Hydrogen-energy systems : Scientific challenges and technological bolts

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Hydrogen-energy systems

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

Hydrogen-energy systems

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
    - Reduced 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**

	Well to Tank(%)	Tank to Wheel(%)	Overall Efficiency (%) = Well to Wheel
Gasoline Engine	88	16	14%
Prius	88	32	28%
New Prius (THSII)	88	37	32%
FCV	58 *1 (Compressed Hydrogen)	38	22%
FCHV	58 *1 CNG,Hydrogen	50	29%
FCHV Target	70	60	42%

**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**
  - Wider use of renewables
  - Intermittency of renewables

- **First alternative: “classical” solutions**
  - Electrochemical batteries, flywheels
    - High cost, 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 with mobile applications
  - ⇨ **Attractive alternative**

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Part 1 – Fuel Cell technology and Hydrogen FC Systems

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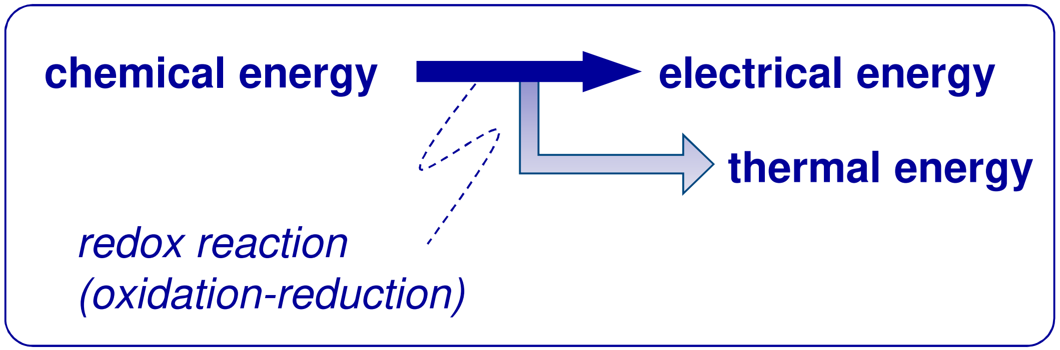
Fuel Cell technology

– Principle of a fuel cell

▪ What is a Fuel Cell?

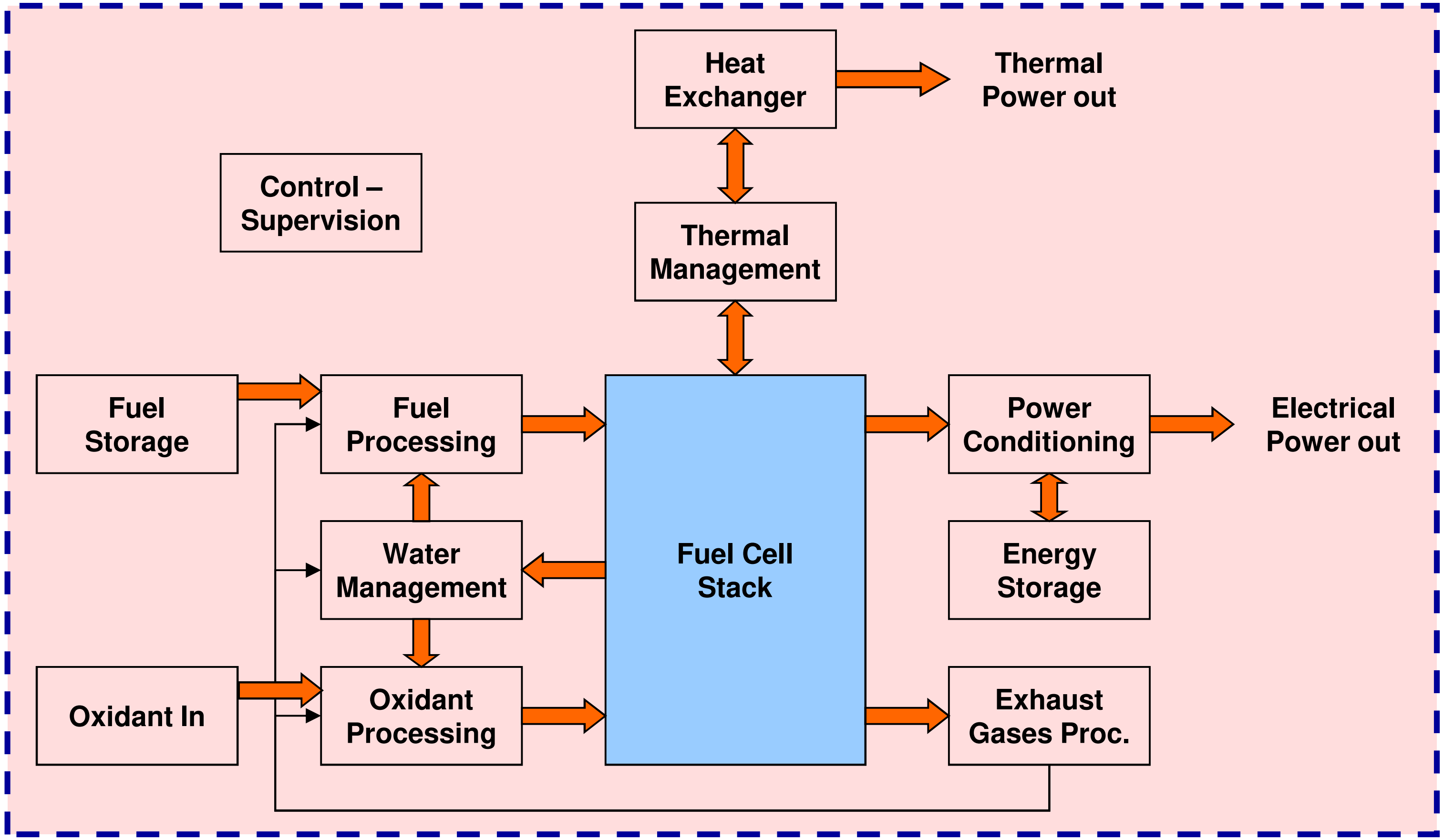
- US Fuel Cell Council definition, modified by FC Testing and STandardisation NETwork
  - An **electrochemical device** that continuously converts the chemical energy of a fuel and an oxidant to electrical energy (DC power), heat and other reaction products. The fuel and oxidant are typically **stored 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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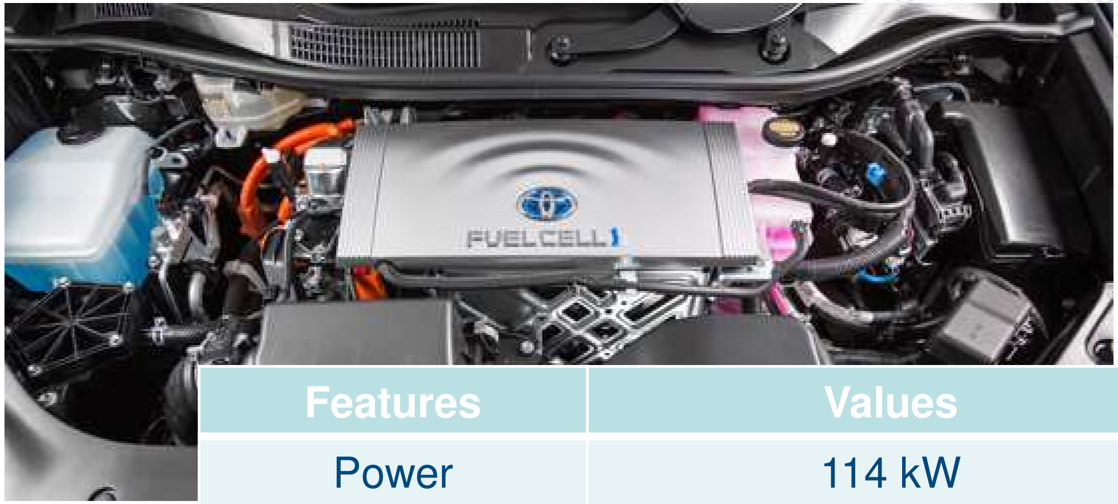
Part 2 – What are the targets for a mass market ?

Commercial applications already exist !

– **Toyota Mirai**

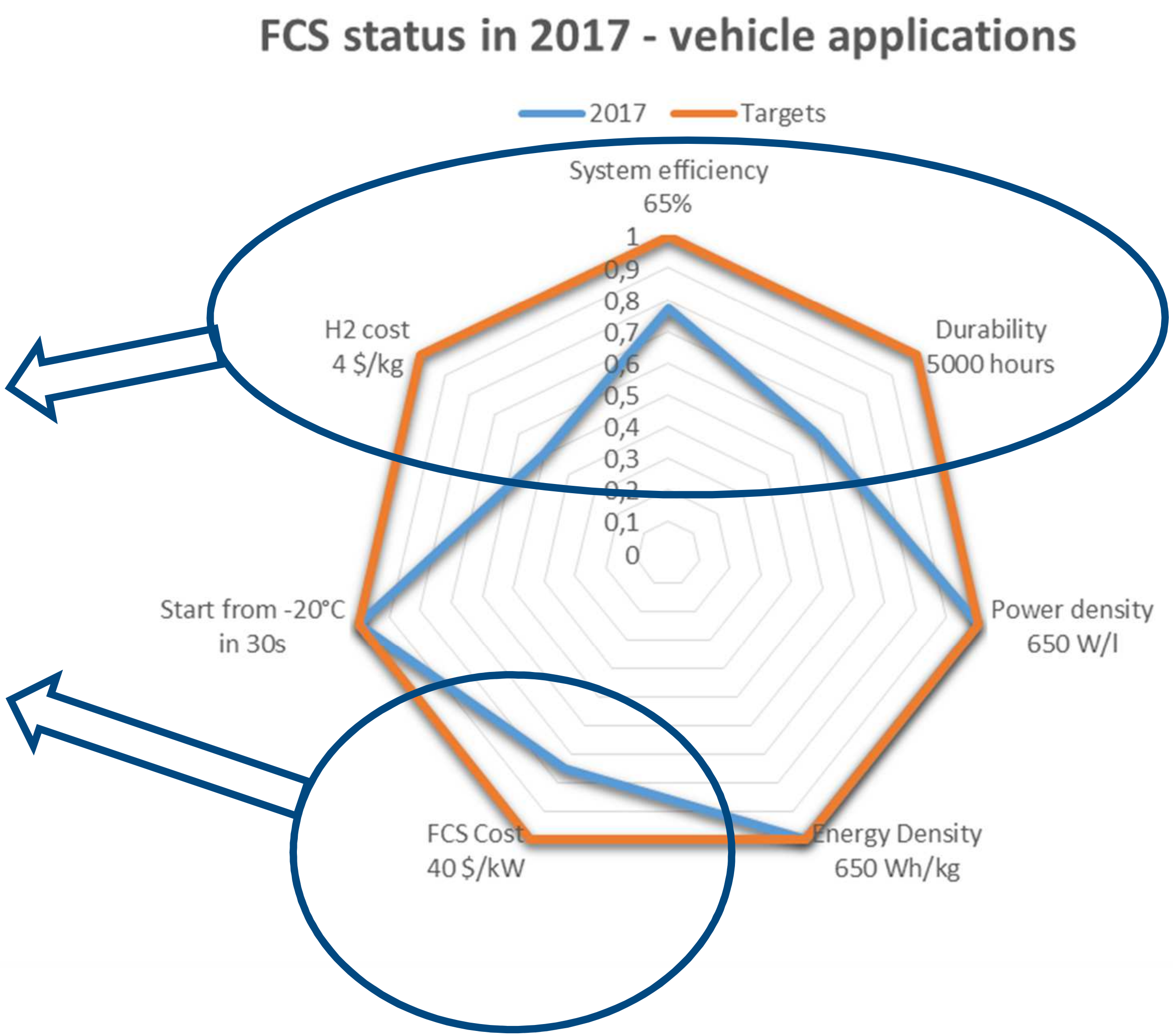


Features	Values
Power	114 kW
Power density	2 kW/kg, 3.1 kW/l
NiMH battery	1.6 kWh
H_2 tanks	700 bars, 10 kg
Autonomy	500 km
Price	Around $60k (or leasing)

– **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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Hydrogen-energy systems

Part 3 – Open issues & ongoing research actions

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Where are the development headings ?

– Towards enhanced performances

- **Scientific challenges 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 (3000 hours obtained)
      - 30000 hours are required for trucks
      - And up to 80000 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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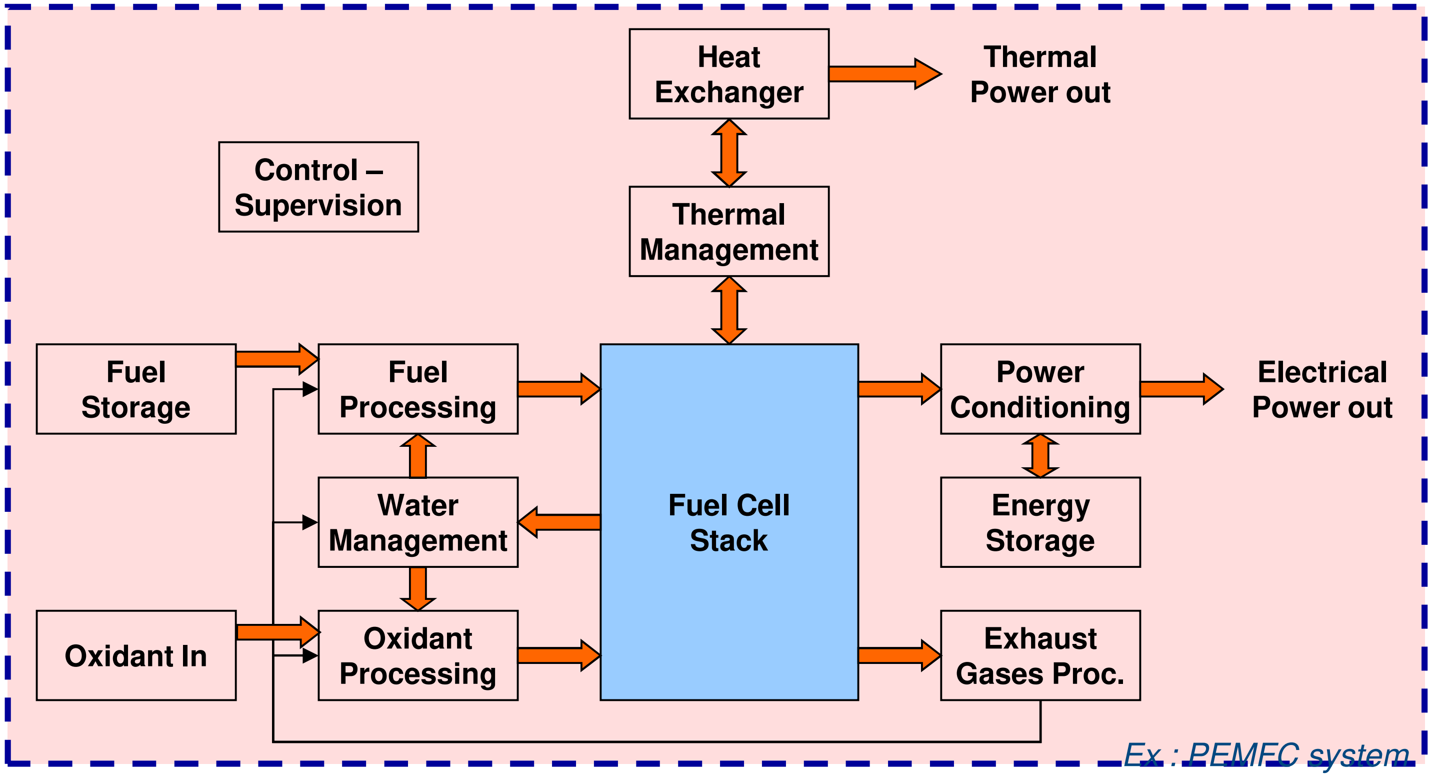
Areas of research : efficiency

- **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**

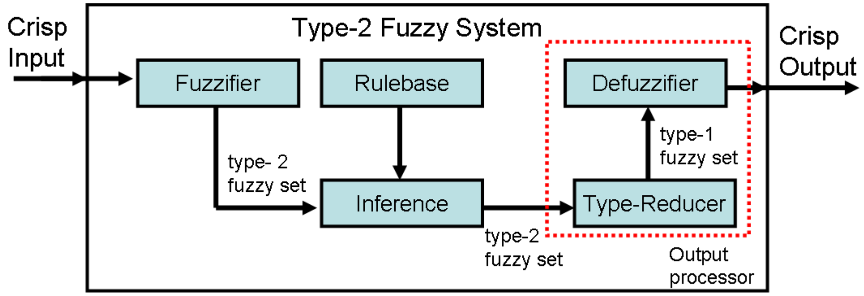


Areas of research : efficiency

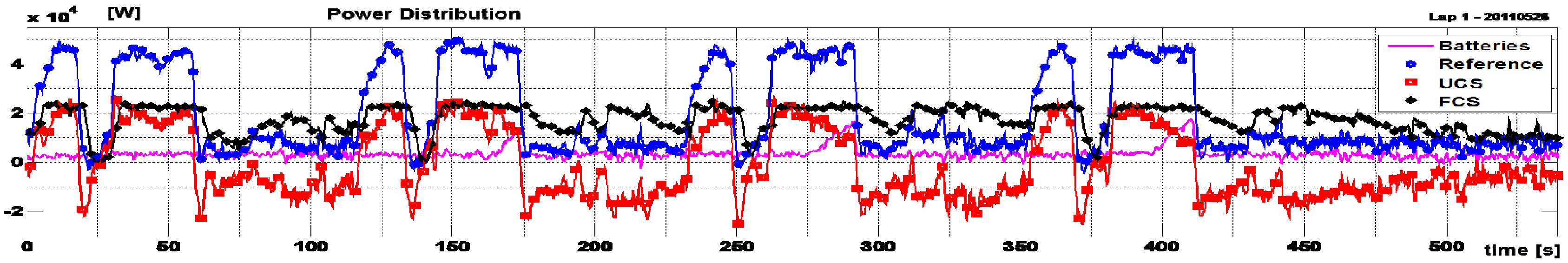
– **Optimize energy flows…**

Use of AI approaches

Propose efficient (& real-time) energy management strategies



Ex : PEMFC system



– **Optimize simultaneously the energy flows and the vehicle architecture…**

Use of new metaheuristics

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Durability

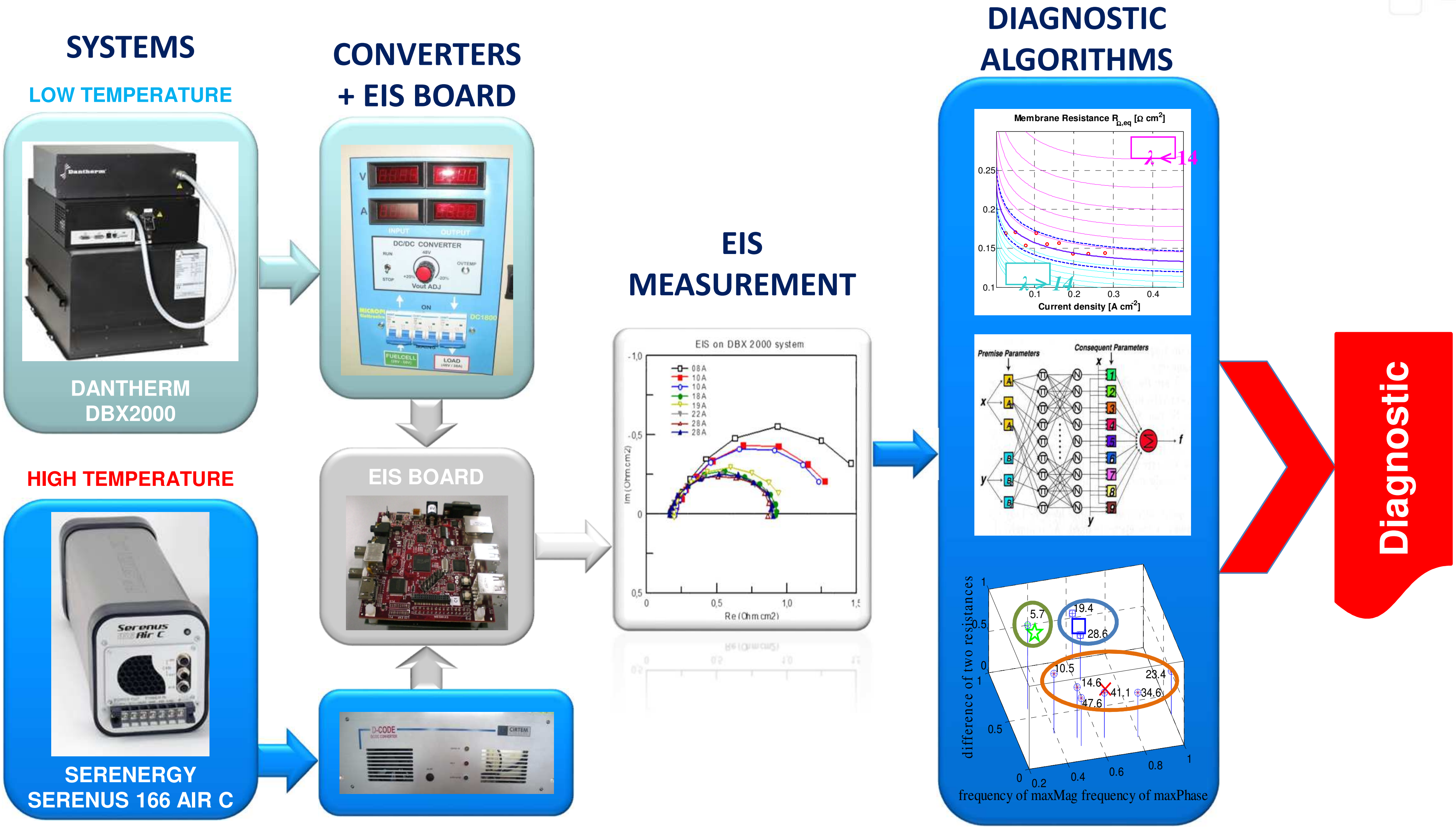
- **Objectives**
  - Increase durability of the fuel cell stack and of the fuel cell system
  - Increase efficiency of the FC system
  - Increase reliability of the FC system
  - Increase dynamic performances of the FC systems

→ **FC STACK S.O.H. DIAGNOSTIC 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 : signal-based FDI

– **Example : DC-DC converter based diagnostics for PEM systems**



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Areas of developments : costs

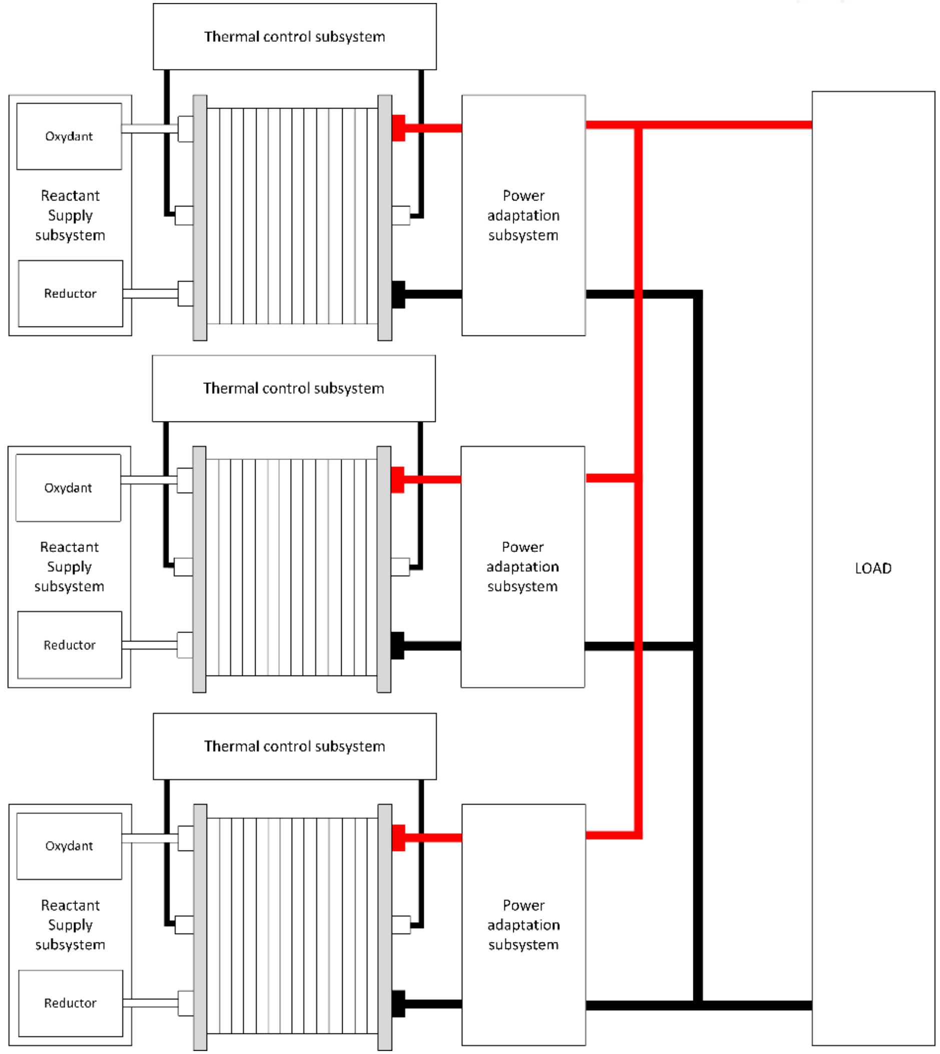
– **Reduce the costs**
  - **A strong industrial interest** *(source US DOE annual market report)*
    - Fuel cells receive far more patents than other renewable energy technologies (950 patents in 2011 versus 450 for photovoltaic)
  - **2017's prices**
    - About 500€-2000€/kW for one single stack – projected cost for 500000 units / year = 27€/kW
    - 35% FC stack + 35% FC ancillaries + 30% electrical powertrain
  - **A (small) hydrogen refueling station ≈ 1M€**

– **What can be done ?**
  - Use of lower cost components (EME)
  - Process automation (especially for bipolar plates)
  - Design of specific ancillaries (e.g. the air compressor)
  - Understand in deep the degradation mechanisms
  - Optimize the whole system not only the components
  - Focus on "interesting" emerging markets (forklifts, micro-CHP, backup power, storage of renewables, military applications (U-boats, portable, backup), aeronautic applications, …)
  - Increase modularity of FC systems

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

Hydrogen-energy systems
for transportation applications

Concluding remarks

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Concluding remarks

– The interest of H2 technology

- **H2**
  - Best candidate for next generation fuel?
  - Will play a key role in the future energy economy
  - Still issues on H2 production, public acceptance, on-board storage, distribution facilities

- **FC are promising energy converters for next generation EVs**
  - High efficiency & low noise level
  - Possibly no dependency to fossil fuels
  - Applications can be considered in transportation, mobility, micro-CHP, storage of renewables
  - Still issues at system-level :
    - Lot of interactions between the FC stack & its ancillaries
    - Limited durability under varying operating conditions
    - Reliability, Diagnostic & Prognostic
    - Dedicated ancillaries on a tiny market
    - Global optimization is required (architecture, stack, ancillaries, control, costs, efficiency, …)

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