Hydrogen economy and open research issues

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Hydrogen economy and open research issues

Motivations

Part 1 – Fuel Cell technology and Hydrogen FC Systems

Part 2 – What are the targets for a mass market ?

Part 3 – Open issues & ongoing research actions

Concluding remarks

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Motivations

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Towards FC systems

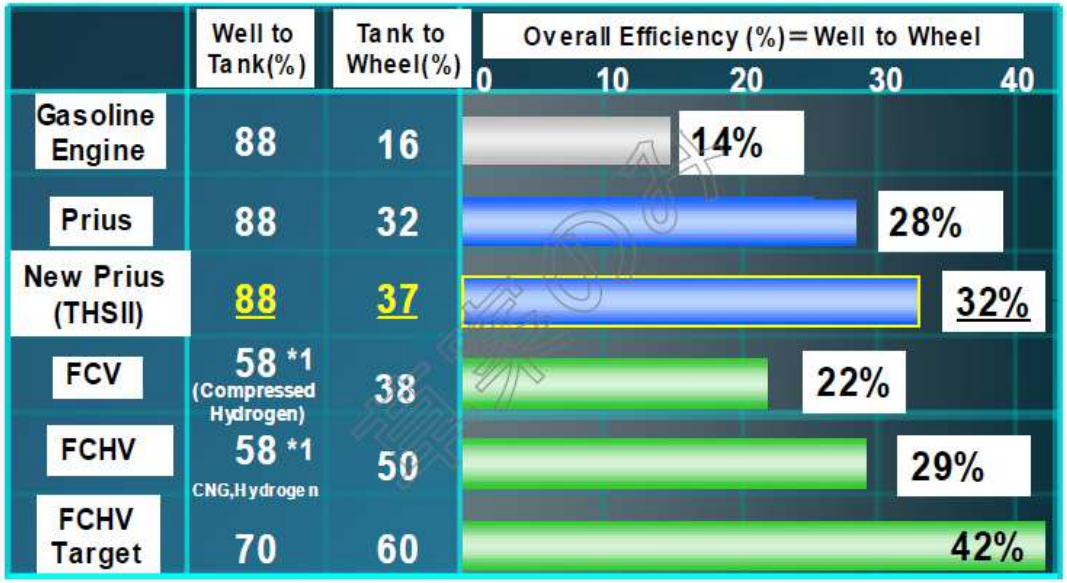
– Switching to fuel cell ? - Transportation applications

- **Fossil fuel ICE**
  - Low efficiency
  - Limited fossil resources

- **First alternative: BEV or HEV**
  - BEV : Significant progresses have been made BUT
    - – Long duration recharging operation
    - – Limited autonomy of the electrical vehicle
    - – Limited durability of the batteries
  - HEV : reduce rather than eliminate the dependency on fossil fuels…

- **Second alternative: FCV / FCHV**
  - High efficiency
  - (*Theoretical & in-situ*) pollutant emissions is zero
  - Fast recharging – high autonomy

  ⇨ **Attractive alternative**



**1 : natural gas to hydrogen*

T. Teratani, Toyota Motor Corp., Electric Propulsion Vehicles and Total Energy Management, IEEE VPPC 2012, Seoul, South Korea.

Towards FC systems

- **Switching to fuel cell ? – Stationary applications**
  - **Increasing interest for the storage of electricity**
    - Wide use of renewables
    - Intermittency of renewables
  - **First alternative: "classical" solutions**
    - Electrochemical batteries, flywheels
      - – High cost, limited durability, limited energy density
      - ➔ moreover, limited ability to store electricity for long time
    - Pumped storage
      - – Large scale only at specific places

  - **Second alternative: hydrogen**
    - Based on the duality between electricity & hydrogen
    - Ability for long duration storage
    - Can be considered at a microgrid level and at a grid level
    - Can be coupled to refueling of FCV fleets
    - ⇨ **Attractive alternative**

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Part 1 – Fuel Cell technology and Hydrogen FC Systems

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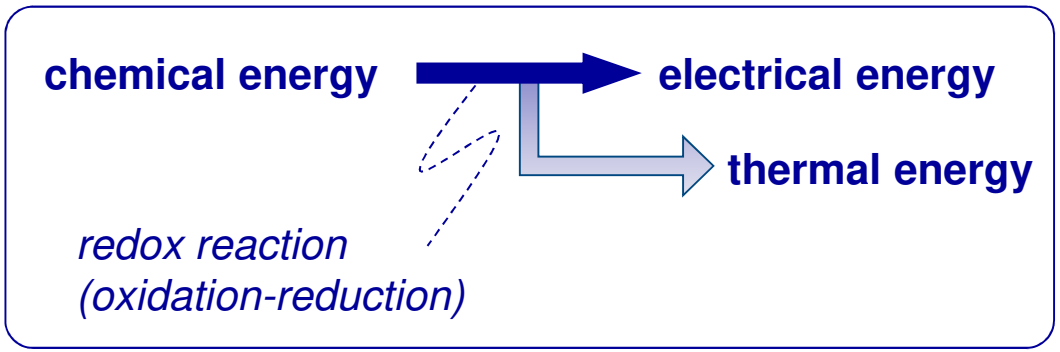
Fuel Cell technology

– Principle of a fuel cell

▪ What is a Fuel Cell?

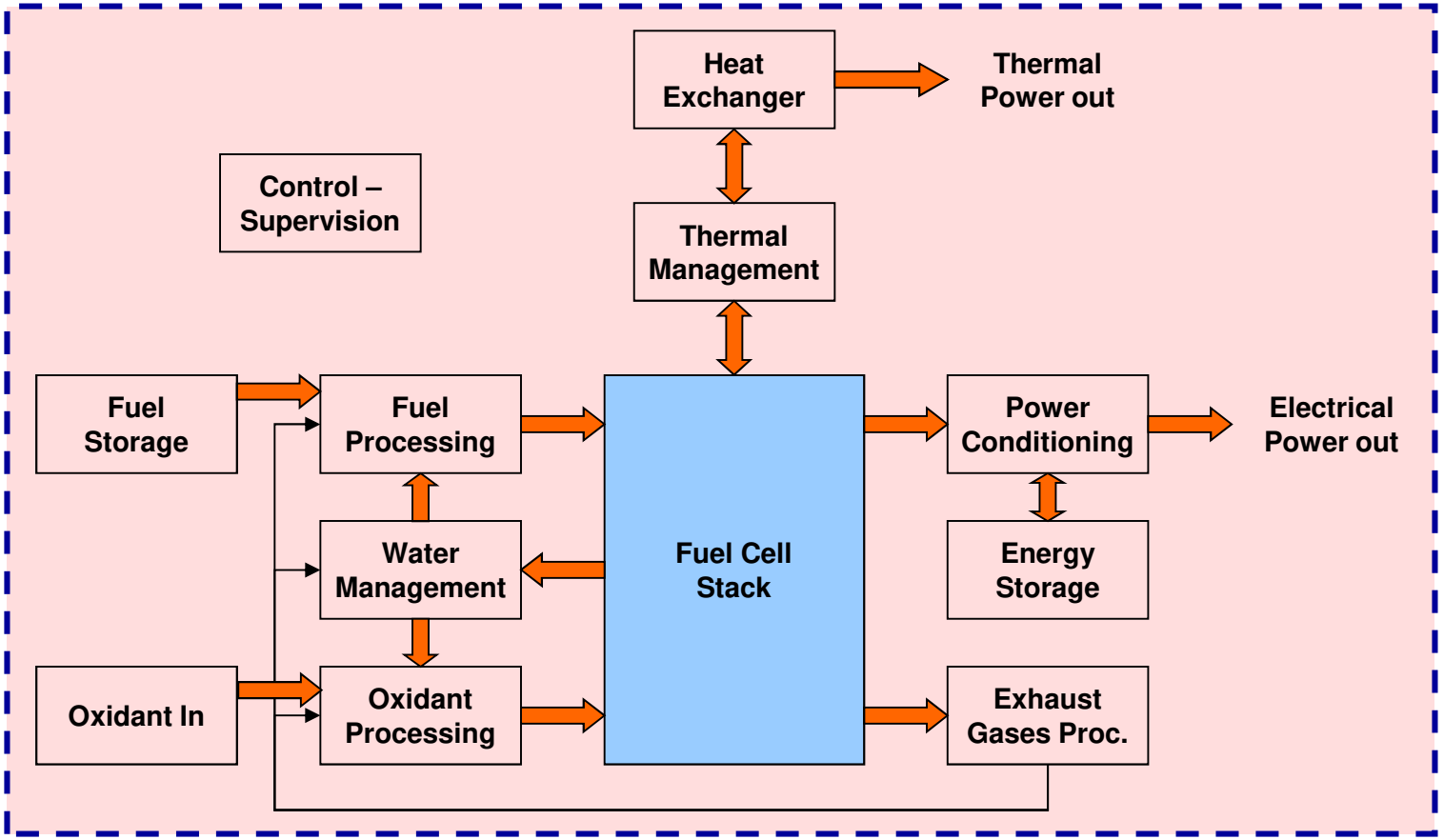
- US Fuel Cell Council definition, modified by FC Testing and STandardisation NETwork
  - An **electrochemical device** that continuously converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and other reaction products. The fuel and oxidant are typically **stored outside** of the cell and transferred into the cell as the reactants are consumed.
- Main differences with "traditional" battery
  - Fuel is **supplied continuously** & **stored outside**
  - **Fast charging** capability
  - **Energy** / **Power decoupling**



ElringKlinger PEMFC NM5

Hydrogen FC Systems

- **Fuel cell stack + ancillaries + H2 storage + electrical storage**
  - **Complex multiphysics system**
  - **Scientific interdisciplinarity:**
    - Electrochemistry, but also: electrical engineering, electronics, control, signal & data treatment, artificial intelligence, industrial computer science, mechanics, thermal science, … & human and social sciences…



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Part 2 – What are the targets for a mass market ?

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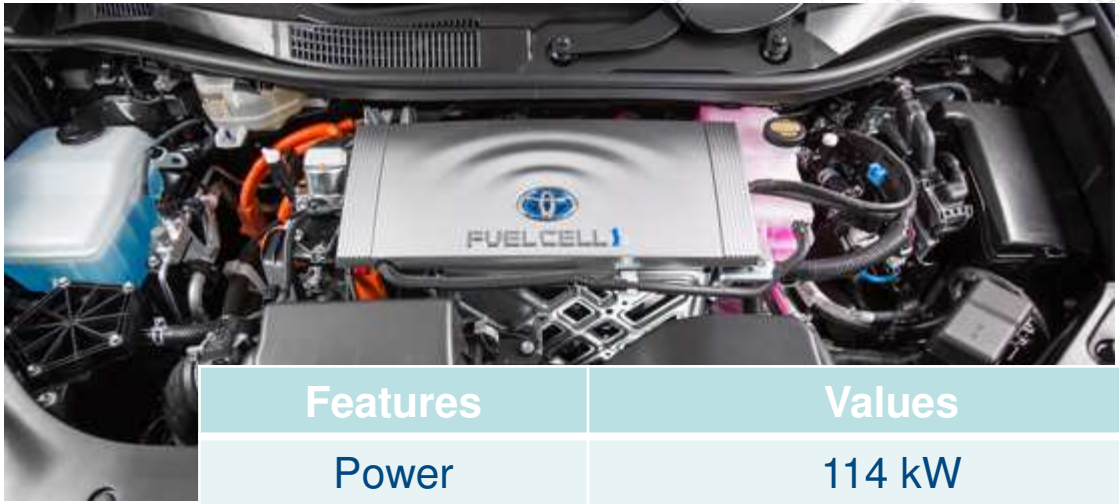
Commercial applications already exist !

- **Toyota Mirai**

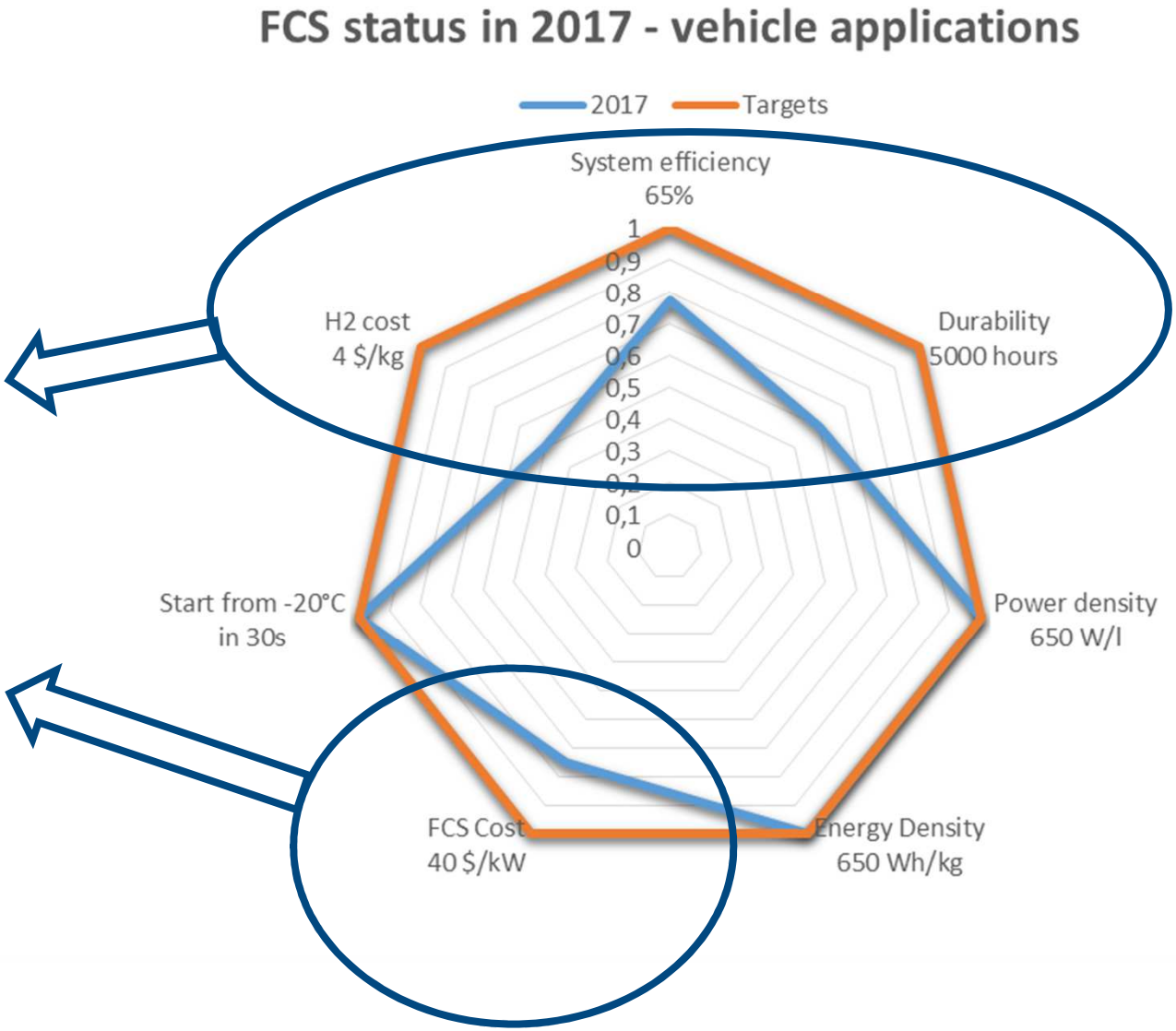


Features	Values
Power	114 kW
Power density	2 kW/kg, 3.1 kW/l
NiMH battery	1.6 kWh
H_2 tanks	700 bars, 10 kg
Autonomy	500 km
Price	Around $60k (or leasing)

- **And also residential applications**

Where are we today ?

– **Radar plot regarding the DOE targets**



Research work must be performed on :
- **Efficiency**
- **Durability**
- **Costs**

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Part 3 – Open issues & ongoing research actions

Where are the development headings ?

- **Towards enhanced performances**
  - **Scientific and technological bolts**
    - Fuel cell system **efficiency**
      - Increase it (elec. only) from about 40-45% to about 55-65%

    - Fuel cell system **durability**
      - Ex. for PEMFC systems
        - 5000 hours are required for light vehicles (2500-3000 hours obtained)
        - 30000 hours are required for trucks
        - And up to 100000 hours for stationary applications & railways
    - **Cost** (whole life cycle)
      - Linked to industrial deployment

    - Public **acceptance**
      - Socio-economic aspect: hydrogen-based energy is unknown
      - Strong link with public policies

    - **"Green" H_2 availability**
      - Production, storage, distribution

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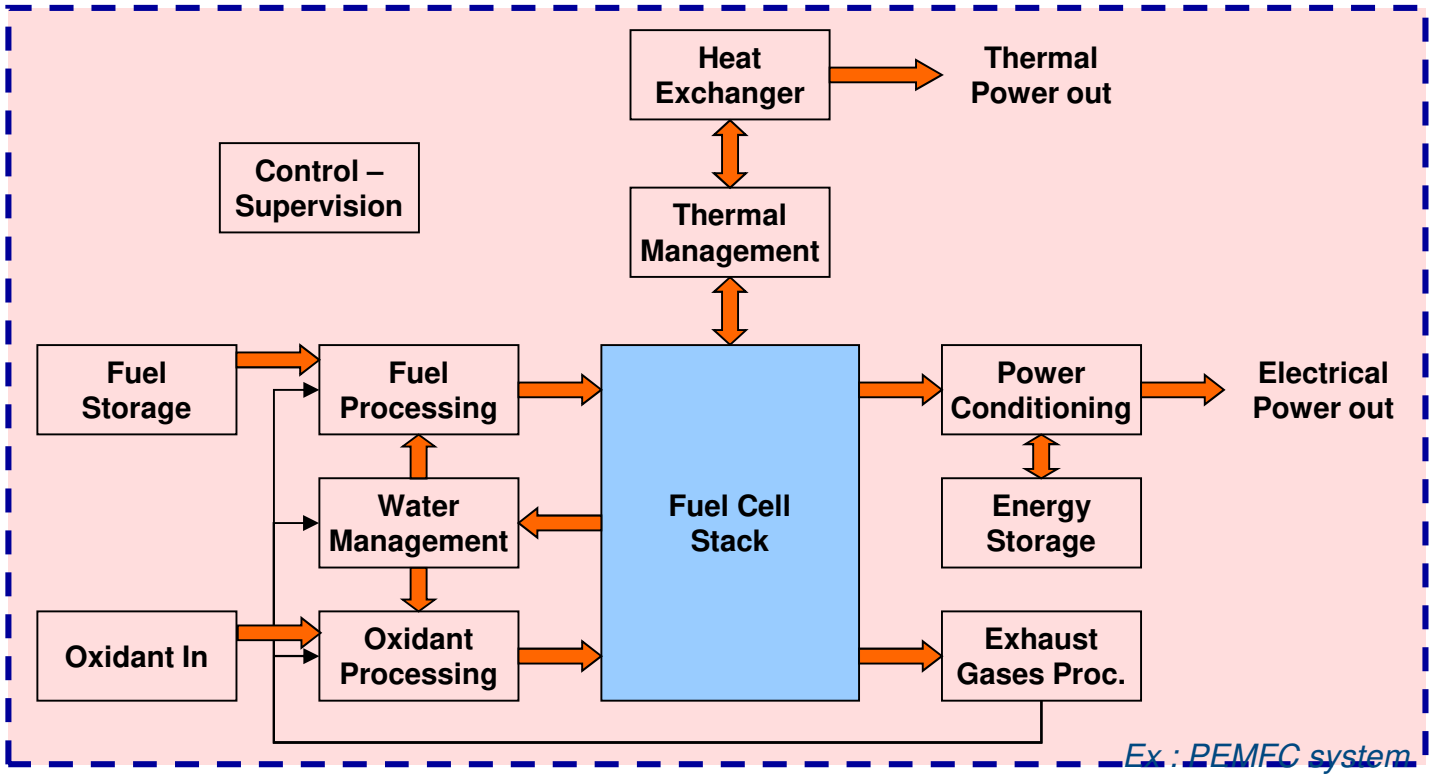
Areas of research : efficiency

- **Efficient & dedicated ancillaries are required…**
  - Specific power converters, specific air compressor, fuel storage, …
- **"Systemic" optimization of the architecture, taking care of all energy flows**
  - Electrical flows, thermal flows, gas flows…
  - Hybridization with batteries, ultracapacitors, …
- **Advanced control laws**



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Durability

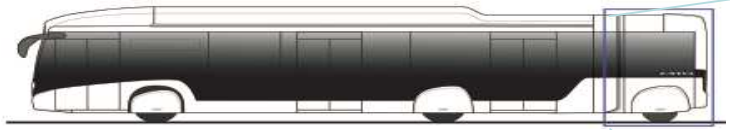
- **Objectives**
  - Increase durability of the fuel cell stack and of the fuel cell system
  - Increase efficiency of the FC system
  - Increase reliability of the FC system
  - Increase dynamic performances of the FC systems

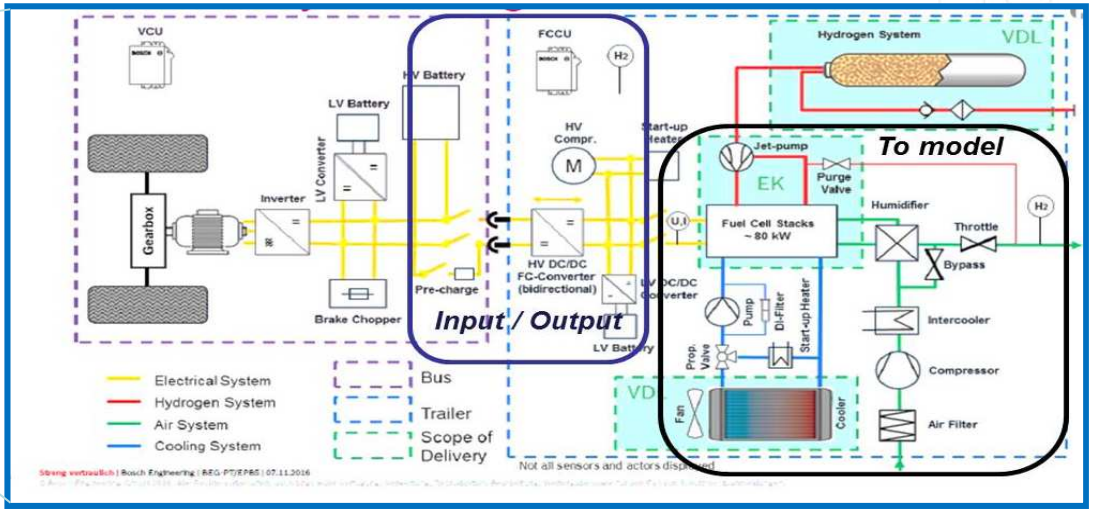
FC STACK S.O.H.
DIAGNOSTIC / PROGNOSTIC METHODOLOGIES ARE A KEY ISSUE !!!

- **Constraints**
  - Use of a minimal number of actual sensors
    - For complexity purpose
    - For cost purpose
    - For reliability purpose
    - For real-time control constraints

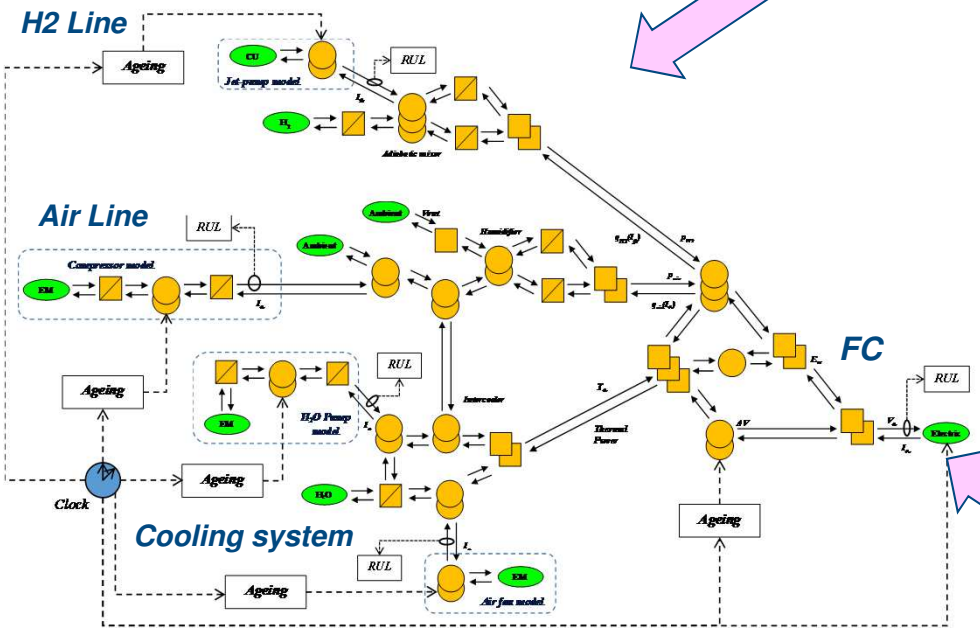
Example : on-line RUL estimation

– **Example : integrated diagnostic/prognostic algorithm for embedded PEM systems**



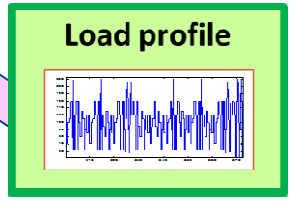


Model based prognostic algorithm



Online estimation of :
- **Performances**
- **Ageing** of the FC system
- Remaining Useful Lifetime (**RUL**)

Input



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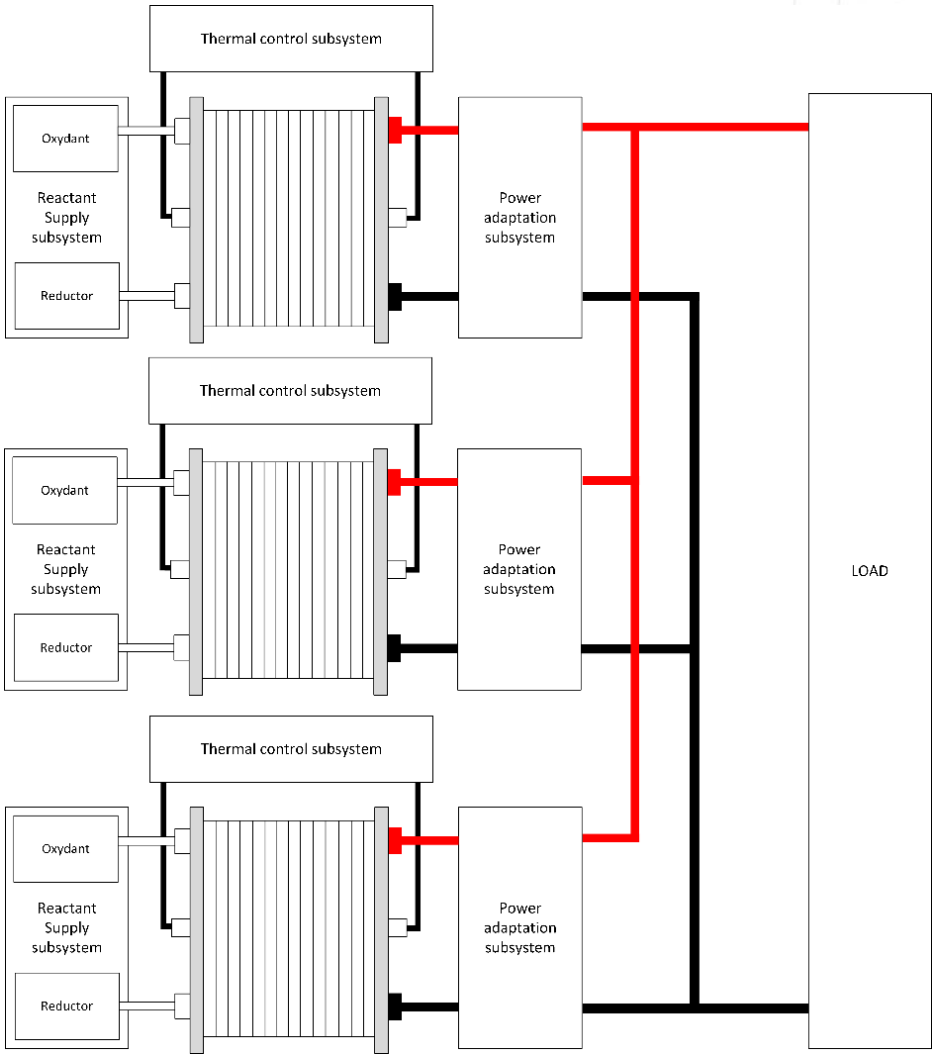
Example : Modularity of FC systems

Interests

- Ability to manage degraded mode operation
- Better performances:
  - Maximize efficiency
  - Increased lifetime
- Simplified implementation on board
- Easy scaling-up
- Modular system
  - Same FC system can address different applications (road, trucks, rail, …)
  - Cost reductions



[REF] N. Marx, “Multi-stack FC systems for automotive applications”, Cotutelle PhD. Univ. Franche-Comte, Univ. Quebec Trois-Rivières, 2017.

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Areas of research : public acceptance

- A global framework

- **Historical approach of H2 & FC**
  - Diachronic and synchronic approaches

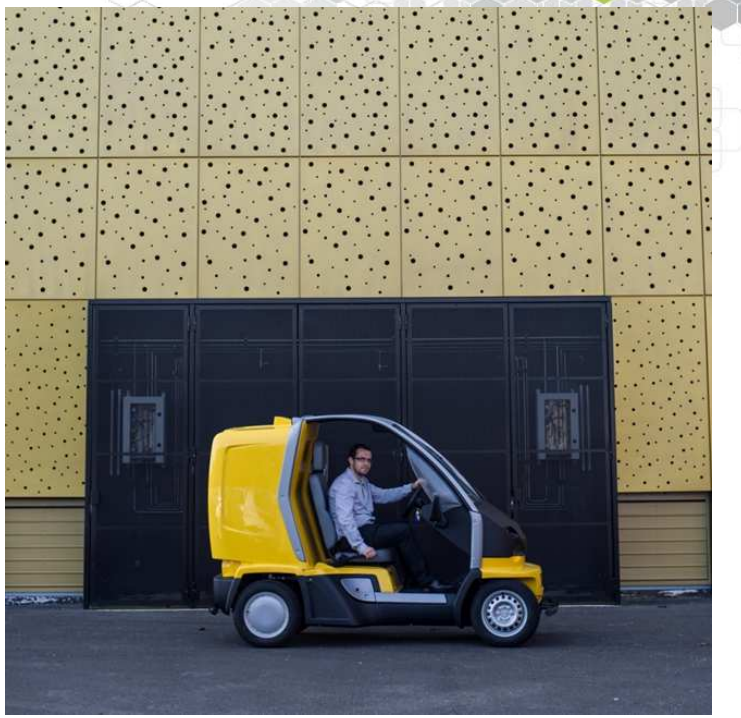
- **Public policies**
  - Strong involvement of governments is required (funding, taxes, …)
  - Funding for innovation & for research
  - Key countries: Japan, Germany, Canada, USA, South Korea, France, …

- **Evaluation / mitigation of risks**
  - Normalization / standardization
  - Certification / evaluation of security issues

- **Demonstration programs**
  - Assessment of the technology in real world applications

- **Awareness on the technology**
  - Demonstration programs
  - Teaching fuel cell from lower classes

Example : Assessment in real world



Mobypost EU project – La Poste objectives

- Economic perspectives :
  - Proof of concept for the vehicle + local production of H2
  - Demonstration of economic viability of H2 for captive fleets
- Energy transition :
  - Reduce CO2 emissions and dependency to fossil fuels
  - Coupling with renewables and storage of excess production
- Social acceptance :
  - Increase postmen's security and working conditions
  - Feedback on regulatory constraints

Key numbers

- **2** demonstration territories in B-FC region
- **2** years experimental trial
- **8** European partners
- **10** FC vehicles
- **920** MM work
- **1682** postal routes covered
- **2017** (demonstration ended in…)

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Areas of developments : green H_2 availability

- **Increase H_2 production from renewables**
  - **Today, about 95% of H_2 is coming from fossil fuels**
    - steam reforming or partial oxidation of methane
    - coal gasification
  - **Key issue** for :
    - public acceptance
    - sustainable energy developments
    - decentralized energy production
    - coupling to biomass

- **What can be done ?**
  - **Seasonal storage** of renewable electricity
  - **Convergence** between stationary applications & mobile applications
  - Developments of PEM & SO **electrolyzers**
  - Developments of new materials / solutions for hydrogen storage (increase of mass storage percentage)
  - **Exergetic optimization** of the whole electrolyzer / storage / fuel cell system
  - Development and deployment of refueling stations

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Hydrogen economy: myth or reality ?

Concluding remarks

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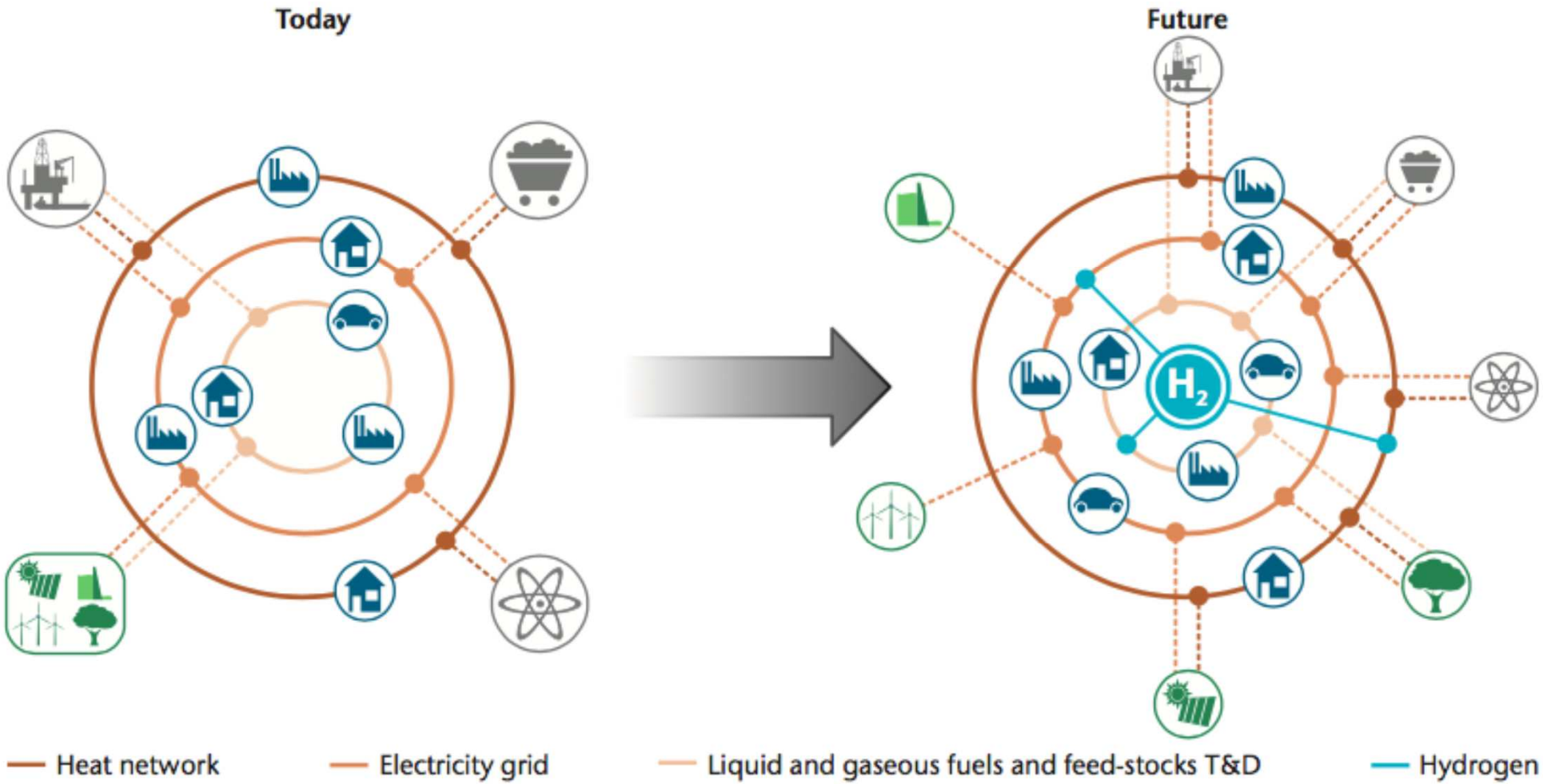
Concluding remarks

– **H2 as the missing link of the energetic transition ?**



Concluding remarks

– **Reminders !**

- **Always 3 point of views**
  - **Engineer:** technological solutions
  - **Economist:** cost and ROI constraints of the solutions
  - **Consumer:** decides by him(her)self… based on the perceived value

- **Never forget the golden rule in innovation !**

  Considering industrial era, in the whole history of innovation, a substitution technology can only prevail if :

  1/ it provides (at least) the same level of perceived value than the former technology, at a 30% reduced price

  OR

  2/ it provides (at least) 30% increased perceived value, at the same price

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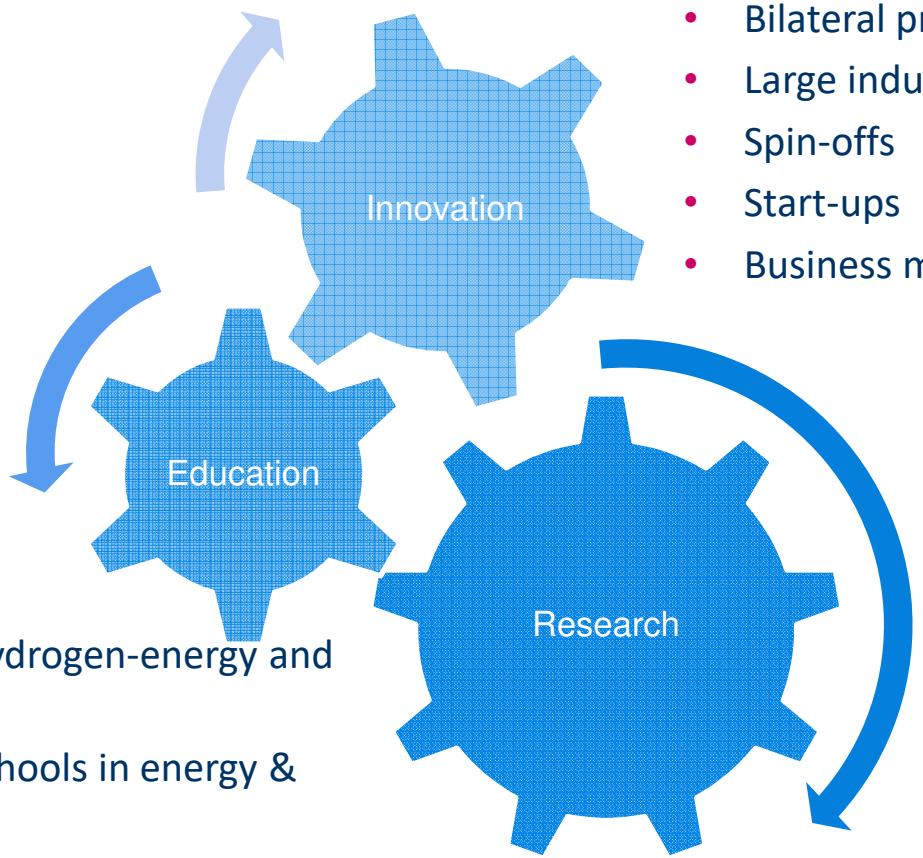
FCLAB : Key features

- About **1200m²** of dedicated testing areas (H2, nanoparticles, electricity, coupling to the grid) + **2000m2** of offices (for hosting up to 120 researchers)
- A single & specific unique building at UTBM campus
- **>8M€** investments in infrastructure + **>5M€** investments in test facilities
- **>50M€** including salaries & collaborative projects since 1999
- Fuel cell test benches **from 100We to 30kWe (120kWe** under development)
- Mobile FC test benches (vehicles) up to **100kWe**
- Vibrating table + climate/temperature chambers
- **Long duration tests** (24h/7d) under actual operating conditions (electrical cycling, thermal cycling, …)

FCLAB : Key features



- **Innovation**
  - H2&FC Expertise (tests, design, control, diagnostics, prognostics, hybridization, …)
  - Bilateral projects
  - Large industrial projects
  - Spin-offs
  - Start-ups
  - Business models

- **Education**
  - Unique M.Eng. in hydrogen-energy and energy efficiency
  - High engineering schools in energy & transport
  - Bachelor & M.Sc. in energy systems
  - Ph.D. programs
  - Graduate School (EIPHI)

- **Research**
  - From TRL3 to TRL7
  - System-oriented (hydrogen & FC)
  - Increased energy efficiency
  - Durability improvement
  - Socio-technical issues

Thanks to our research team !

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