FROM RESEARCH TO INDUSTRY

cea tech

liten

CEA LITEN
NEW TECHNOLOGIES FOR ENERGIES

Division of Electricity and Hydrogen for Transport

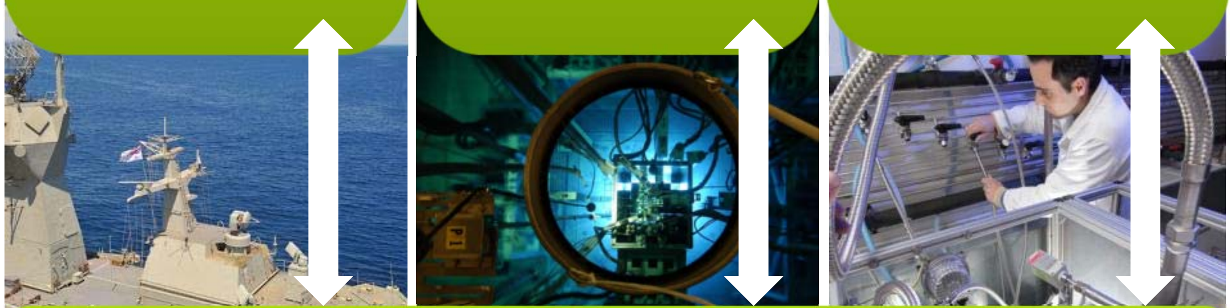


CEA LITEN DEHT | nov 2019

CEA AT A GLANCE

The three divisions of our business

Defence Security	Nuclear Energy	Dept. Research & Technology
Defence Applications Division	Nuclear Energy Division	Technological Research Division
French strategic independance	**French energetic** independance	**French economic** competitiveness



Fundamental Research

Material Science Division / Life Science Division

TECHNOLOGY

SCIENCE

16000 employees

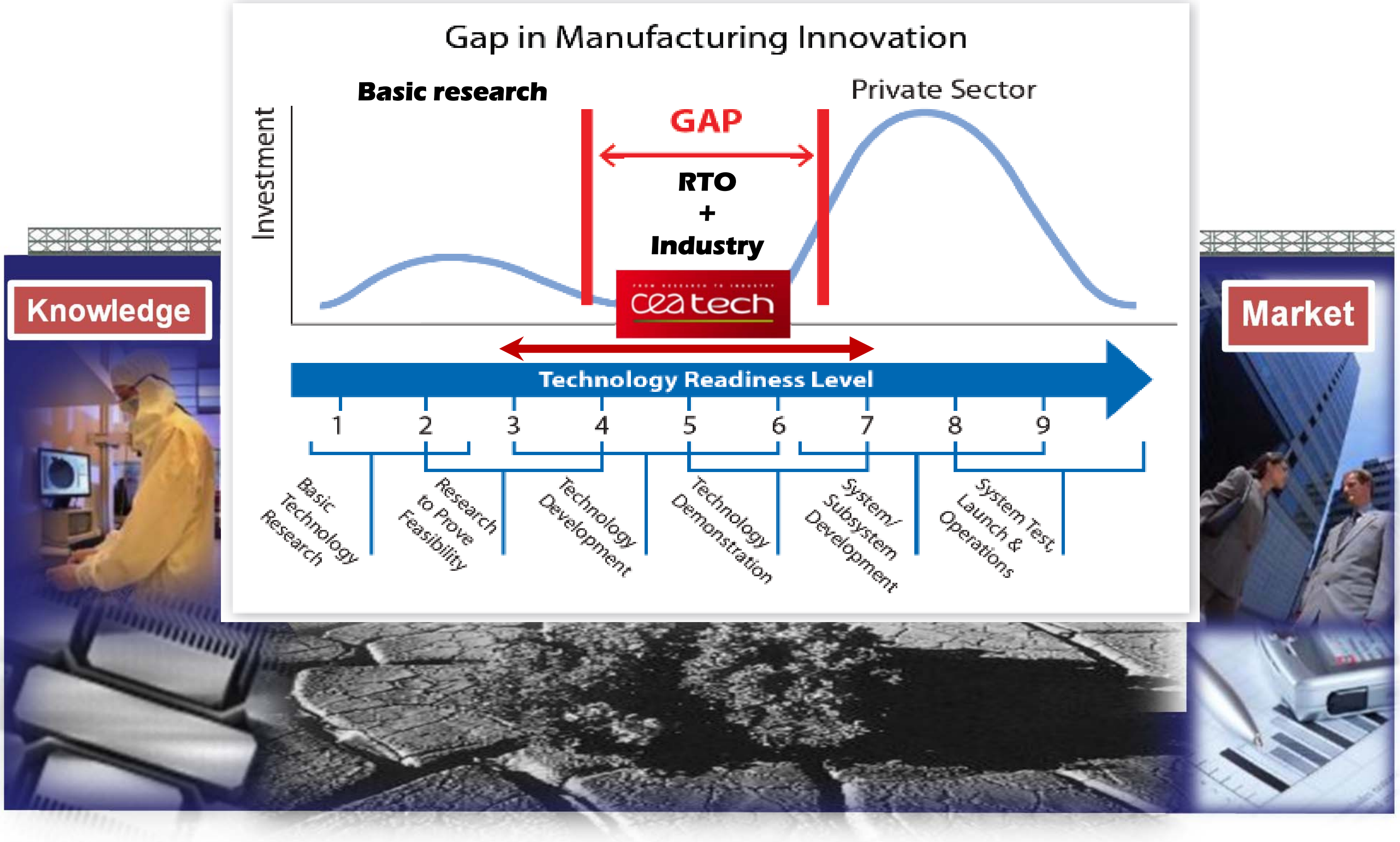
10 Research centers

4B€ annual budget

600 priority patents filed / year

150 new high tech companies created since 1984

FROM RESEARCH TO INDUSTRY: MIND THE GAP !



DIRECTION DE LA RECHERCHE TECHNOLOGIQUE
3 RESEARCH INSTITUTES

leti

Laboratory of Electronics and Information Technologies

1967 - Grenoble

Staff 1800 - 240 M€

Micro-nanotechnologies and system integration

list

Laboratory of Integrated Systems and Technologies

2003 - Paris Sud

Staff 800 - 70 M€

Software-intensive systems

liten

Laboratory of Innovation for new Technologies for Energy and Nanomatérials

2005 - Grenoble / Chambéry

Staff 1400 - 170M€

New energy technologies and nanomaterials

ines
INSTITUT NATIONAL DE L'ENERGIE SOLAIRE

OUR MANDATE: MIXING INDUSTRIAL COMPETITIVENESS WITH ENVIRONMENTAL RESPONSIBILITY

Contribute to national and European climate Plans

Support industry through key enabling technologies integrated in systems

Contribute to energy independency

3 KEY DRIVERS

ENERGY EFFICIENCY

- Energy storage
- Buildings
- Transport & electromobility
- Smart grids

RENEWABLE & LOW CARBON ENERGY

- Photovoltaics
- Solar thermal
- Biomass
- Hydrogen

EFFICIENCY OF MATERIALS

- Efficient materials
- Recycling
- Low energy processes

The Electricity and Hydrogen for Transport Division activities

Electric Transport

Modelling

Testing

batteries

Design, prototyping & test of battery systems
Materials & processes
Cells
Pack architecture
BMS

PEM Fuel cells

Design, prototyping & test of FC systems
Materials & processes
Components - stacks




Vehicle integration

Integration of FC/batteries in EV/hybrid vehicles
Monitoring



CEA LITEN PLATFORMS – BENCH TESTS

sophisticated tools for industry & Facility to overcome technological hurdles

NATIONAL PLAN ON ENERGY STORAGE

NANO CHARACTERZATION
80 researchers & technicians
30 million € investment

POWDER METALLURGY
20 researchers & technicians
5 million € investment

LARGE SURFACE PRINTED ELECTRONICS
50 researchers & technicians
8 million € investment

ENERGY MICROSOURCES
40 researches & technicians
20 million € investment

NANOMATERIALS & PORTABLE ENERGY

ELECTROMOBILITY
20 researchers & technicians
4 million € equipment

FUEL CELLS
60 researchers & technicians
10 million € equipment

BATTERIES
200 researchers & technicians
40 million € investment

Tests (electrochemical and abuse)

MOBILITY

SMARTGRIDS
30 researchers & technixcians
2 million € investment

SOLAR PHOTOVOLATICS
200 researches & technicians
100 million € equipment

BUILDING & SMART GRID

HYDROGEN PRODUCTION AND STORAGE PLATFORM
40 researchers & technicians
6 million € investment

BIOMASS
40 reserachers & technicians
7 Million € investment

THERMAL SYSTEMS
75 researchers & technicians
15 million € investment

HEAT & FUELS

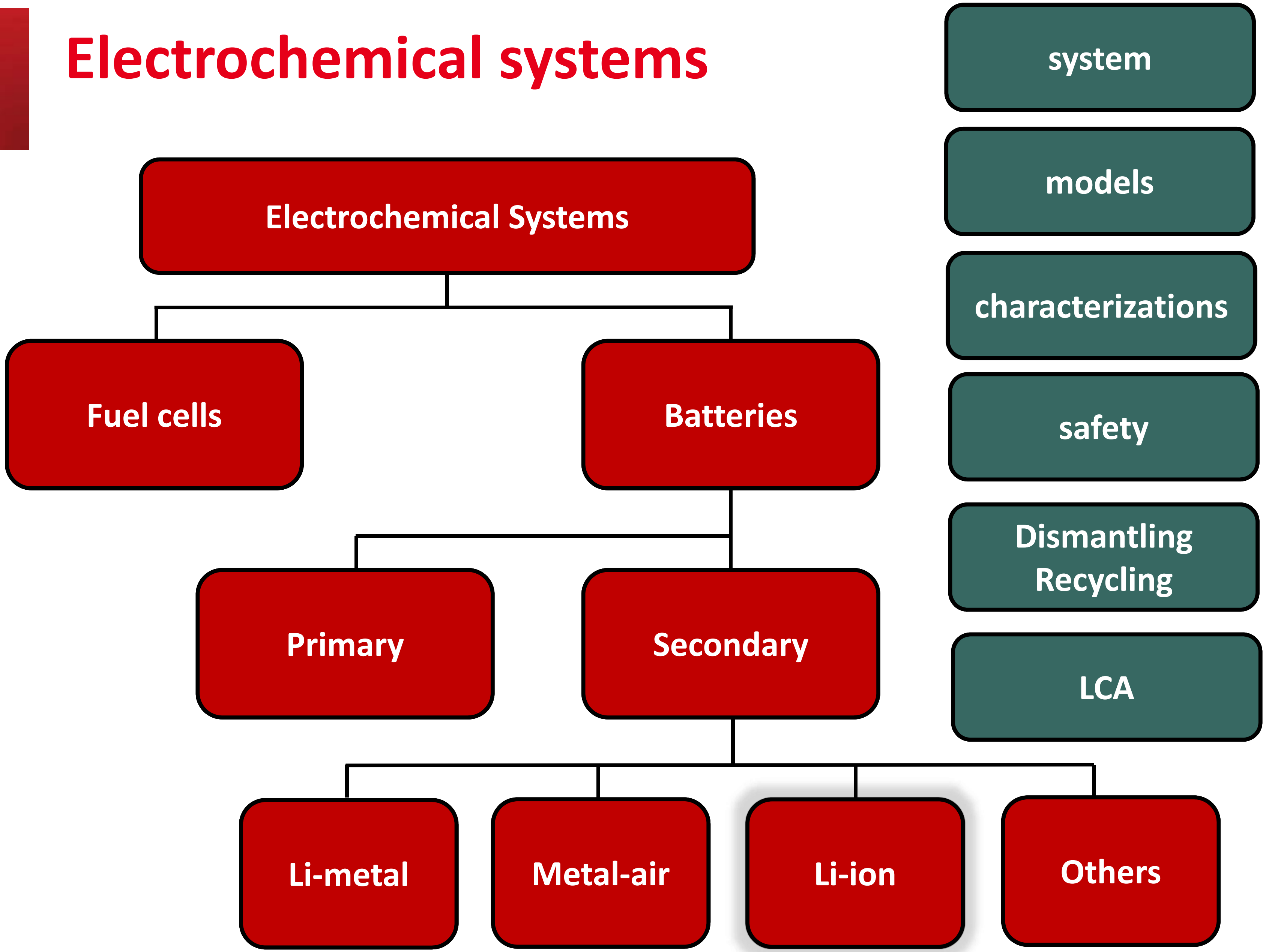
The Electricity and Hydrogen for Transport Division Integrated Approach (Battery&FC)

Industrial Collaborations at all levels

ADDED VALUE FOR INDUSTRY

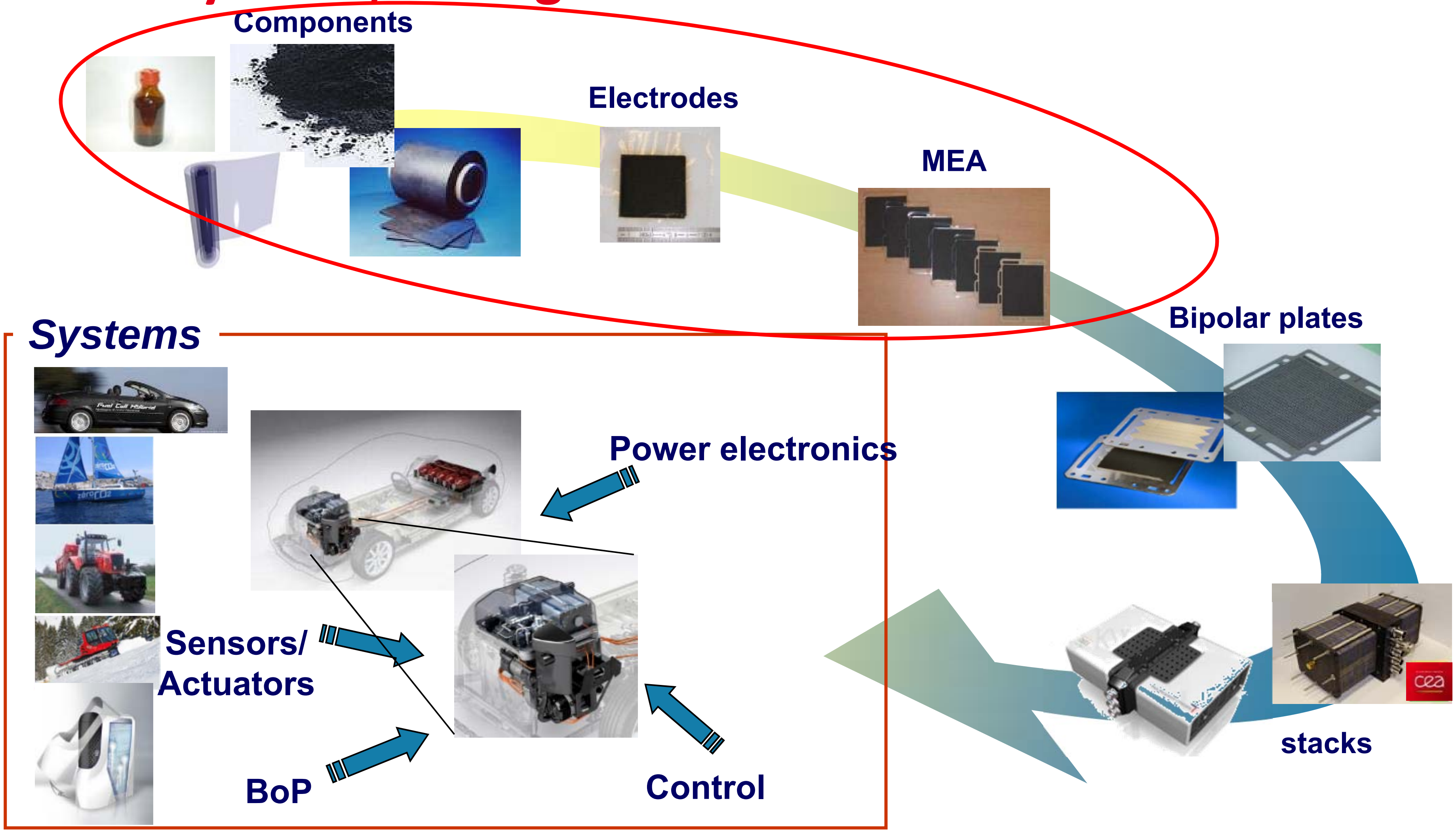
1) Be at the forefront of science and technology in the field of fuel cells
2) Integrate and validate innovations in stacks and systems in a very short delay
3) Transfer innovations to world class industrials

Electrochemical systems



Fuel Cells

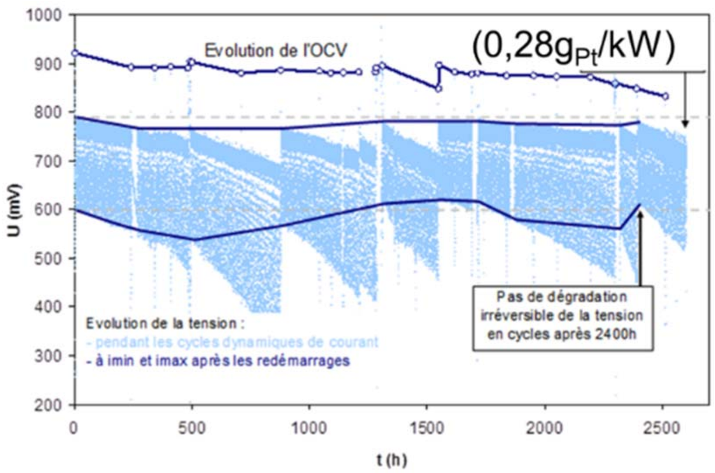
LITEN objective: innovate and support industry on the whole value chain, from components to systems, through assemblies and stacks



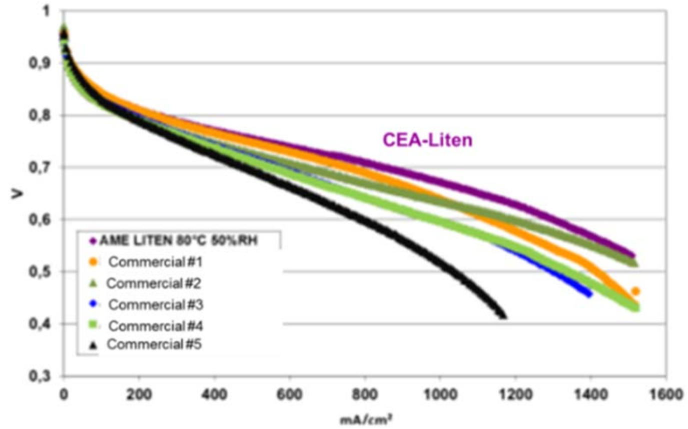
MEA developments

Key drivers

- ↘ **Cost (precious metal content)**
- ↗ **Performance**
- ↗ **Durability**



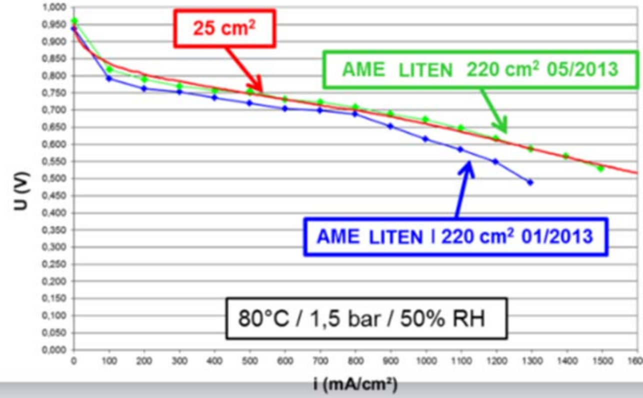
- Benchmark vs. commercial grades
  - Continuous comparison & improvements



- Developed jointly with the stack
  - From lab to stack

- MEA portfolio with series production

10kW stack with Liten MEAs operating in a system

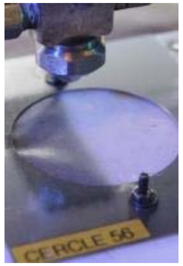


MEA developments
Laboratory resources

Inks formulation, electrochemical characterisations




Electrodes fabrication, fuel cell cores assembling, cell integration



Performance and durability tests, new components, with pollutants…

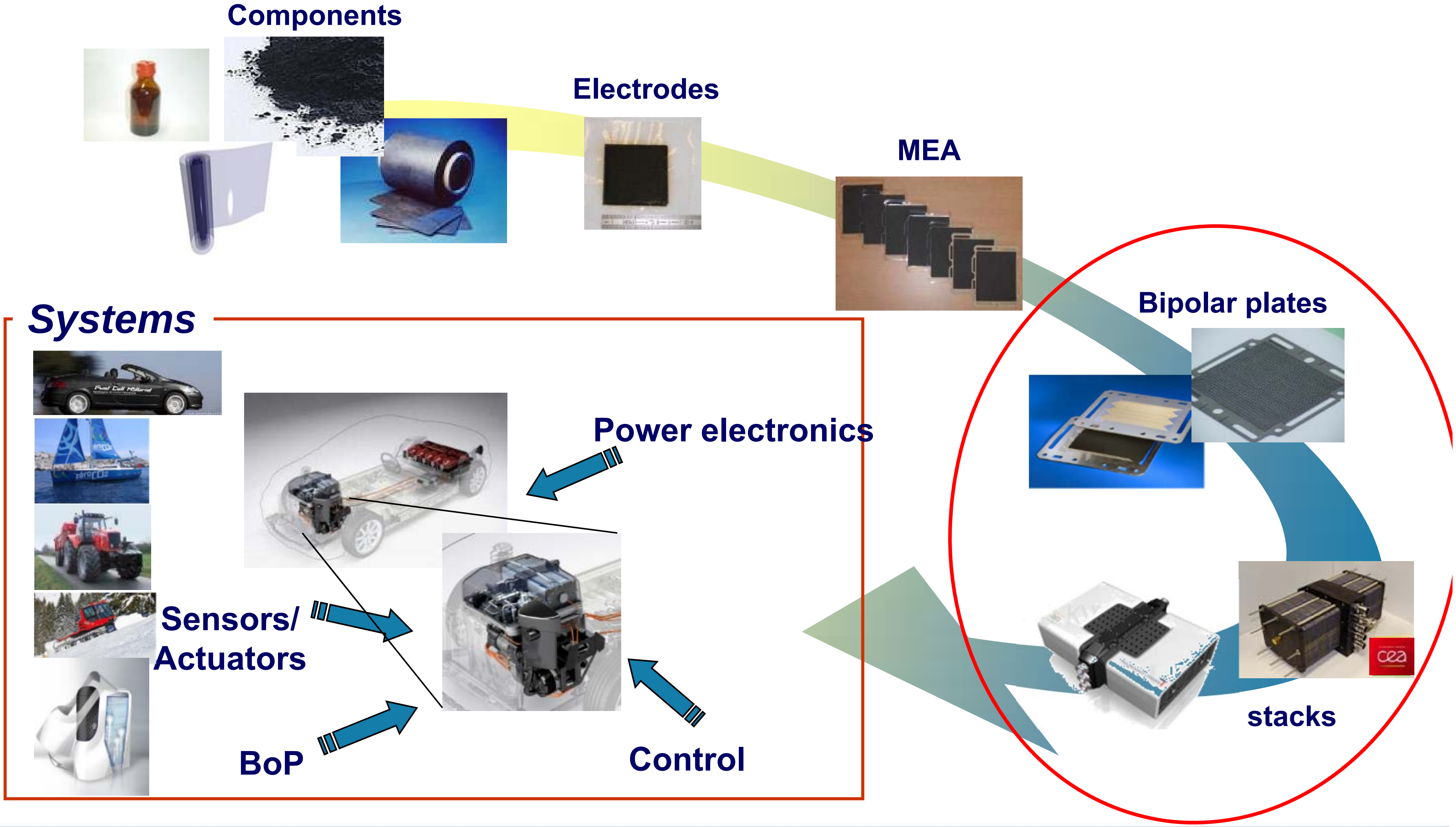




MEA developments
Electrode production platform

Roll to roll process
Versatile design: changes within ½ day
Capability: 180 CCM or CCB electrodes/hour

LITEN objective: innovate and support industry on the whole value chain, from components to systems, through assemblies and stacks



Bipolar Plates & Stack Developments
Design, prototyping to industrial transfer

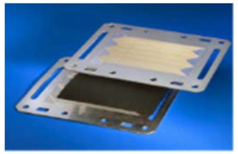
CEA design is based on a 15 years experience

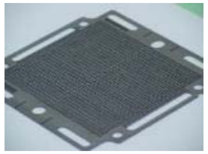
Input

- MEA performances
- System specifications
- Stack specifications

Output

- BP designs
- Stack power densities





Laboratory soft tooling

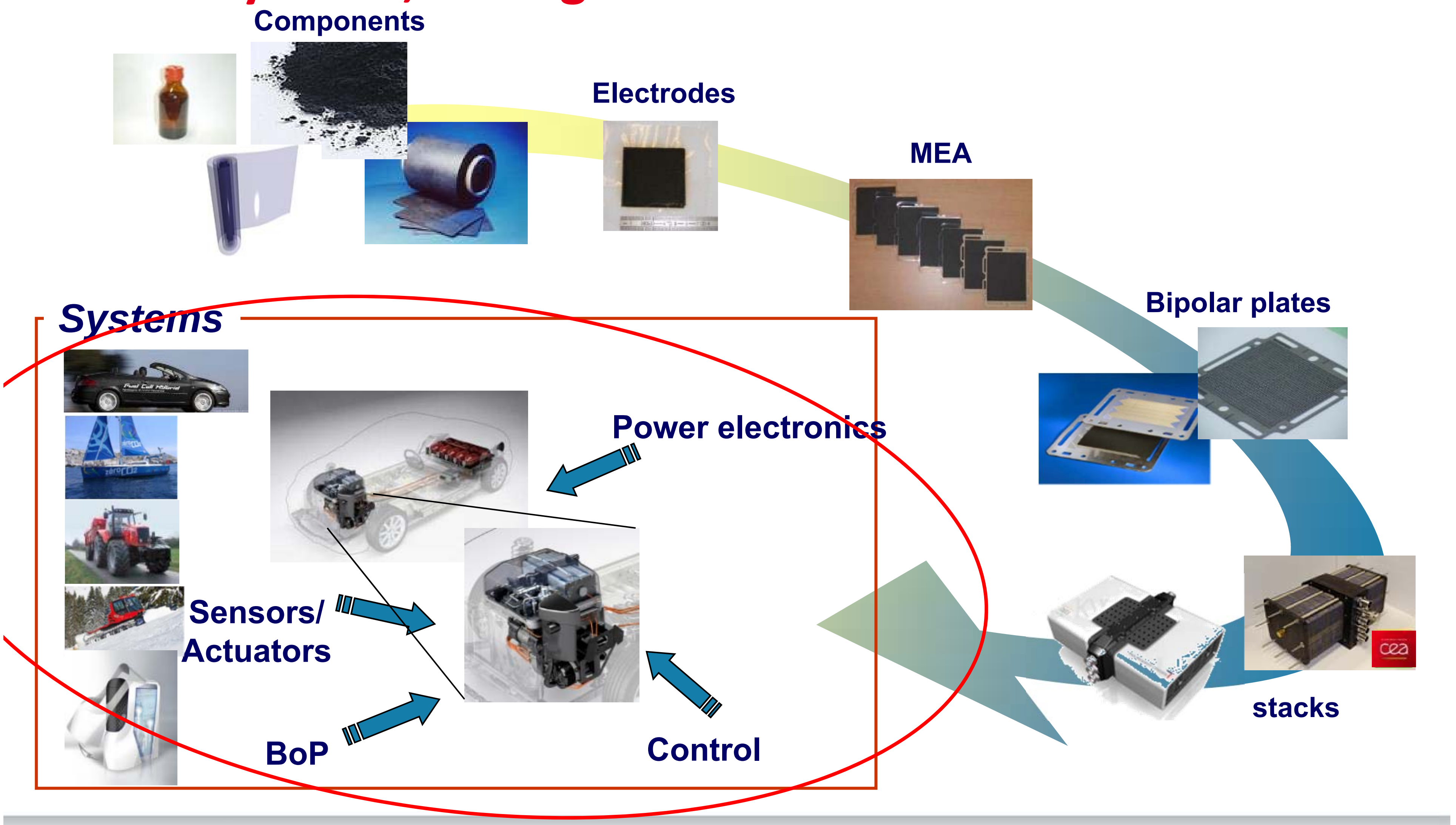
BP Press

Laser cutting&Welding

Gasket deposition

300+ stacks assembled since 2005 for a total over 1,000 kW

LITEN objective: innovate and support industry on the whole value chain, from components to systems, through assemblies and stacks



Automotive and also other markets, with lower cost constraints and/or competitive advantages

Maritime

Specific transport

Space/aeronautic

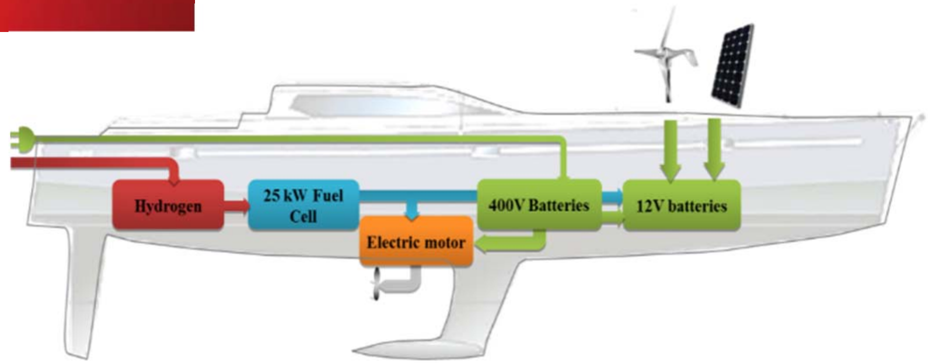
Electricity and heat Generator Emergency unit / back up power

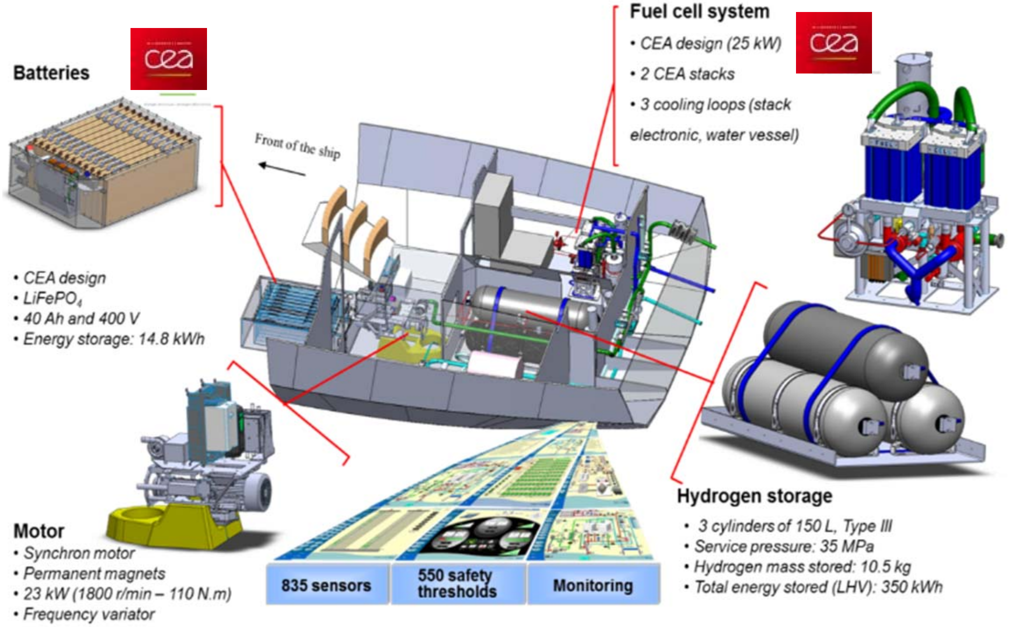
CEA prototypes

RES coupling for isolated site electrification or grid injection

Hybrid & Plug in « Zero CO_2 » sailboat
Behaviour in severe maritime environment

New Observer demo





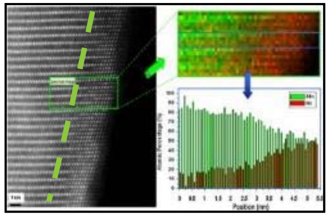
Field return

2011

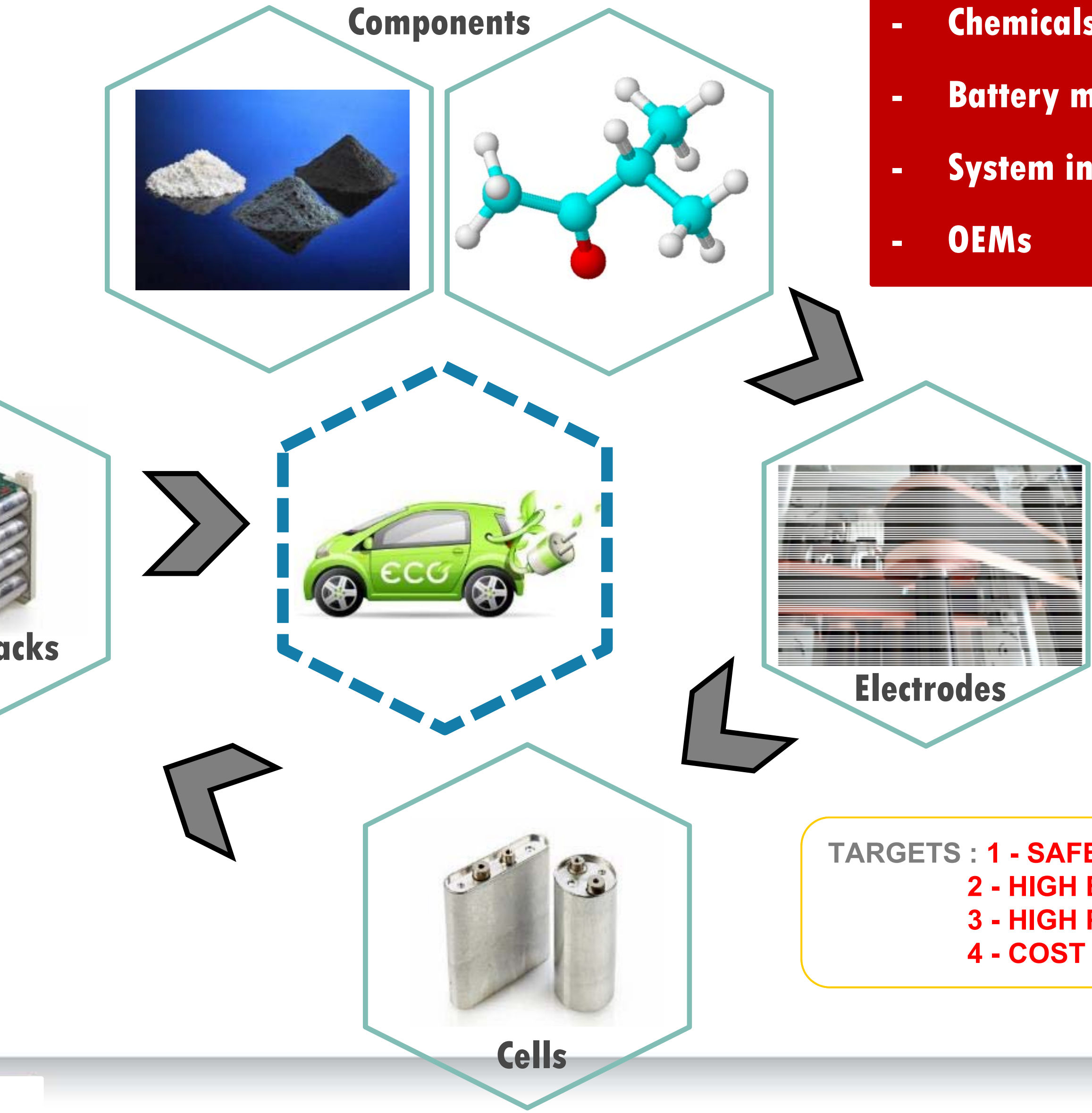
A Technical & Scientific Plaform

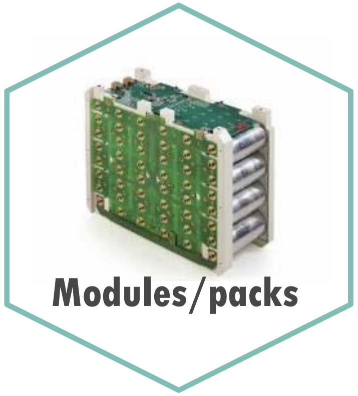
Batteries

A GLOBAL POSITIONNING



Characterization & modeling





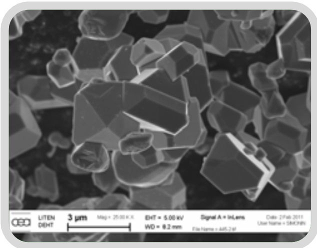
LCA/Recycling

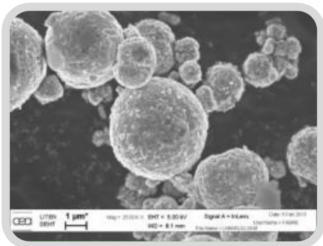
R&D on every parts of the value-chain for:

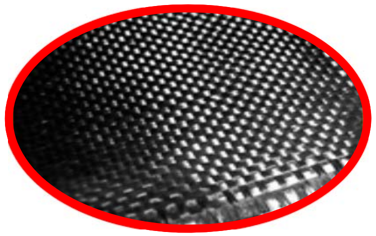
- Chemicals companies
- Battery manufacturers
- System integrators
- OEMs

TARGETS : 1 - SAFETY
2 - HIGH ENERGY
3 - HIGH POWER
4 - COST REDUCTION

Materials for Li-ion batteries







- <u>Positive Electrode Materials</u>:

- Safe Polyanionic structure materials,
- High Voltage Spinel Oxides,
- High Capacity Layered Oxides (Li-rich).

- <u>Negative Electrode Materials</u>:

- High Power, Safety, Cycle life Ti-based oxides,
- High capacity Si/C composites.

- <u>Electrolytes</u> (high voltage, T°c, safety) :

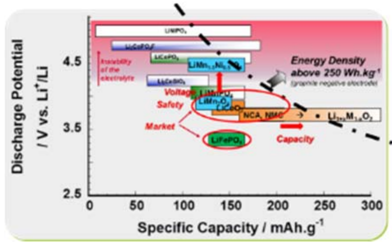
- Liquid (salts, solvents, additives, ionic liquids),
- Gelified,
- Solid (polymer / inorganic / glass).

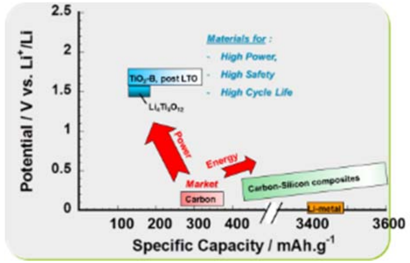
- <u>Separators</u> (safety, rate capability) :

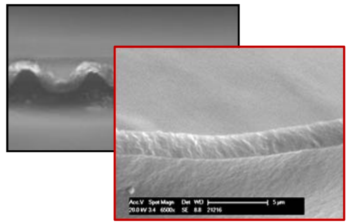
- PE/PP, PVdF, PEO, New materials, …

- <u>Packaging</u> (safety) :

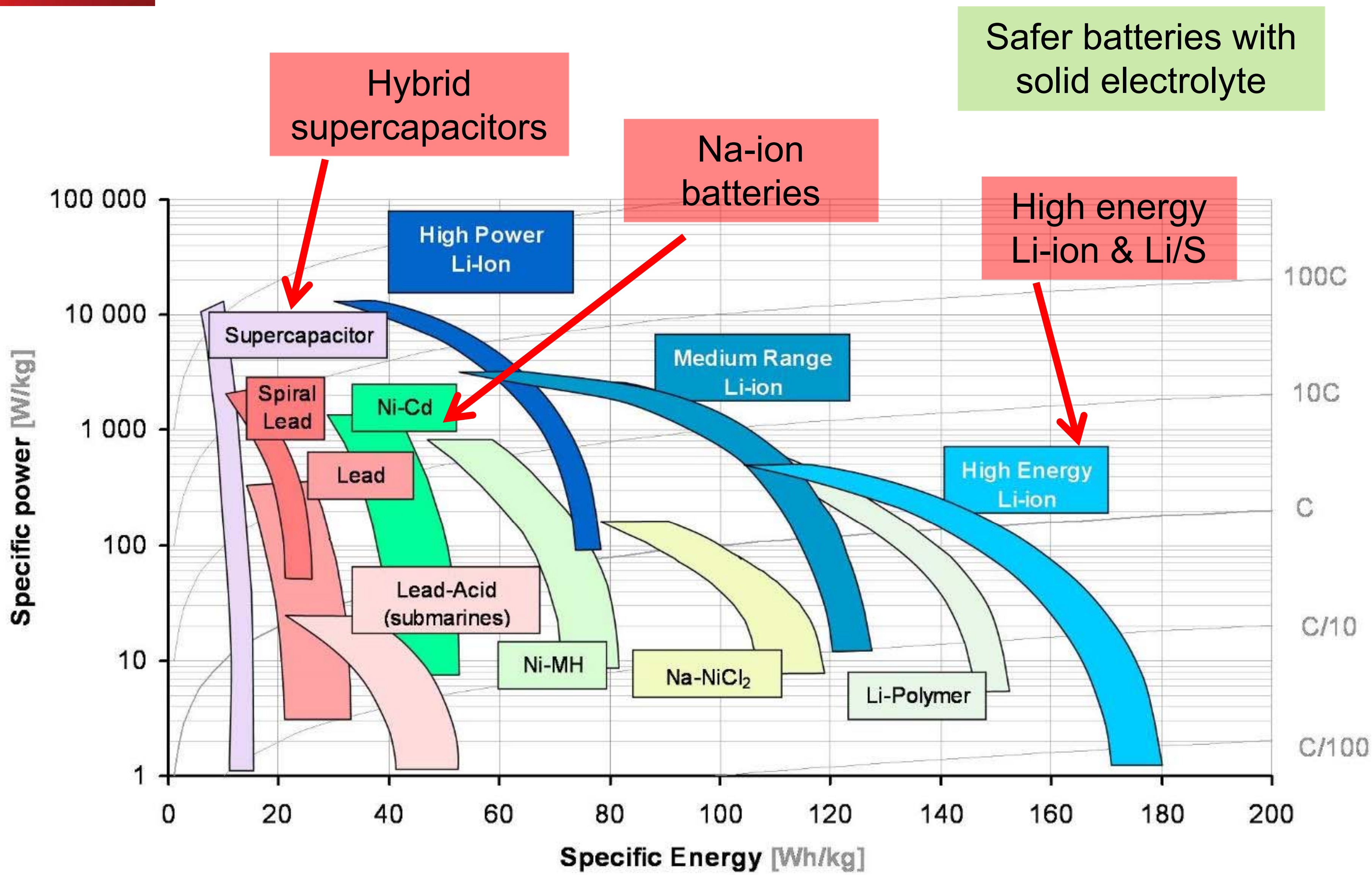
- Polymer reinforced packaging,
- New polymer materials.



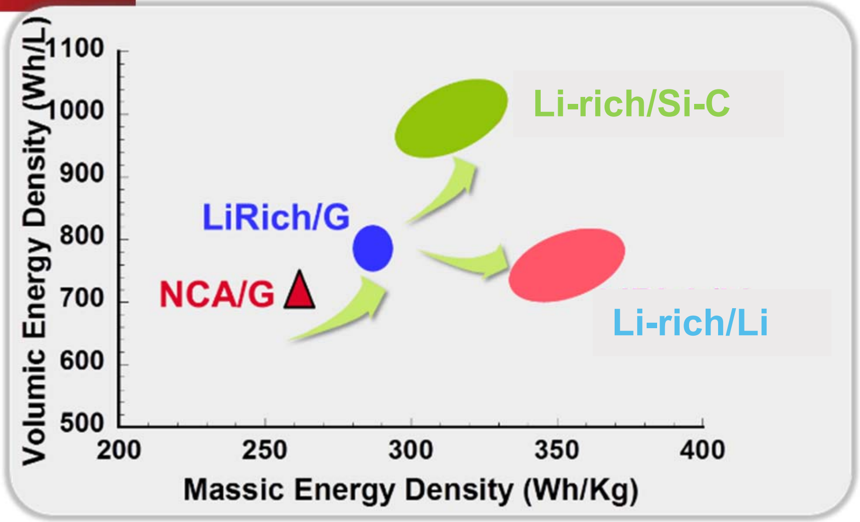




POSITIONNING OF THE BATTERY TECHNOLOGIES

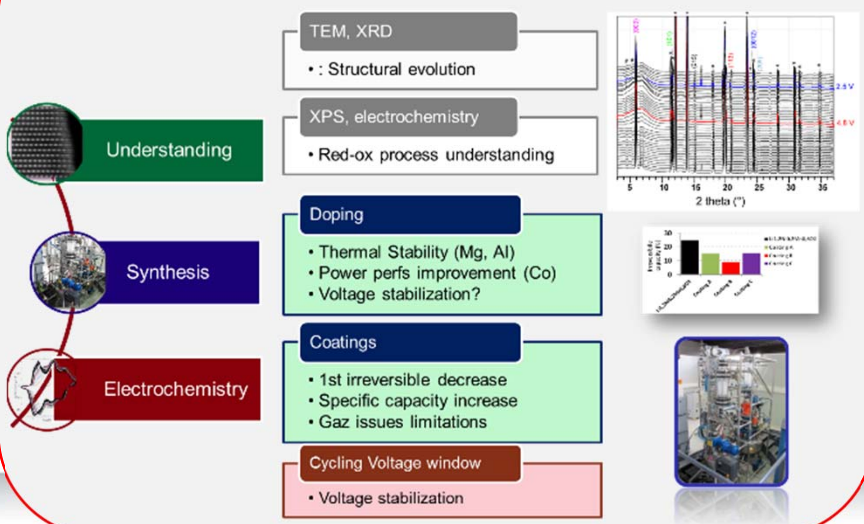


HIGH ENERGY Li-ION BATTERIES



- **Li-rich** material (post NMC) is one of the best solution for cathode
- **Silicon** based material is probably the best solution for anode
- **Li-metal** anode should also be considered again

Li-rich (Ni-rich) cathode



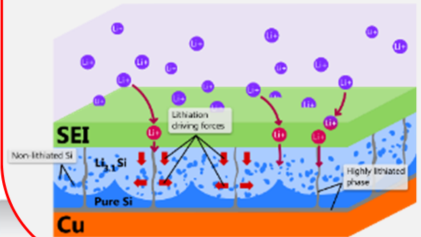
Silicon anode

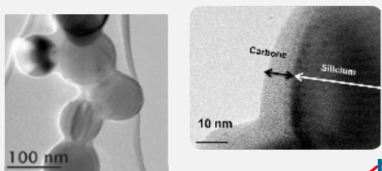
Limited cycle life due to volume change

- Mechanical pulverization
- Loss of electrical contacts
- Evolution of solid/electrolyte interface

Several approaches should be investigated to improve cycle life

- Synthesis of composites and alloys
- Electrolyte development
- Electrode Formulation
- Characterization & understanding
- Prelithiation & implementation

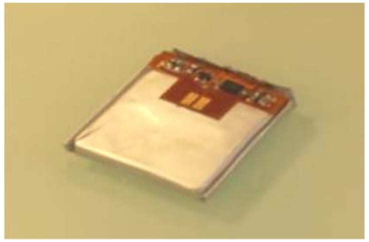




Examples battery development

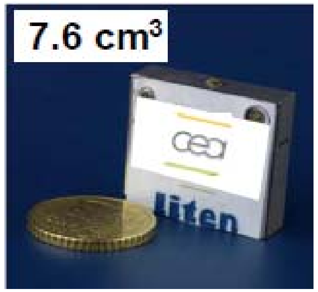
Military application

Si-C Technology
3.4V - 1.25Ah 260Wh/kg cells
Reduced cyclability
For 70Wh 13.6V Si Battery pack
Higher autonomy at 20°C (+60%) & -20°C (+180%) versus commercial
For Security, Beacons…



Security (beacons)

NMC/Si-C Technology
3.4V – 1.2Ah, 250-270Wh/kg
Operating from -20°C to 55°C
In a power mode
Cospas-Sarsat approval
UL1642-qualified

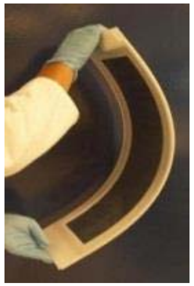


Spatial Sensor

NCA/G Technology
3.6V - 450mAh
Cell mechanical design
to sustain extreme environment
(vibration, acceleration, vacuum…)

Aeronautic Large Capacity/High Energy Li-ion cells

Si-C Technology
3.4V – 40Ah
300Wh/kg (C/10 @45°C)



Micro Hybrid – Start & Stop

High Power
Fast charge
24V – 15Wh
Bipolar Architecture

EVs, Buses, other large vehicles

Various P/E ratio
3.3V – 10Ah **$LiFePO_4$** Technology
1.9V – 11Ah **$Li_4Ti_5O_{12}$** Technology
Designed electrolytes, components…

Materials development

Laboratory scale (g)

Innovation - Patents
(synthesis-composition)
Caracterization

Pilot scale (kg)

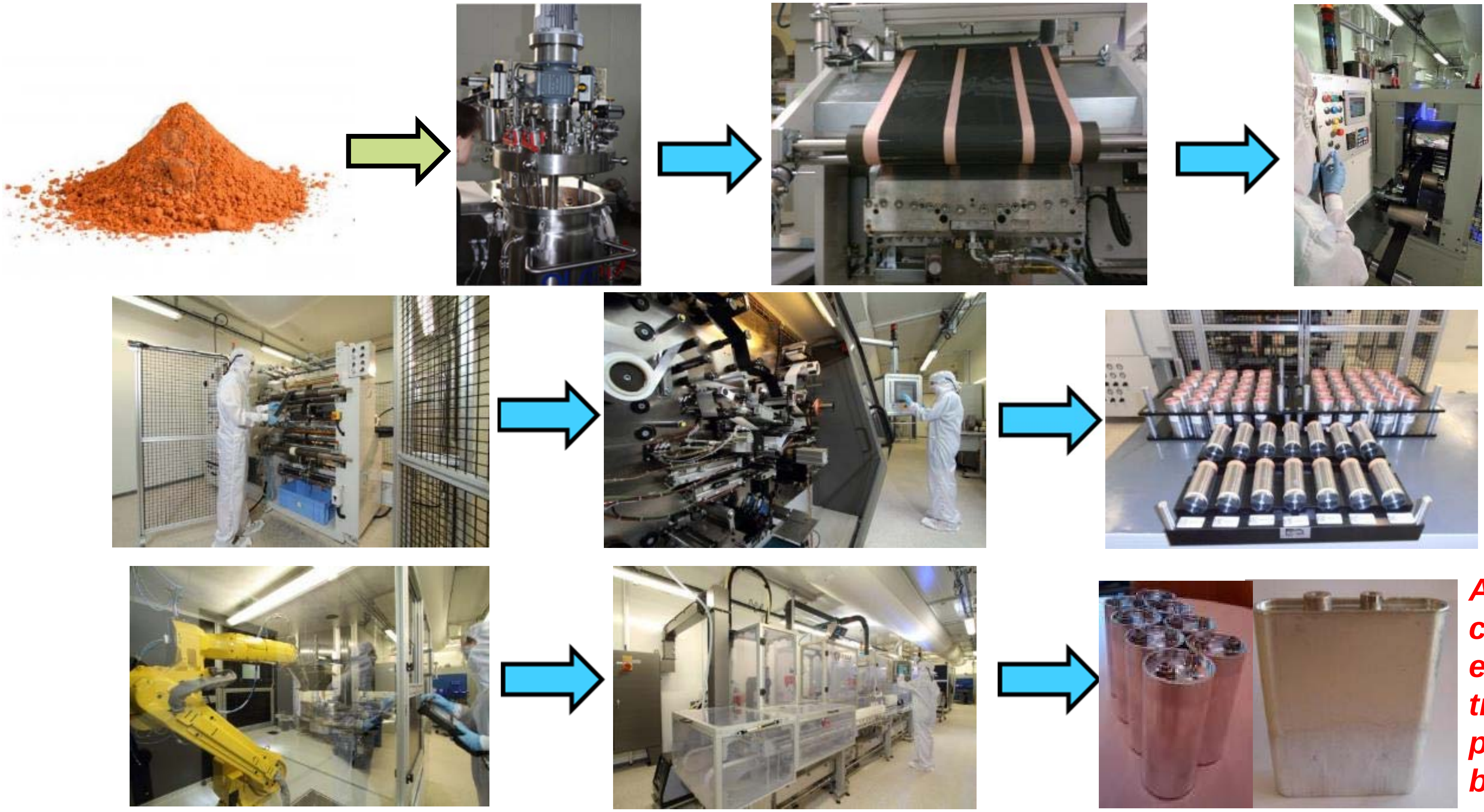
Synthesis scale-up
Process optimization
Reproducibility





PLATFORM: PRODUCTION REPRESENTATIVE ENVIRONMENT

Semi Industrial Line: Dry room ~ 1000m² (Dew points: -20°C & -40°C)



All materials & components electronically tracked during the process thanks to bar codes

- **A stabilized design to investigate chemistries with capability to produce prototypes in a production relevant environment**
- **Prototypes Performances stable, Manufacturing process definition established, Process flow validated… Manufacturing yield compatible with an industrial transfer…**

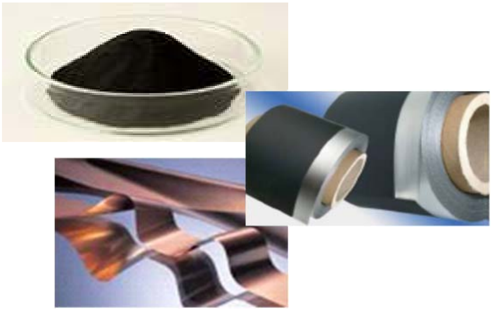
PLATFORM: BATTERY SYSTEM FROM TRL3 TO TRL6-8

Electrical test benches:
High power ~300 channels
Low power (Includes formation) 480 channels

Battery Modules & Packs Assembly ~500m²
ca. 20 to 40 battery packs (EVs sizes)/month/shift

Battery Modules & pack assembly with e-management
Semi automatic assembly with full components tracking

Battery pack for existing vehicles
CEA cells



Raw material

Cell

Module

Assembly

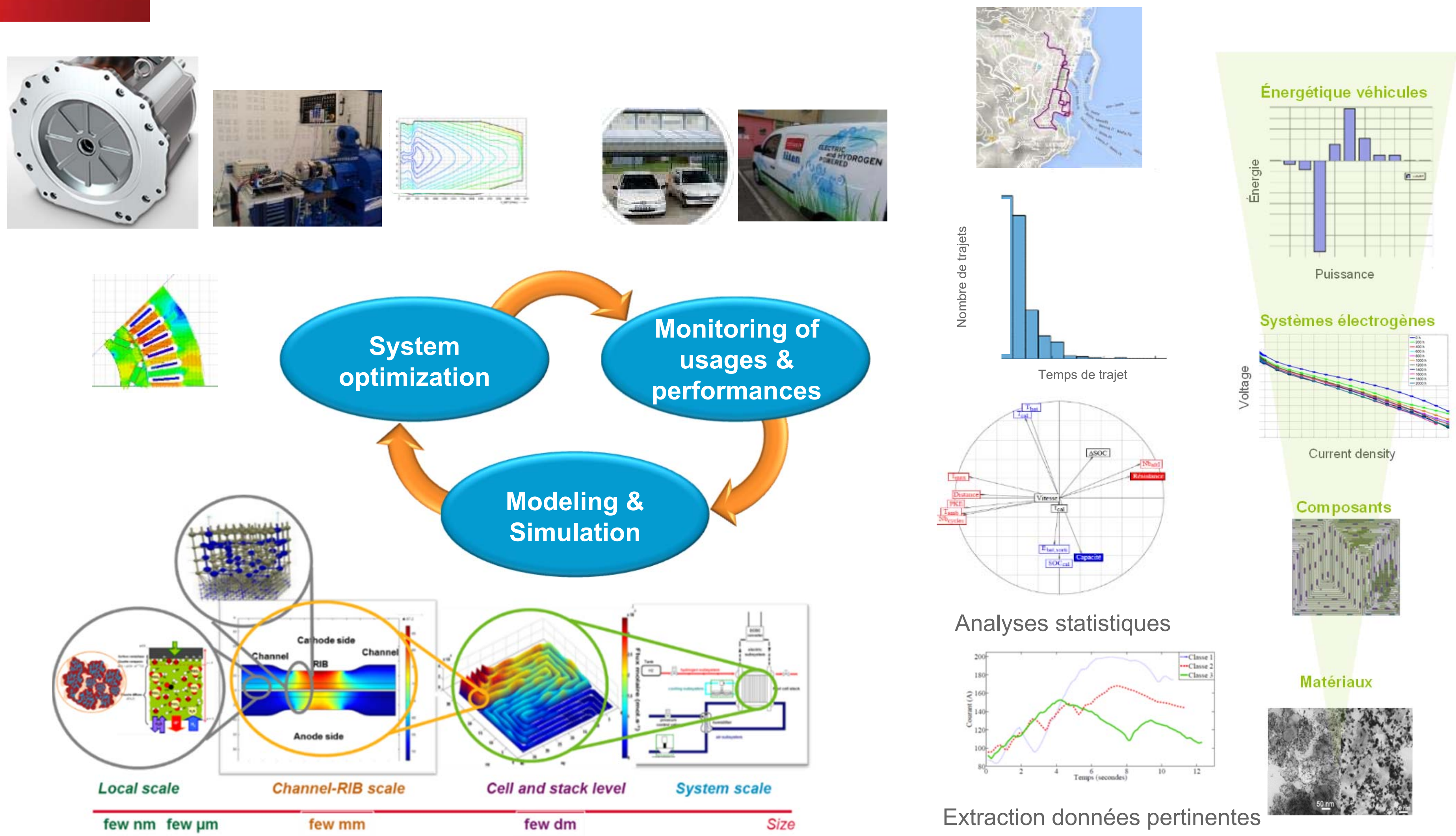
Pack & Conditioning

models

AN INTEGRATED APPROACH

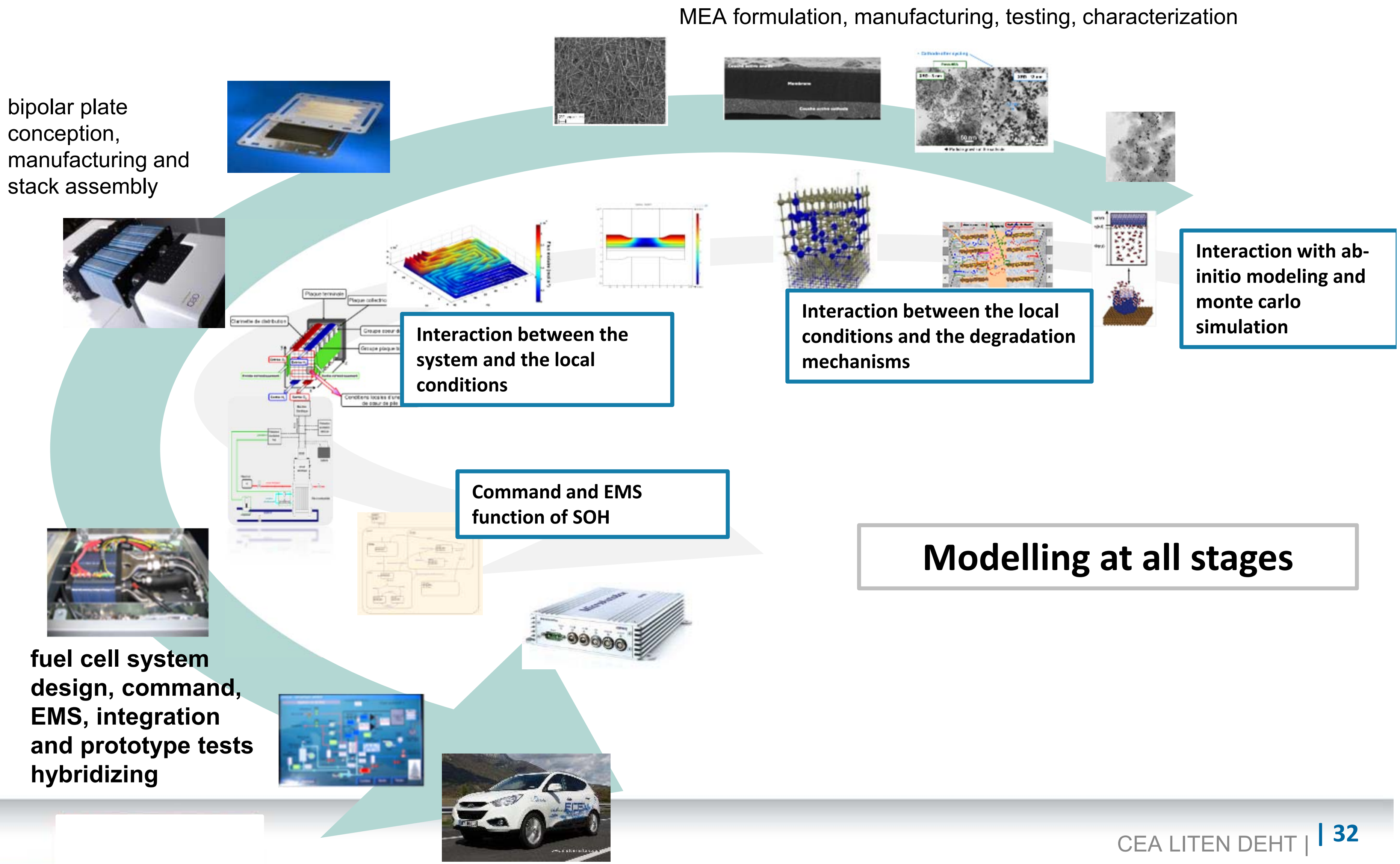
Real usages

Characterizations in real usages



Multiscale modeling

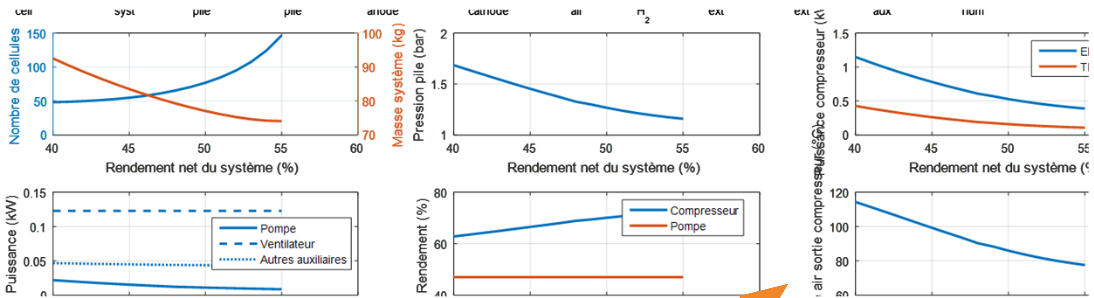
Faster & deeper understanding and development



Modelling at all stages

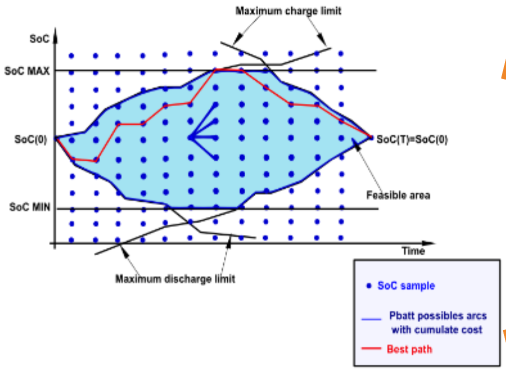
SYSTEM OPTIMIZATION

OSS PEM optimization



Optimization of the operating condition by minimizing criteria

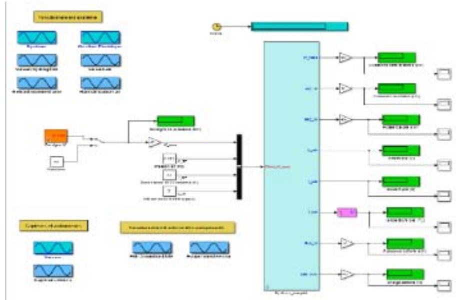
DPM



Dynamic programing for global optimization

- Optimization of the hybridization rate for a battery / fuel cell system
- Optimization of the operating conditions to minimize criteria: mass, H_2 consumption, …
- Validation of the sizing with 0D energetic models

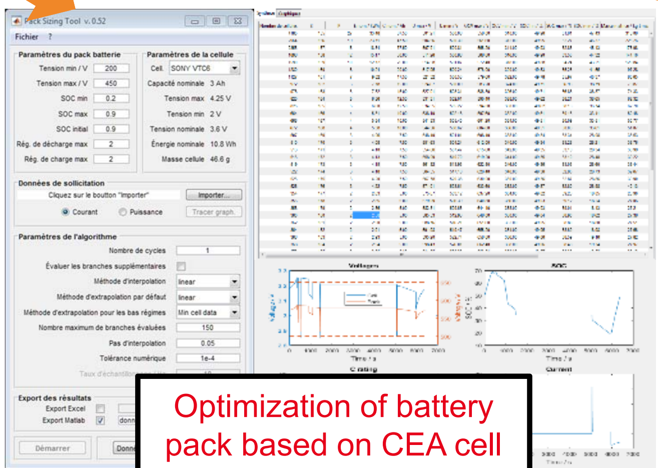
MePHYSTO



0D model to validate the sizing and the energy management strategies

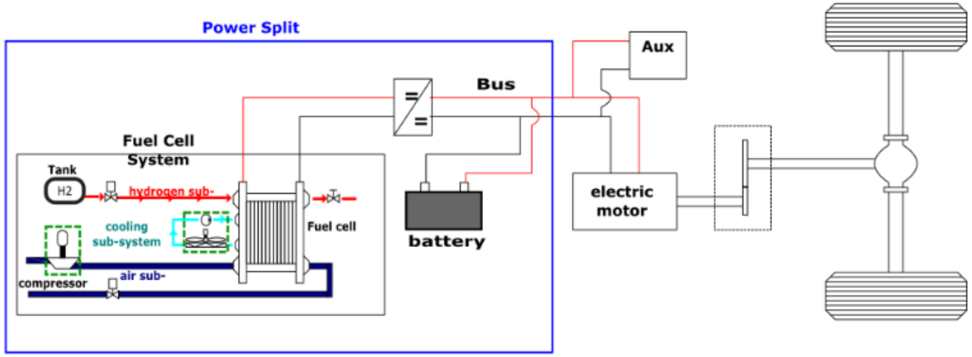
Vehicle model

PST Battery optimization



Optimization of battery pack based on CEA cell database

SYSTEM OPTIMIZATION



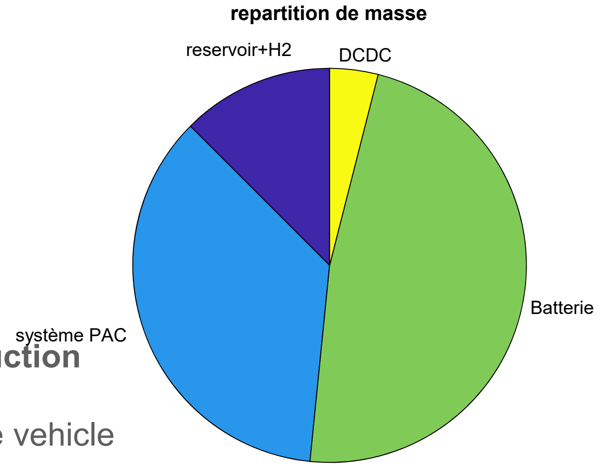
Example of a hybrid system with high power

- **Hybrid serie architecture**
  - Optimal sizing to minimize the mass within the constraints

Parametric analysis | **Optimization of the hybrid energy management**

$$m_{tot} = m_{sys\ PAC}(P_{sys\ PAC\ max}) + m_{DCDC}(P_{sys\ PAC\ max}) + m_{batterie} + m_{H2+reservoir}\ (conso\ H2)$$

- **Selection of battery chemistry**
  - Power chemistry
- **Modification of the power profile:**
  - Power electric regeneration during breaking, which limit?



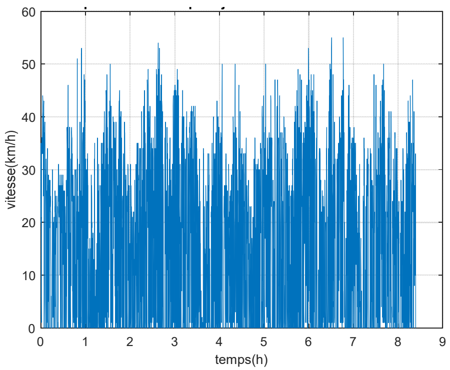
- Full H_2 vs hybridation: **with a hybrid fuel cell/battery, 30% of mass reduction**
- Reduction of breaking energy recovery → increase of the autonomy of the vehicle
  - Selection of a more energy battery with less power to recover

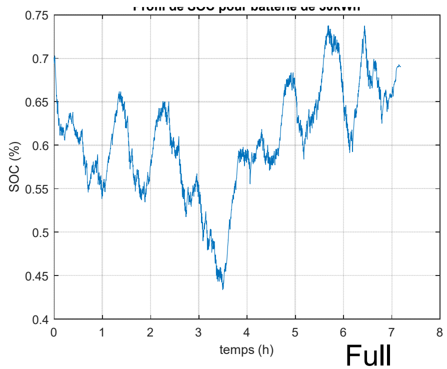
SYSTEM OPTIMIZATION

Electric bus vs H2 bus

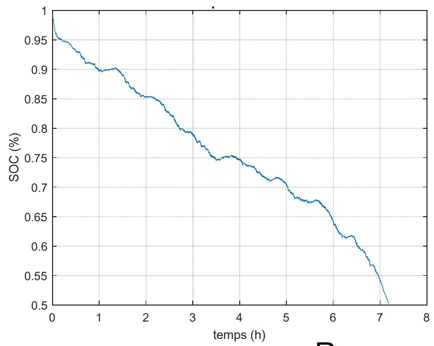
Two configurations studied compared to commercial electric bus

- Full hybrid :
  - Fuel cell system: 100 kW
  - Battery: 20 kWh
- Plug in/ range extender:
  - Fuel cell system: 40 kW
  - Battery: 100 kWh





Full hybrid



Range extender

Hybrid H_2 bus gives more autonomy than a pure battery bus

Full hybrid:

- Energy: 212,3 kWh
- Battery: 0,2 kWh
- H_2: 231,2 kWh, 15,5 kg

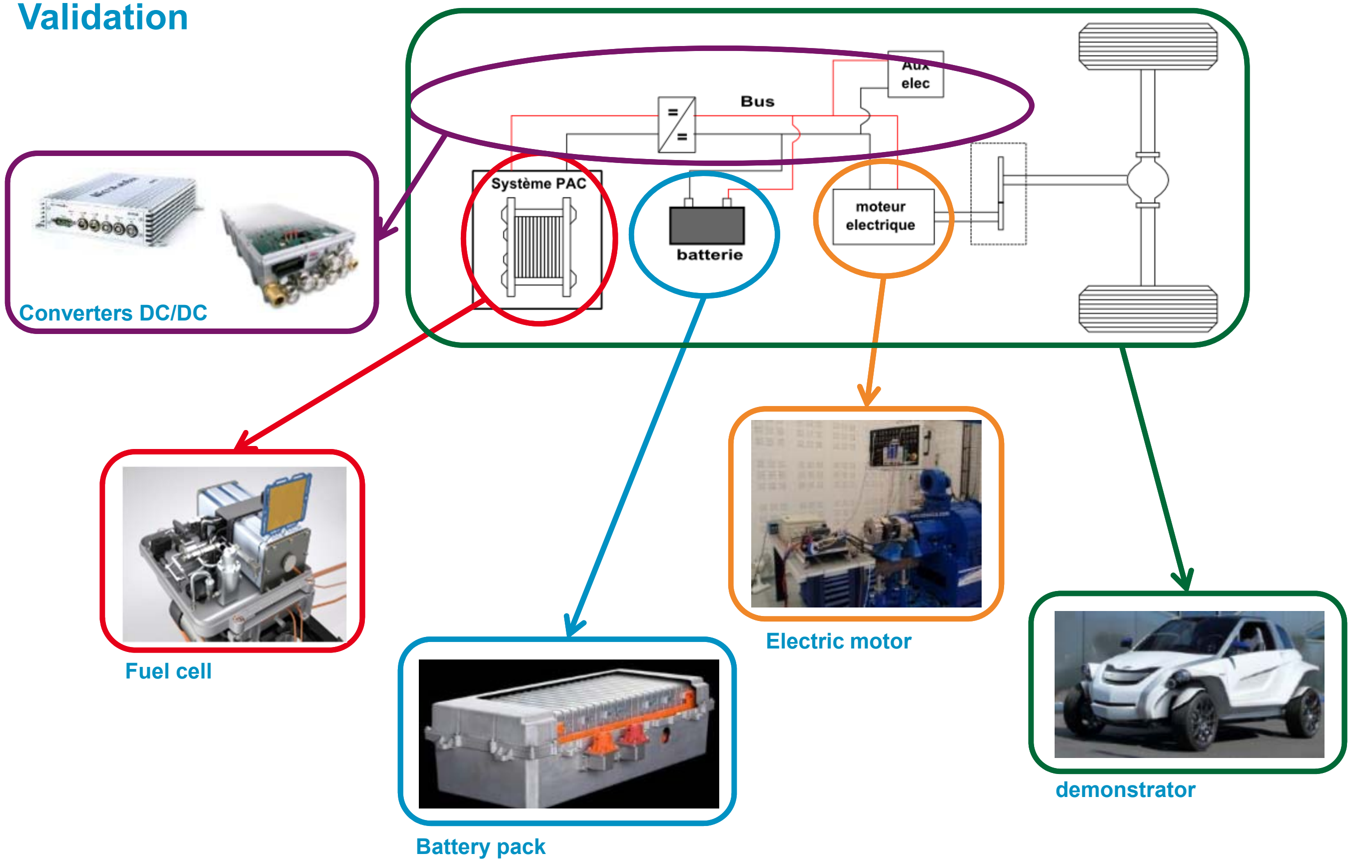
Range extender:

- Energy: 212,3 kWh
- Battery: 50,18 kWh
- H_2: 176,5 kWh, 12,7 kg

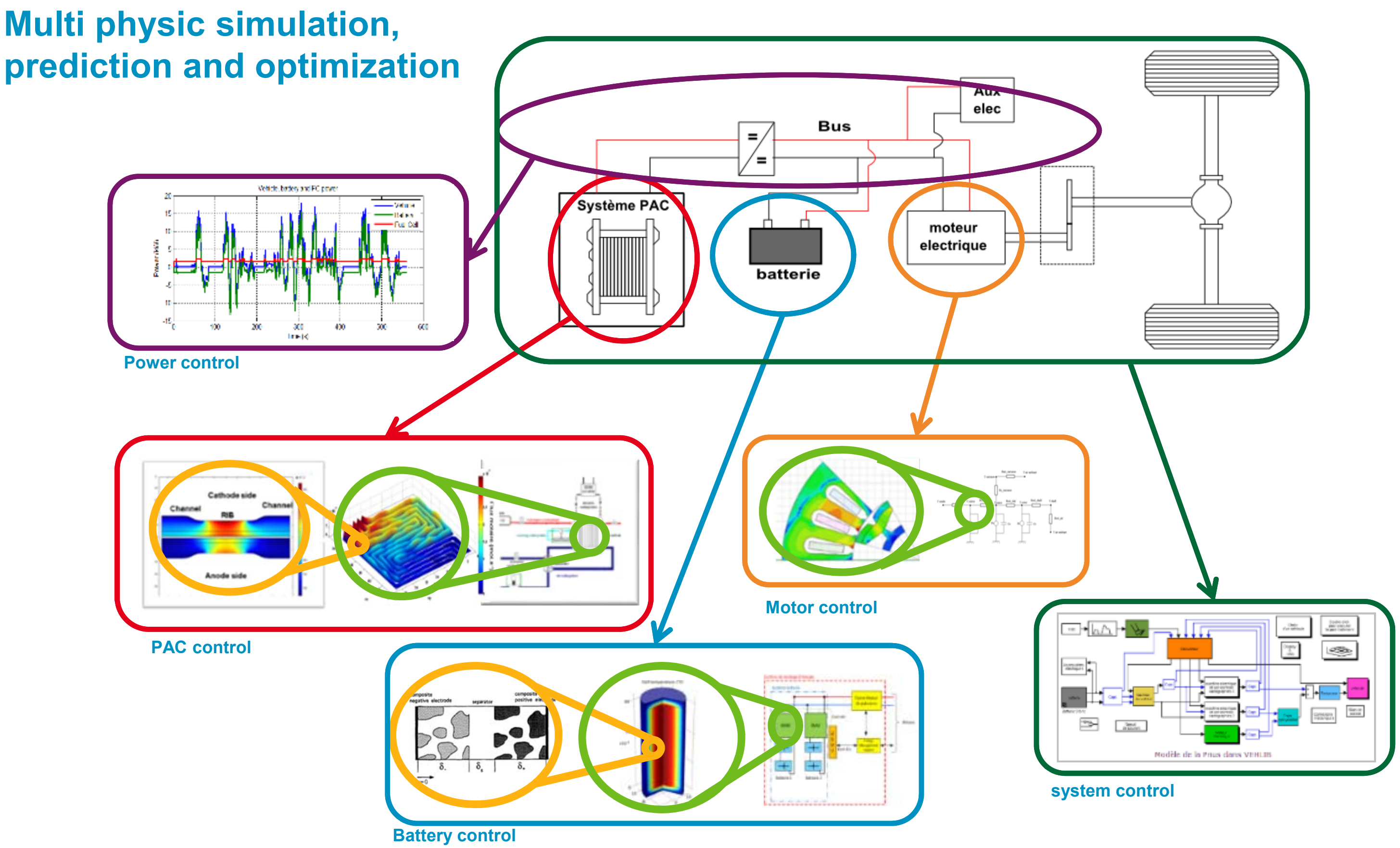
![liten ceatech logo]

SYSTEM OPTIMIZATION – PRESENTATION

Validation



SYSTEM OPTIMIZATION – PRESENTATION

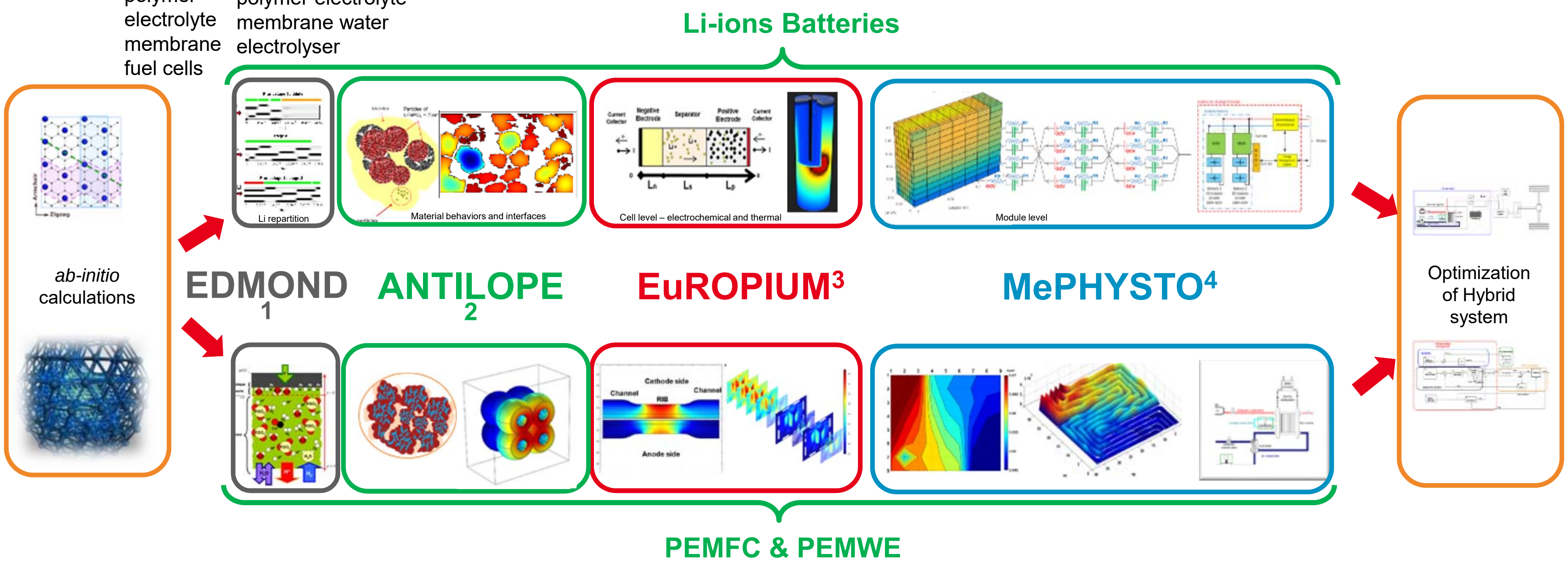


SIMULATION AND CHARACTERIZATION PLATFORM

A common multi-scale and multi-physics platform for PEMFC, PEMWE and Li-ions Batteries

polymer electrolyte membrane fuel cells

polymer electrolyte membrane water electrolyser



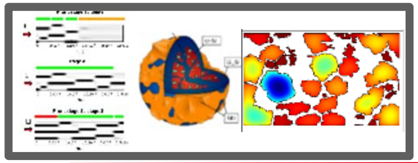
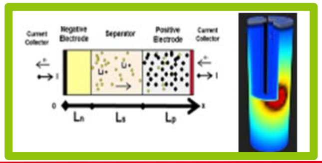
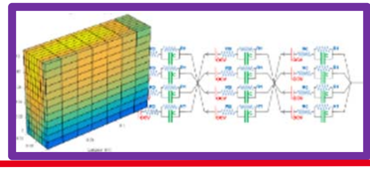
[1]**E**lectrochemical **D**ouble layer **MO**del for **N**ano **D**ynamics

[2]**AN**alysis of **T**ransports **I**n **L**ayers **O**f **P**orous and active m**E**dia

[3]**E**lect**R**ochemistry **OP**t**I**mization **U**nderstanding **M**odeling framework

[4]**M**ulti**PHYS**ical **S**imulation **TO**ol

SIMULATION AND CHARACTERIZATION PLATFORM:

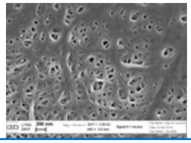

few nm — few µm — few cm — few dm — *Size*

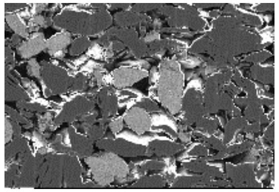
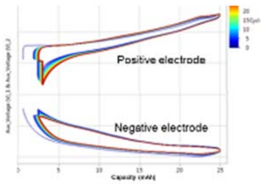
Local scale to better understand elementary mechanisms: Li transport, degradations, morphologic properties …
→ **Calculation of effective parameter properties and degradation laws**

Micro scale to simulate local conditions and performances including ageing mechanisms and safety (thermal runaway)
→ **Optimization of components properties and cell design**
→ **Understanding of degradation mechanism and safety**

Cell and module scale to simulate global performance including lifetime and safety
→ **Validation of electrical, thermal and mechanical architecture**

Battery system scale to simulate global behaviors of the system
→ **Optimization of the battery system, validation of BMS algorithm, MiL and HiL validation**



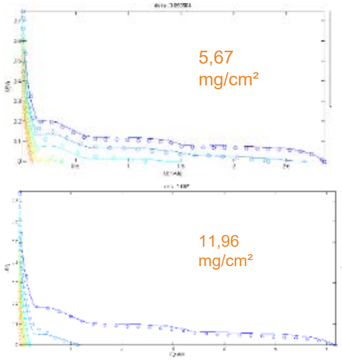




→ **All the scales are coupling experiments/modeling**

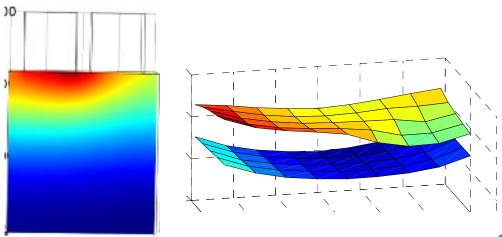
EXAMPLES OF MULTISCALE AND MULTIPHYSICS MODELING AND SIMULATION OF BATTERIES

Performance

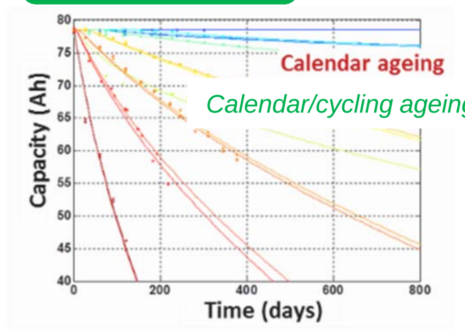
Electrode optimization

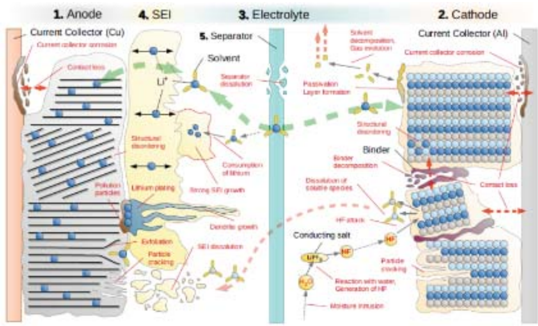


Cell design optimization



Durability

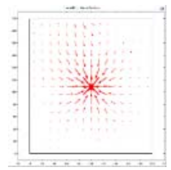




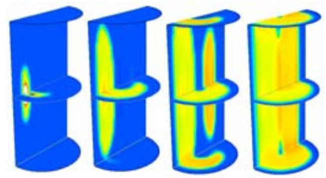
2014 IEEE Transportation Electrification Conference and Expo: Components, Systems, and Power Electronics - From Technology to Business and Public Policy, ITEC 2014

Safety

Short circuit



Thermal runaway

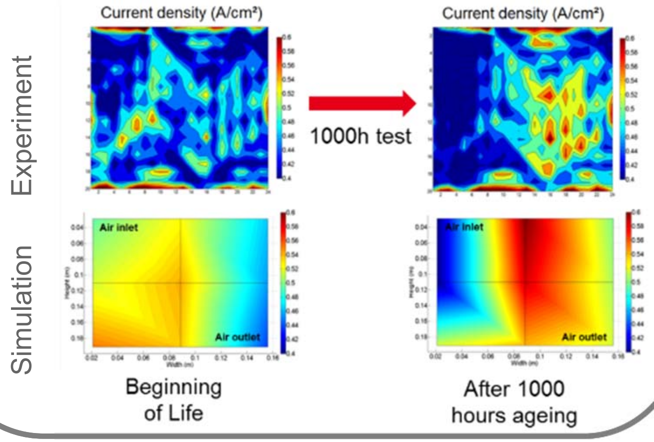


MULTISCALE MODELING: FASTER & DEEPER UNDERSTANDING & DEVELOPMENT

Degradation Mechanisms

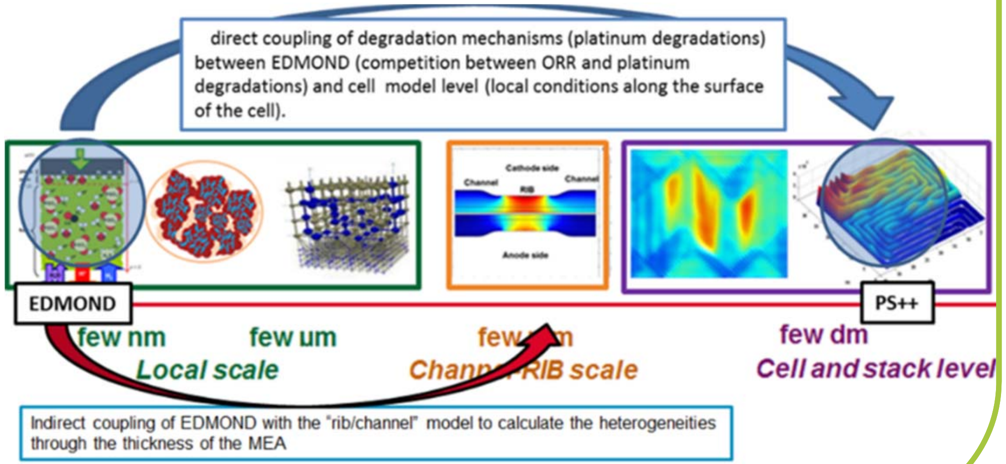
Problem

Different degradation between inlet/outlet depending on the operating conditions



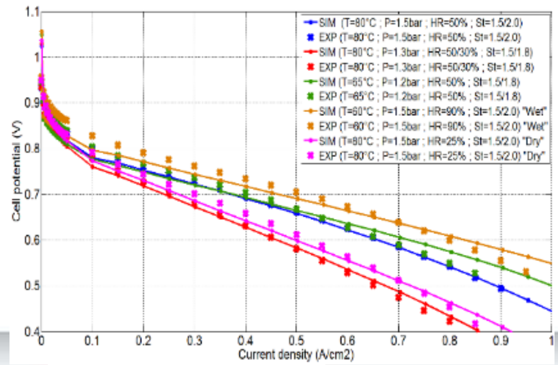
Actions

1. Physical mecanism
2. Integration at the nm scals
3. Coupling with the higher scales

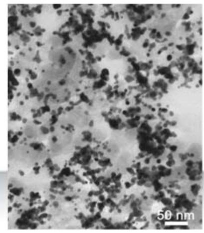


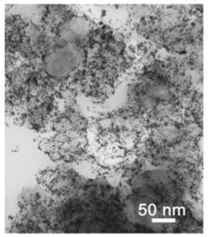
Results

Comparison between experimental and simulated polarization curves after 2000 h



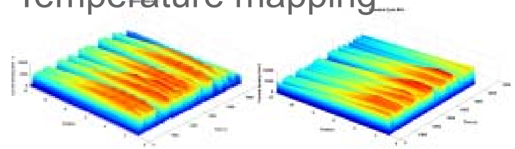
Simulated performances at the EoT





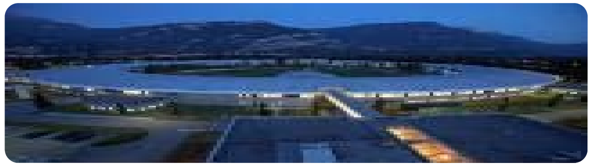
Explanation

Temperature mapping



Tests – characterizations

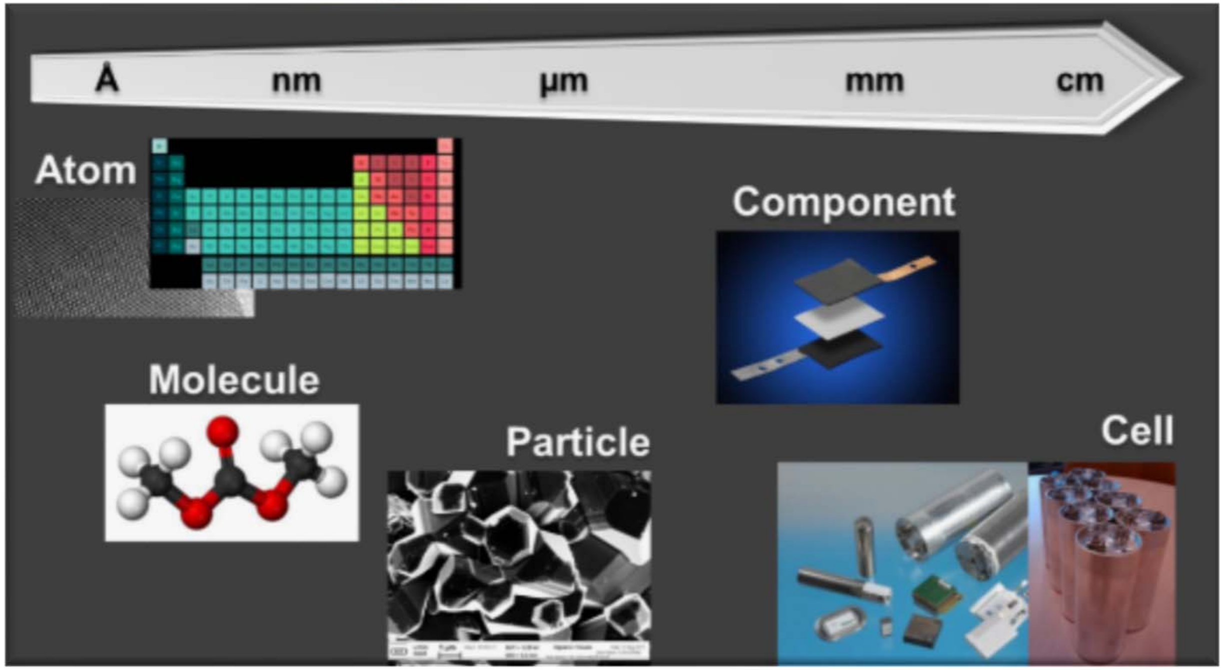
CHARACTERIZATIONS



Numerous techniques of characterization at

Atom, Molecule, Particle, Component and Cell levels

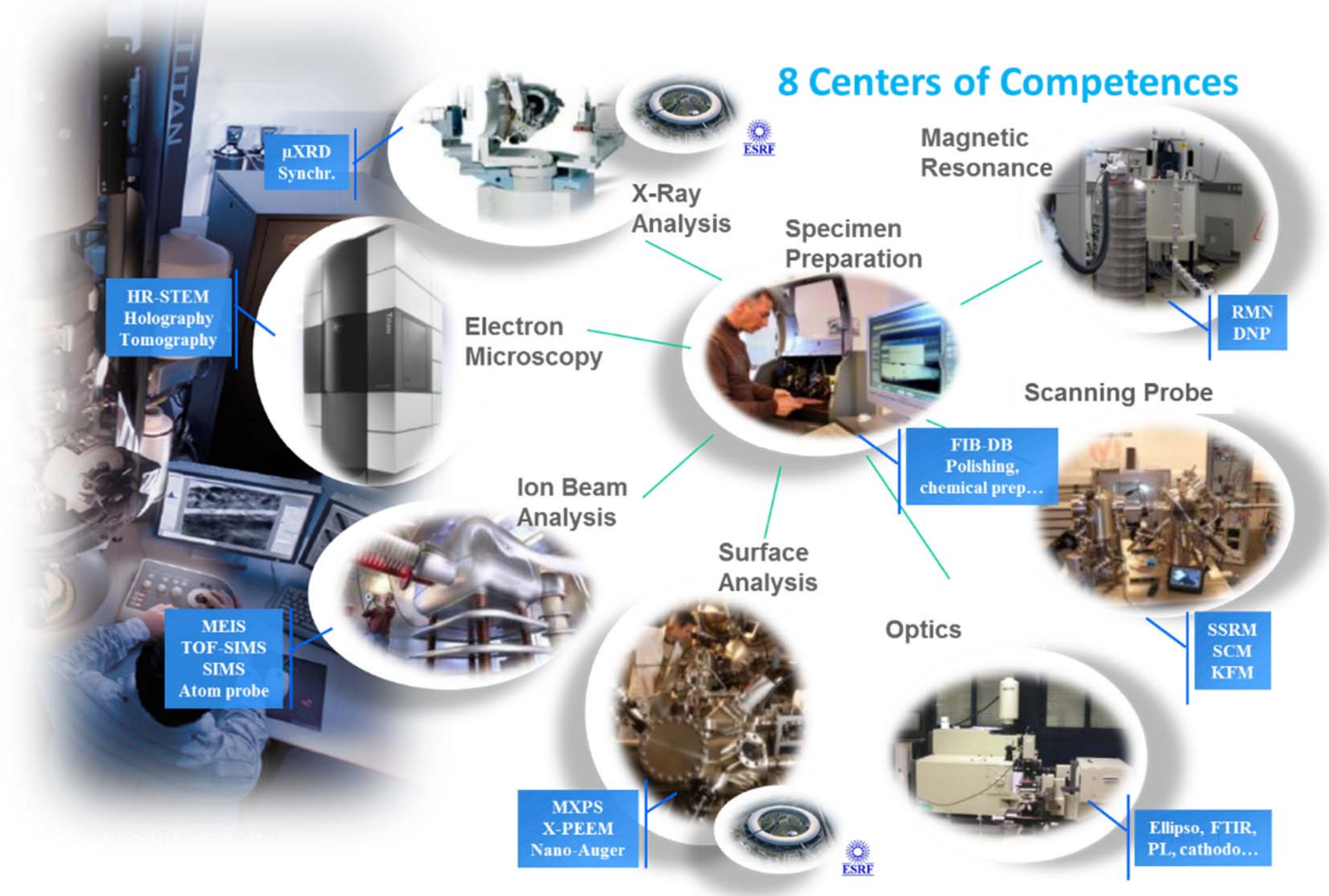
to analyse the defects and improve the performance



- TEM / SEM
- NMR
- XPS, AES
- Neutron diffraction
- X ray Synchrotron
- Contact Angle
- Gas Permeation
- Profilometer / AFM
- Magnetic measurements
- Abuse tolerance facilities
- GC/MS
- LC/MS
- HPLC / SEC
- FTIR / UV
- X-Ray diffraction
- Electrochemistry
- DSC / TGA-DTA
- Rheometer / DMA
- Cloud point analyser
- Specific surface area
- Laser granulometry
- Conductivity / EIS

Nanocharacterization platform

40 equipments / 2500m^2 of facilities / 3.5M€ of investments/year



- TEM / SEM
- NMR / SQUID
- XPS
- Neutron diffraction
- X ray Synchrotron
- Contact Angle
- Gas Permeation
- Profilometer / AFM
- GC/MS
- HPLC / SEC
- FTIR / UV
- X-Ray diffraction
- DSC / TGA-DTA

FACILITIES, BENCHS FOR BATTERY

- **The STORE Platform: an outstanding test facility in Europe**
    - ♦ **More than 200 cycling channels (up to 700 V, 1000 A, 250kW)**
    - ♦ Thermo regulated baths, climatic chambers (-40°C, +120°C)
    - ♦ Two laboratories for physical-chemical analyses, safety tests
    - ♦ **For all storage systems investigation** (simulation, emulation, profile of use testing, ageing…)

- Zebra Sodium-beta (High T°)
- Supercapacitors
- Li-ion, Lead-acid, Ni-MH, Ni-Cd
- Redox Flow…

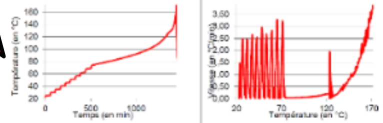
BATTERY SAFETY EVALUATION

In partnership SERMA TECHNOLOGIES

- ✓ **SERMA Technologies**: standard
- ✓ **CEA**: analyses + R&D

Abuse test platform: materials, cell, module and pack

Electrical tests
Thermal stability and abuse tests on cells with ARC (Accelerating Rate Calorimeter)



Electrical tests
Post-mortem analysis
Nano-characterizations
Modeling
Pack assembly

“Classical” tests

- ✓ *Over-charge*
- ✓ *Over-discharge*
- ✓ *External short-circuit*
- ✓ *Nail penetration*
- ✓ *Gas analysis*
- ✓ *Drop*
- ✓ *ARC tests*

Specific tests and analyses

- ✓ *Over-instrumentation*
- ✓ *Modules et packs*
- ✓ *DSC*
- ✓ *Specific interpretations*

SAFETY: GENERAL APPROACH

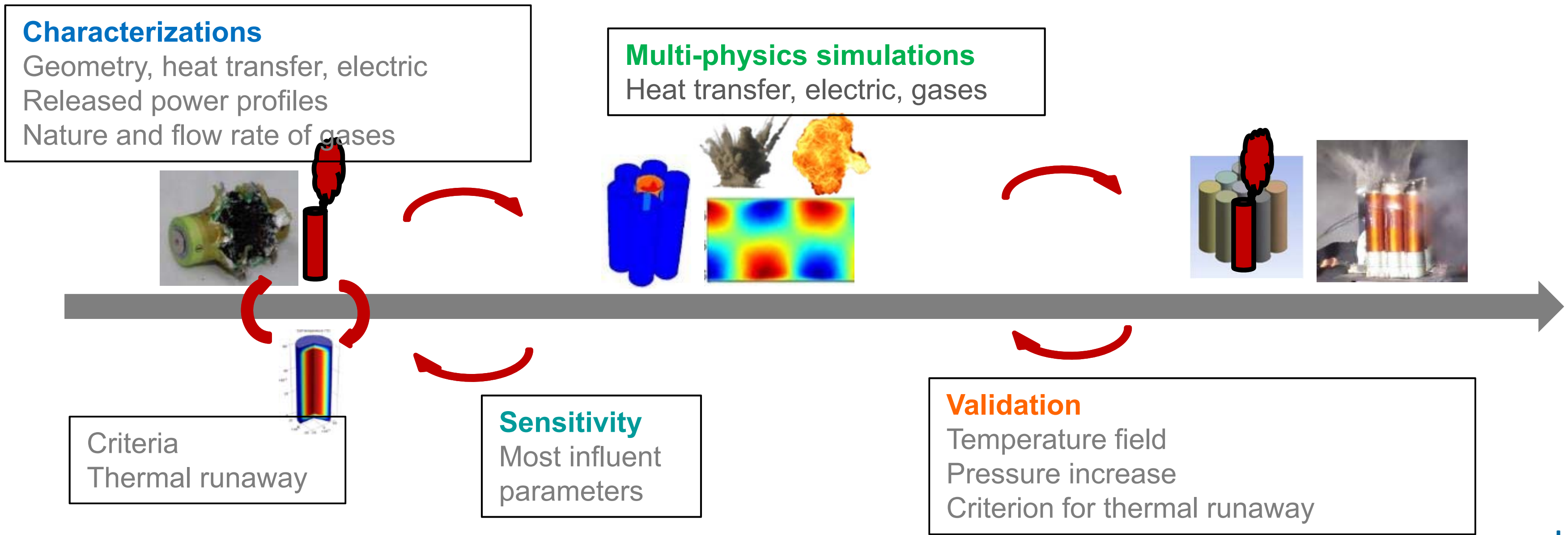
OBJECTIVE: Ensure a **high level of safety** of batteries to avoid a battery fire accident

The approach

- **Experimental characterizations**: input data; validation data at different scales
- **Multi-physics simulations**: key parameters *via* sensitivity; envelope solicitation cases

- Control the methods, the tools and the data (in each physical domain) **to design by improving the safety of battery packs**

- Get more precise data towards greater **predictively** to shorten the design time



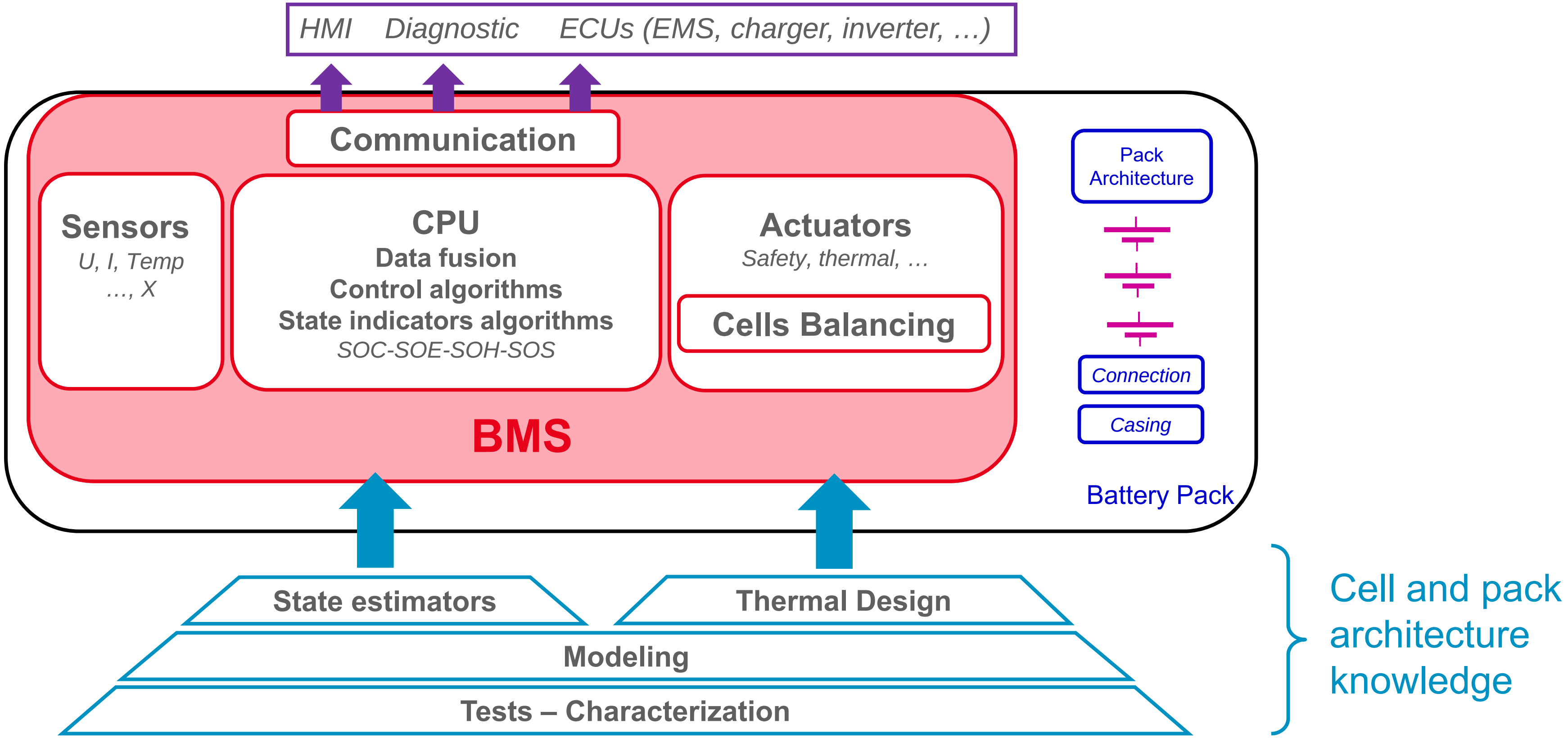
Battery Management System

BMS

BATTERY MANAGEMENT SYSTEM (BMS):

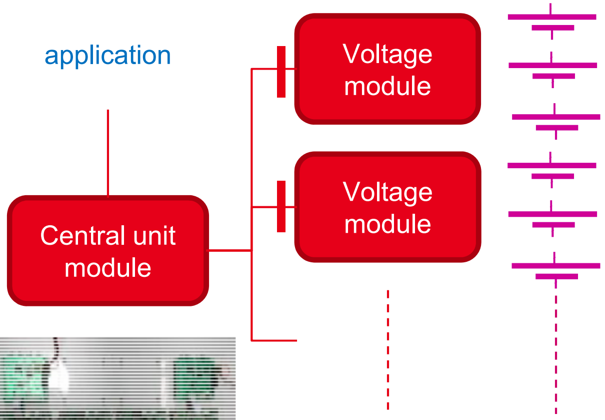
Services

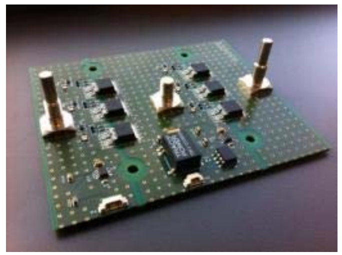
- ✓ Ensure **safety**
- ✓ Improve **diagnosis**, **service**, **maintenance**
- ✓ Service **continuity**
- ✓ Improve **performances**: Life Cycle Cost (€/kWh, €/km)
- ✓ Improve **information** for end user (SoH, SoC, ….)

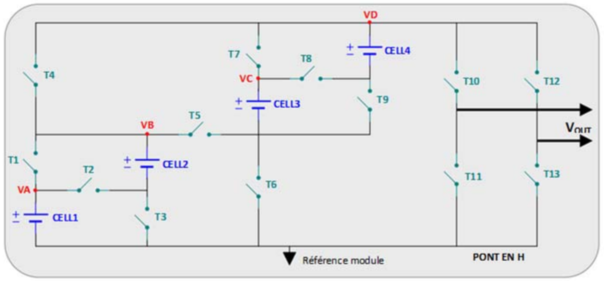


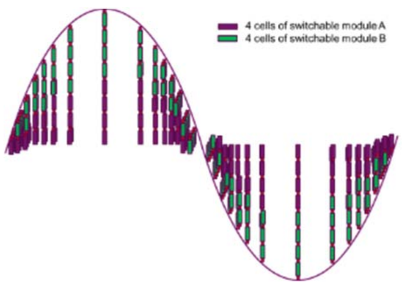
ADVANCED BMS FROM LETI/LITEN COMMON LAB

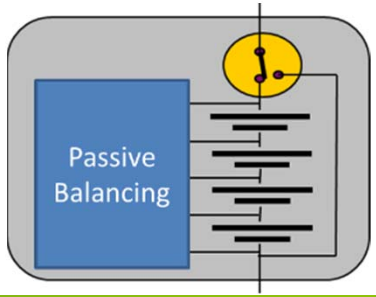
- **Modular BMS**
- **Chained BMS**
- **Parallel plug BMS**
- **Active balancing BMS**
- **Serial switching BMS**
- **Switched cell BMS**







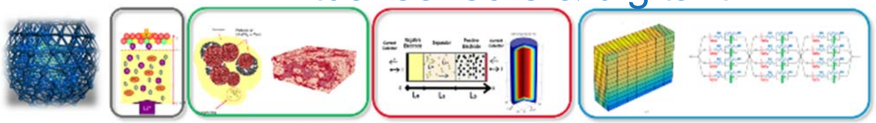




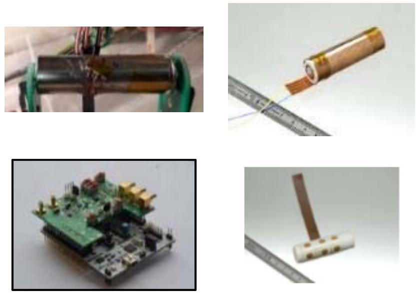
BMS ROADMAP

Predictive modeling of batteries

➔ Virtual sensors & digital twin



Integration of sensors inside the cells or modules

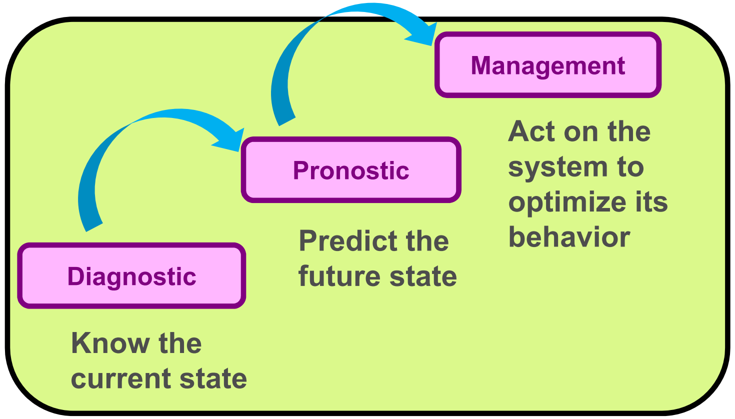


Development of advanced algorithms

Onboard integration

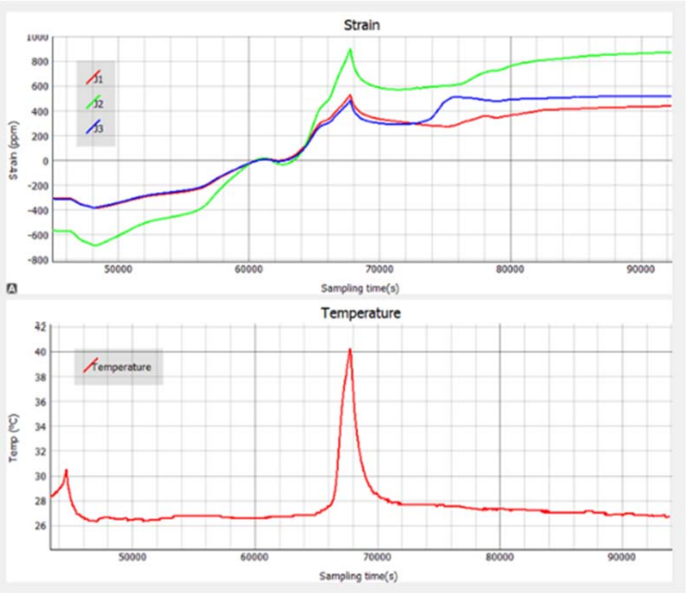
Smart cell / module

Advanced pack functions

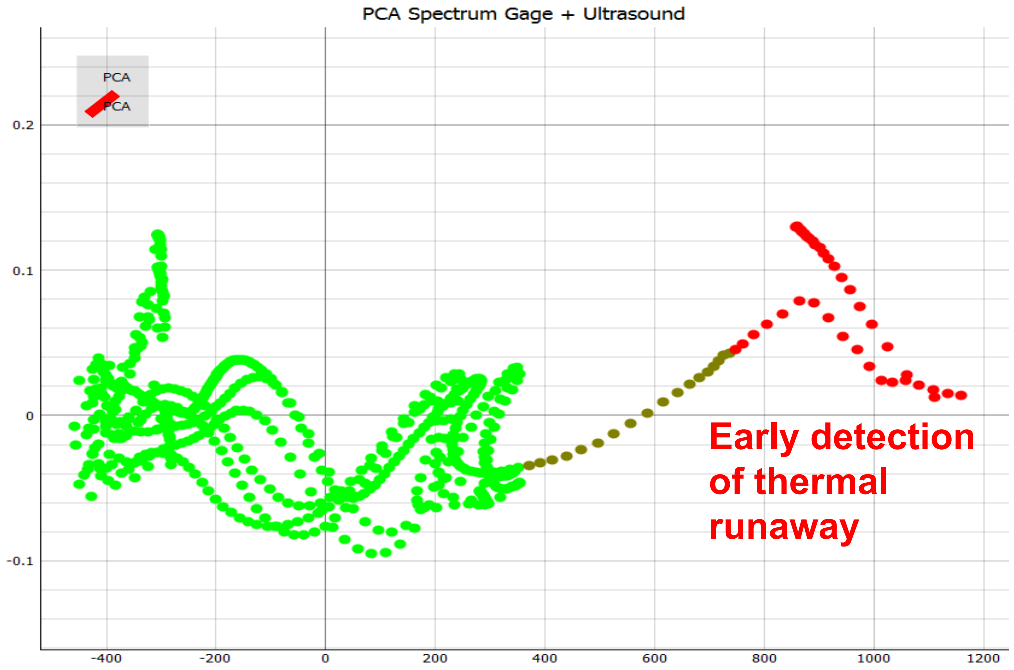


MACHINE LEARNING FOR DIAGNOSTIC

- Signal projections and visualizations
- Feature selections
- Classification algorithms



Strain gage signal and temperature

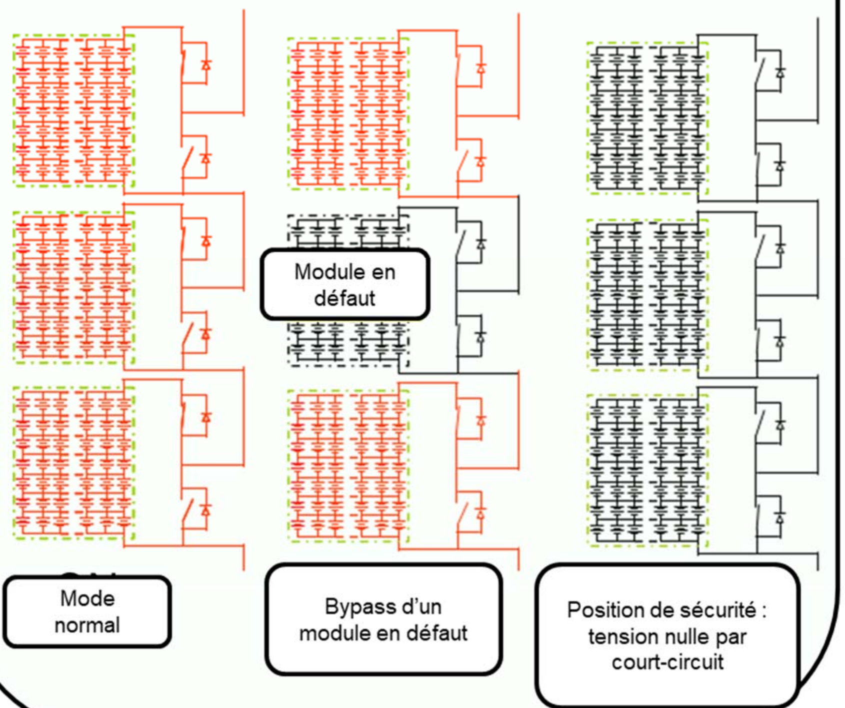


Principal Component Analysis of Strain Gage and Acoustic Signal

➔ Performance analysis of decision tree or Support Vector Machine algorithms

ELECTRICAL ARCHITECTURES

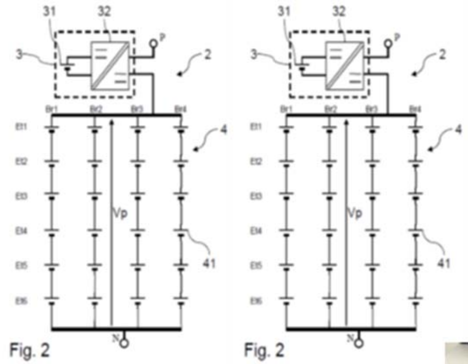
Commutation de modules dans la mise en série par courts-circuits : impact sur la tension



=> Seconde vie

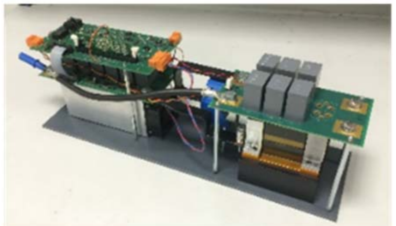
Brevets

- Packs en parallèle avec des convertisseurs de faible puissance en série assurant seulement l'écart de tension



0V à 80V

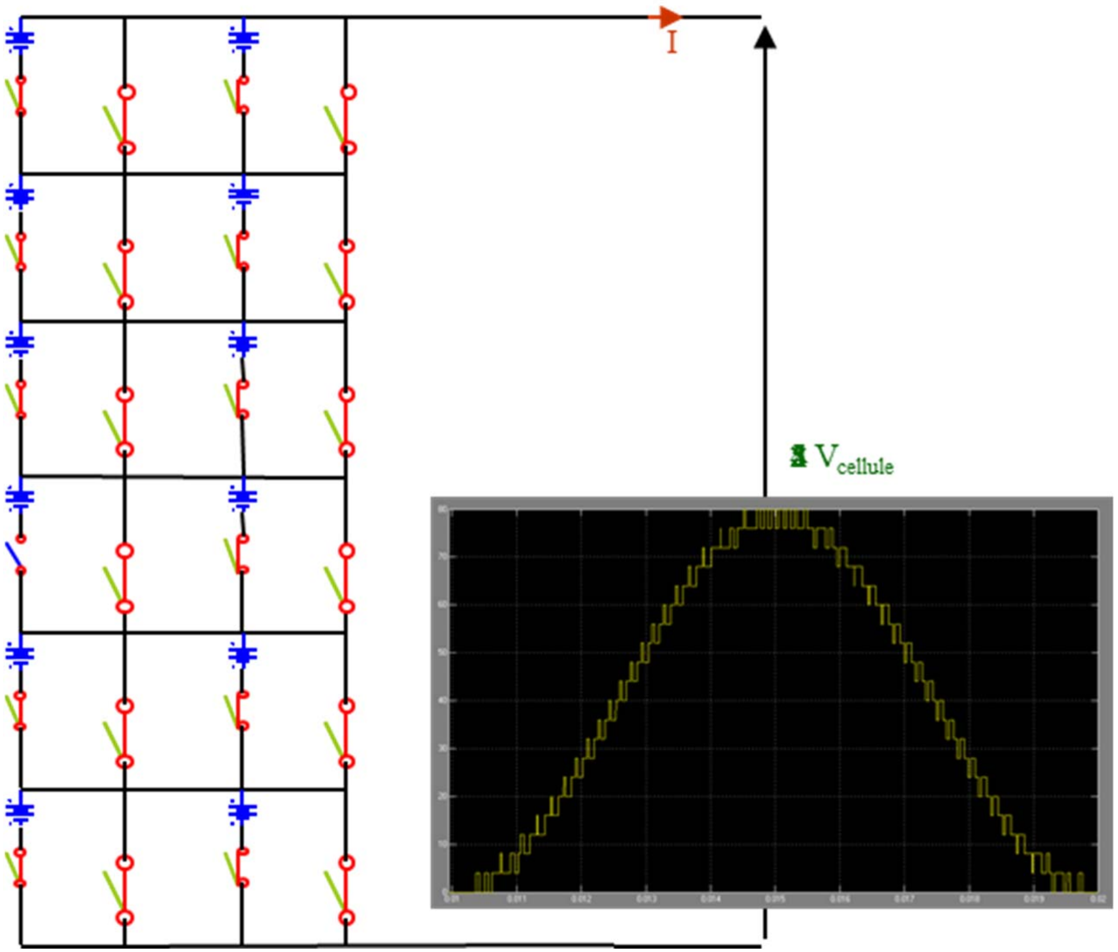
Convertisseur 8 kW



- Equilibrage des courants entre les packs
- Continuité de service, système tolérant aux défauts

SWITCHED-CELL BMS

Description



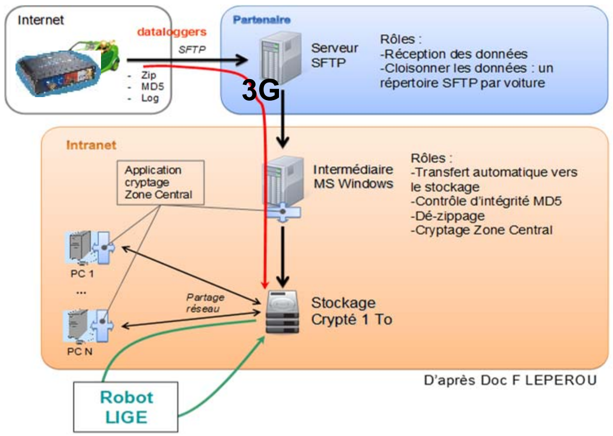
Functions & advantages:

- Availability of the battery pack in case of cell failure => service contiunity
- Replaces the motor inverter
- Replaces the charger
- Real time cell balancing

Monitoring Activities

Evaluation of the batteries, the powertrains and of the driving cycles

Electrical vehicle fleet: more than 35 today
Monitoring with no driver interaction



CEA LITEN DEHT | April 4, 2014 | PAGE 55

CONCLUSIONS

- Our mandate: mix industrial competitiveness with environmental responsibility
  - Energy efficiency
  - Renewable & low carbon energy
  - Efficiency of materials
- To bridge the gap between academia & industry (TRL 3-7)
- Offers a *wealth of opportunities for industry*: Exploit our extensive technological capabilities and access complementary technological solutions via CEA-tech
- *Comprehensive offering*: European institute present at *every* level of the value chain (batteries, PEMFC)
- *Extensive technological infrastructure and bench tests*: technology platforms, battery bench tests, Hydrogen bench tests
- *Technological heritage, large data base* : 1000 + patent family and a reputation for delivering *high-impact factor* publications

For further contact: philippe.michallon@cea.fr +33 6 42 55 00 48

SHIFT2RAIL
Appels à propositions 2020 ouverts aux non-membres
Matinée d'information
Paris
12 décembre 2019

Organisateur : Point de contact national (P.C.N.) Transport, avec soutien SNCF

Au programme:

- ***Séance plénière le matin, en présence de la direction de Shift2Rail et de membres représentant les différents programmes d'innovation***
- ***Déjeuner de réseautage***

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A12

FROM RESEARCH TO INDUSTRY

cea tech

Batterie:______________________________Sebastien Patoux (sebastien.patoux@cea.fr)
PEMFC:______________________________Sebastien Benoit (sebastien.benoit@cea.fr)
Système/caracterisations/modelisations: Didier Jamet (didier.jamet@cea.fr)

liten

THANK YOU

Diapositive 58

A12 need to liven this up graphically
Auteur; 06/06/2014