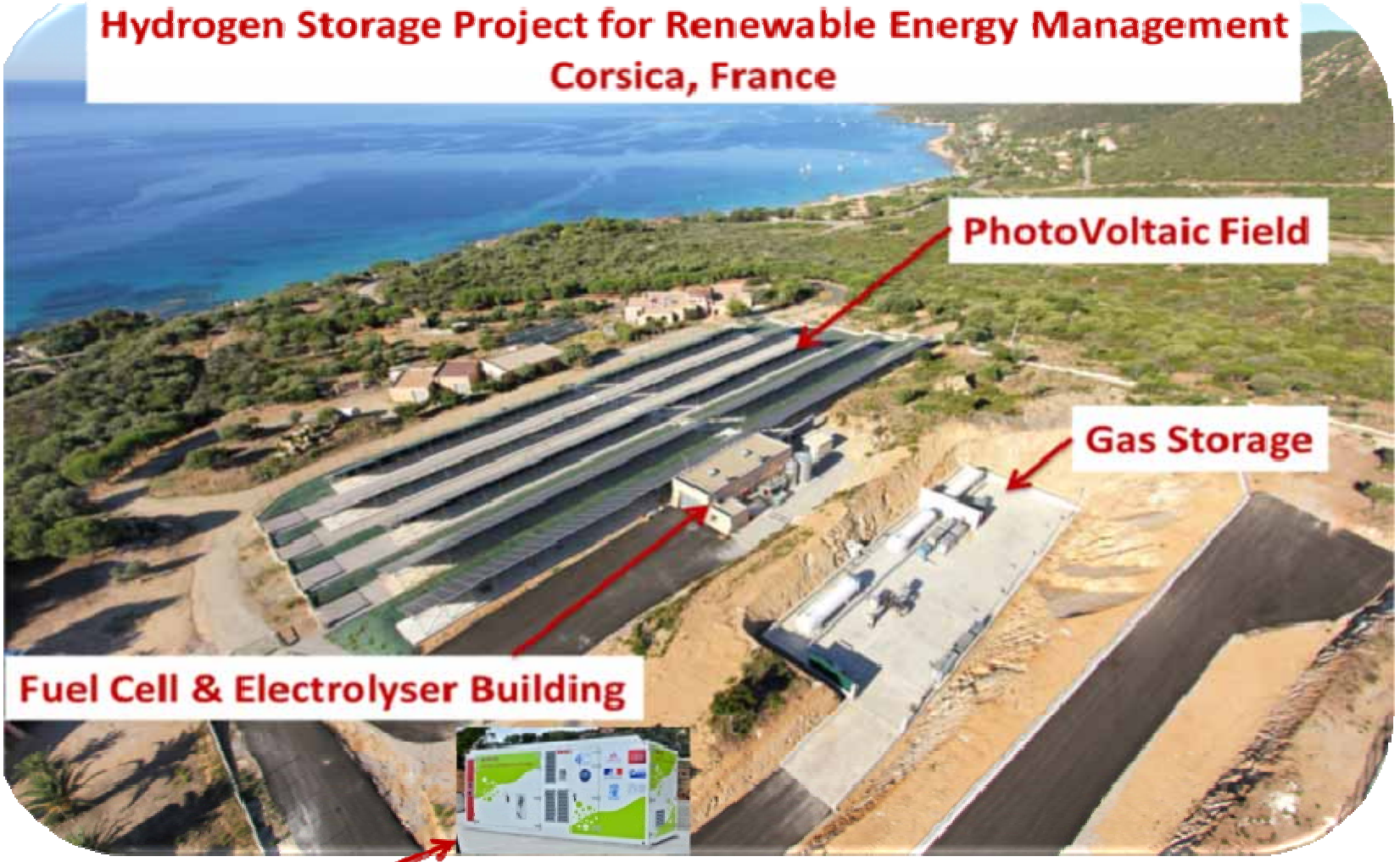
MYRTE Platform



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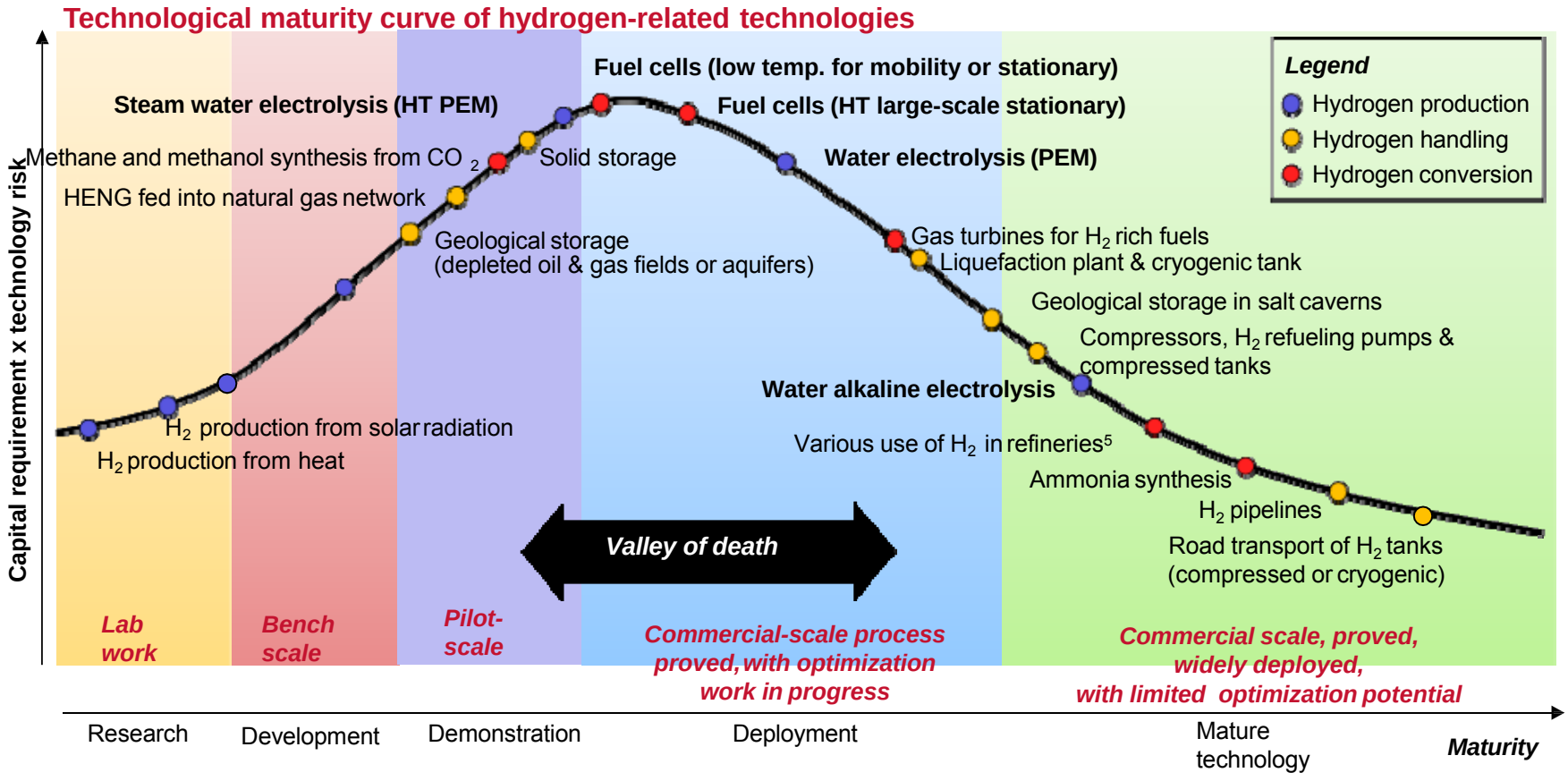
In conclusion fuel cells and hydrogen-related technologies are technologically mature for different applications, but most of them are in the “valley of death”

COMMERCIAL MATURITY CURVE OF INTEGRATED HYDROGEN PROJECTS



Source: Areva, SBC Energy Institute analysis.

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…THANK YOU…

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