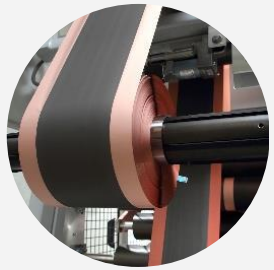
DE LA RECHERCHE À L'INDUSTRIE

New Energies – Integrated Approach

Summary

MAIN TOPICS – NEW ENERGIES, AN INTEGRATED APPROACH

RENEWABLE ENERGY PRODUCTION



ENERGY STORAGE & HYDROGEN VECTOR

ENERGY GRIDS

CIRCULAR ECONOMY OF MATERIALS

CARBON CIRCULAR ECONOMY

DIGITAL TOOLS FOR ENERGY

INSTRUMENTATION AND CONTROL OF ASSETS

DATA, AI & DIGITAL TWIN

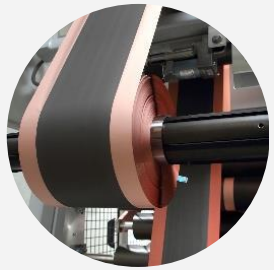
CYBERSECURITY

Summary

MAIN TOPICS – NEW ENERGIES, AN INTEGRATED APPROACH

RENEWABLE ENERGY PRODUCTION

- High efficiency solar PV solutions
- PV everywhere
- Make the PV smart



ENERGY STORAGE & HYDROGEN VECTOR

- Batteries
- Hydrogen

ENERGY GRIDS

- Scenario study & analysis
- Optimal EMS design
- Digital tools & modelling
- Electrical conversion components & Systems
- Thermal systems for energy efficiency

CIRCULAR ECONOMY OF MATERIALS

- Strategic Materials recycling
- Materials Saving & Sobriety - Additive Manufacturing
- Environmental impact reduction

CARBON CIRCULAR ECONOMY

- Thermocatalysis / Thermoconversion
- (Photo) electrocatalysis
- Biology/ Biohybrides

- Sensors and system integration
- Non destructive testing

- Asset management
- Complex system optimization
- Decision making
- Prediction

- Vulnerabilities identification
- Secure Industrial IOT
- Anomaly-based network intrusion detection & reaction
- End-to-end encryption
- Trusted ledgers for data and service

DIGITAL TOOLS FOR ENERGY

INSTRUMENTATION AND CONTROL OF ASSETS

DATA, AI & DIGITAL TWIN

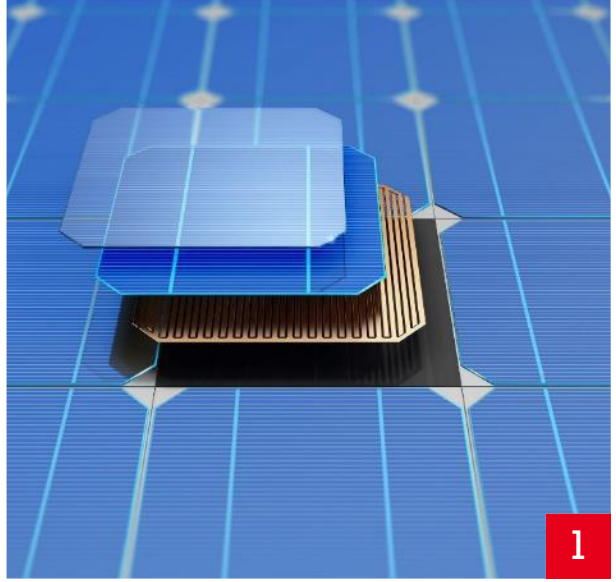
CYBERSECURITY

RENEWABLE ENERGY PRODUCTION

1 High efficiency solar PV solutions

2 PV everywhere

3 Make the PV smart



Developping High efficiency solar technology at competitive cost

Large solar power plant

PV Everywhere

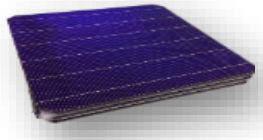
Optimising PV systems efficiency

PV SOLUTIONS

- Large scale industrialization of heterojunction technology towards european eco-system
- Focus on the perovskite / heterojunction tandem technology as a long-term goal
- Increase efficiency by reducing electrical and optical losses
- Develop new PV modules high-level requirements
- Increase modules lifetime
- Imagine ecodesigned modules with low footprint from materials to end-of-life
- Optimize productivity by using digital tools for modelling, diagnostics and monitoring
- Adapt the system to include the flexibility needs

TECHNOLOGY

PILOT LINE & PLATFORM



- High efficiency SHJ cells
- High performances modules
- IEC-61215 & 61730 certification

SHJ Pilot line

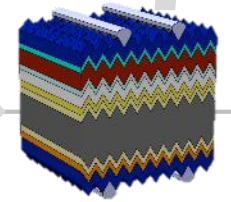
(Since 2005)

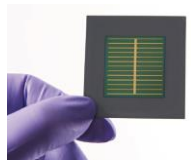
2020 - World Record efficiency **of +25%**

2020 - World Record efficiency **of 20% on an 11cm² module**

2018

Tandem technology : **silicon & perovskite**

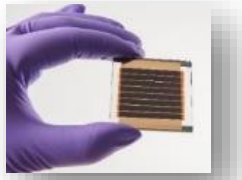




30% 2023 @cell level

Perovskite platform

(since 2016)



- High performances perovskite cells and modules (20% on 11 cm²)
- Stability assessment via specific materials encapsulation

TECHNOLOGY

SILICON HETERO-JUNCTION (SHJ)

Key Features

- **Top efficiency 25%**
- High quality materials
- Reduced number of process steps compared to upgraded standard technologies
- Use of ultrathin wafers (<100µm) due to outstanding surface passivation capabilities
- Compatible with advanced interconnection solutions (xBB)

Assets

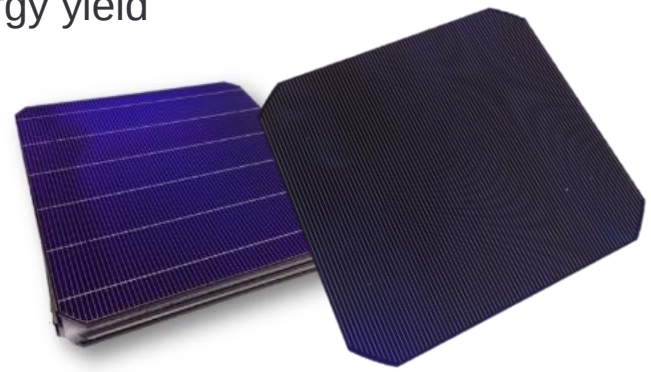
- Bifacial cells and modules, with a low temperature coefficient
- Compatible with smartwire swct
- High throughput, High efficiency & Higher energy yield

Success stories

enel Green Power

JUSUNG ENGINEERING

MEYER BURGER



SUCCESS STORY

SHJ CELL : NEW PV PRODUCTION SITE IN EUROPE

CEA and Enel Green Power have reached a heterojunction solar cell record efficiency of 25.0% active area (213 cm²) on M2 wafer on industrial pilot line at INES.

World-class result certified by CalTeC

https://www.enelgreenpower.com/

Crédit photo ©Enel

TECHNOLOGY

PV EVERY-WHERE

Key Features

- Develop PV Technologies with high efficiency at competitive cost
- Custom Integration even with high-level requirements (weight, flexibility, irradiations…)
- Enables energy self-sufficiency

Success Stories

- Stratobus

DEFENCE & CONSTRUCTION
Light modules (4 kg/m²)

MONITORING
Ultra-light modules (700 g/m²)

TELECOM
Stratospheric module

MARITIME APPLICATION
Specific & Bifacial modules

ROAD INTEGRATION
Multi-use modules

High value-added segments
Highly positive externalities segments

SUCCESS STORY

STRATOBUS

CEA has developed for Thales a working module answering all requirements for a real stratospheric airship.

The next step will be the integration of modules on the Stratobus, an autonomous, multi-mission stratospheric airship, midway between a drone and a satellite.

https://www.thalesgroup.com/en/worldwide/space/news/whats-stratobus

©Thales Alenia Space/Briot except first version by ©Thales Alenia Space/Master Image Programmes

TECHNOLOGY

MAKE THE PV SMART

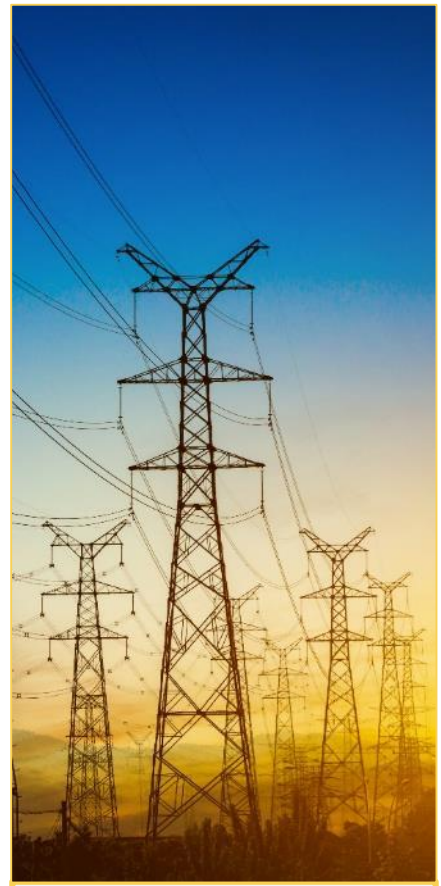
Key Features

- **Software (SW) solutions for forecast & dynamic management (considering financial and technical constraints/objectives)**
- Components sizing & system design :
  - SW designed for various applications and requirements, including production prediction depending on the forecast
  - In-house libraries of models
- Energy Management System (EMS) :
  - Predictive and real-time control strategies
  - Mathematical optimization methods
  - Information system for feedback of operating data and control

Success Stories

- PV production prediction - Steady Sun

steadysun

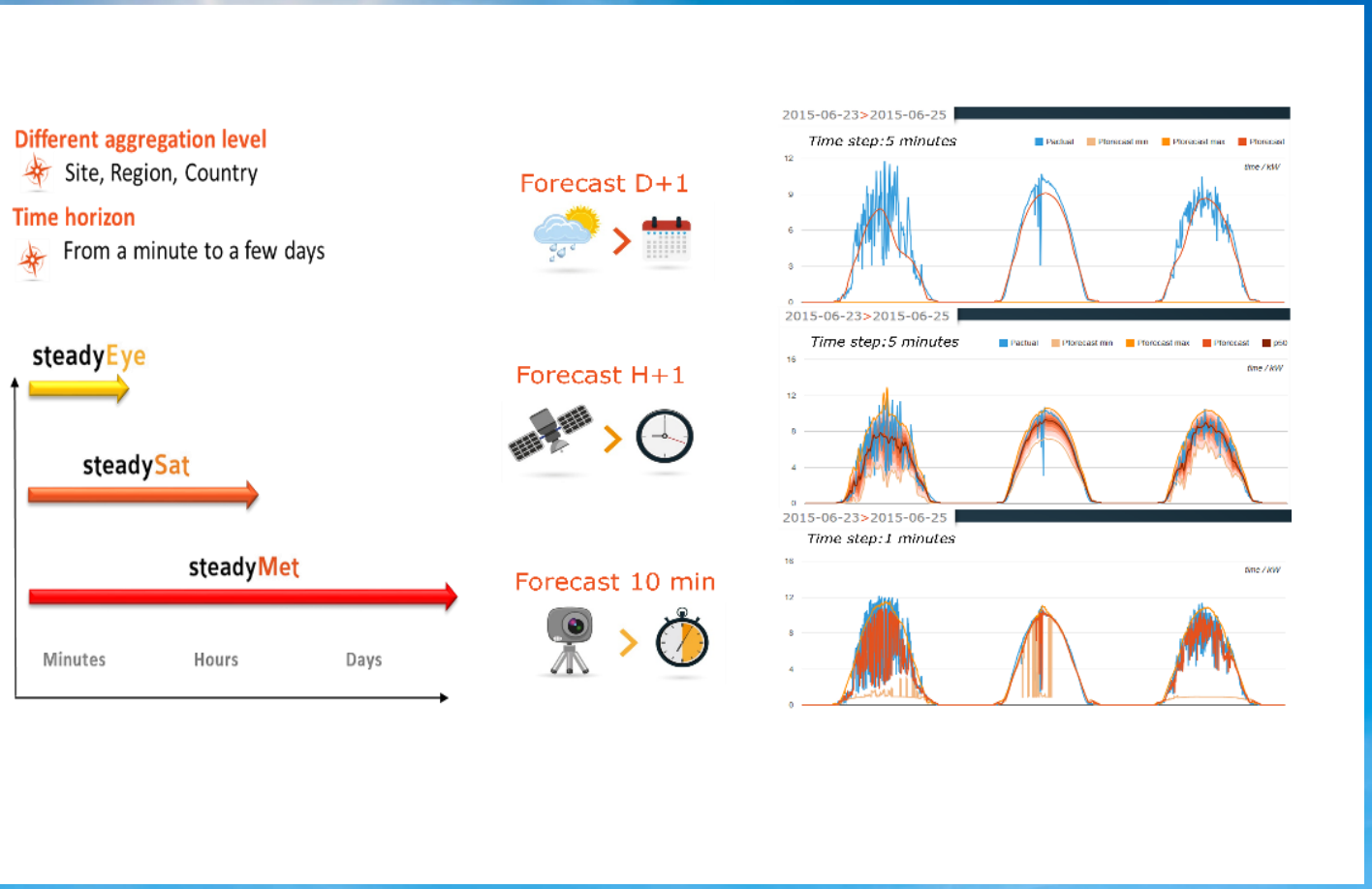


FROM LOCAL TO GLOBAL

SUCCESS STORY

STEADY SUN

Development of an algorithm for PV production prediction, at minutes, hours and days levels and according to different regions.

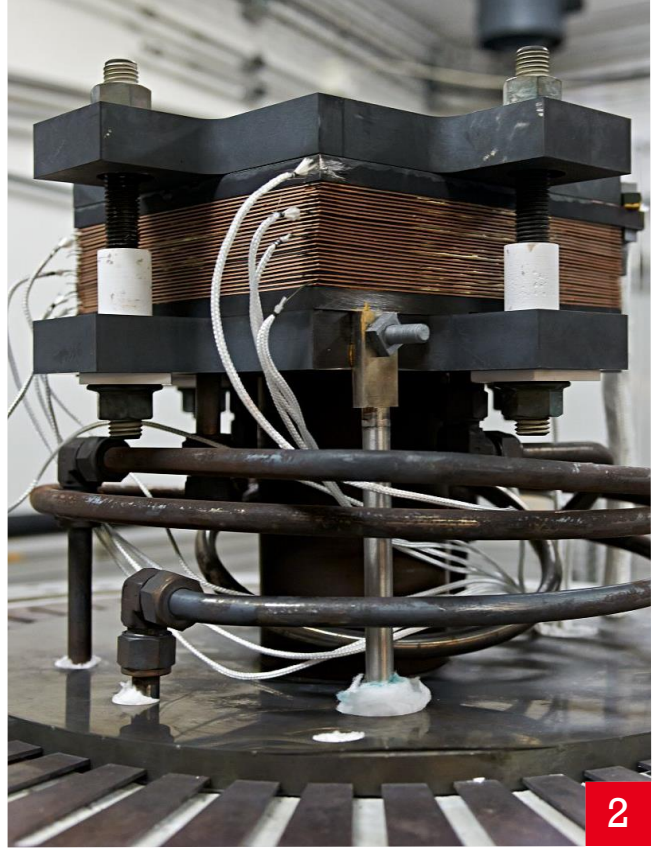


steadysun

ENERGY STORAGE & HYDROGEN VECTOR

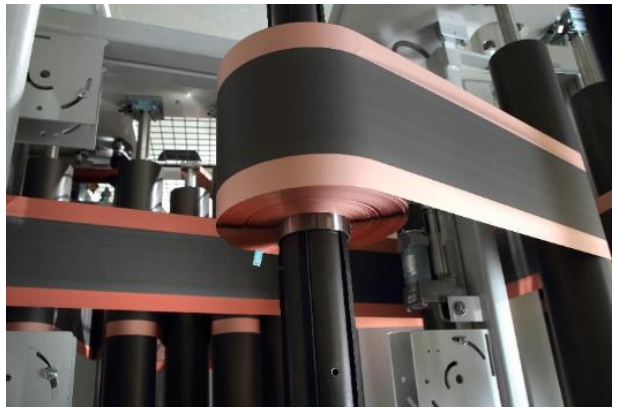
1 Batteries

2 Hydrogen



TECHNOLOGY

BATTERIES
(FOR STATIONNARY & MOBILITY APPLICATIONS)



Key Features

- A positionning all along the value chain for 25 years
  - From materials to components and packs
  - Characterization & modeling
  - Electrodes, cells & modules
  - LCA/recycling
  - Safety

Assets

- A unique battery platform in Europe focusing on lithium-ion battery development (to boost battery performances, improve reliability and cut costs)
  - Including close relationships with industrial partners on all the value chain

Success stories

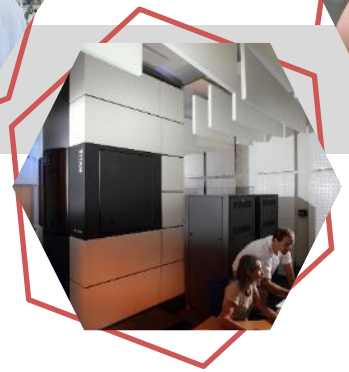
- Various battery experimentation projects: Mettaliance, Iveco, Renault…

SOLVAY umicore RENAULT saft a company of TOTAL

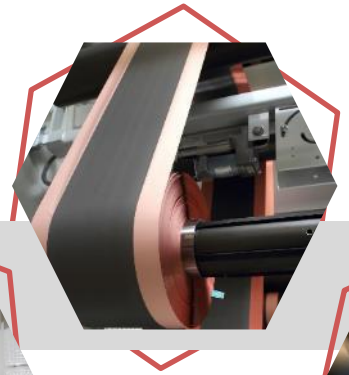
PLATFORM

MATERIALS & TESTS PLATFORM

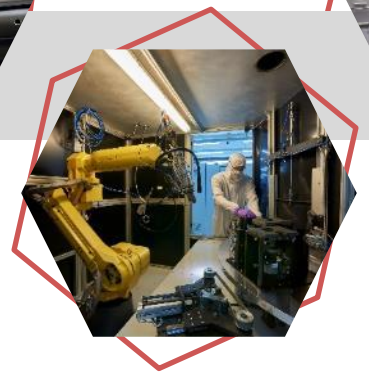
Materials Synthesis



Characterization from nanoscale to system
(Component and Cell levels)



Electrode Coating



Cell assembly and testing

Abusive tolerance testing

200 pers.
3000m² ›

Cells & modules design; battery development and characterization; electrochemical, mechanical, thermal behavior…

NEW ! Battery Platform extension at Pessac, 350 m² for Combinatorial Synthesis & High Throughput Screening, Surface & Interface Engineering :

- Vacuum deposition techniques
- Thin Films
- Complex Materials
- Automated Screening

TECHNOLOGY

BATTERIES (SUCCESS STORIES)

Materials

Cells

Packs & BMS

Recycling

Characterization & Multi-scale modelling

TECHNOLOGY

BATTERIES

(FROM MATERIAL SYNTHESIS TO ASSEMBLY

Key Features

- Li-ion, Li-metal, from gram to kg
- **Positive electrode material** : High voltage Spinel Oxides, High Capacity Layered Oxides; LiFePO4 & other polyanionic materials, New cathode materials (rocksalt, glasses,…)
- **Negative electrode material** : High power/safety/lifetime, Ti-bases anodes, High capacity Si/C composites, Li metal
- **Electrolyte** : Liquid (salts, solvents, additives), Gel (i.e. SolgainTM), Solid (polymer, inorganic, glass, hybrid)
- **Inks & electrodes** : mix (10ml to 60l)
- **Enduction** : lab coater, pre-pilot & pilot scale
- Assembly from button-size to dozen-Ah batteries

Assets

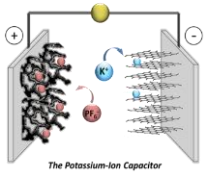
- Anhydrous lab (about 1000m^2)
- Increase performances (power energy, durability),
- Decrease costs (economical, environmental, risks)
- Widen operational conditions (temperature, form factor)
- Beyond conventional Li-Ion Batteries : Many battery chemistries using Li ions or other ions (Na, K, Mg, Al,…), Different cell designs, Alternative processes

Sodium-ion

Lithium-sulfur

All solid state (Li, Na)

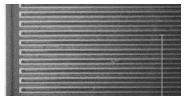
Hybrid Supercapacitors



Organic

Flexible

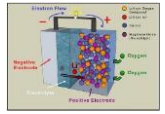
Printed



Redox Flow

Ni-based

Metal-air (Li)



Mg-, Al-, K- ion

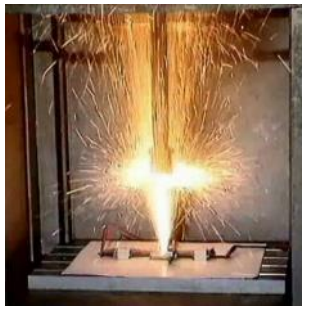
Primary

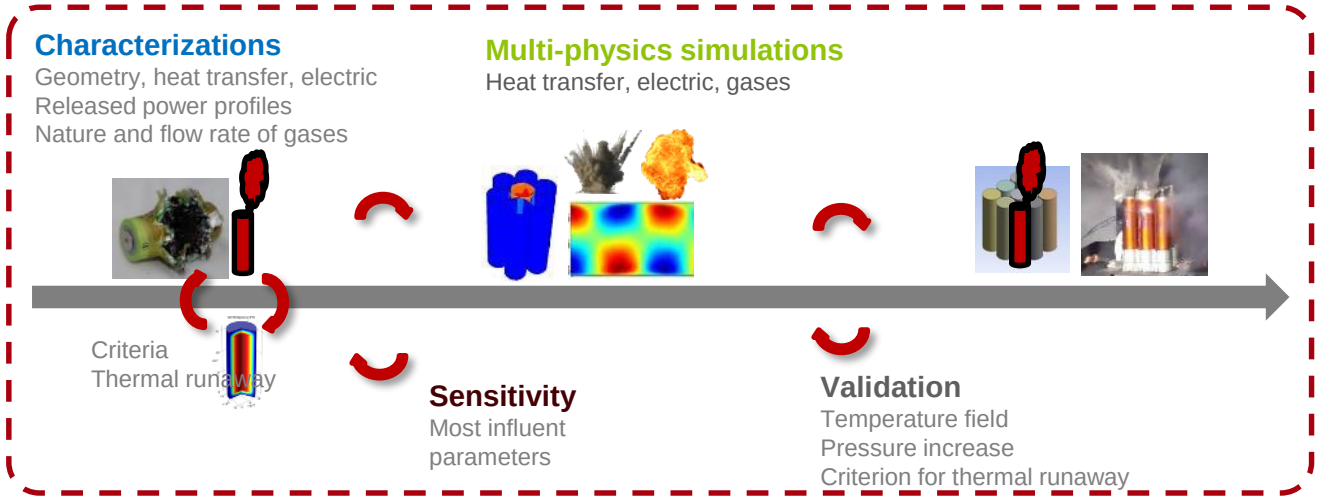
PLATFORM

BATTERIES (SAFETY TEST PLATFORM)

Key Features

- All kinds of abuse tests **: Electrical, Thermal, Mechanical**
- Systematic measurements (Voltage, current and temperature profiles, HD camera)
- Specific measurements and analyses (IR camera, Gas ana volume, composition Any other specific need…)





TECHNOLOGY

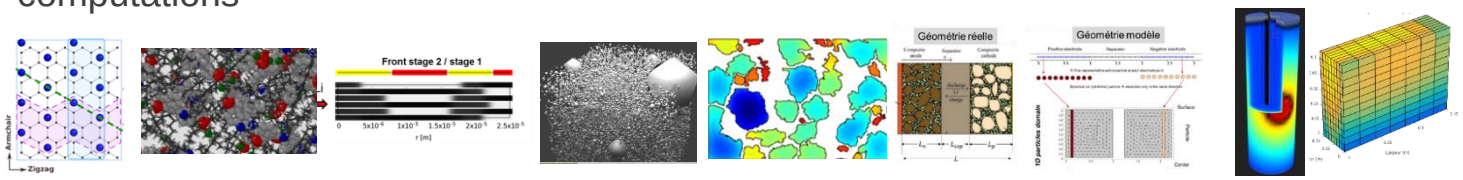
BATTERIES

(MULTI-SCALE MODELLING & SIMULATION)

Key Features

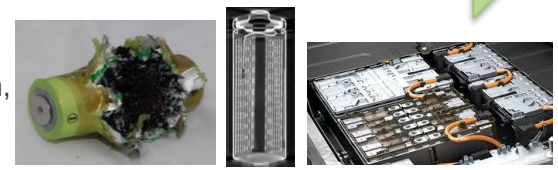
Common approach for batteries and PEMFC - Close link between Modelling & Caracterization

- **Model development :**
  - **Truly multi-scale**
  - **Multi-physics:** electro-chemical, transport phenomena, heat transfer, mechanics
    - Depends on the scale of interest & the issues at stake
  - **Predictive models :** Performance, Durability, Safety
- **Software development :** Development of reference codes, Interoperable codes, HPC computations



atomic nano meso micro system

- **Database management** : Material and cell database
  - **Automation of Data collection**, Treatment for model parametrization, Analysis
- **Advanced experimental characterizations**
  - **Support to modelling :** Observation of the phenomena, Characterization of the parameters, Validation of the models
  - *Operando* and at all scales
  - World-class equipment and teams : CEA nano-characterization platform; ESRF Synchrotron ; ILL neutron scattering

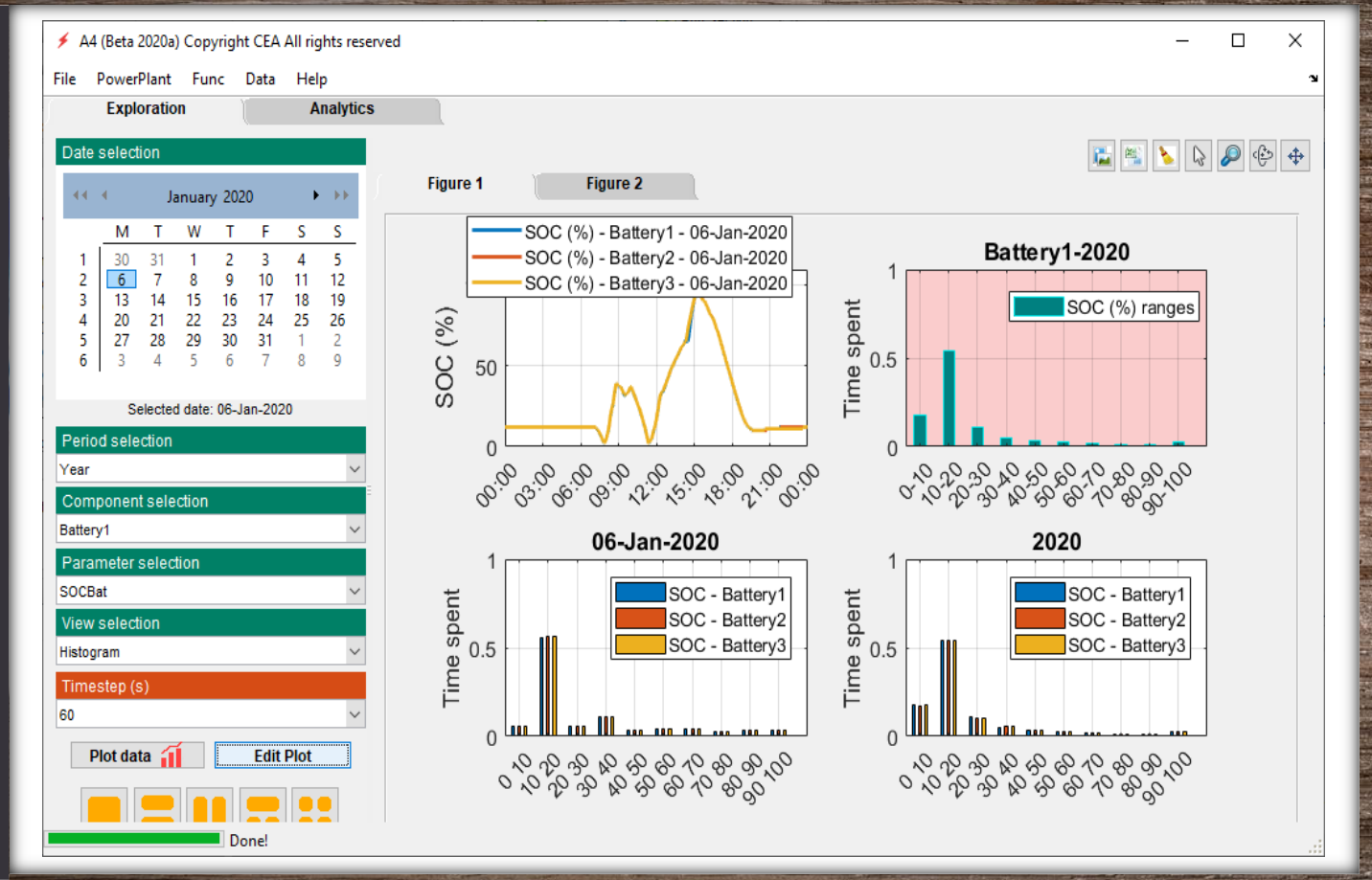


SUCCESS STORY

BATTERY ENERGY STORAGE SYSTEM (BESS)

BESS Management – Operation follow-up & predictive maintenance

- State, solicitation, diagnosis and health indicators implementation, tracking and analysis
- Control laws & strategies of use tracking and analysis
- Maintenance operation forecasting & planning
- Development of an algorithm for SoH calculation and other ageing markers
- SoH extrapolation to calculate the remaining lifetime



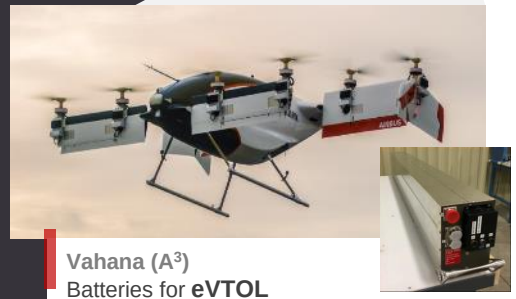
SUCCESS STORY

AEROSPACE : SAFETY FIRST AT A COMPETITIVE COST

Battery packs design for aerospace applications where safety is one of the top priorities

Hybrid E-Fan Plus
Batteries for hybrid-electric planes
Oshkosh, Wisconsin USA
July 2016

CityAirbus
Batteries for **eVTOL**
Donauwörth, Germany, May 2019



Vahana (A³)
Batteries for **eVTOL**
Pendleton, California USA
May *2018*

E-Fan
Batteries for **all-electric planes**
Lydd UK-Calais France
Traversée, July 2015

OneWeb
Batteries for **Satellites**
February 2019

Skyways
Batteries and BMS for **Drones**
Singapor, february 2018

AIRBUS

TECHNOLOGY

SIGMA CELLS (COMMUTED ARCHITECTURE)

otonohm

SWITCH ESS

Key Features

- BMS function with reconfigurable architecture, enabling chargers and engine inverter functions
- Signal generator
- **Continuity of service with deficient cell(s) isolation**
- Up to 20% autonomy
- Increased battery life (up 15%)
- For stationary or nomadic storage

Assets

- Technical means at the best worldwide level
- Skills across the entire value chain (from the electrochemical cell to the full system)

Success stories

- Nomadic application - Otonohm
- Stationnary application - SwitchESS

Hydrogen production by electrolysis

High-Temperature Electrolysis (HTE)

↓ Levellized Costs of H2 (LCOH)
↓ Environmental Impact (LCA analysis)

↑ Durability
↑ Safety - Reliability

Hydrogen transport

Hydrogen embrittlement

Hydrogen Carriers

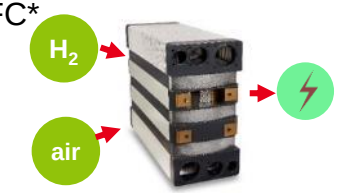
↑ Safety - Reliability

↑ Sustainability

Hydrogen conversion

Fuel cells low T° - PEMFC*

Fuel cells High T° - SOFC*



↓ Levellized Costs of Energy (LCOE)
↓ Environmental Impact (LCA analysis)

↑ Durability
↑ Safety - Reliability

Hydrogen storage

Hyperbaric storage for transport

Liquid massive storage

↓ Levellized Costs of H2 (LCOH)
↓ Environmental Impact (LCA analysis)

↑ Durability

HYDROGEN ACTIVITY AT CEA

From production to transport, storage and conversion, CEA works on the whole value chain.

**PEMFC : Proton Exchange Membrane Fuel Cell*
**SOE : Solid Oxid Electrolysis - HTE*
**SOFC: Solid Oxid Fuel Cell*

TECHNOLOGY

HYDROGEN PRODUCTION (HIGH TEMPERATURE ELECTROLYSIS)

CARBON-FREE HYDROGEN PRODUCTION

SYSTEM DEVELOPMENT

STACK DEVELOPMENT

BASIC CONCEPTS DEVELOPMENT

In 15 years of R&D:

Performance improvement: **x 8**

Lifetime: **> 2500 hours**

Number of Cells/stack: **x 25**

1st prototype of Integrated System

Demonstrated efficiency at the System Level: **84% LHV**

Cost Reduction of the Stack: **-80%**

SYDNEY
1st integrated system

PISTEUR
In demonstration at a partner

Core stack 25 cells Of 100 cm² active area

CEA Cell at the state of the art

Characteristics :
operating point -1A/cm²
Degradation 2-3% 1000h
Active Surface 100cm²

Bonus : Reversible Technology

Background Patent Portfolio PI:
More than 40 patent family

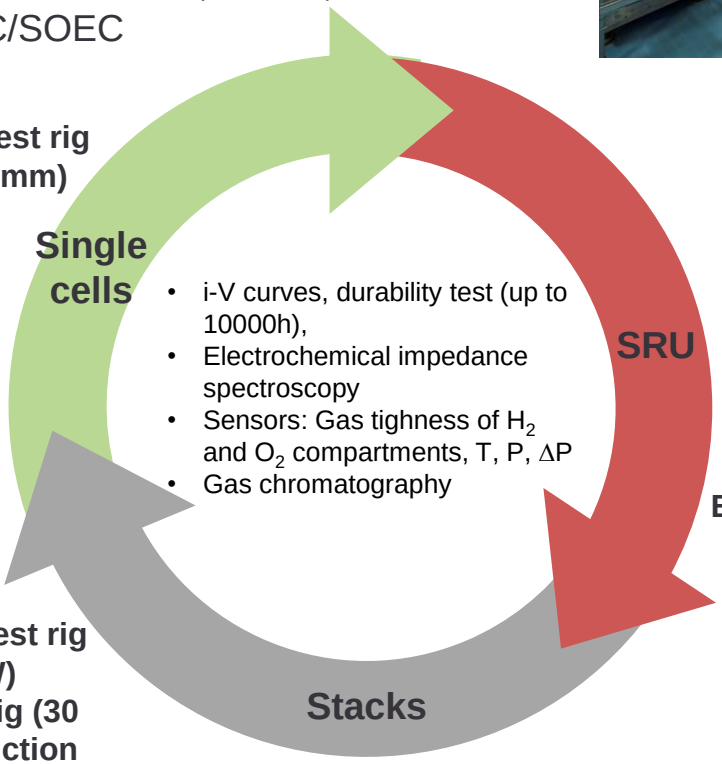
PLATFORM

HTE TESTING EQUIPMENTS (PERFORMANCE AND DURABILITY)

Key Features

- System test : up to stack box 100 kW
- Characterization of BoP components and of the behaviour of the stacks in real environment
- System able to operate in SOEC, SOFC, and reversible SOFC/SOEC

Electro-chemical test rig (Single cells Æ 50 mm)



Pressurized test rig

30 bars

Electrochemical test rig (large stacks 6 kW)
Pressurized test rig (30 bar) upon construction

Electro-chemical test rig (SRU and small stacks 3 kW)

TECHNOLOGY

HYDROGEN PRODUCTION (HIGH TEMPERATURE ELECTROLYSIS)

Key Features

- Clean Hydrogen efficient production technology (84% LHV efficiency at 700°C) with a low environmental impact via high temperature steam electrolysis
- Building a strong HTE French ecosystem with the first up-to-scale 300 kW demonstrator in 2023.
- Industrialisation of the reversible technology (HTE) also able to operate in reversible mode
- The main objective is the launching of a Gigafactory in 2025

Assets

- 15 years of expertise in HTE

Success stories

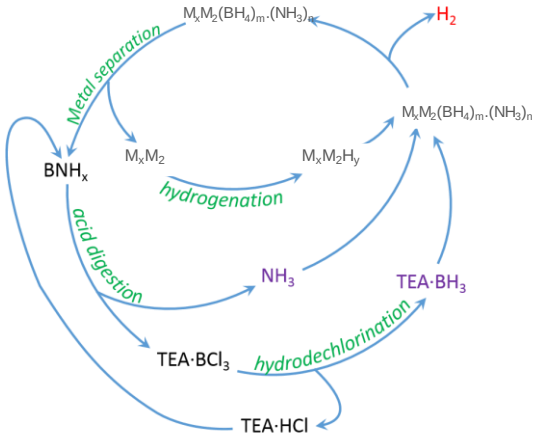
The Genvia joint venture will focus on the development and industrial deployment of a game-changing electrolyzer technology for clean hydrogen production

TECHNOLOGY

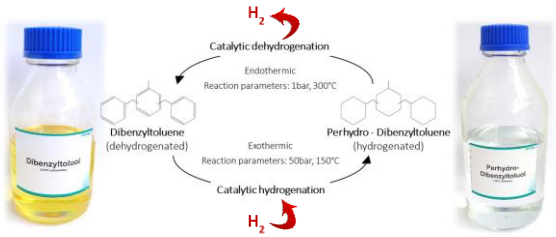
CHEMICAL HYDROGEN STORAGE &TRANSPORT

Key Features

- **Hydrogen is chemical bonded to an organic or inorganic material for safe storage**
- Solid storage using lightweight element B, Mg, Na, N…
  - H_2 yield up to 12 %, stable at 85 °C, low impurities, easy novel synthesis
  - Hydrogen is released by thermolysis or hydrolysis
  - Assessment of product synthesis reliability
  - Using by-product to optimize the circular economy of hydrogen by enhancing product regeneration at competitive cost



- Liquid storage using organic molecule
  - liquid at atmospheric conditions, no H_2 gas, no loss during storage, Low toxicity, non-explosive and non-flammable liquids.
  - H_2 routing involves transporting a liquid using existing or dedicated infrastructures dedicated to liquid transport
  - New CEA molecule, efficient catalyst and optimized reactor



Assets

A full suite of tools and expertises to develop materials (molecule, catalyst, chemical processes…) and tank/reactor design with LCA / economical assessment.

TECHNOLOGY

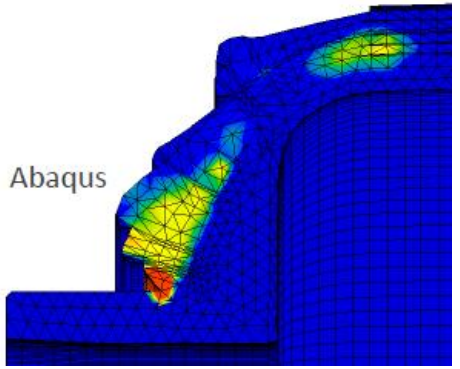
HYDROGEN STORAGE & TRANSPORT (GASEOUS STORAGE)

Key Features

- **Design of H_2 Composite Vessels and abusive testing for gaseous storage**
- **Type IV tank set up and structure**
  - Liner (function : H2 tightness)
  - Composite Overwrapped Shell (function: pressure withstand)
- **Type IV tank design and calculation**
  - Abaqus (2D & 3D finite elements)
  - + Composicad (fibers trajectories calculation)
  - + CEA Customized Plug-in FiWiQus®
- **Multi-instrumented test :** pressure, temperature, optical fibers, strain gauges, acoustic emission, LVDT, fast camera, 3D digital image correlation

Assets

- **Expertise & Testing Facilities** : impact, burst, drop (up), leak (bottom), fire (up), Guntest (Bottom)



TECHNOLOGY

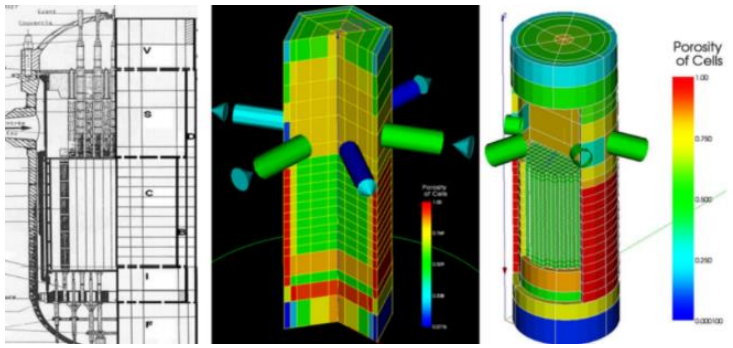
THE CATHARE CODE (FOR HYDROGEN APPLICATIONS SIMULATION)

Key Features

- **Thermal-hydraulic simulation of multiphase flow dynamics**
- Code for thermohydraulic analysis, fluid flow simulation in industrial processes
- Used for the design, the safety assessment and real time simulation of **complex systems**
- Support REFPROP database for dealing with different fluids (H_2…)
- Safety in cryogenic conditions : Sizing of the safety device & Thermal flux arriving on the cryogenic components
- Performant & user-Friendly HMI « GUITHARE »

Assets

- 40 years of development
- Thermal-hydraulic simulation at system and component scale of multiphase flow dynamics
- Safety analysis and design purpose – plant or components
- Quantify the conservative analysis margins
- Define and verify emergency procedures
- Specific module developments and CATHARE code licencing



TECHNOLOGY

HYDROGEN STORAGE &TRANSPORT (EMBRITTLEMENT)

Key Features

- **Analysis of Hydrogen embrittlement (HE) on metal under Hydrogen gas or gas blends pressure**
- Quantification & understanding of mechanisms observed under H_2
- Interactions between H and dislocations / vacancies / microstructure (traps) , consequence on mechanical properties
- H content in the micro-structure
- Impurities & gas mix effects
- Lifetime prediction (development of criteria, modelling)

Mechanical testing up to 40 MPa bar H_2

Assets

- A full suite of tools and expertises to study possible embrittlement phenomenon on materials

Disc test < 100 MPa H_2

Success stories

- Hydrogen embrittlement in pipes
- Mathryce European project

GRTgaz

storengy

SUCCESS STORY

HYDROGEN EMBRITTLEMENT IN PIPES

Impact of hydrogen embrittlement on steel, at lab and industrial scales. Understanding the impact of natural gas and H_2 mix on networks components and pipes.

PLATFORM

PEMFC PLATFORM

MEA Production

Production of bipolar plates

Stack Assembly

Stack characterization

PEMFC system assembly and characterization

50 pers.

25 patents/year

› Electrochemistry, Simulation, Fluidic modelling, Mechanical, System

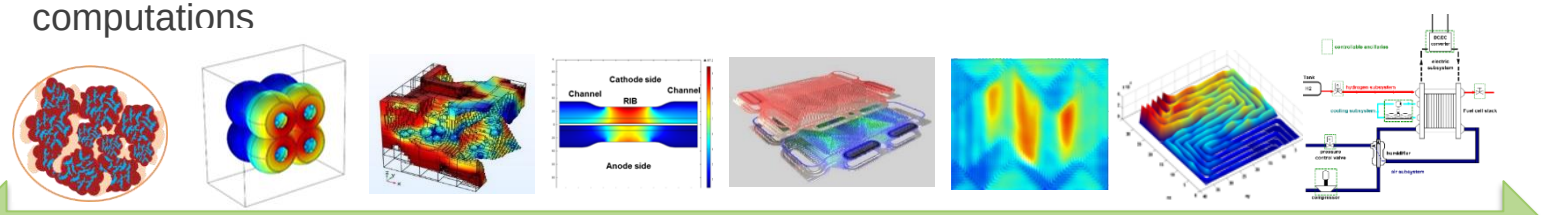
TECHNOLOGY

PEMFC (MULTI-SCALE MODELLING & SIMULATION)

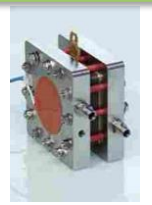
Key Features

Common approach for batteries and PEMFC - Close link between Modelling & Caracterization

- **Model development :**
  - **Truly multi-scale**
  - **Multi-physics:** electro-chemical, transport phenomena, heat transfer, mechanics
    - Depends on the scale of interest & the issues at stake
  - **Predictive models :** Performance, Durability, Safety
- **Software development :** Development of reference codes, Interoperable codes, HPC computations



atomic nano meso micro system



- **Database management** : Material and cell database
  - **Automation of Data collection**, Treatment for model parametrization, Analysis
- **Advanced experimental characterizations**
  - **Support to modelling :** Observation of the phenomena, Characterization of the parameters, Validation of the models
  - *Operando* and at all scales
  - World-class equipment and teams : CEA nano-characterization platform; ESRF Synchrotron ; ILL neutron scattering

TECHNOLOGY

HYDROGEN CONVERSION (PEMFC)

Key Features

- 4kW/L stack
- 700W/L system

Assets

- A fuel cell platform with advanced technologies and flexible processes that meet manufacturers' unique prototyping needs: form ink formulation to system integration & durability tests
  - 500sqm space
  - 6M€ investment
  - 20 test benches
  - 10 to 20 patents/year
  - More than 10 industrial partners

Success stories

- Main CEA achievements in terms of system integration
- Future development roadmap CEA-Symbio

SYMBIO
A FAURECIA MICHELIN HYDROGEN COMPANY

MICHELIN

Faurecia

SUCCESS STORY

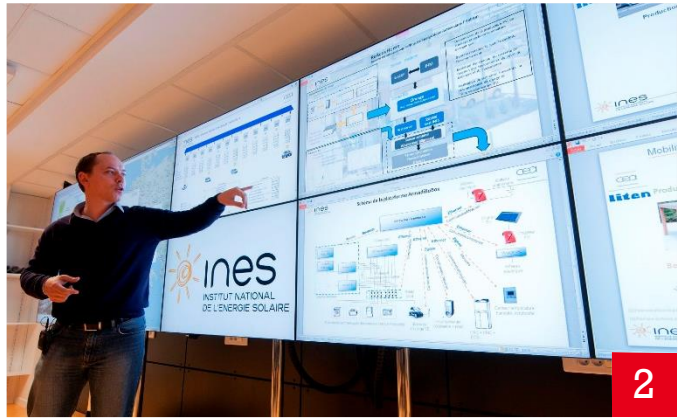
ENERGY OBSERVER

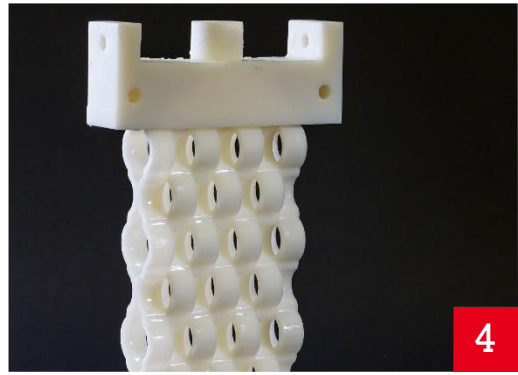
Energy Observer is self-sufficient in energy boat, with zero emissions. The CEA has developed of compact model of PEM electrolyser, which can produce up to 4 Nm3 per hour of pure hydrogen, and consumes 3.66 litres of deionised water per hour.
https://www.energy-observer.org/

Energy Observer

ENERGY GRIDS

1. Scenario study & analysis
2. Optimal EMS design : multi-scales, multi-vectors, multi-criteria
3. Digital tools & modelling
4. Thermal systems for energy efficiency
5. Electrical conversion components & Systems





Strategic Expertise

Selection of the right technologies and preparation of master plans

Techno-economic feasability study and design

Analysis of the innovative solution sutainability based on real-use concepts and apply relevant business models

Regional demonstrators design

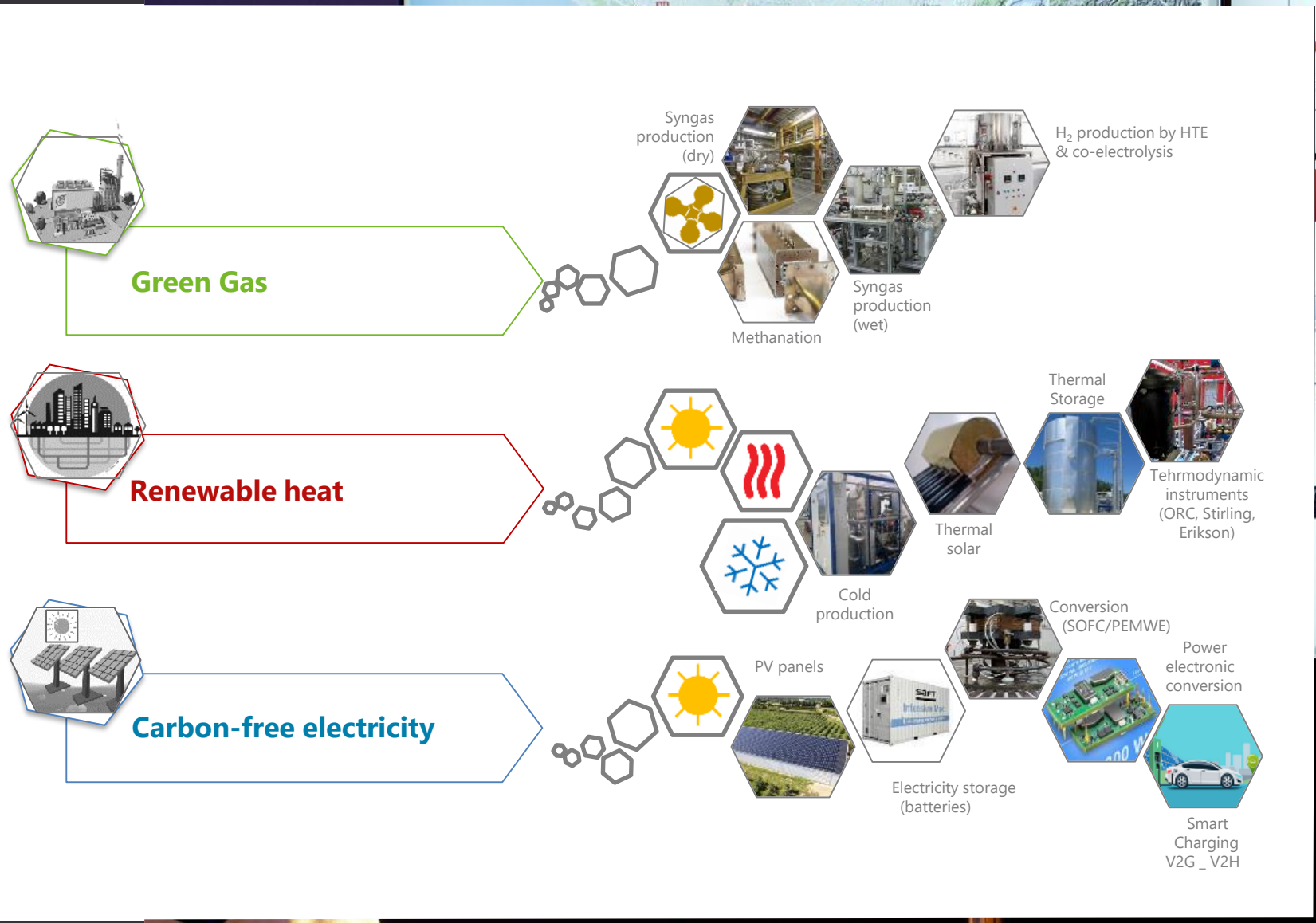
Up-to-scale demonstrators co-design, with management système, monitoring, and transfer to operators

ENERGY GRIDS AT CEA *

With various competencies in conversion technologies, experimental platforms, demonstrators and digital tools, a unique offer to meet the energy transition of Territories and eco-industrial parks.

TECHNOLOGY

ENERGY SYSTEMS (CONVERSION)



PLATFORM

COMPLEX ENERGY SYSTEMS PLATFORMS

Already available :

PISE (Platform Smart Grid INES)

< 1MW – Multi-vector in a Semi-vitrual environment

- « Control/Power hardware-in-the loop »
- Real-condition technical validation
- EMS & Systems testing
- Robustness to flaws, impact of real-time communication

Virtual Emulation Environment

Information System
Cybersecurity
Data management

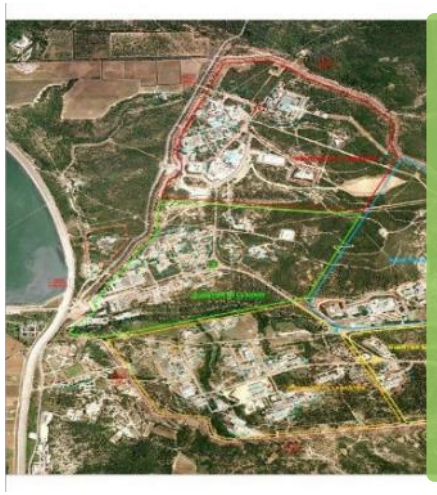
Coming-up soon :

SMART CAD (Living Lab)

>10 MW – equivalent to 5000 inhabitants consumption

Existing uses monitoring, demonstrators
Consumption 40GWh gas, with140 buildings, 113 GWh (eq.Aix-en-Pce) , 200 VE with 110 charging points

- Slicing
- PV cells
- High yield
- Systems & grids
- Silicon crystallization
- BIPV buildings energy efficiency
- Mobility
- Solar
- Storage selection & system management



- Data acquisition
- Heat
- Electricity
- Cold
- Cybersecurity
- Natural Gas
- Electric vehicle
- Hydrogen
- Hydraulic network

TECHNOLOGY

ENERGY SYSTEMS (TERRITORIAL DEMONSTRATORS)

GRHYD

Renouvelons nos énergies

- *Injection into the gas network* to supply a new district
- *Natural Gas-H_2 fuel* for GNV buses

- Control and sizing software creation
- Impact of Natural Gas-H_2 mix (SOFC, network materials compressors)

Jupiter 1000

- *Management of surplus* from renewable energy production
- *Massive storage* of electrical power
- *Gas network decarbonation*

- Techno-economic study
- Demonstrator control tool

TOTEM

- *100% self-sufficient in electrical power*
- *Latest technology integration* : electrolyzer AME 5 kW, PEM 10 kW, storage 100 kg H_2, 66 KWc of PV, batteries storage

- Advanced energy management
- Bifacial Heterojunction CEA technology - 9kWc

TECHNOLOGY

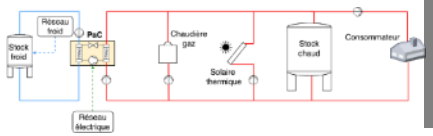
SMARTGRID, CONVERSION & ENERGY EFFICIENCY PROJECTS

Heat network - Grenoble

Advanced Control

Behavior analysis
Dynamic modelling
Advanced management
Master plans 2016/2026

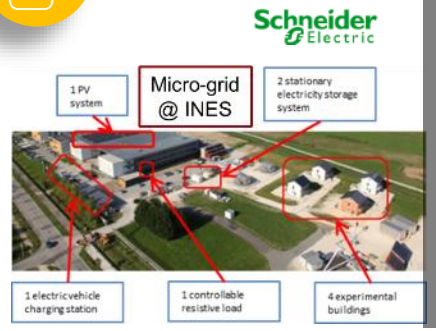
Grid flexibility



Power-To-Heat

District heat network heating & cooling for electrical grid flexibility
Advanced Control

District self-consumption



Advanced Control

Self-consumption PV : microgrid scale
Energy trade and selling thanks to self-consumption & according to the market

Distribution network management

Tension adjustment and peak shaving

Voltage regulation on a distribution network with PV with storage ; evening peak shaving

TECHNOLOGY

SMARTGRID, CONVERSION & ENERGY EFFICIENCY PROJECTS

Already available :

Fast charging

Buses fast charging

Bidirectional charging
Sizing
Electrical architecture
Tests follow-up

Smart Charging

DRIVECO

100% Solar Multiple Stations

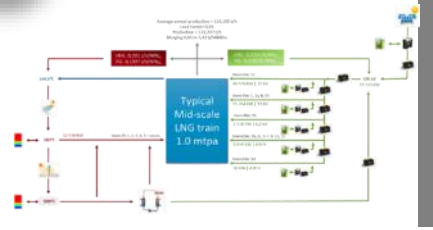
Management of multiple Solar charging stations management
Regional scale optimization : Corsica

Buiding Energy Efficieny

Optimized design and management

Energy saving by innovative energy management systems and PV integration
Testing follow-tup

Industrial Energy Efficiency



Renewable Energy integration in processes

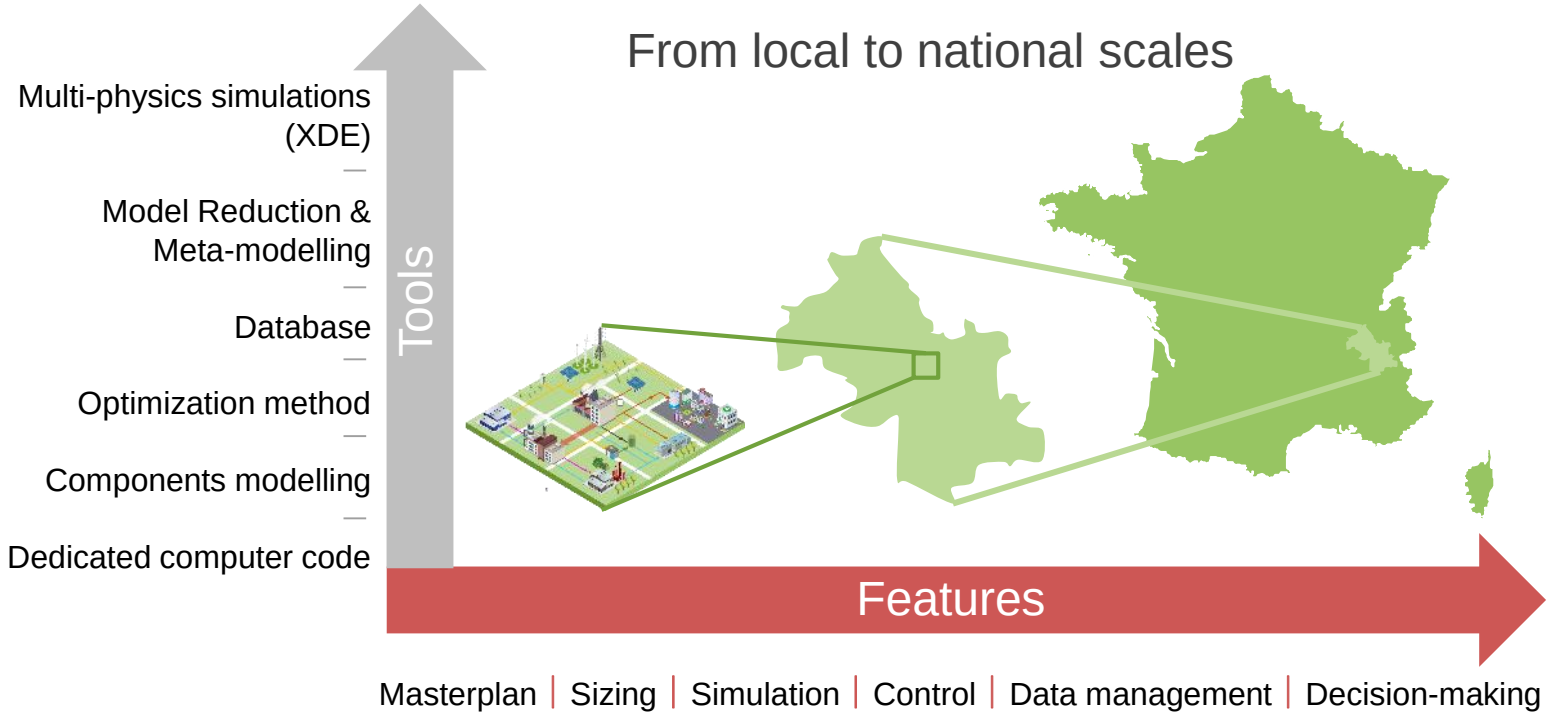
Energy systems sizing
Techno-economic profit assessment

TECHNOLOGY

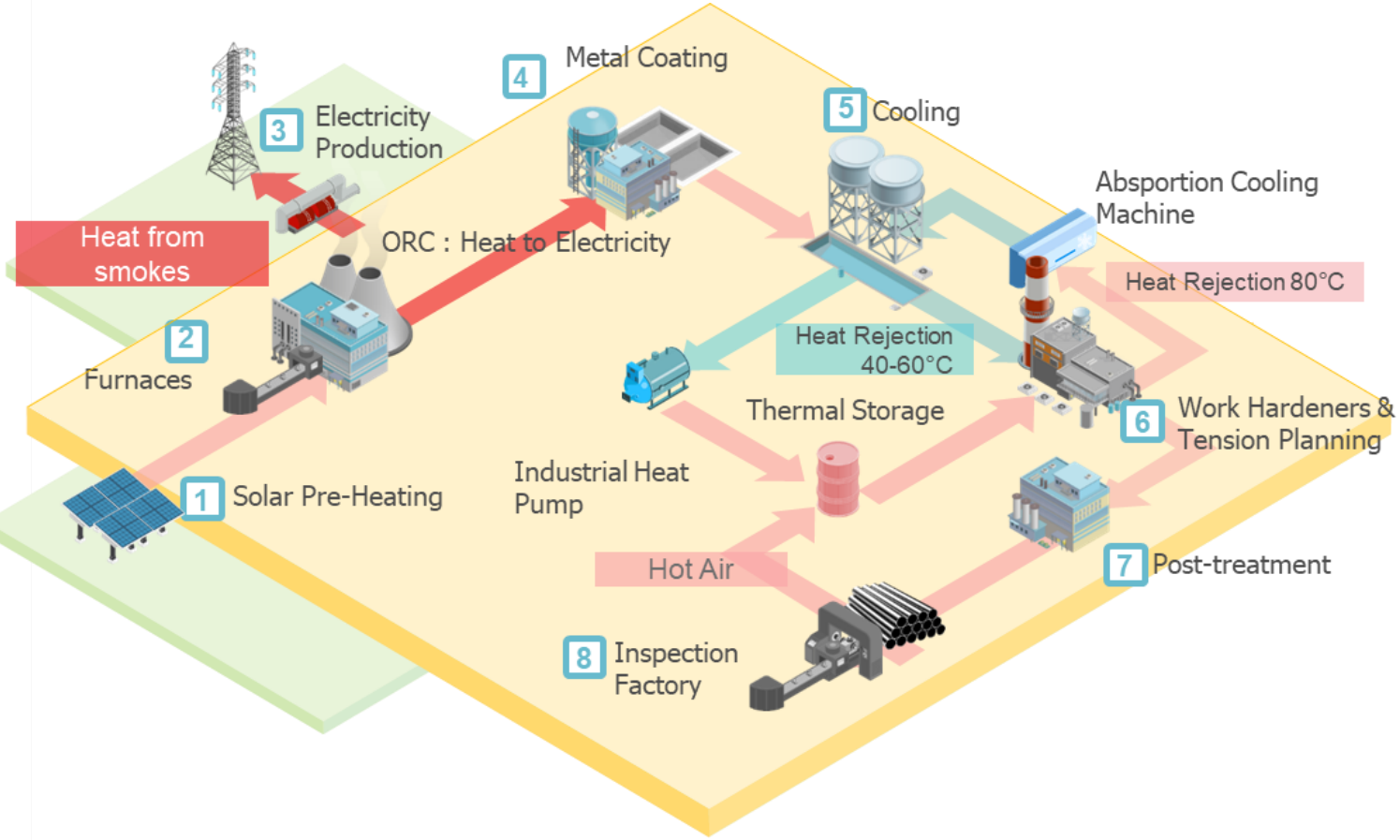
DIGITAL TOOLS & MODELLING

Key Features

- Digital tools for multi-scale and multi-vector energy systems,
- Modelling from components to systems and grids



CEA SYSTEMIC APPROACH



Idealization of industrial process energy optimisation

THERMAL SYSTEMS* FOR ENERGY EFFICIENCY

Energy Efficiency for industry:

- **Waste heat recovery & use**
- **Thermal components development (heat exchangers, absorption cold production, organic Rankine cycle, heat storage)**

TECHNOLOGY

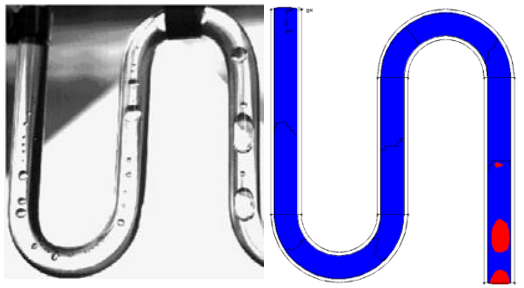
EXPERTISE IN THERMAL SYSTEMS

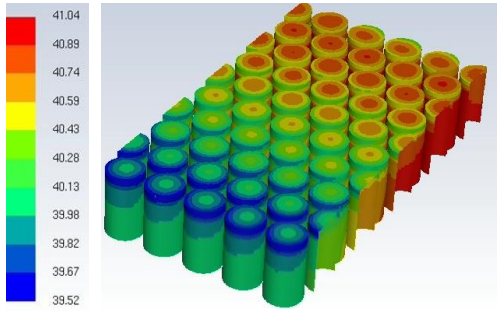
Key Features

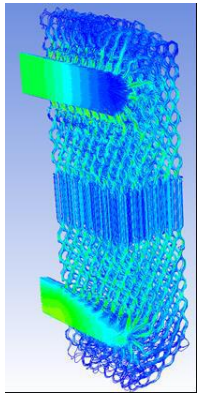
- **Thermal energy :** Heat transfer : conduction, convection, radiation
- **Thermo-hydraulics:** laminar, turbulent, two-phase flows,
- **Thermal and thermodynamic systems :** heat exchangers (heat transfer intensification and fouling), Organic Rankine Cycles, Absorption Cycles for heat and cold production
- **Simulation and experimental loops :** air, water and oil loops, heat storage dedicated loops at different temperature levels up to demonstrators (2MWh), instrumentation for different flow rates and temperature ranges
- **Complementarity with Nuclear Division expertise** :
- Thermomechanical behaviour and Mastery of usual codes (RCC-MRx, CODAP, ASME ...)
- Special Heat transfer fluids: supercritical CO_2, molten salts, Sodium, PbLi, Helium, Nitrogen

Asset

- Good knowledge of the industrial context in the thermal field : heat exchangers manufacturers and users
- Waste heat recovery and conversion







TECHNOLOGY

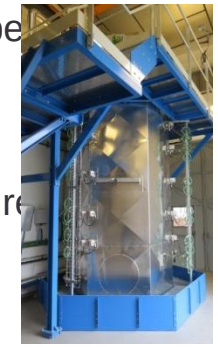
THERMAL SYSTEMS PLATFORMS

Heat transfer and Fouling

- Performances and fouling of water/water heat exchangers 150°C, 10
- Performances of air/air or air/water heat exchangers, Up to 850 °C, A
- Particulate fouling of air/water heat exchangers, up to 150°C, air flow

Heat Storage

- Hot water tank for thermocline stability analysis
- Sensible Heat storage with rocks & oil (<300°C)
- Latent Heat Storage (from phenomenological loop with paraffin up to high tempe steam storage 450°C)

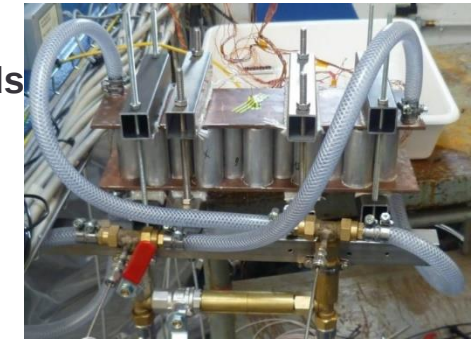


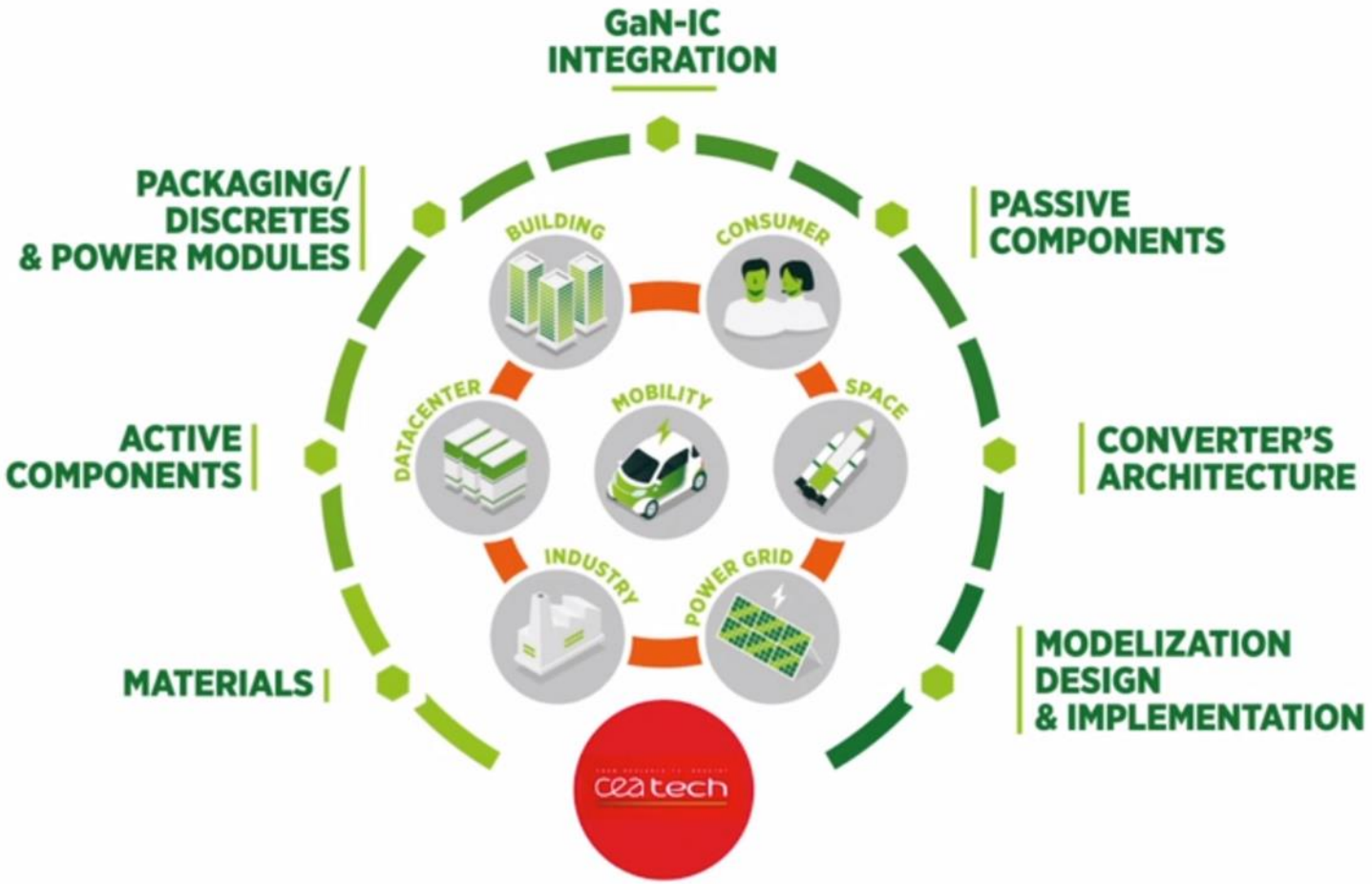
Electronic cooling

- Various industrial applications: batteries, LEDs, computers, veh ure aeronautics, spatial (0 gravity) …
- Various heat pipes configuration (capillary, pulsated)
- Ventilation, water circulation, PCM thermalisation

Asset

- **Highly accurate Instrumentation expertise with various fluids**





POWER ELECTRONICS

*

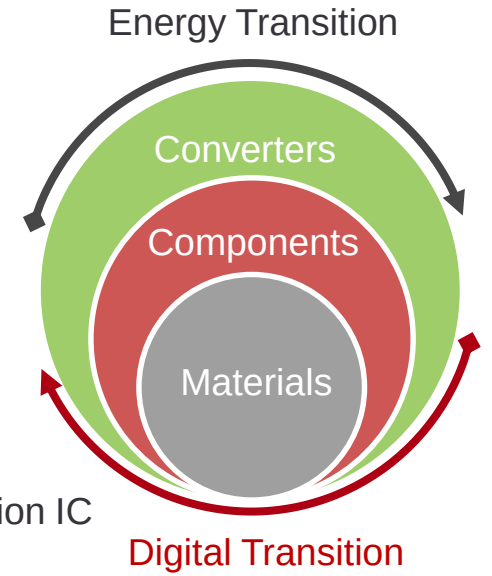
More than 150 researchers working on power electronics on 3 sites, with design centers, clean rooms, pilot lines, tests labs, labs for prototypes and experimentations indoors and outdoors

PLATFORM

POWER ELECTRONICS PLATFORM

Key Features

- **Power Electronics Platforms**:
- 200 mm GaN epitaxy tool
- Power GaN/Si technology (diodes and transistors)
- Packaging & Power modules
- GaN IC integration, SiC Smart Cut wafers
- Electrical Characterization & Industrial Test (GaN, SiC, Si)



- **Converters :** for mobility, smart grids, datacenters : Increasing compactness and yield at competitive cost
- **Components :** Wide bandgap, passive HF, Packaging, Integration IC

Wide bandgap diodes & transistors, low loss HF transformers, integrated sensors for prognosis/diagnosis, packaging, IC and 3D integration, High power modules

- **Materials & Magnetic components :** Wide bandgap substrates, HF ferrites, 3D ceramics

GaN & SiC Wide bandgap substrate at competitive cost, disruptive wide bandgap (Diamond, ferrites for HF conversion, additive manufacturing, 3D ceramics)

Assets

- 3 sites with high expertise in power electronics : Grenoble, Chambéry & Labège

Success stories

- **2 start-ups created**

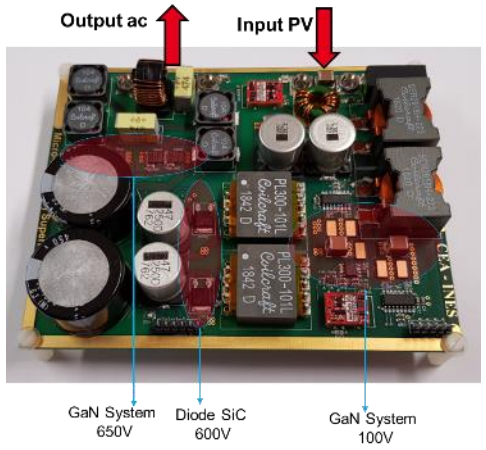
EXAGAN Accelerate Power Transition

wise-integration

TECHNOLOGY

POWER ELECTRONICS (CONVERTERS FOR NTE)

GaN micro inverter for PV

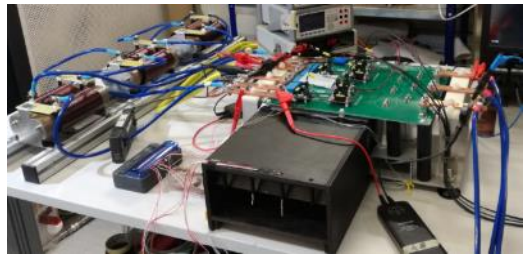


- Power : 400 W
- Switching frequency : 200 kHz
- Power density : 1,1 kW/liter
- Input : 25-60 V_{DC}
- Output : 230 V_{AC} / 50Hz
- GaN based

Full SiC 5kW PV inverter

- Power : 5 KW
- Switching frequency : 200 kHz
- Power density : 1,1 kW/liter
- Input : 400 V_{DC}
- Output : 400 V_{AC} triphasé
- Full SiC 1 MHz et 10 kW/l

PV inverter 80 kW



- Power : 80 kW
- max. PV voltage : 1000 V_{DC}
- AC voltage : 690 V_{RMS} 3~ /50 Hz
- CSI topology
- Custom power modules
- SiC based (power-module 1700 V switches)

SUCCESS STORY

EXAGAN

Accelerate mass-market adoption of gallium-nitride (GaN)-based power devices.

STMicroelectronics acquired Majority Stake in Gallium Nitride innovator Exagan.

http://www.exagan.com/en/

EXAGAN
Accelerate Power Transition

life.augmented

SUCCESS STORY

WISE INTEGRATION

Ultimate Power Supply miniaturization using custom GaN IC

Applications:

- **Chargers**
- **In wall USB C charger**
- **E-mobility**
- **Data centers**

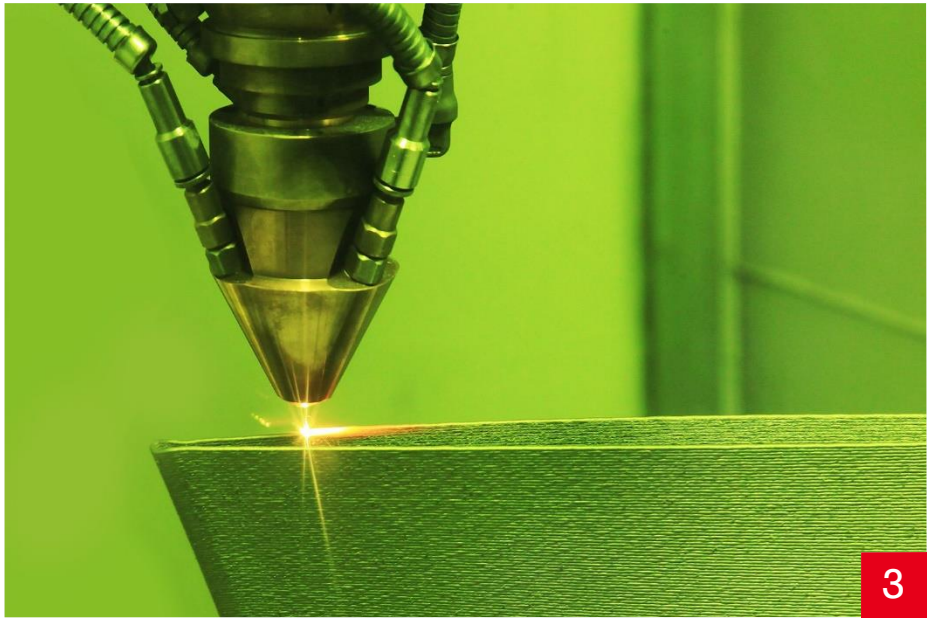
https://www.wise-integration.com/

MATERIALS CIRCULAR ECONOMY

1. Strategic Materials recycling

2. Environmental impact reduction

3. Materials Saving & Sobriety thanks to Additive Manufacturing



CIRCULAR ECONOMY OF MATERIALS

Our aim is to find the economic and environmental sustainability in the Energy transition

Circular Economy

Energy Efficiency & Sustainable Technologies

Energy & material efficiency

- Additive Manufacturing & Net shape processes
- Structural electronics
- Thermal management

Circular Economy of Carbon

- Thermochemical valorization of carbon-containing waste (liquid, gas, solid)

Reducing the environmental impact

- Life cycle & technical economic analysis
- Recycling & Chemistry

PLATFORM

STRATEGIC MATERIAL RECYCLING

Recycling processes & critical metals recovery

Photovoltaic panels
Ag, Cu, Al

Permanent magnets
Rare-Earth materials

E-WASTE (PCB)
Au, Pd

Li-ion Batteries
Transitions metals, Li, Al

Fuel Cells PEMFC
Catalysts (Pt, Co), Nafion

Nuclear Fuels
Radioactive catalysts, Material Radionuclide

Development of hydrometallurgy processes

- Selective leaching
- Separation by continuous chromatography
- Recovery of particular interest items by selective precipitation
- Ionic liquids & molten salts
- Electrodissolution & Electrochemical reduction

TECHNOLOGY

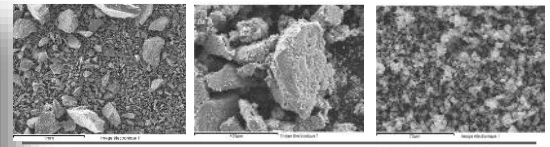
STRATEGIC MATERIAL RECYCLING

Key features

- Recycling processes development within one sector and multi-sectors
- Secondary deposit exploitation (Rare Earth, Co, Li…)

Pilot project of batteries recycling process

New batch process (5L) transferred to a partner specialist in



		Ni	Mn	Co
1 step	Purity	> 97,5%	> 96%	> 98,5%
2 steps	Purity	> 99%	> 99%	> 99%

Material composites recycling

Support to our partner Extracthive for Long fibers C recycling by solvolysis

Hard magnet recycling (NdFeB)

Re-melting and strip casting with more than 25% of recycled magnet reaches equivalent performances than new magnets

TECHNOLOGY

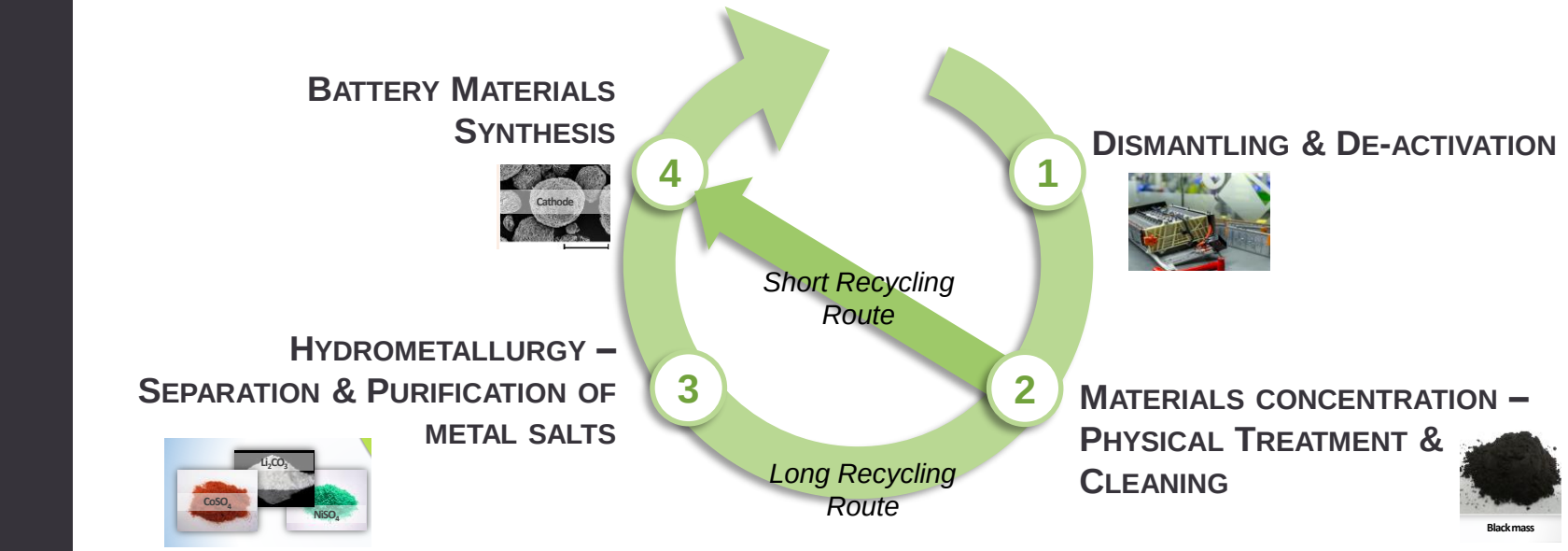
STRATEGIC MATERIAL RECYCLING (BATTERIES)

Key Features

- Joint laboratory with an industrial partner
- 4 main steps : deactivation, valuable metal concentration, hydrometallurgy and materials valorization

Assets

- Innovative recycling route
- Full hydrometallurgy processes
- Recycling materials valorization (new battery materials)

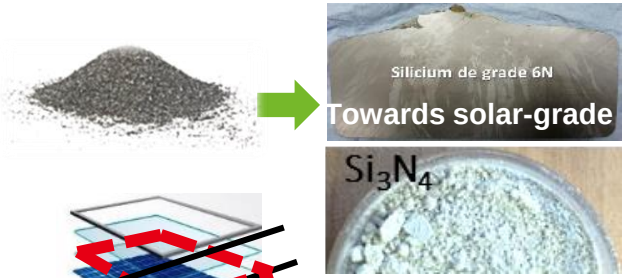


TECHNOLOGY

STRATEGIC MATERIAL RECYCLING (PV)

Key Features

- Separation (wire slicing or supercritical fluid)
- Slicing and material concentration
  - Si Kerf : 35 % of losses
- End-of-life modules recycling
  - Layer separation
  - Wired Miling – Mechanical process
- Valorization & Treatment
  - Cost effective
  - Green
  - Innovative
  - Reuse of the liquid medium



Other Applications

TECHNOLOGY

ENVIRON-MENTAL IMPACT REDUCTION

Key Features

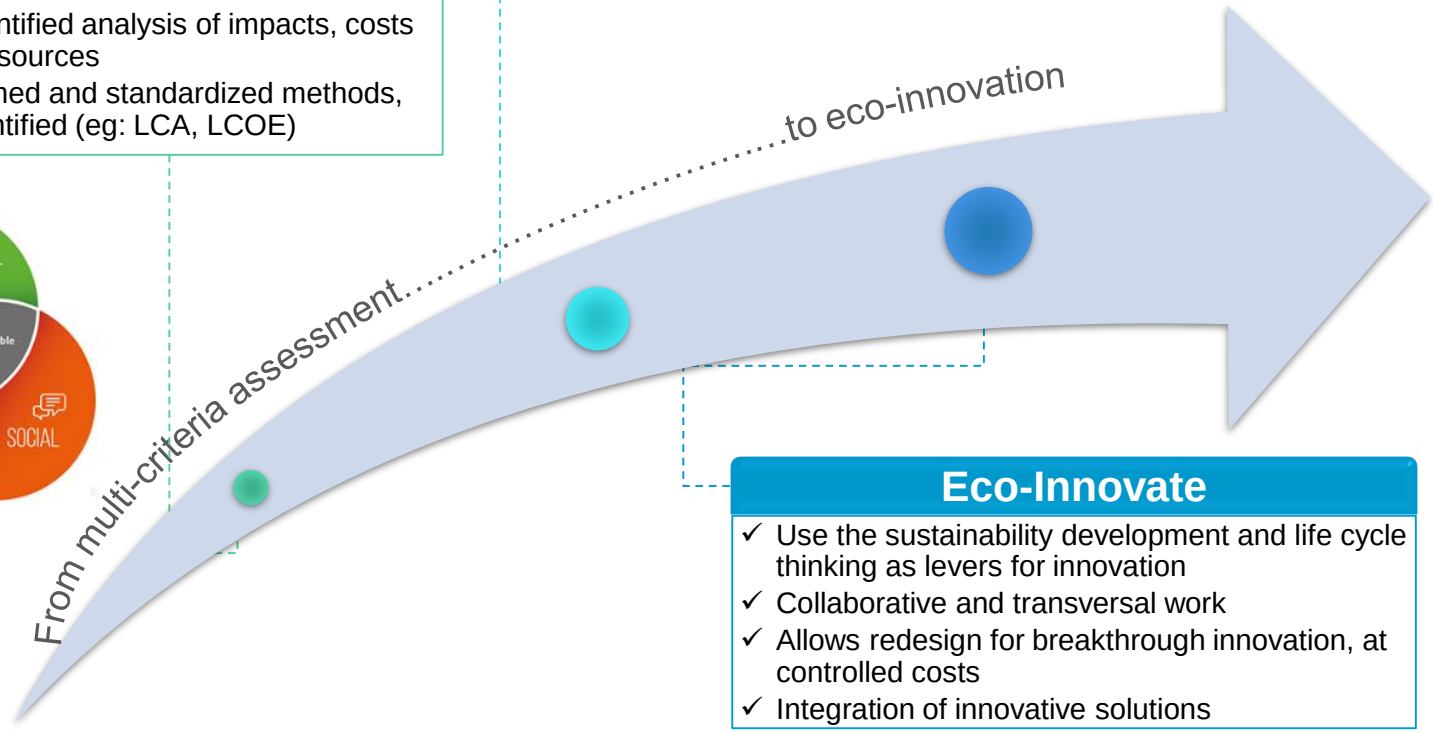
- Eco-innovation activities

Assess

- ✓ Identification of issues approx. & eco of a domain
- ✓ Knowledge of technology issues and trends
- ✓ Quantified analysis of impacts, costs and sources
- ✓ Framed and standardized methods, quantified (eg: LCA, LCOE)

Improve

- ✓ Environmental and economic support for technical developments
- ✓ Eco-design and tech-eco optimization techniques
- ✓ Feedback on product, process and system design



Eco-Innovate

- ✓ Use the sustainability development and life cycle thinking as levers for innovation
- ✓ Collaborative and transversal work
- ✓ Allows redesign for breakthrough innovation, at controlled costs
- ✓ Integration of innovative solutions

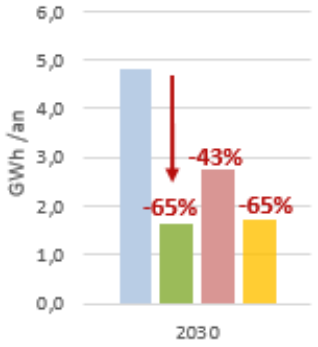
TECHNOLOGY

ENVIRON-MENTAL IMPACT REDUCTION (REALIZATION)

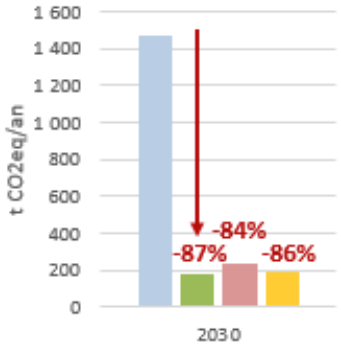
Key Features

- **Evaluation of the different engines of a bus fleet:** 100% H_2, 100% battery, or Hybrid
- **Significant reduction in energy consumption and GHG emissions** from electrified battery and hydrogen solutions
- Increased investment in electrified solutions due to vehicle electrical storage and conversion components as well as charging and supply infrastructure
- Compensation possible by a reduced fuel cost in the TCO calculation, in particular if the taxation of fossil fuels is increased (taken at € 100 / ton in 2030)

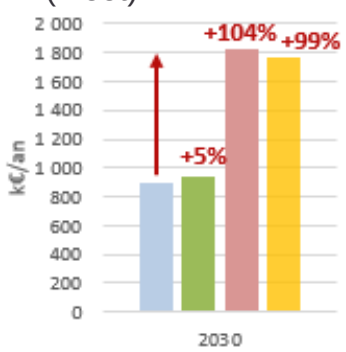
Primary energy consumption



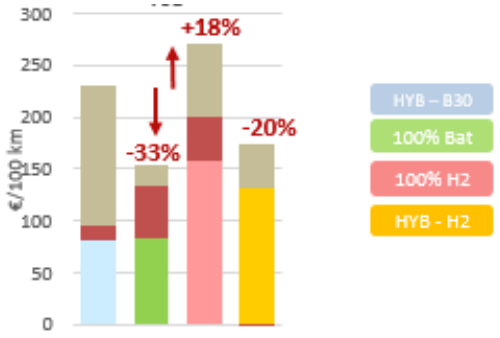
Annual GHG emissions



Annual CAPEX (Fleet)



TCO

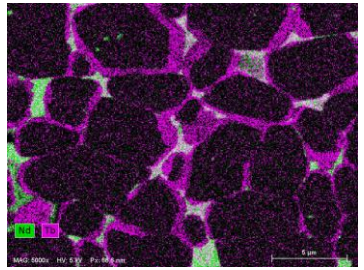


TECHNOLOGY

SUSTAINABLE MATERIALS (MAGNETIC COMPONENTS)

Key Features

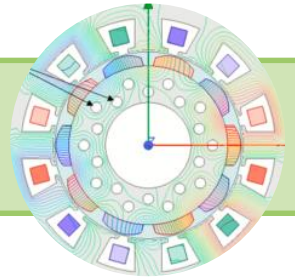
- **Magnetic components development for electrical motor**
- **Sintered Permanent Magnets design**
- Rare Earth reduction with new magnet compositions (Dy=-50%, Total Nd=-20%)
- Closed loop recycling with a Cradle to Cradle approach (up to 25% of used magnets incorporated)
- **3D design & fabrication for a higher compacity & power efficiency** by thermal cooling by 3D printing or injection molding
- Magnet, Rotor, Stator Casing

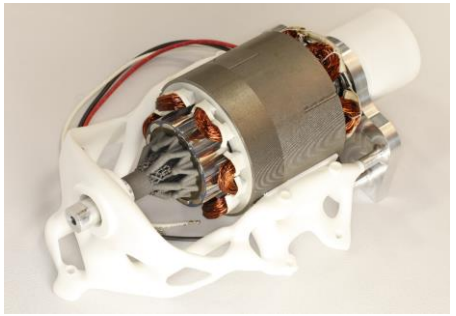


Assets

- **Expertise in magnet design with a reduction of rare earth elements content**

Cooling Channels inside the Rotor





TECHNOLOGY

3D PRINTING (VALUE CHAIN COVERAGE)

Key Features

- **A strong presence all along the value chain, from prototyping to mass production**

DESIGN

- CAD models
- Simulation software's
- Process control software's
- Topological optimization

MATERIALS

- Polymers (binder, wire, powder)
- Metallic alloys (powder)
- Magnetic materials
- Ceramics and composites
- Recycled materials

3D PRINTING

- Powder bed fusion
- Stereo lithography
- Binder Jetting
- Fused Deposition Molding

POST-TREATMENT

- Thermal treatment
- Debinding and sintering
- Surface treatment
- Cleaning

CONTROL

- Non Destructive Control
- Chemical and Physical Properties
- Health Security Environment

- 3D@manufacturing base: AI & database for design of flawless spare parts
- 360° vision on Additive Manufacturing technologies
- Strong partnerships with key OEMs on disruptive technologies
- Industrial Ecosystems Animation on 3D Printing Polymers & Metals

Success Stories

- Additive manufacturing processes qualification
- 3D Print Ecosystem for the energy sector

Multi Jet Fusion
Polymers

PRODWAYS
Stereo Lithography
Polymers / Metals / Ceramic

AddUp
Laser Beam Melting
Metals

TECHNOLOGY

3D PRINTING (EXAMPLE OF ACHIEVEMENT IN ENERGY)

Key Features

- Heat Exchangers & Reactors

Assets

- Complex design implementation
- Disruptive design for improved performances
- Easier manufacturing process
- Less assembly operations
- Embedded sensors
- Lower costs
- Lower leadtimes

Thin channels and walls (Source: CEA Tech/LITEN)

Complex absorption exchanger reactor

3D Printed Methanation Reactor

Sept 2020

Methanation reactor and complex internal structure

FAMERGIE
Plateforme Fabrication Additive Métallique pour l'Energie

1st proof of concept designed and manufactured with FAMERGIE multi-lasers LBM machine

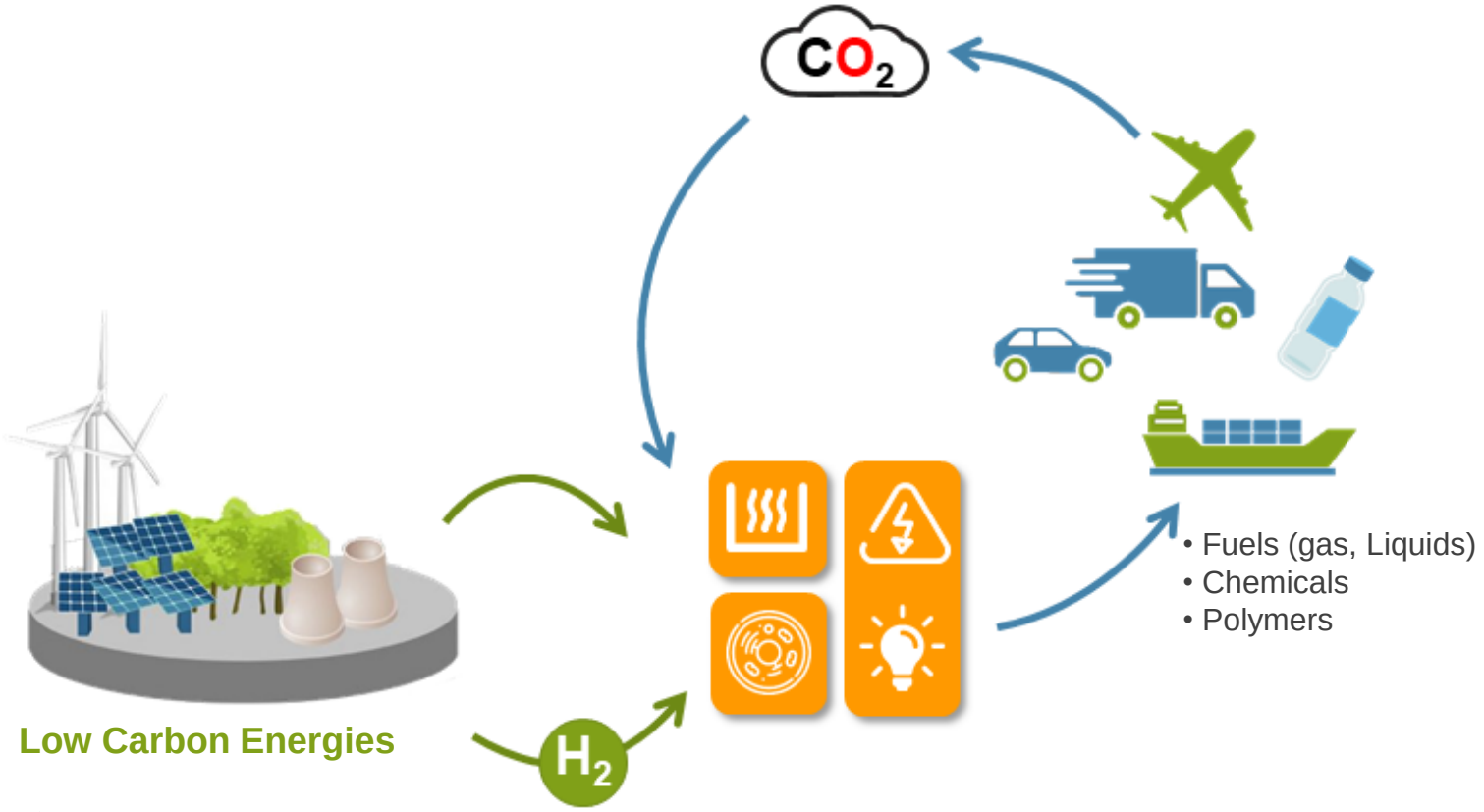
+ Complex channels design allowing better thermal control of the methanation reaction, improved heat exchanges, assembly operations reduction

CARBON CIRCULAR ECONOMY

1 (Photo)electrocatalysis

2 Biology/Biohybrides

3 Thermocatalysis / Thermoconversion



2050 Objectives (SNBC)

Reducing Energy consumption to 1 060 TWh

➔ 580 TWh from electricity
➔ 480 TWh other – including non-fossil carbon molecules

CARBON CIRCULAR ECONOMY*

- **Some sectors will not be able to decarbonize only through electrification, hydrogen (H_2), or energy efficiency. Carbon will still be used.**
- **Complementarily to biomass, CO_2 must be seen as a resource, a substitute to fossil energy, in order to make theses sectors sustainably decarbonised.**
- **To do so, low-carbon energies are combined with innovative CO_2 conversion technologies to produce fundamental molecules for energy and chemistry**

TECHNOLOGY

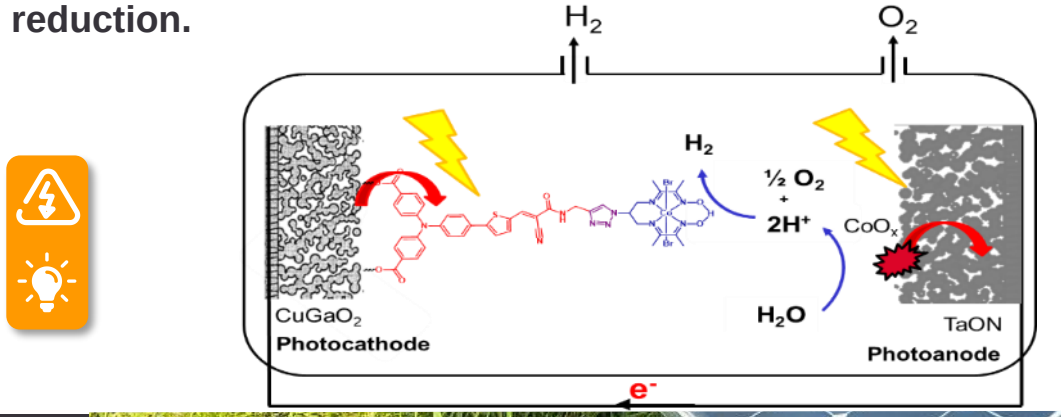
(PHOTO) ELECTRO-CATALYSIS

Key Features

- **CO_2 and water co-electrolysis for C1 or C2+ molecules production** (methanol, syngas, acid)
  - Alternative liquid media: ionic liquids, Deep Eutectic Solvents
- **Artificial photosynthesis (solar fuels)** : photo-electrocatalysis (TRL 1-4)
  - H_2 production
  - Towards carbon molecules through direct conversion
- **Improve reaction efficiency** (Materials and catalysts development)
- Using non-critical metals & materials
- From multi-scale modelization to prototype development

Assets

- **First bioinspired photoelectrocatalytic cells realized in France, with a successful production of H_2.The next step will be the CO_2 reduction.**



TECHNOLOGY

BIOLOGY BIOHYBRIDES APPROACHES

Key Features

- **Microorganisms biological strains expertise & engineering** (bacteria, cyanobacteria, microalgae) including metabolism, genetic engineering, lipidomics…
- Cultivation processes and conditions
- Pilot-scale (photobioreactor), GMO-compliant, modular and characterization platform
- Extraction and separation processes
- Application such as production of biofuels, biopolymers, terpenes, alkens

Asset

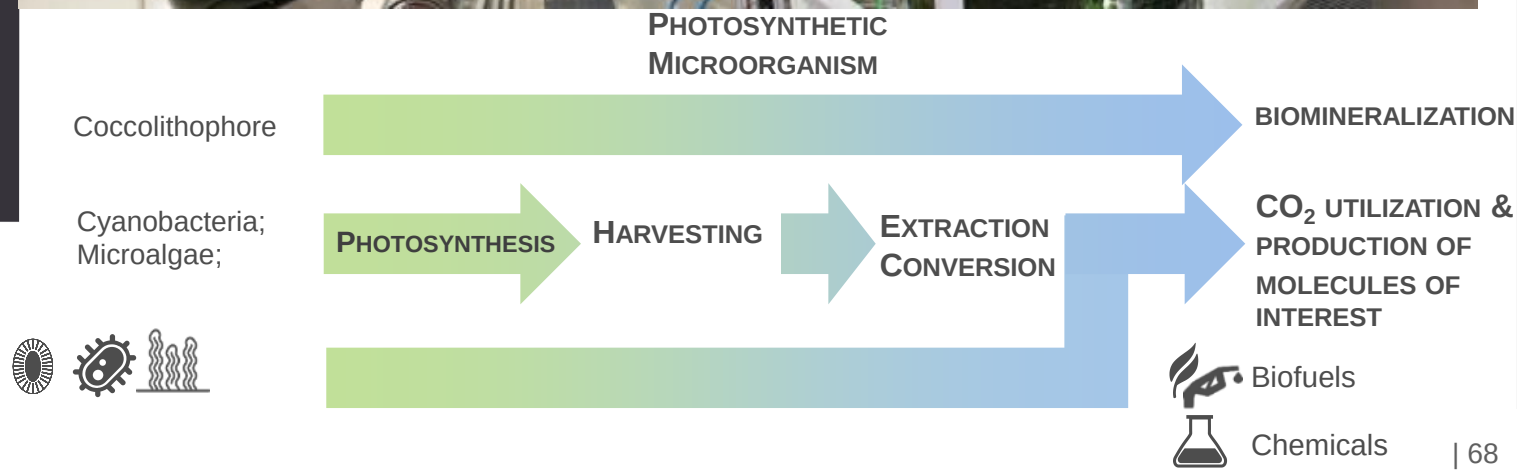
- **Assess and engineer strains** according to application criteria and process constraints with optimal production yield
- **Pilot-scale units for microalgae cultivation**, harvesting, pretreatment, extraction of biomass and conversion (from 1 to 100l/h)
- Development & Characterization Platforms

Crédits photo L. Godart

SUCCESS STORY

TOWARDS 3RD GENERATION BIOFUEL WITH MICROALGAE

Long-term collaboration for the transformation of the CO_2 by microalgae into synthetic products of interest such as 3rd generation Biofuel from renewable energy sources

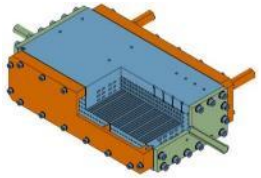


TECHNOLOGY

THERMO-CATALYSIS

Key features

- Improved yield and compacity, thanks to reactor-exchanger design, optimised for heat control

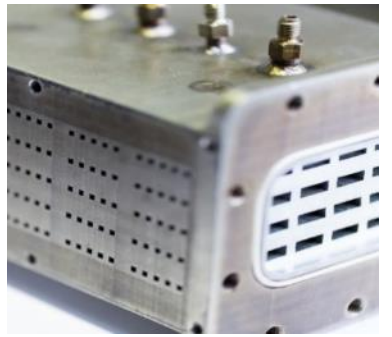


Assets

- Know-how in reactor design in relationship with reaction kinetic and heat-exchange, modelling, sizing
- Platform for methane, methanol, hydrocarbons, CO and CO_2 (WGS and RWGS) etc.
- Components, system and technology coupling approach
- Academic partnerships on catalytic reaction kinetics and thermodynamics

Success story

- **Khimod:** HIP millistructured reactor for Power2X
- **Jupiter1000**: Power-to-Gas, first french industrial demonstrator



Jupiter 1000

KHIMOD
ALCEN

TECHNOLOGY

THERMO-CONVERSION

Key features

- High carbon conversion rate and high energy integration of biomass conversion into energy carriers and building block molecules
- Process adaptation for variety of ressources
- Waste-treatement solution

Assets

- Platform for dry (torrefaction, pyrogasification) and wet (hydrothermal liquefaction and gasification) conversion
- High pression and high temperature process know-how

Success stories

- **Pulp&fuel:** biofuel by hydrothermal gasification of black liquor, a pulp&paper waste
- **Gaya:** Expertise of gasification process, modelling and gas analysis

PULP&FUEL
pulp and paper industry waste to fuel

gaya

DE LA RECHERCHE À L'INDUSTRIE

DIGITAL TOOLS FOR ENERGY

Digital tools for Energy systems integration

Energy production prediction

Networks : Sizing, management (production, consumption, storage) & real-time control

Remote assets monitoring

Cybersecurity for energy networks and systems

Batteries operation modelling, V2G control

Industry Energy Optimization

Buildings Energy Management, V2H

Acquisition & treatment of data treatment, Big data

Consumption prediction

Digital Twin

Consumption prediction (heating, ECS)

- Sensors and system integration
- Non destructive testing

- Asset management
- Complex system optimization
- Decision making
- Prediction

- Vulnerabilities identification
- Secure Industrial IOT
- Anomaly-based network intrusion detection & reaction
- End-to-end encryption
- Trusted ledgers for data and service

DIGITAL TOOLS FOR ENERGY

INSTRUMENTATION AND CONTROL OF ASSETS

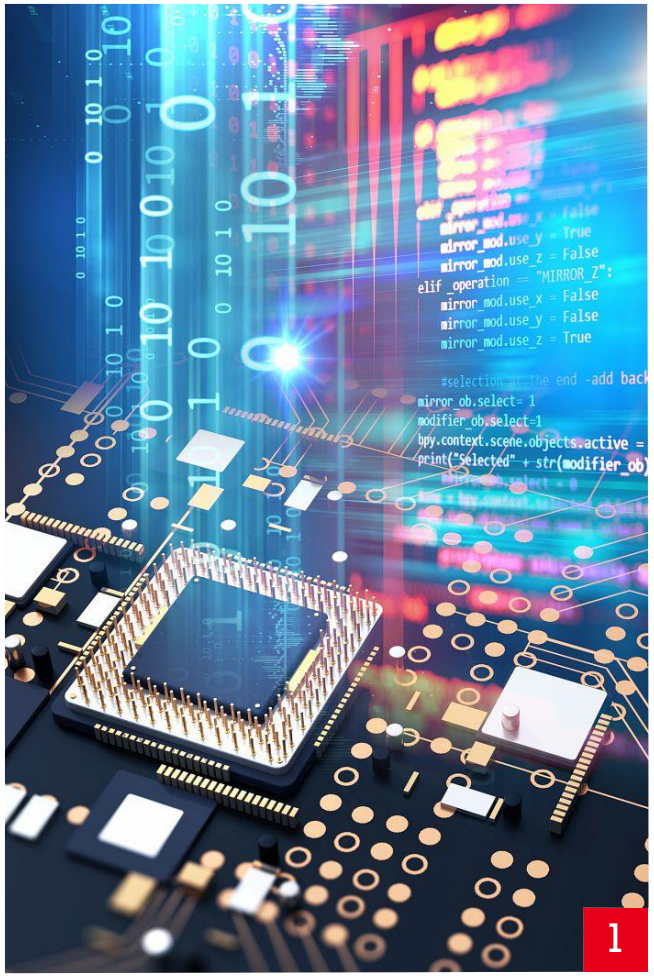
DATA, AI & DIGITAL TWIN

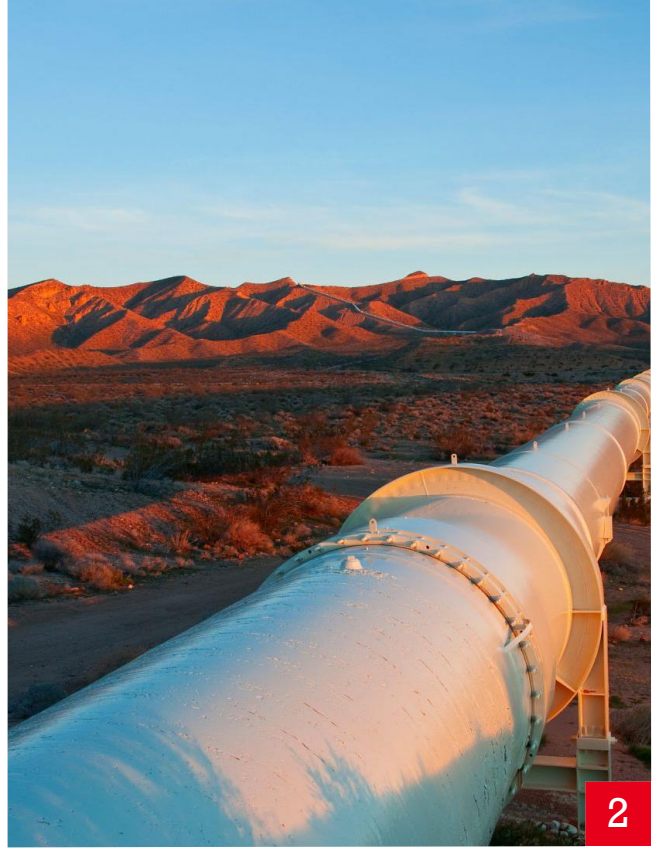
CYBERSECURITY

INSTRUMENTATION & CONTROL OF ASSETS

1 Sensors and system integration

2 Non destructive testing

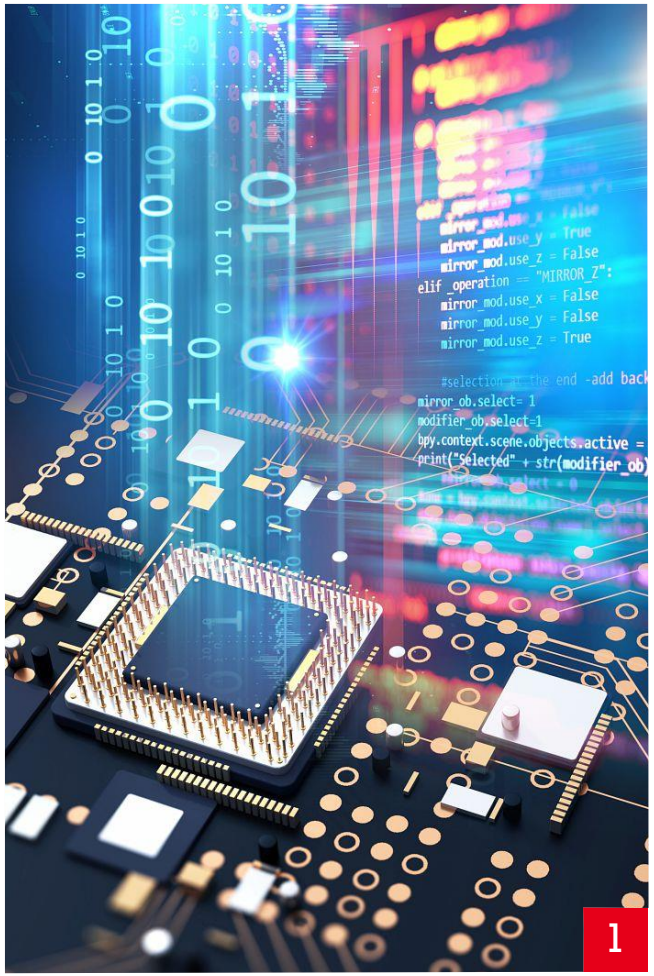


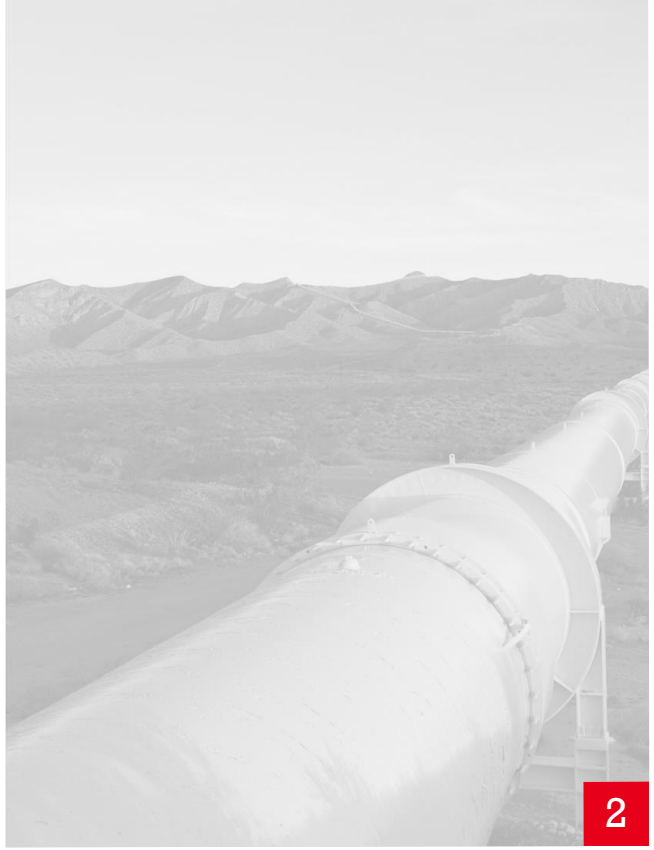


INSTRUMENTATION & CONTROL OF ASSETS

1 **Sensors and system integration**

2 Non destructive testing

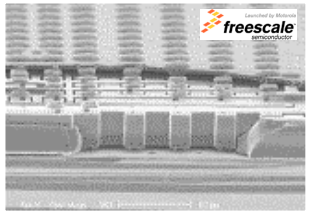




SENSORS AT CEA

With strong expertise in microelectronics, CEA proposes various innovative sensors, and tailored solutions for energy challenges.

Components

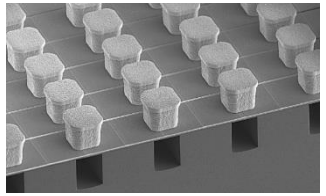


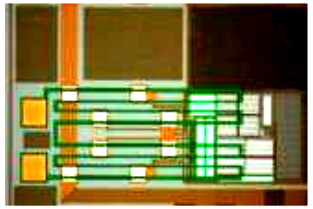
Inertial sensor

Pressure sensor

Acoustic sensor

Force sensor


Thermoelectric sensor

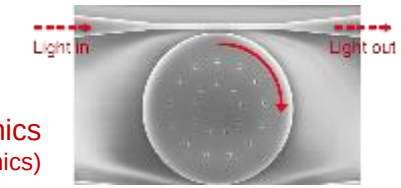

Magnetic sensor (TMR)

Gas sensor

Bio sensor

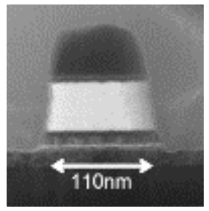
Ultrasonic sensor (MUT)

Technologies background

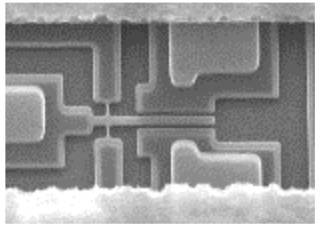


Optomechanics
(NEMS + Photonics)

Spintronics



NEMS



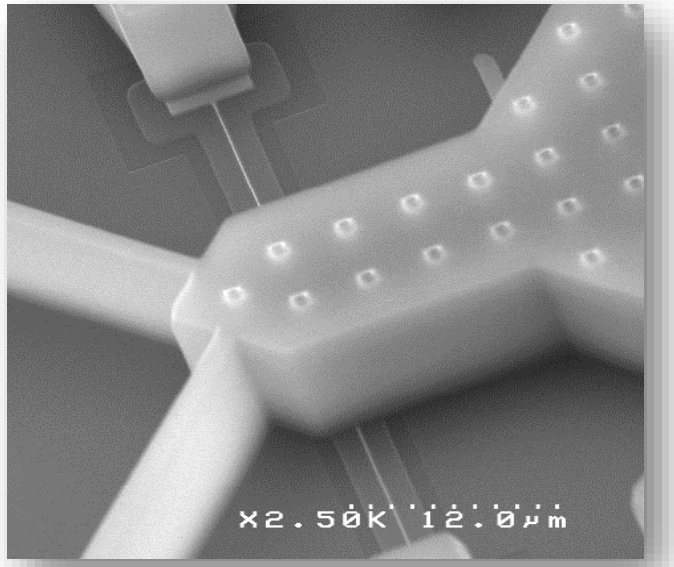
PLATFORM

MULTI-SENSORS PLATFORM

MEMS size mechanical part

Separate optimization

Nano-size piezoresistive gauge



200 & 300 mm Microsystems Clean Room

- **Multi-sensors / Multi-axis**
- **Very Efficient transduction** (stress concentration)
- **Ultra-Miniaturized sensors**

TECHNOLOGY

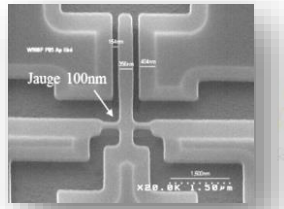
GAS SENSORS

Key Features

- **NEMS-based Multi-Gas Analyzer**, based on Gas chromatography / mass spectrometry
  - Multi-gas
  - Resolution: few ppm to few 10's ppb
- **Low-power NDIR CO_2 sensor**
  - Low power consumption: < 1,5 mW @ 100% duty cycle
  - Small footprint (2x2x1 cm²)
  - Resolution: 10 ppm @1000 ppm concentration for CO_2 gas
  - Designed for CO_2 or CH_4
  - Reference channel
- **QCL Photo-Acoustic Spectroscopy**
  - Measurement of light absorption by the molecules of interests and the resulting acoustic waves
  - Assembling a quantum cascade maser (QCL) source and a photonic integrated circuit (PIC)
  - Low power consumption during operation (less than 10 W)
  - Suitable for continuous monitoring
  - Gas detected : methan, buthen, CO, CO_2, propan, ethylene…
  - Smaller and cheaper than current QCL technology
  - Up to 3 different gas detected at the same time
  - Limit of detection down to 1 ppm at 10mW

Success Stories

- APIX technology



APIX ANALYTICS

- Start-up eLichens

elichens

- Start-up Mirsense – QCL sensors

mir sense

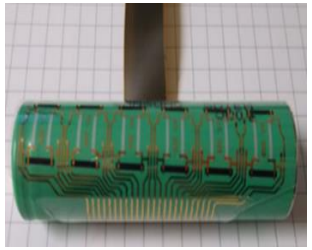
PLATFORM

PRINTED ELECTRONICS PLATFORM

Key Features

- **A complete set of printing tools**
- Gravure printing
- Screen printers (x3)
- flexogravure
- Slot die
- µspray
- Ink jet
- **On various substrate materials**
- Metal, Plastics, Glass, Fabric, Paper
- **Characterization and post-processing tools**
- Automatic Inspection
- Ellipsometer
- Pick & Place
- Laser Ablation
- Laminating
- Thermoforming

SHM / sensors for Batteries



Wearable / Robotics

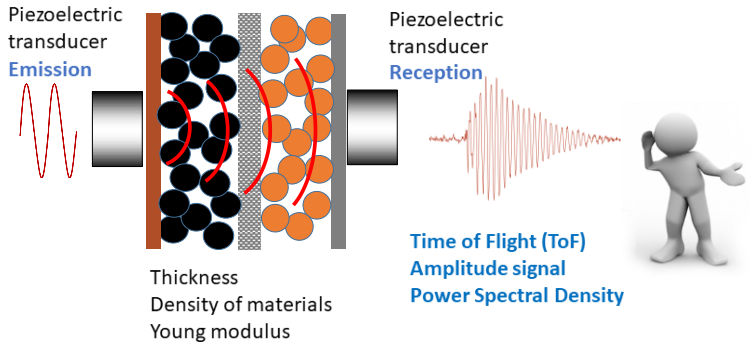
Human-Machine Interface

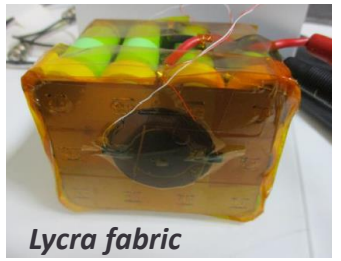
TECHNOLOGY

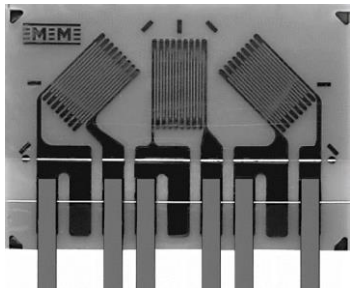
PRINTED PIEZO-ELECTRIC (FOR BATTERY SHM)

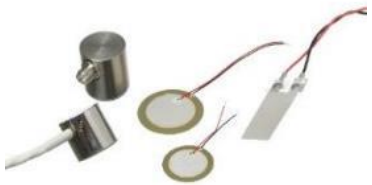
Key Features

- **Printed piezo can be used for Structural Health Monitoring**
  - Ultrasonic emitter/recepter (MHz range)
  - Determination of the State of Charge
  - Detection of abnormal behaviour (over charge, under discharge, over heating)
  - Prevention of safety issues
- **Co-Integration of multiple functionnalitites possible**
  - Conductive lines,
  - temperature,
  - Strain/stress sensors on the same foil
- **Easier Integration**
  - Piezopolymer thin and conformable compared to bulky and rigid piezoceramics
  - Integration in plastic casing
  - Integration directly on battery cell









TECHNOLOGY

AUTONOMOUS & LOW POWER SYSTEMS (USING ENERGY HARVESTING)

Key Features

- Development of autonomous IoT devices by using energy harvesting
- **Whole energy harvesting system** design for autonomous IoT devices
  - Mechanical energy (vibration, shock…), Air & Water flow, Heat Solar energy, MEMS systems, Microbial Fuel cells
- **Ultra-Low Power electronics**
- Optimizing the code and the microcontroller states to minimize its power consumption
- **Wireless Power Transfer**
  - Acoustic Power Transmission
  - Electrodynamic

Assets

- Whole system design & Advanced multiphysic systems
- Characterization equipment
- New components, new materials

Success stories

- Energy harvesting from water flow

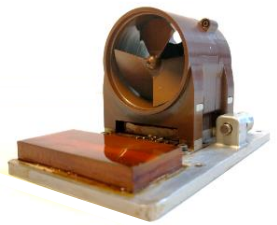
TECHNOLOGY

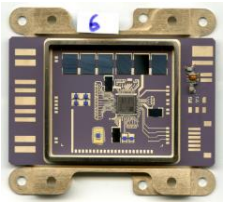
SYSTEMS FOR COMPLEX ENVIRONMENT

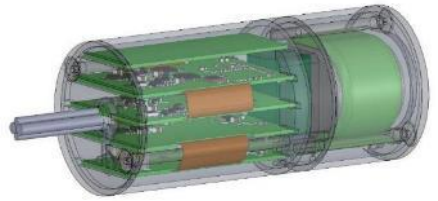
Key Features

- **High Temperatures**
  - Autonomous sensors for aeronautics

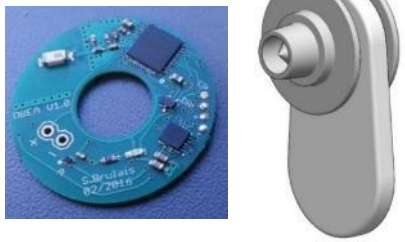
  (180°C/20G) (energy harvesting, wireless power transfer)
- **High-G**
  - 3A @ 500’000G Dataloger
  - Shock Energy Harvesting @ 20’000G (shocks)
- **Constrained Environments**
  - Integration of data acquisition systems
  - Electronics & Mechatronics





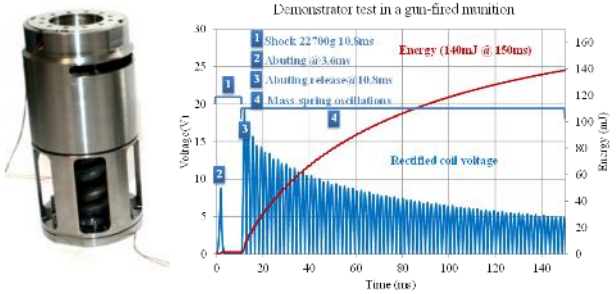


3A 500’000G Datalogger



Cattle monitoring (T°, Acc)

Drop time of nuclear reaction control rods (3A – 200G/800Hz)



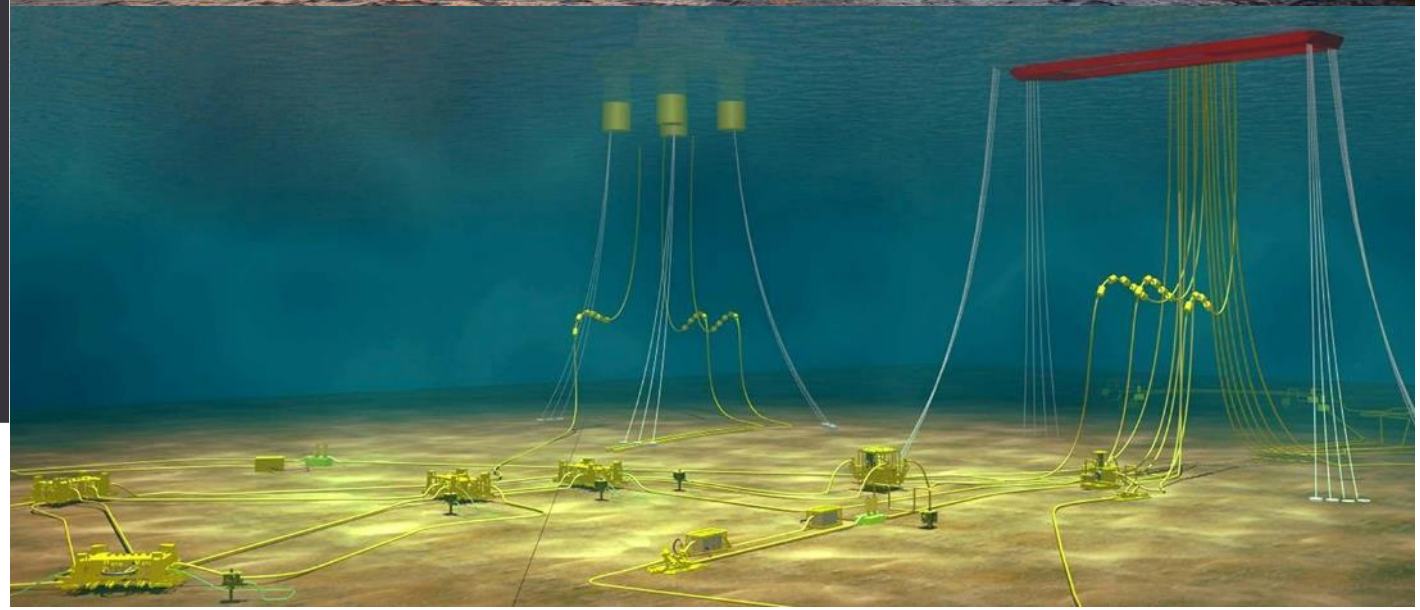
Shock Energy Harvesting (20’000G)

SUCCESS STORY

MORPHOPIPE

Analysis of deformation using data fusion algorithm.

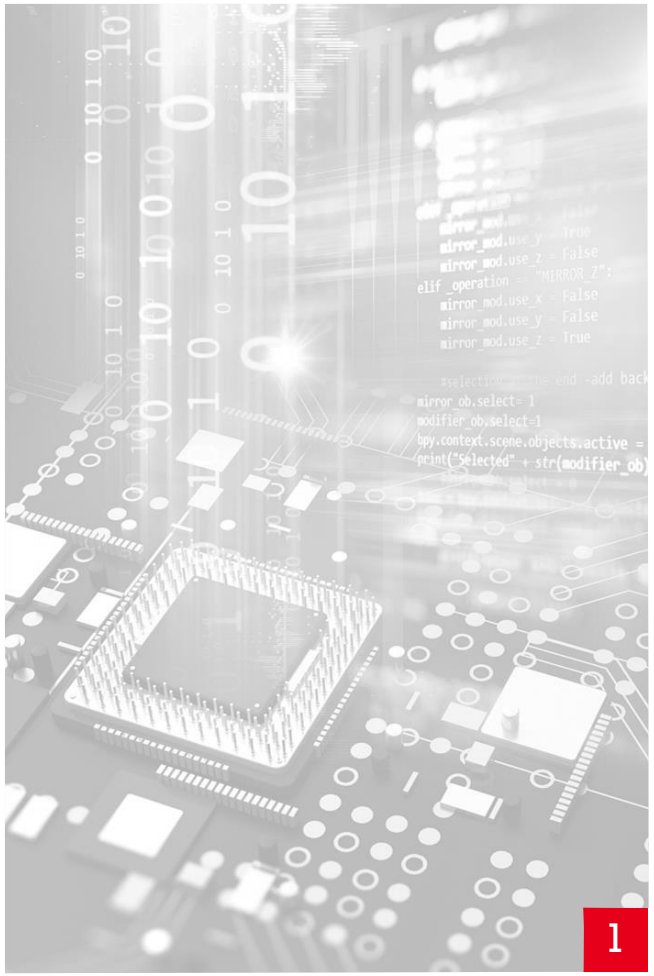
Composed of an accelerometer sensors network, flexible and connected, for deformation analysis of a riser.

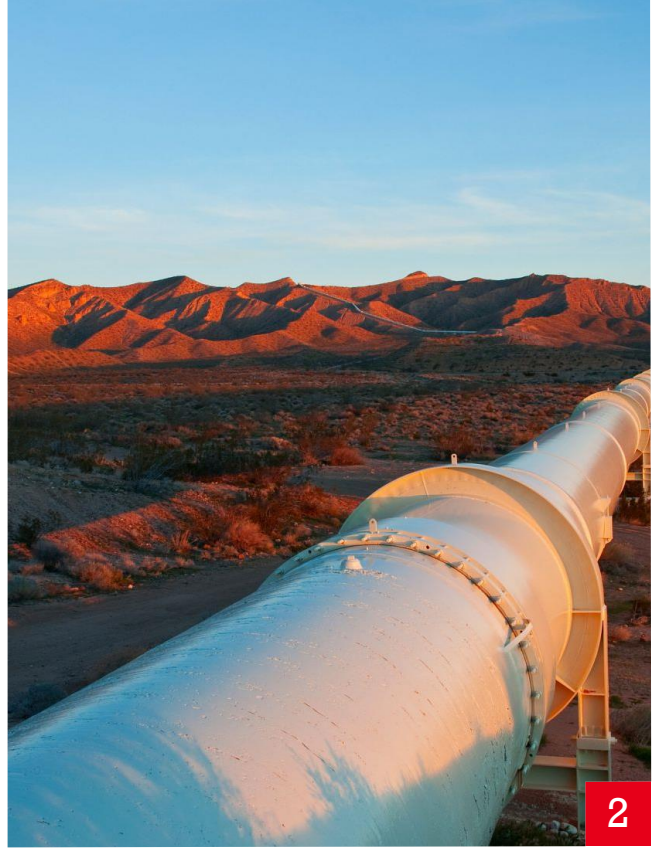


INSTRUMENTATION & CONTROL OF ASSETS

1 Sensors and system integration

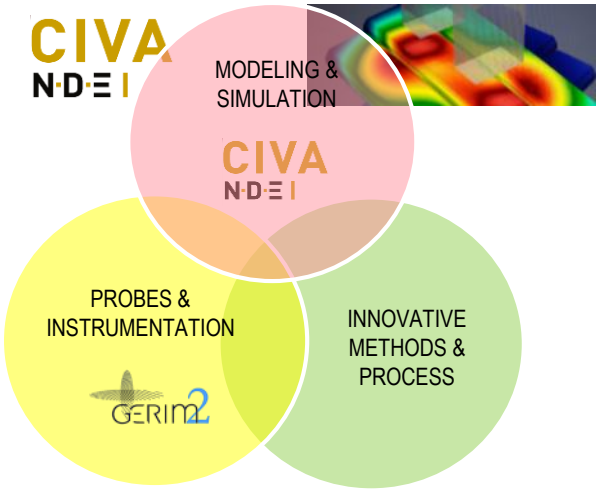
2 **Non destructive testing**





TECHNOLOGY

NON-DESTRUCTIVE TESTING



Success stories

TechnipFMC

Key Features

- Numerical tools & simulation : Simulation, POD (Probability of detection), Imaging, data analysis & automatic diagnosis (AI for NDT), Optimization tools , Assisted NDT for operators (AR/VR)
- Instrumentation NDT : Flexible and adaptative sensors, embedded processing, real time imaging, Robotized NDT
- Technologies : Ultra-Sound, Eddy Current Testing, X-Ray, XR/CT, InfraRed Testing

Assets

- Improving detection systems, developing embedded instrumentation and innovative solutions
- Modelling abilities possible with a powerful tool (CIVA) used in more than 40 countries
- Data analysis & diagnosis

SUCCESS STORY

USING ULTRASOUND FOR OIL & GAZ MONITORING

- Evolving of current standard for the qualification of UT AUT inspection in the Oil & Gas industry
- Develop and promote simulation tools for qualification or validation of AUT inspection of welds according to evolving standards
- Collaboration with third parties DNVGL JIP to get recognition of AUT simulation
- Providing a CIVA AUT Oil & Gas module for AUT (Automatic UltraSonic Testing)

SUCCESS STORY

AUTOMATIC DIAGNOSIS FOR WELDING MONITORING

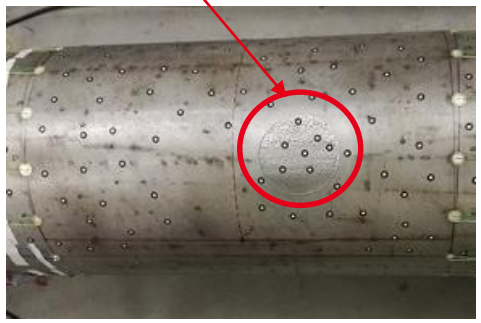
- Automation of the diagnosis of ultrasonic welds of an offshore wind farm
- Automatic generation of inspection reports
- Increased productivity and reliability
- Manual analysis: several months
- Automatic analysis: one day

SUCCESS STORY

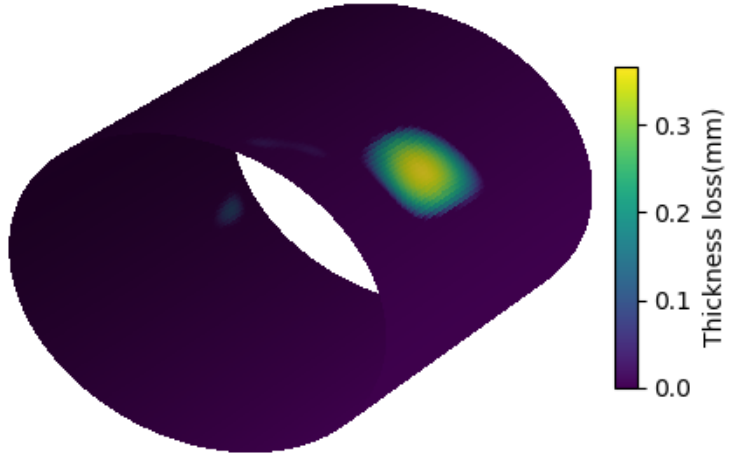
PIPE THICKNESS MAPPING IN THE ENERGY SECTOR

- Continuous monitoring of metal piping to detect and monitor corrosion
- Passive system based on the exploitation of ambient noise and ultrasonic guided waves
- Measurements obtained using two receiver rings
- Reconstruction of the thickness map (Passive Tomography)

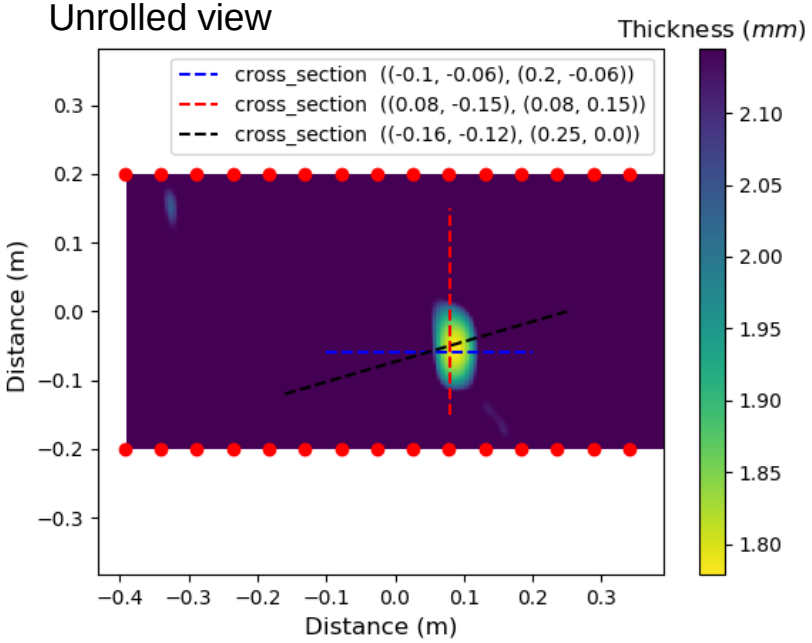
Electrolysis-induced corrosion



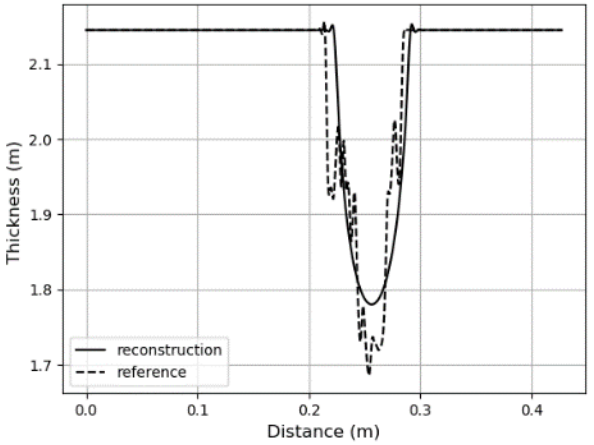
Passive reconstruction



Unrolled view



Cross section



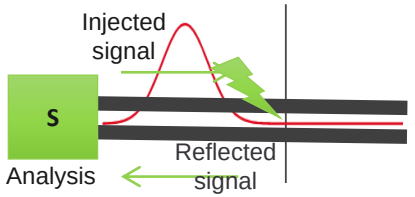
TECHNOLOGY

NON-DESTRUCTIVE ELECTRICAL MAINTENANCE (REFLECTOMETRY & TRANSFEROMETRY)

Key Feature

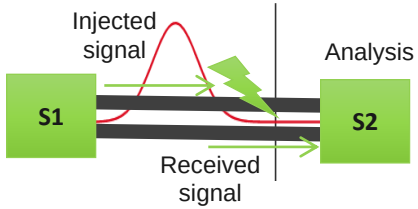
- **A specific test signal is injected down the cable:**
  - **Reflectometry:** reflected echoes at each fault are recordered for data analysis
  - **Transferometry:** transmitted signals are recordered for data analysis.
- **Applications:** electrical cable diagnosis, cable/fault characterisation, ageing monitoring, network topology reconstruction, environment health monitoring, structures health monitoring, hardware integration

Reflectometry



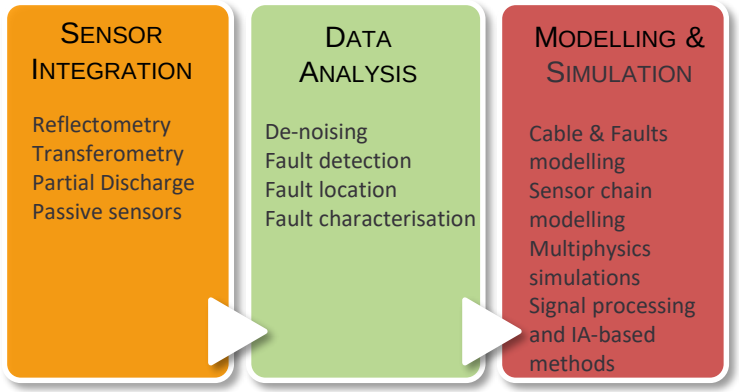
DEFECT

Transferometry



Asset

- Embedded diagnosis (i.e. electronic board, chip, etc.).
- Cable monitoring in real time with respect to EMC constraints.
- Detection even in hard-to-access areas
- Numerical tools & simulation to evaluate the performance of the reflectometry in different configurations (based on simulation/experimentation).
- **Reflectometry** : Enables fault detection and location even when the system is off
- **Transferometry** : Permits to overcome the signal attenuation in long cables and to monitor the cable aging



Success stories

- **Electrical wiring systems troubleshooting, testing & monitoring**

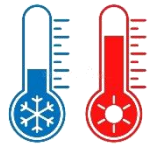
WiNMS Nexans TechnipFMC socomec Innovative Power Solutions

TECHNOLOGY

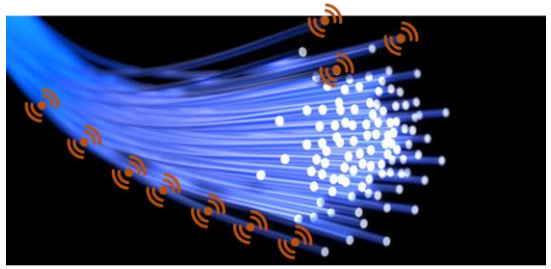
HEALTH MONITORING (THROUGH OPTICAL FIBER SENSORS)

Key Features

- **Development of Optical Fibers sensors and laser processes allowing multiple, distributed sensing along a single fiber, over small or large distances, even in harsh environments (high T°, cryogenic, high Pressure, radiation, submarine…)**
- Non-destructive testing through Optical Fiber Multiplexed Bragg gratings
- Example of applications :
- Pipe monitoring, pressure measurement without tapping for existing or new Oil & Gas installations, in liquid or gas ; erosion measurement in submarine parts
- Fiber optic embedded in composite materials for life monitoring of Hydrogen tank



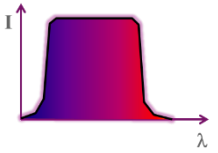
Temperature
4K – 1400K



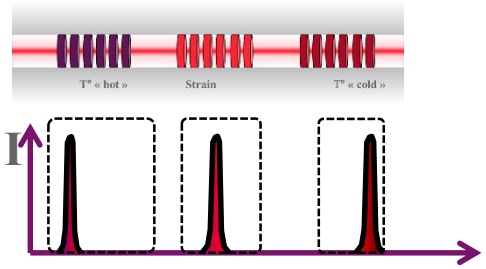
Wavelength multiplexed Bragg gratings

Assets

- **Sensors are engraved along the fiber through the protective sheath using a cutting edge CEA laser process, ensuring both high mechanical and thermal resistance**
- Wide range of techniques available allowing for instance discrimination of temperature & strain



$$\frac{\Delta\lambda_B}{\lambda_B} = a\Delta T + b\frac{\Delta L}{L} + c\Delta P$$



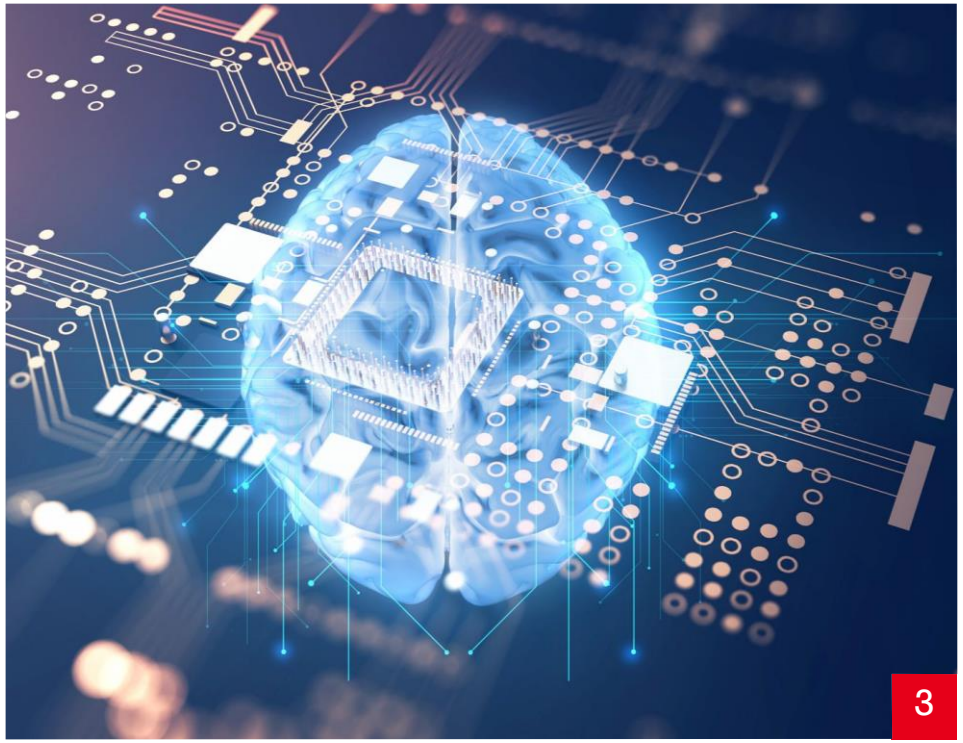
DATA, AI & DIGITAL TWIN

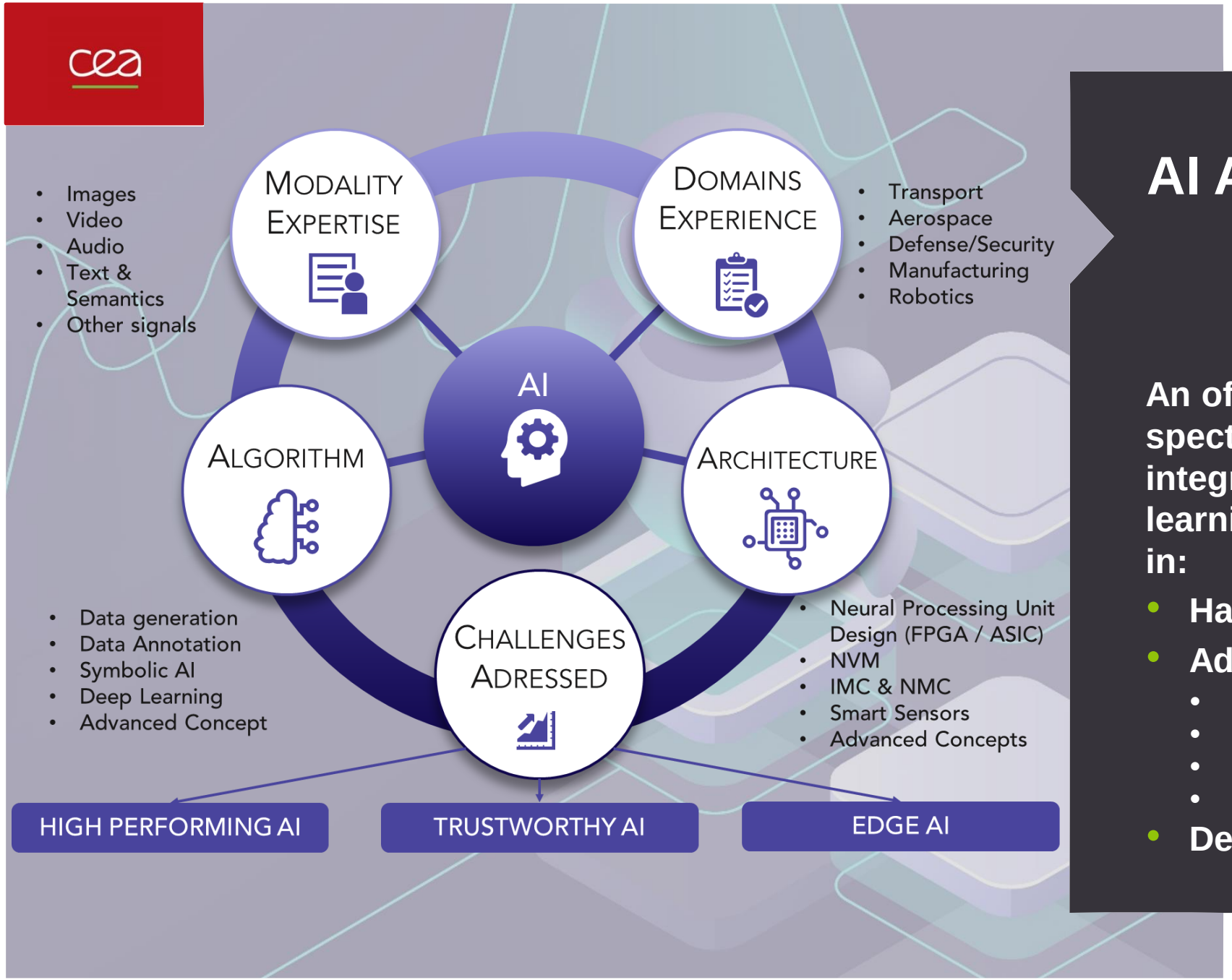
1 For asset management

2 For Complex system optimization

3 For Decision making

4 For Prediction





AI AT CEA

An offer that covers the whole spectrum, from algorithm to its integration. Indeed, CEA own deep learning tools, and is also expert in:

- **Hardware design**
- **Advanced Implementation**
  - RRAM synapses
  - 3D stacking
  - Mixed A/D design
  - FDSOI 28nm
- **Deep learning Research**

DATA, AI & DIGITAL TWIN

1 For asset management

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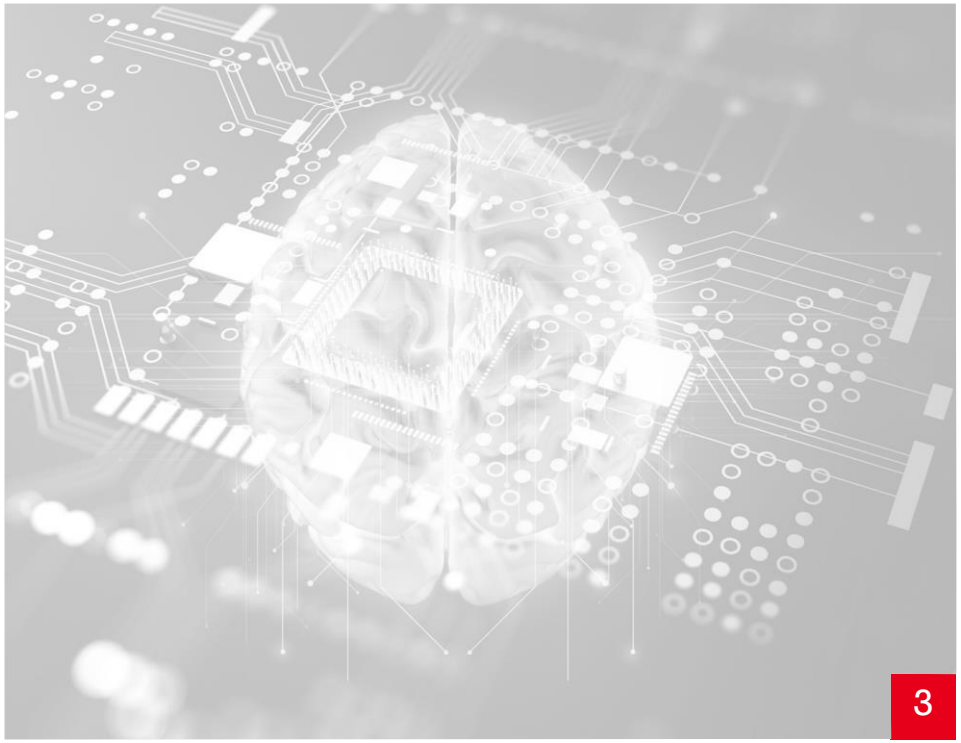


SUCCESS STORY

COMPUTER VISION

Mastering the entire value chain of machine vision

- Proprietary solutions
- 70 Scientists to tailor solutions meeting industry challenges
- Smart data annotation
- For waste management: item segmentation and classification
- Default inspection on power electric

Partenariat confidentiel

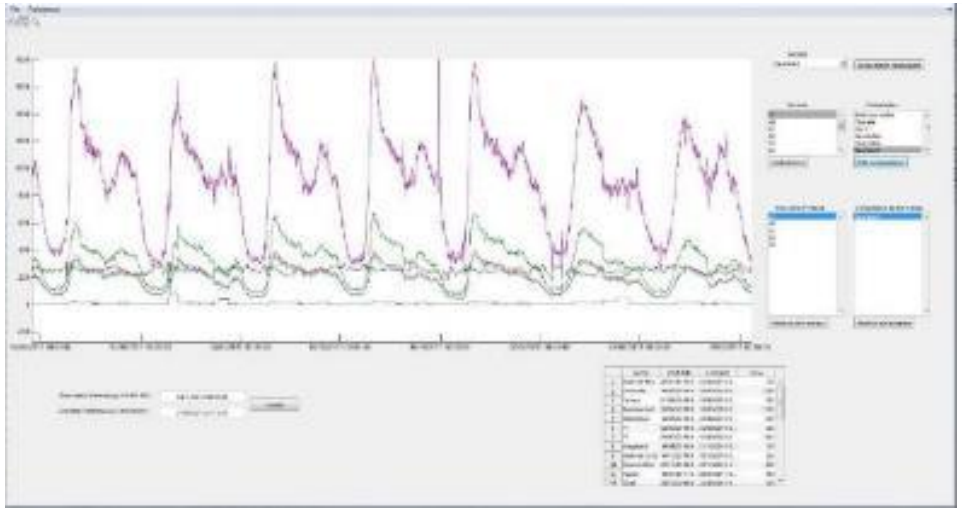
SUCCESS STORY

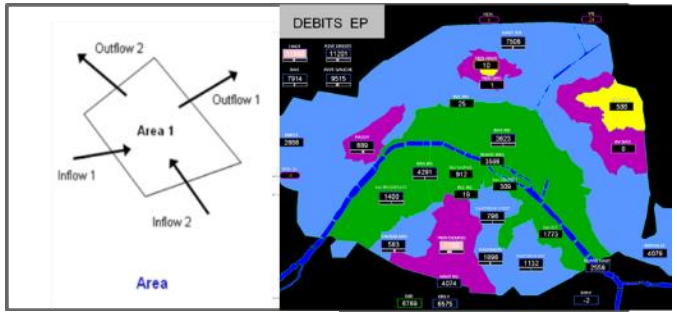
NETWORK PIPELINES INSTRUMENTED FOR LEAK DETECTION

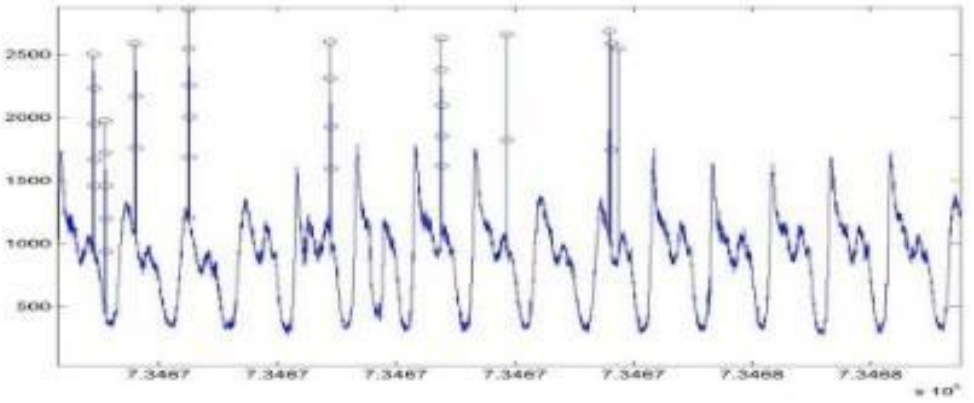
Implementation of a real-time monitoring and alerting tool for smart network management

Approach implemented :

- **Signal processing for data cleaning**
- **Statistical modelling and machine learning for the detection of anomalies**
- **Confrontation with contextual data**







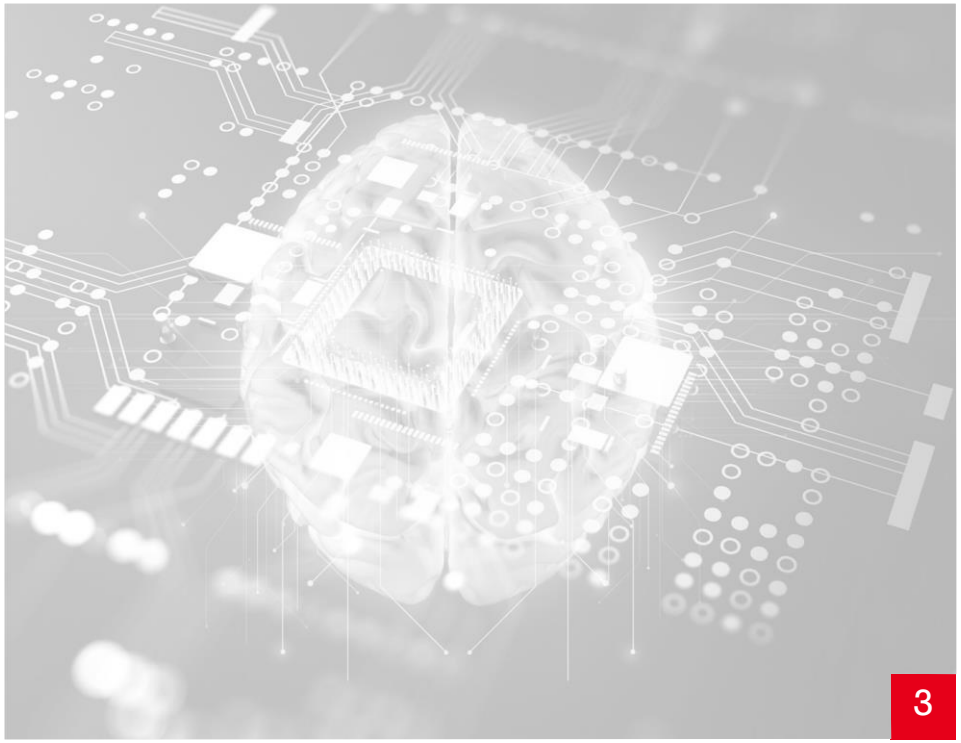
DATA, AI & DIGITAL TWIN

1 For asset management

2 **For Complex system optimization**

3 For Decision making

4 For Prediction



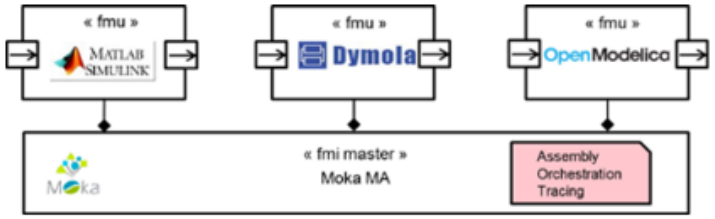
TECHNOLOGY

DIGITAL TWIN
(FOR ENERGY GRIDS)

Key Features

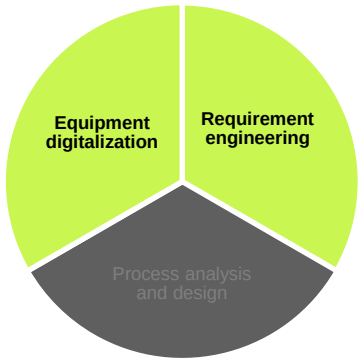
- Simulate & optimize complex systems
- System verification assessments
- Monitoring (supervision at real time)
- Safety and security analyses
- Grid System architecture modeling
- Interface with equipement models & simulator
- Global Simulation orchestration

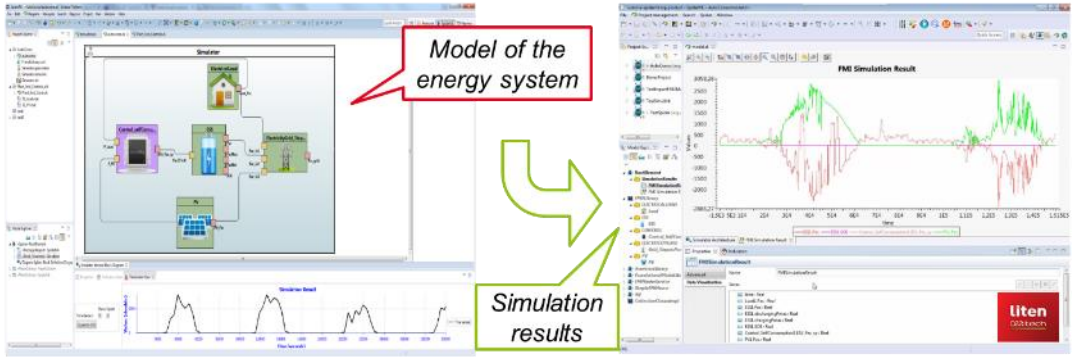
Cosimulate the heterogeneous models



Assets

- Open and flexible modelling platform
- Can be easily customized to fit in specific application
  Highly modular tool architecture





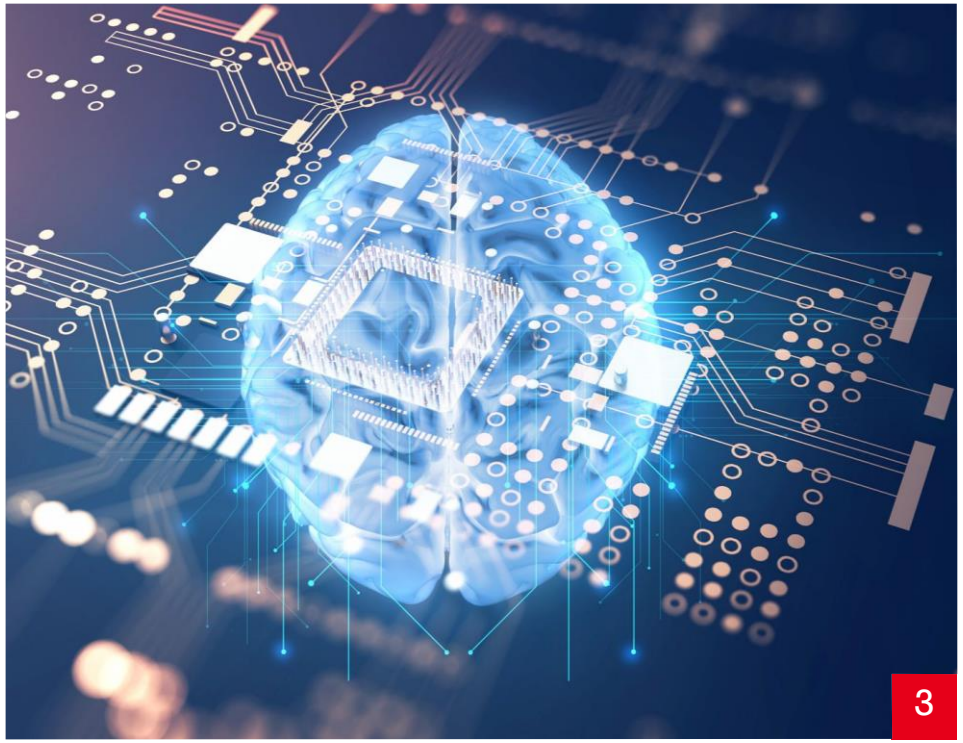
DATA, AI & DIGITAL TWIN

1 For asset management

2 For Complex system optimization

3 **For Decision making**

4 For Prediction

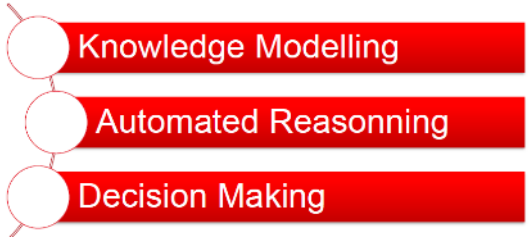


TECHNOLOGY

EXPERT SYSTEM (EXPRESSIF®)

Key features

- Expert system for Knowledge modelling
- Automated reasoning for decision making
- Application : Increasing the chance of relevant excavation for underground gas network pipe maintenance
  - In situ measurment of network data
  - Risk assessment
  - Development of the 300 rules
  - Optimizing rules
  - Development of an Human-Computer interaction system
  - Reasoned evaluation of Risk assemment
  - Rules modifications



Asset

- Less data needed than for machine learning (digital frugality)
- Explanability of decision
- **5 –fold increase of real positive**

Success story

TERĒGA
GAS, ACCELERATING THE FUTURE

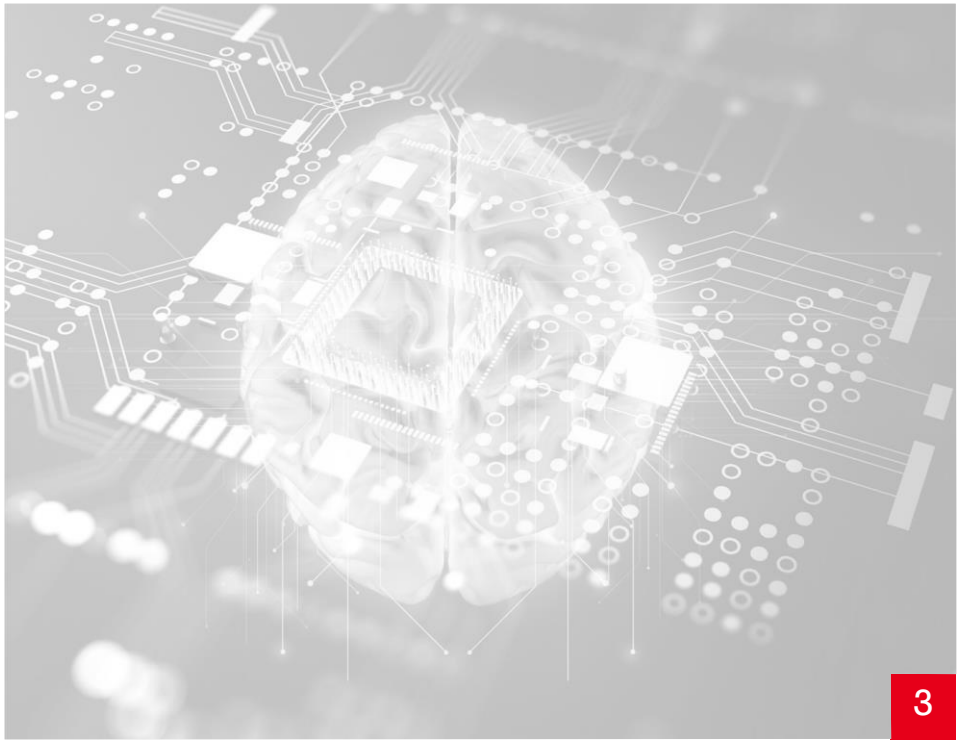
DATA, AI & DIGITAL TWIN

1 For asset management

2 For Complex system optimization

3 For Decision making

4 **For Prediction**



SUCCESS STORY

E-FLUID : IMPROVE THE PREDICTION SOFTWARE

Integration of human rhythms (public holidays, school vacations) and weather conditions for forecasting electricity consumption:

- **Improved performances for 92% of customers**
- **Forecast improvement by 15% on average with a significant financial impact on the managed population**

Load curve example

CYBERSECURITY

CYBERSECURITY AT CEA*

A **research** driven by a strong understanding of **critical infrastructures** cybersecurity

A **technological** and a **scientific** expertise known internationally for more than **20 years**

A central place as a recognized **trust actor** within French Ecosystem, with strong links with **local authorities**

Management of **strategic** programs in **France** and in **Europe**

PLATFORM

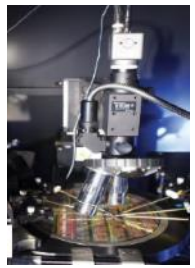
CYBERSECURITY METHODS & PLATFORMS

Critical function and data security enhancement

A proven methodology pour master complexity and interdisciplinarity

Threat analysis → Proof-of-concept → Validation → Transfer

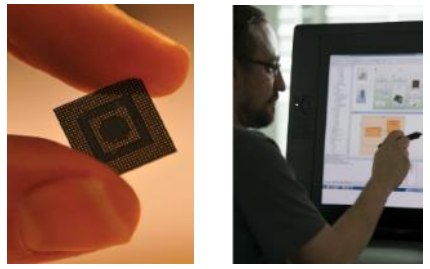
State-of-the-art technological platforms



Cybersecurity

200 & 300 mm microsystems

Chip design



Software & system engineering

Critical system design

Infrastructure supervision

Smartgrid

TECHNOLOGY

HARDWARE
VULNERABILITIES IDENTIFICATION

Key Features

- Conformity analysis of critical hardware
- Penetration test with beyond state-of-the-art attack Benches : invasive, fault injection, side-channels, software
- Characterisation tool to validate embedded systems security

Integrated circuits and hardware components
Common Criteria up to EAL7

TECHNOLOGY

SOFTWARE

VULNERABILITIES IDENTIFICATION

Key Features

- Next generation code-auditing tools
- Automated analysis platforms based on advanced reasoning, providing mathematics-based security proofs
- Deep code verifications based on advanced reasoning embed strong mathematical assurances within software development lifecycles
- Frama-C is used across CEA, and in software production processes across numerous industrial domains (transportation, energy, telecoms, industry, defense, …)

frama C

Software Analyzers

PLATFORM

WONDERICS

SECURE INDUSTRIAL IOT (IIOT) PLATFORM

Key Features

- Simulation & demonstration platform of an Industrial Control System
- Demonstration of attacks
- Testing efficiency of countermeasures at device level

TECHNOLOGY

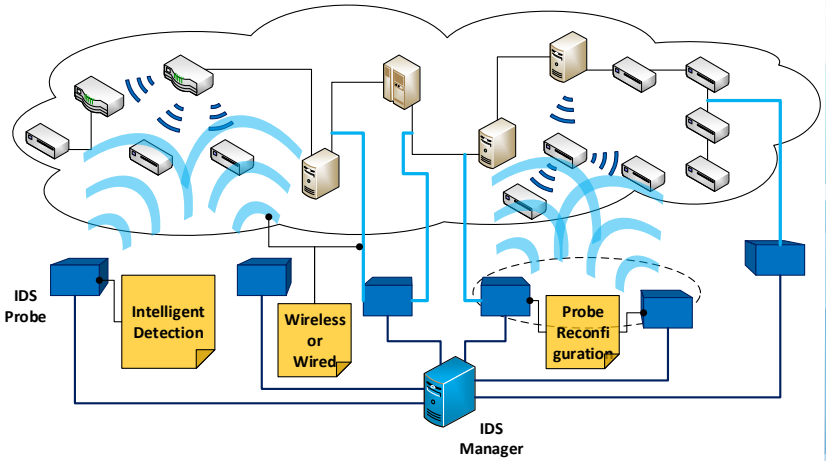
SIGMO-IDS

ANOMALY-BASED NETWORK INTRUSION DETECTION & REACTION

Key Features

- Cognitive System for Network Intrusion Detection & Reaction (IDS) tailored to industrial applications
  - Neural-network –based “protocol-aware” intrusion detection at each probe
  - Orchestration of the overall (multi-probe) detection function, always fitted to the current context
  - DN-based control of the IDS probes
  - Dynamic reconfiguration of the network to counter the detected threats

- Implementations targeting multiple applications
  - Wireless IoT: 6LoWPAN, Zigbee, Thread, LoRA, BLE
  - Smart Grid: IEC 60870
  - Industry 4.0: OPC-UA



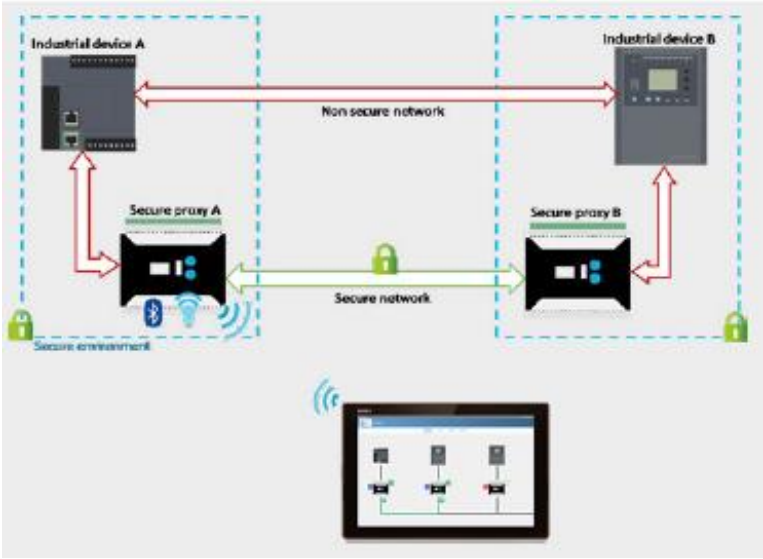
TECHNOLOGY

ARGOS

RETHINK AND SIMPLIFY SECURE INDUSTRIAL IOT (IIOT) DEPLOYMENT

Key Features

- a 3-in-1 solution to improve manageability, sustainability and ergonomics
  - A **secure proxy** for securing existing industrial networks initially based on insecure communication protocols, limiting attacks through service denial & detecting attacks in real time
  - A **supervision solution** with secured end to end communication protocol, a simplified deployment of a configuration in an IIOT network via a mobile phone.
  - **“Hardware in the loop**” architecture integrating simulation of industrial processes and specific attacks.



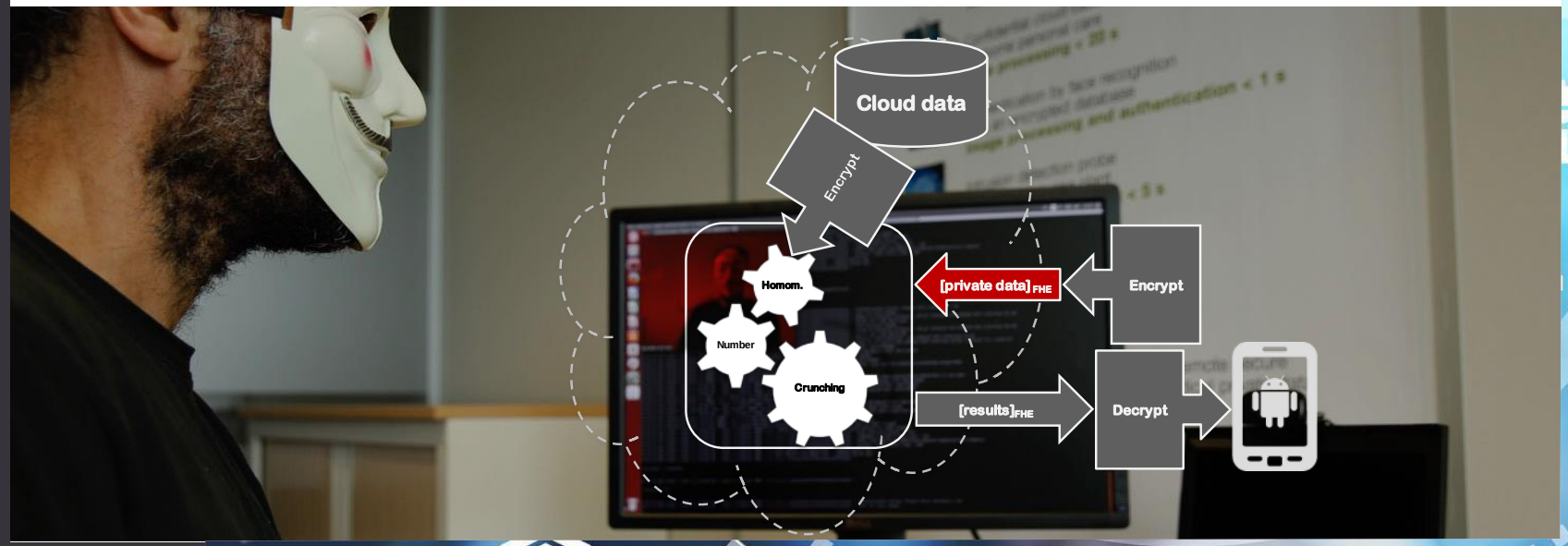
TECHNOLOGY

CINGULATA

TOOLCHAIN, ENABLING END-TO-END ENCRYPTION

Key Features

- Help software developers integrate homomorphic encryption techniques in their apps. Optimize the performance of these operations
- The world's leading compilation toolchain is developed at CEA, allowing engineers to optimize and deploy homomorphic cryptography in real-world applications
- CEA Teams have breached sub-second trans-cyphering capabilities, an essential step for homomorphic deployments to interoperate with legacy environments



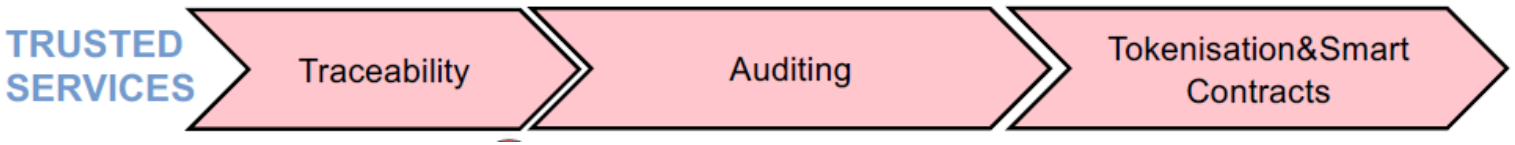
TECHNOLOGY

TRUSTED LEDGERS

FOR DATA AND SERVICE INTEGRITY

Key Features

- Distributed cryptographic protocol enable tamper-proof and undeniable registration of transactions
- Gaining trust in secure distributed protocols
- Design new protocols
- Prototyping trusted service



MAX
MULTI AGENT EXPERIMENTER

KEY PARTNERSHIPS

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COMPONENT PROVIDERS

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