H_2 RESEARCH ACTIVITIES AT CENER

HyGrIn Lab
Innovation for Green Hydrogen

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WHO

What is CENER

CENER, the **National Renewable Energy Centre of Spain**, develops applied research in renewable energies, and provides technological support to companies and energy institutions.

Our mission

To generate knowledge in the renewable energy field and to transfer it to the industry in order to boost sustainable energy development.

Our vision

To be a research centre of excellence in the renewable energies field with international outreach.

BOARD OF **TRUSTEES**

Spanish Ministry of Science & Innovation
Ministry for the Ecological Transition & Demographic Challenge
Regional Government of Navarre
Ciemat

OFFICES

Headquarters at Sarriguren (Spain)
Sangüesa (Spain)
Aoiz (Spain)
Seville (Spain)

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Infrastructures

Headquarters
Sarriguren

Biorefinery and Bioenergy Centre BIO2C - Aoiz

Experimental Wind Farm
Alaiz

Solar Testing Field -
Imarcoain

Wind Turbine Laboratory
HyGrin Lab
ATENEA Microgrid -
Sangüesa

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Figures

100M€ Infrastructures investment

240 Staff employed

20 M€ Income

> 1000 Clients around the world five continents

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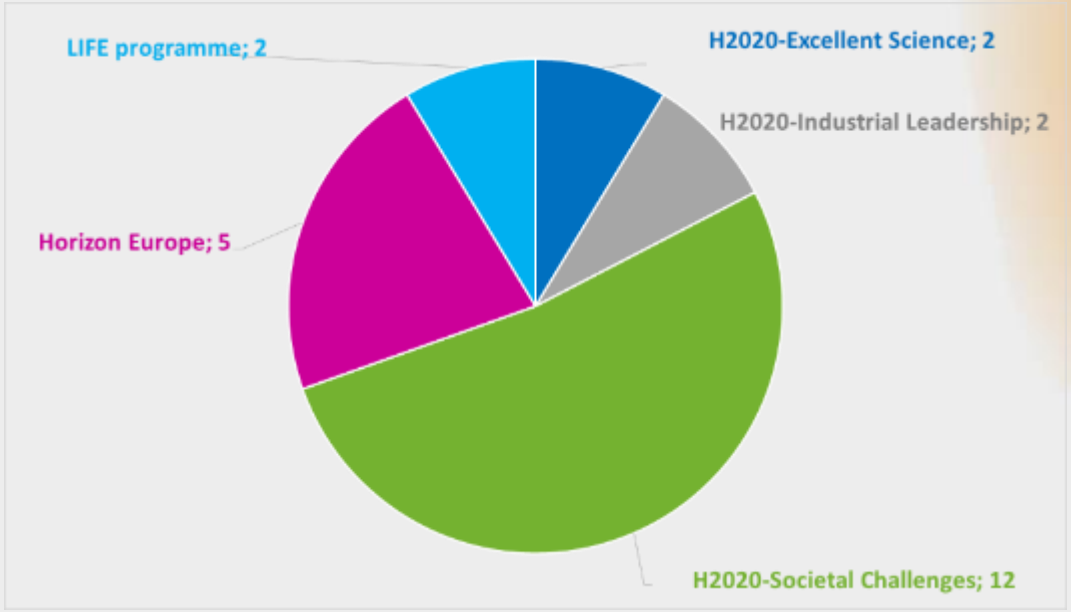
Flow income from activities

Commercial projects

Competitive public funding

Non competitive public funding

23 European projects in the last 5 years (17 ongoing)



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Research areas

ENERGY IN BUILDINGS

BIOMASS

WIND ENERGY

GRID INTEGRATION, ELECTRICAL STORAGE AND HYDROGEN

SOLAR ENERGY TECHNOLOGIES AND STORAGE

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H_2 HYDROGEN AREA (HyGrIn Lab)

Hydrogen can be considered as an **energy vector** for achieving European Green Deal objectives (Net-zero emissions by 2050):

- Contribute to increase renewable energy production
- Enhance system flexibility, through the storage and conversion of energy.
- Be a reliable solution for hard-to-abate sectors

GREEN HYDROGEN **(**produced from **renewable energy), contributes to decarbonization goals in opposition to** standard production of grey or blue H_2 from fossil fuels

H_2 Research

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Participation in Committees (Hydrogen)

Asociación Española de Hidrógeno

European Clean Hydrogen Alliance

Clean Hydrogen Partnership

European Platform of Technology and Innovation on Smart Grids for the Green Transition

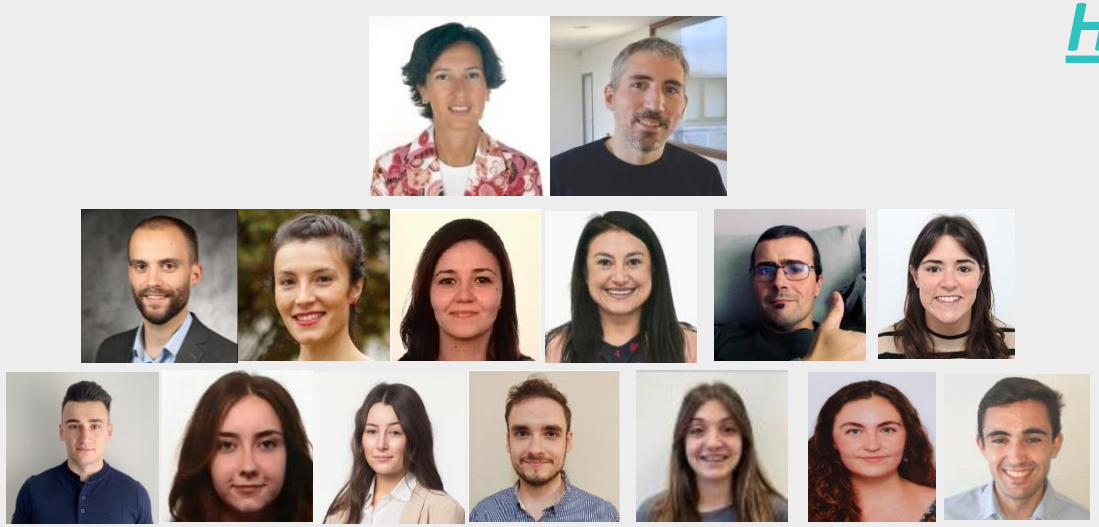
Plataforma Tecnológica Española del Hidrógeno y las Pilas de Combustible

IEA Hydrogen Technology Collaboration Program.
("Renewable Hydrogen" task)

European Energy Research Alliance on Fuel Cells and Hydrogen

European Alliance for Energy Research on Sustainable Bioenergy

European Technological and Innovation Platform on Bioenergy



HyGrIn Lab Team

Head of department: Mónica Aguado, PhD
Manager: Iñigo Garbayo, PhD
Research team:

- **6 senior researchers (PhD) (1 innovation technician)**
- **2 Industrial engineer**
- **4 junior researchers**
- **1 technician**

Mónica Aguado

ORCID: 0000-0002-0349-7011
Ph.D. in Industrial Engineering at Public University of Navarre (2000)
> 25 years of experience in research and engineering.
Associate Professor at the Electric Engineering Department in the Public University of Navarra (UPNA)
Area of expertise: Power Electrical Systems and Renewable Energies.
Main contributions:
> 35 articles
> 70 conferences
2 patents
National and international projects (public/private)
Participation in national and international expert groups and committees
Expert evaluator in national and international evaluation processes.
Mentor in several programs for promoting STEM careers.

Iñigo Garbayo

ORCID: 0000-0003-2494-173X
Ph.D. in Nanoscience (2013) from the University of Barcelona
> 10 years of experience as researcher.
Area of expertise: Materials for energy, electrochemical energy conversion and storage devices.
Research experience at IREC (ES), DTU Energy (DK), ETH Zürich (CH), CIC energiGUNE (ES).
Main contributions:
> 25 articles
> 50 conferences
4 patents
Participation in national and international projects (public/private)
Expert evaluator in international evaluation processes.

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CENER activities in H_2

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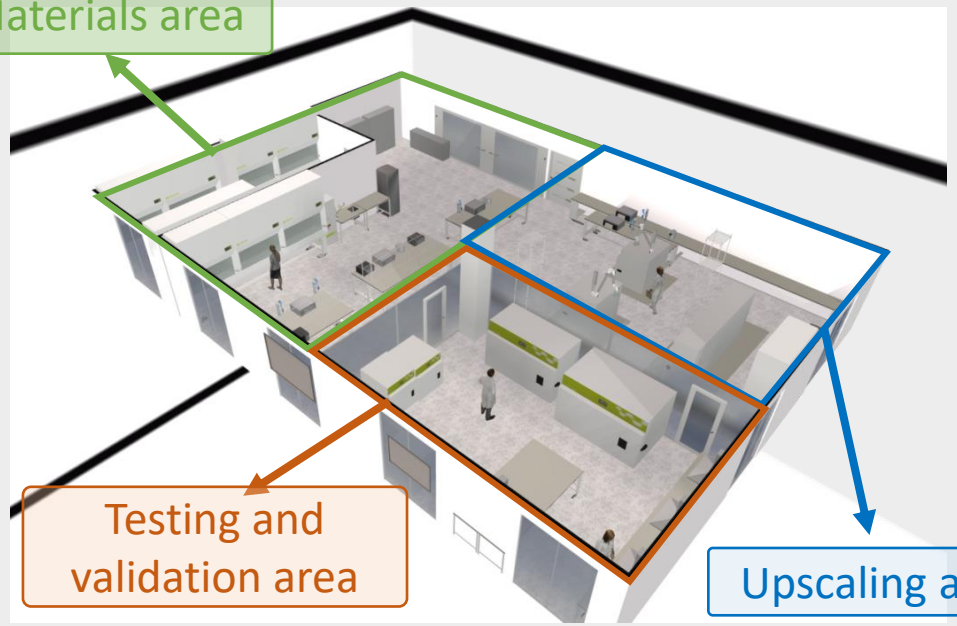
The infrastructures



300 m² lab space in Sangüesa (NA, Spain)

- Inks & slurries formulation and production
- Lab-scale cell fabrication
- Structural and mechanical characterization

- Cell batch production (roll-to-roll)
- Stack design & fabrication (up to kW-scale)

- Cell & stack electrochemical testing, from lab-scale up to 5 kW

Additional facilities:

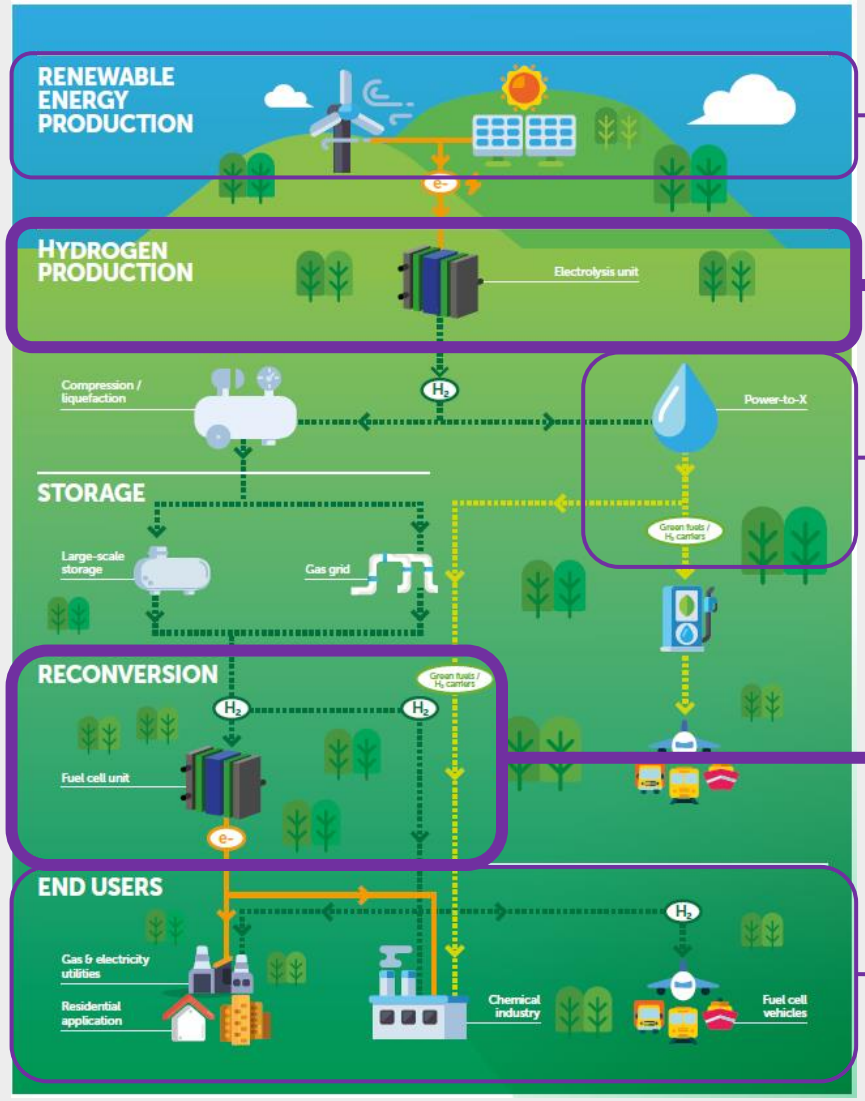
Modelling hub

- 80 cores.
- 512 Gb RAM.
- 56 Gb GPU.

ATENEA microgrid

- 25 kWp PV.
- 20 kW wind turbine.
- 55 kVA diesel-driven generating set.
- > 100 kW Battery (different technologies).
- 70 kW alkaline electrolyzer.

HyGrIn Lab-WHAT WE DO (H_2 VALUE CHAIN)



Coupling of H_2 production with renewables

Solid Oxide Electrolysis Cells (SOEC)

E-fuels, Green Ammonia, etc

Solid Oxide Fuel Cells (SOFC)

Smart Integral Systems (EMS, Smart Grids, H_2 integration)

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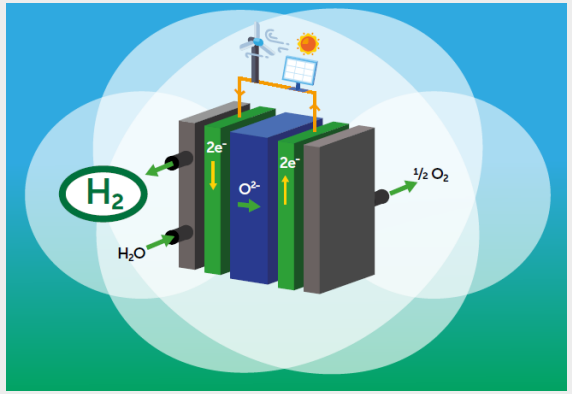
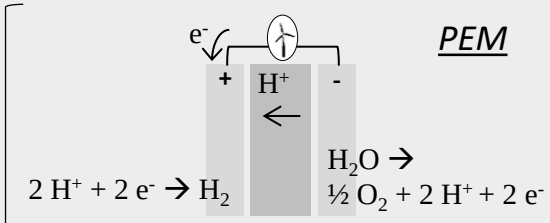
SOEC at a glance: water electrolysis

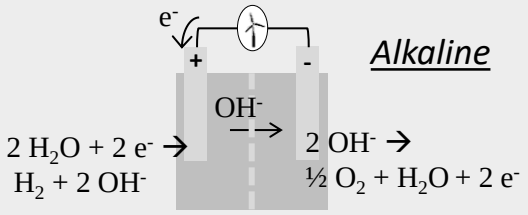
High temperature, > 650 ºC

Low temperature, < 150 ºC

SOEC







SWOT

Strenghts

- Reversibility SOFC/SOEC: *possibility of operation in fuel cell mode*
- High efficiency: *favoured thermodynamics and kinetics*
- Fuel flexibility: *generation of CO from CO_2, or co-electrolysis of CO_2+H_2O to produce syngas)*
- Raw materials availability: *ceramics and cermets vs precious metals*

Weakness

- High temperature operation : heat source required
- Materials degradation due to high temperatures
- R&D still needed

Opportunities

- Few relevant SOEC stack manufacturers in EU (*no presence in Spain*)
- No big scale production: *prototypes in the kW range*

Threads

- Competence from other technologies: *both consolidated (alkaline, PEM) and maturing (Anion Exchange Membrane)*
- New developments from non-EU regions (USA, China)

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Solid Oxide Electrolysis Cells (SOEC)

PPCC-SOEC

Plan Complementario de Energía e Hidrógeno Renovable: Desarrollo de electrolizadores de alta temperatura SOEC

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Financiado por la Unión Europea NextGenerationEU
Europako Batasunak Finantzatua NextGenerationEU
ESPAÑA PUEDE

VALIDSOEC

Desarrollo de Electrolizadores de Óxido Sólido Avanzados: Validación del Sistema e Integración de Nuevos Materiales en Dispositivos Comercializables

Agencia Estatal de Investigación
ESPAÑA PUEDE

COMECOCO2

Producción eficiente de COmbustible verde para transporte Marítimo Empleando CO-electrólisis de CO2 capturado en estaciones depuradoras de aguas residuales

Agencia Estatal de Investigación
CDTI MISIONES
TransMisiones 2024

GACSOEC

Solución integral de tratamiento para el empleo de fuentes de agua no convencionales en electrolizadores SOEC

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STACKSTAMP

Nuevos elementos competitivos y robustos para la fabricación de stacks de electrolizadores SOEC

GREENSEAL

Nuevos procesos de fabricación de sellantes mediante impresión funcional para electrolizadores de altas prestaciones

SISTEMA NAVARRO DE I+D+i SINAI NAFARROAKO I+G+b SISTEMA
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H2ON

Celdas de electrólisis SOEC mejoradas mediante la implementación de nanopartículas cerámicas para la producción eficiente de hidrógeno renovable

Solid Oxide Fuel Cells (SOFC)

SOFC4GreenGrID

Desarrollo e integración de pilas de combustible de óxido sólido en microrredes basadas en hidrógeno verde

CDTI MISIONES

SOFCOMPACT

Fabricación de pilas de combustible SOFC de mayor eficiencia, mediante la disminución de la utilización de materiales críticos, aumento de dimensiones de las celdas planares y sistema inteligente de control de stacks y del sistema final.

PERTE de Energías Renovables, Hidrógeno Renovable y Almacenamiento

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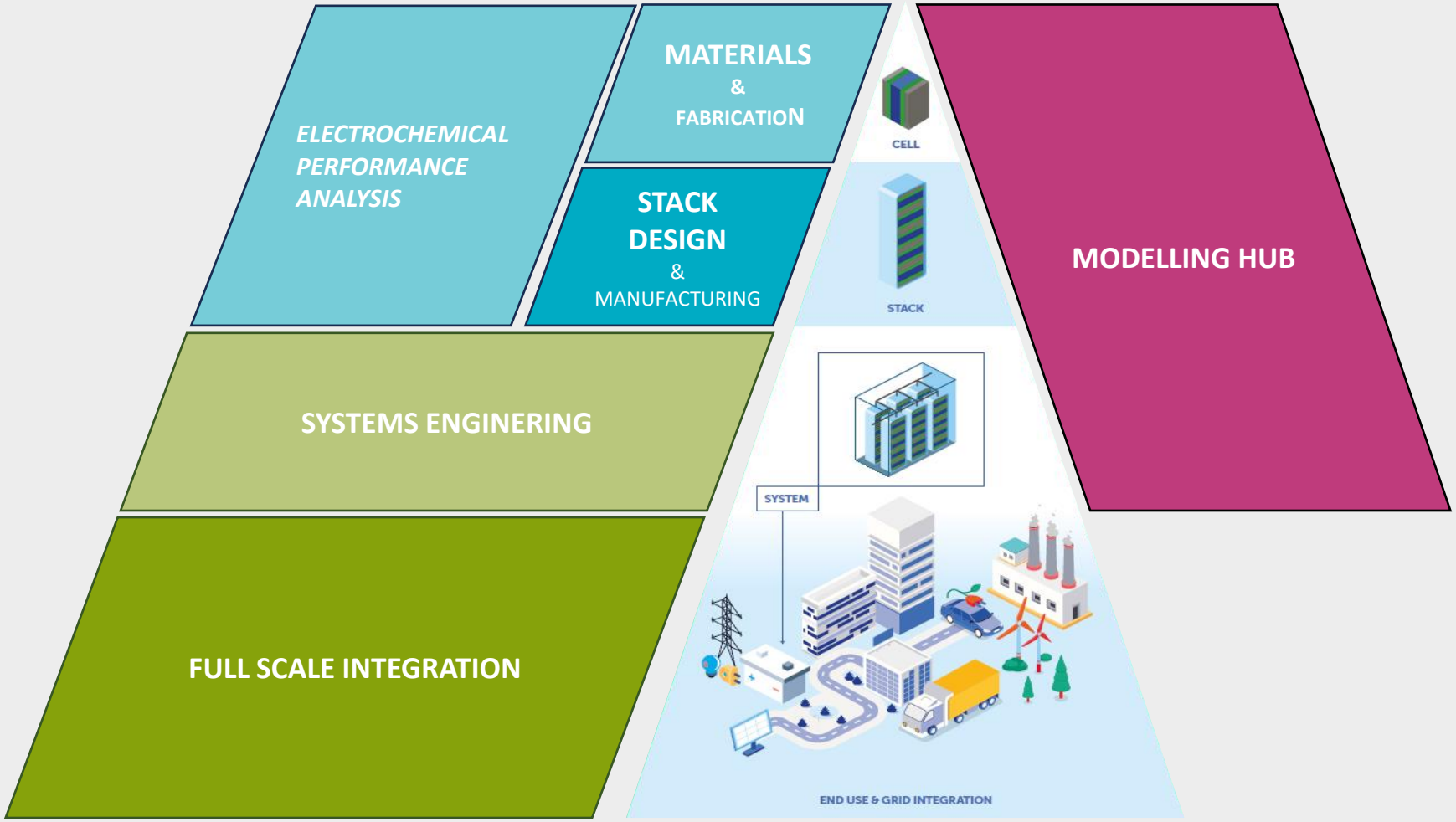
The Research lines



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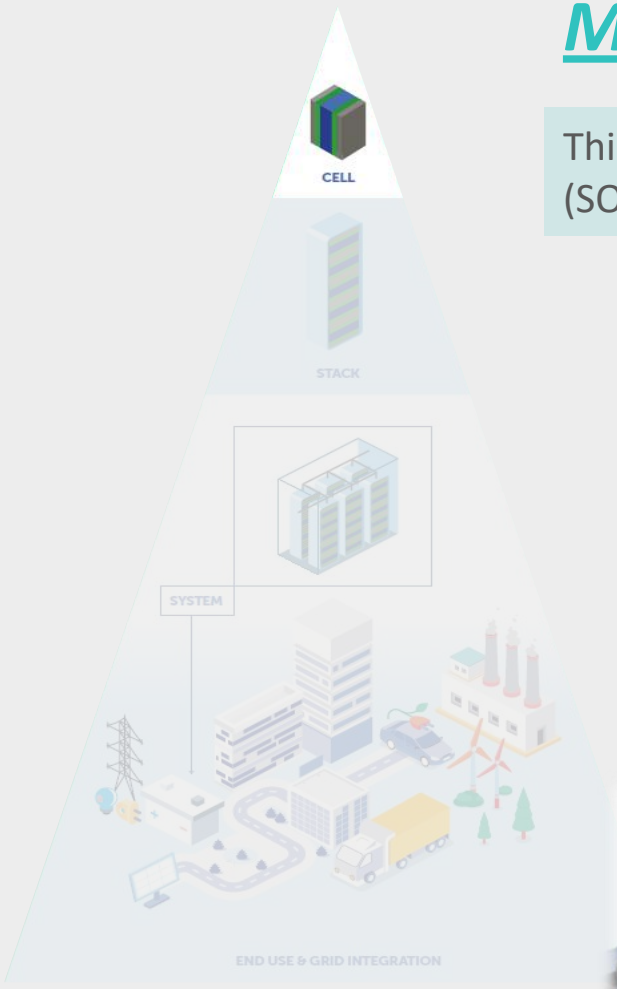
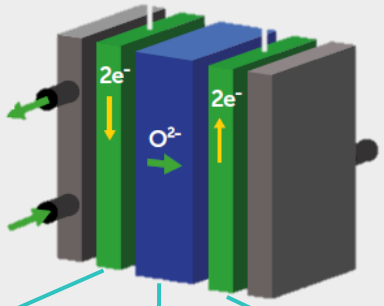


Materials and fabrication

This line focuses on the **fabrication of materials and components** for **solid state electrolysers** (SOEC) and **fuel cells** (SOFC) by scalable routes.



Fuel Electrode
Cermet

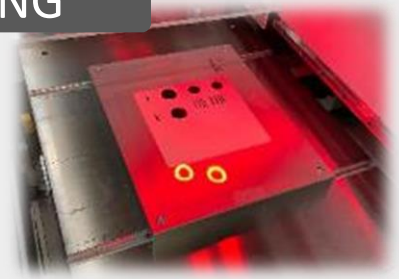
Electrolyte
Ceramic

Oxygen Electrode
Ceramic

TAPE CASTING

SCREEN PRINTING

DRYING & SINTERING



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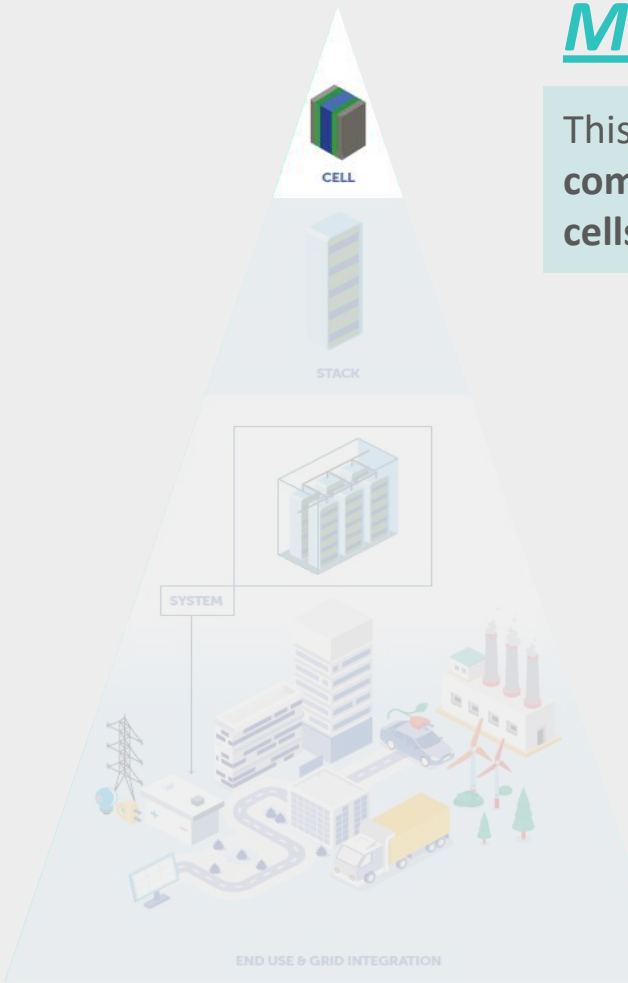
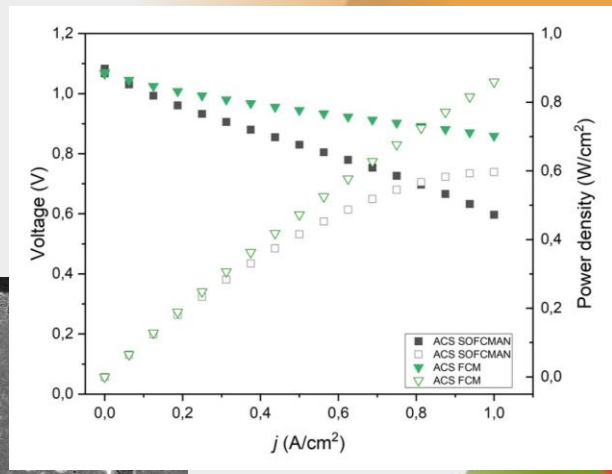


Materials and fabrication

This line focuses on the **fabrication of materials and components** for **solid state electrolysers** (SOEC) and **fuel cells** (SOFC) by scalable routes.

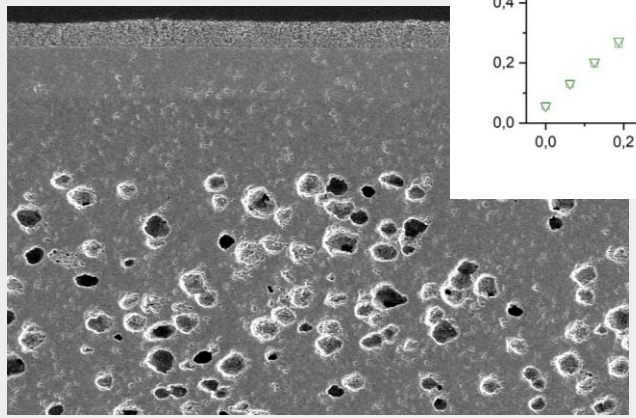
Cells fabrication

- *From lab-scale to **pilot plant** (batch production)*
- *Inks & slurries formulation*
- *Functional printing*
- *Full structural and electrochemical characterization*



Equipment

- HT furnaces (1700ºC)
- Screen printing
- Ball milling & ceramic processing eqpt.
- Tape casting
- Tape casting, semi-automatic
- Welding, cutting & processing eqpt.
- Particle size
- X-Ray Diffraction
- Optical microscopy
- Optic profilometer
- Viscosimeter
- SEM



Back (Research Lines)

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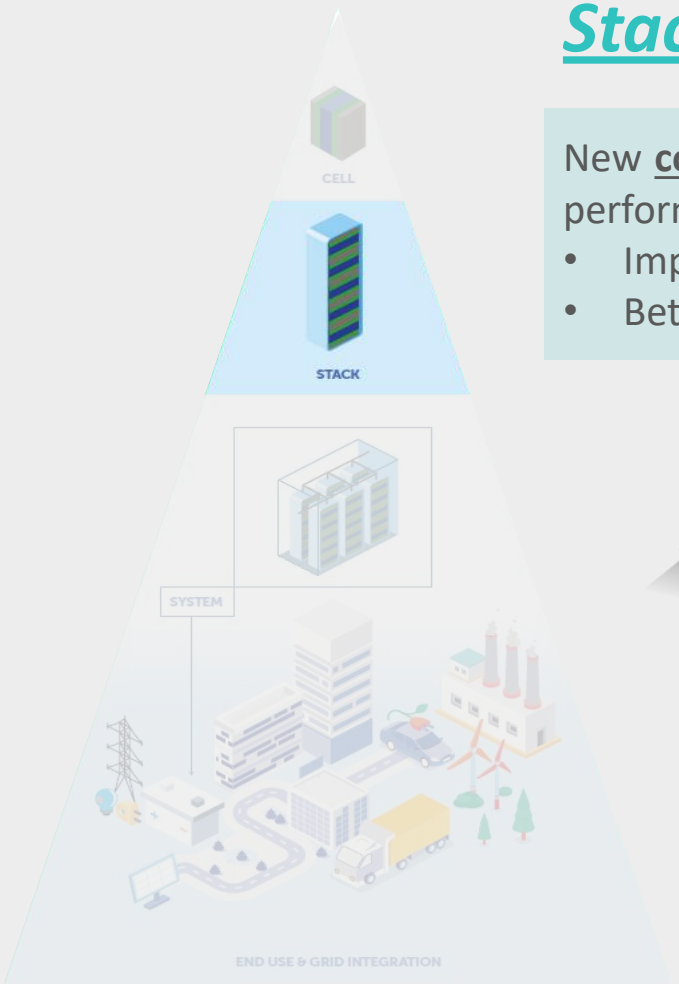


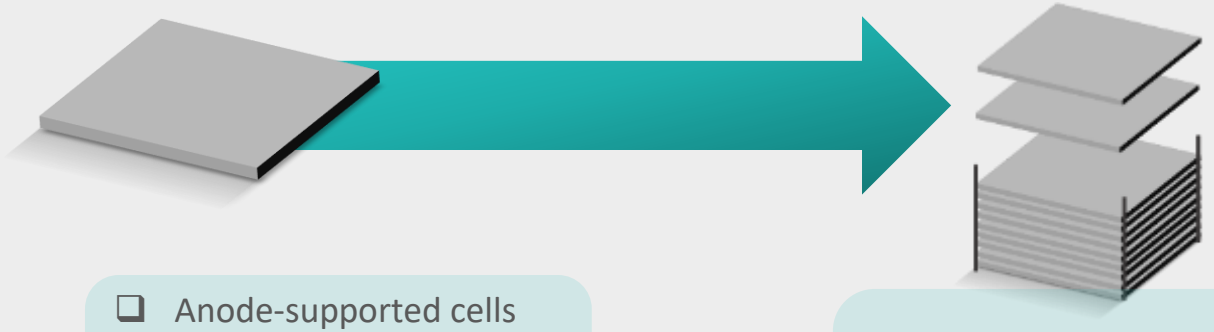
Stack design and manufacturing

New **configurations and components for stacks and full systems**, looking for optimizing their performance. Some examples are:

- Improvement of water/H_2 distribution through new distributions.
- Better heat control (minimization of "hot spots", overall reduction of generated heat).

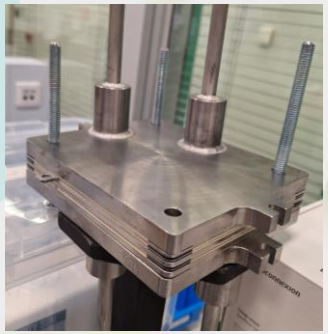
UNIT CELL

STACK



- ❑ Anode-supported cells
- ❑ Sizes up to ~10x10 cm^2
- ❑ Different materials
- ❑ Different configurations

- ❑ Design & fabrication of:
  - ❑ Sealants
  - ❑ Interconnects
  - ❑ Manifolds…



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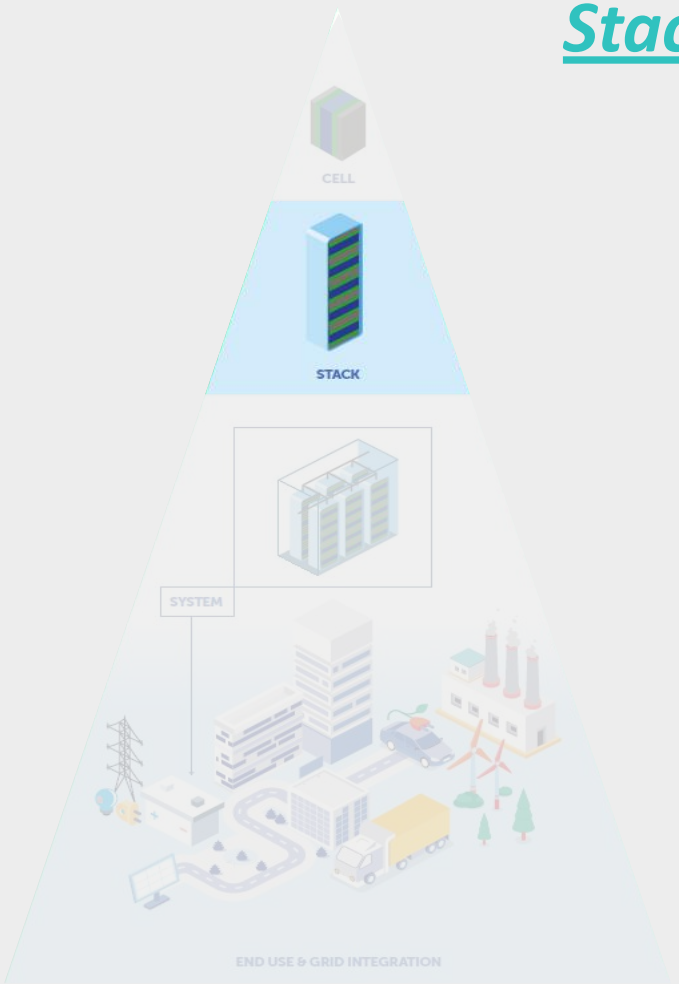
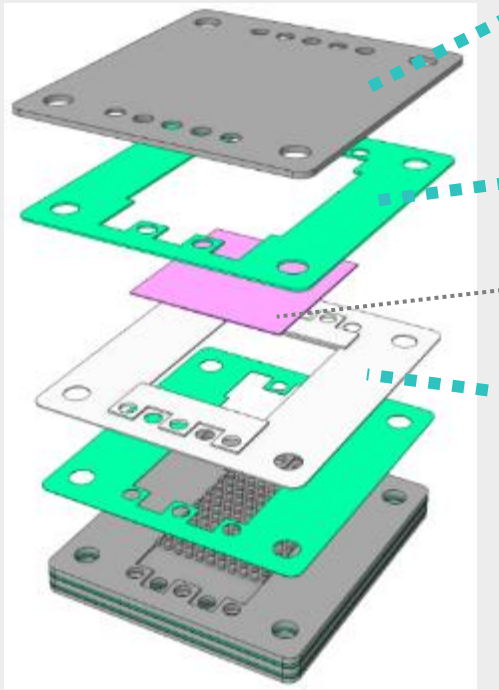
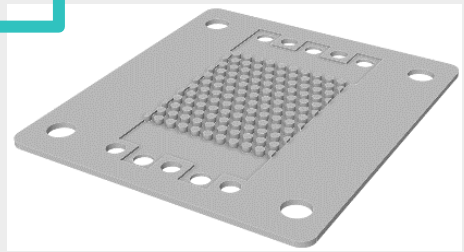


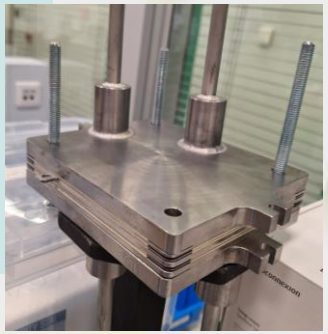
Stack design and manufacturing





CAD-driven development to **optimize stack geometry**:

- ❑ Optimum gas distribution
- ❑ Current distribution
- ❑ Minimized pressure drop
- ❑ Thermal & mechanical stability



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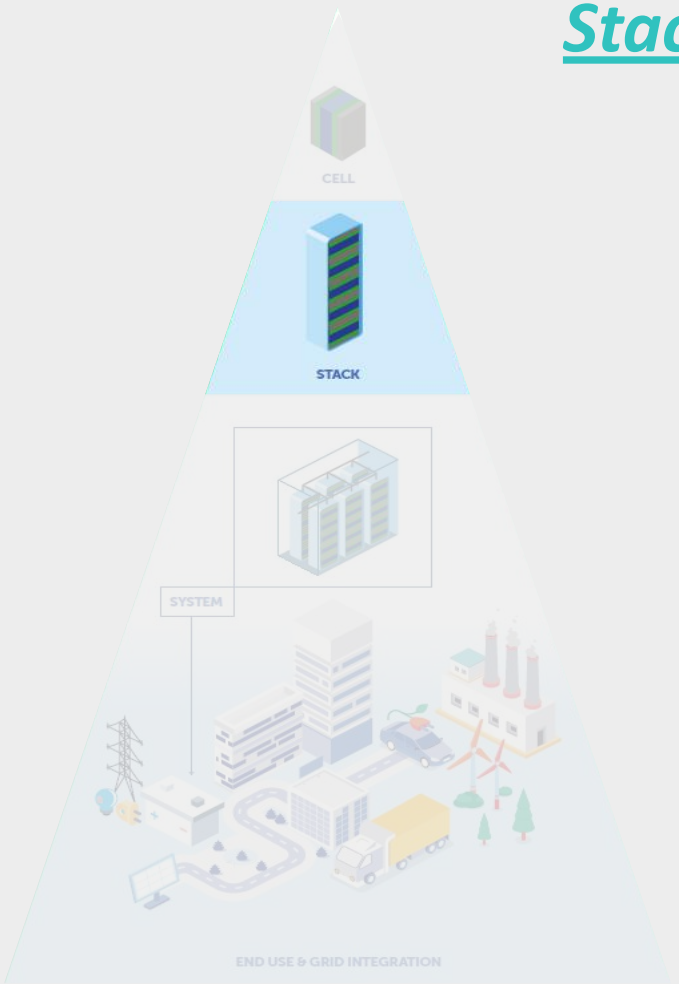
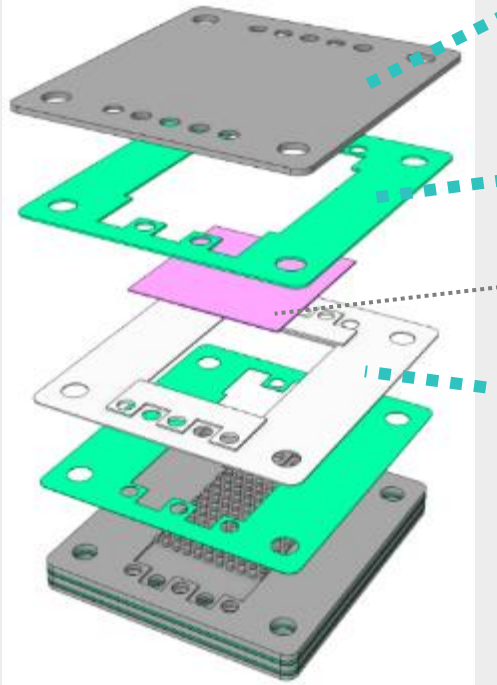
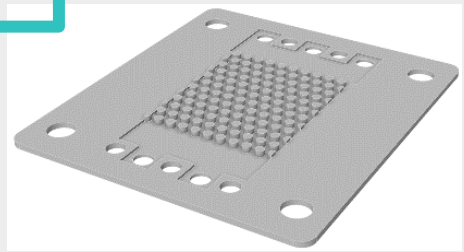
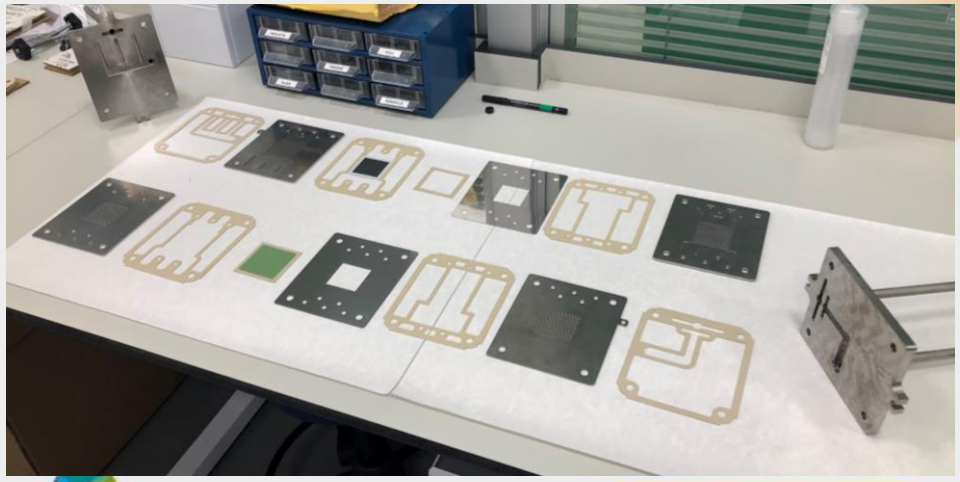


Stack design and manufacturing







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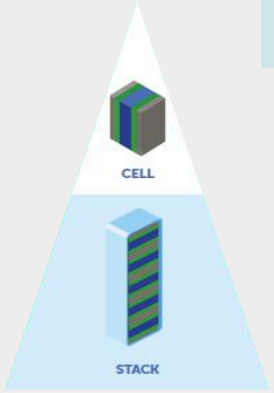
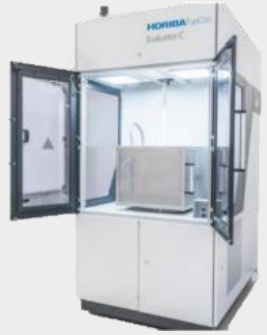
Electrochemical performance analysis

The lab possesses several complementary **measuring stations** for enabling multi-scale testing, from lab-scale proofs of concept (< 1 kW) to pre-commercial prototypes (2-5 kW). This is used for testing the behavior of cells and stacks, and for validating developed models.





High-temperature electrochemical testing station for round cells (< 5 W): PROBOSTAT

High-temperature electrochemical testing station for cells & short stacks [2/3 cells] (< 100 W): FIAXELL

High-temperature electrochemical testing station for mid-size stacks [5x5 and 10x10 stacks] (up to 2 kW): Fuel Cell Materials

High-temperature electrochemical testing station for mid-size stacks (up to 1.5 kW): HORIBA

High-temperature electrochemical testing station for mid-size stacks (up to 5 kW): SOFCMAN

In addition to its scale, existing facilities allow testing cells and stacks at high temperatures (up to 1000 ºC). This is quite useful for solid state configurations (SOEC, PCEL, etc).

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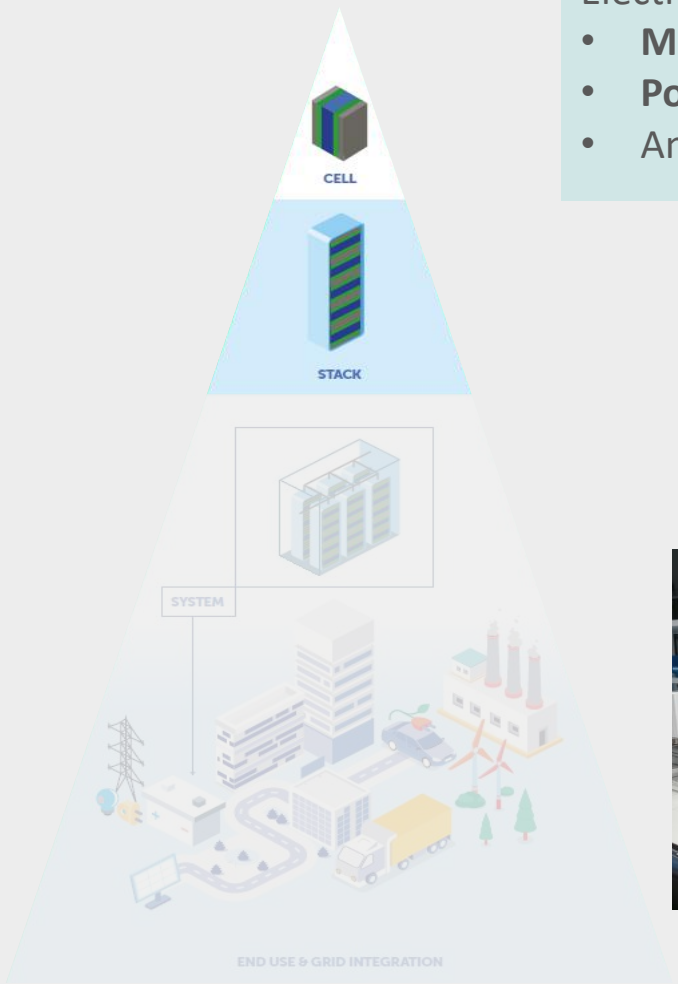
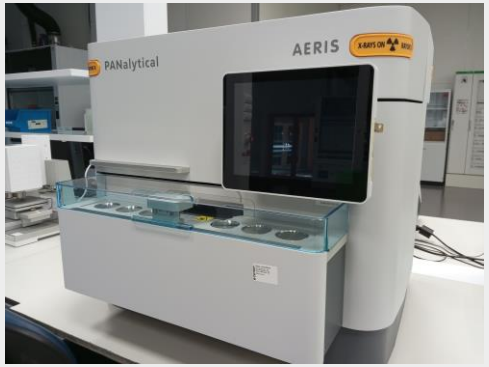
Electrochemical performance analysis



Electrochemical analysis of cells and stacks is complemented by several analytic assays:

- **Microstructural and compositional analysis** of materials and electrodes (SEM/XRD)
- **Post-mortem analysis** of cells/stacks after failure
- Analysis of **hydrogen impurities and subspecies** (co-generation) (Gas Chromatography)



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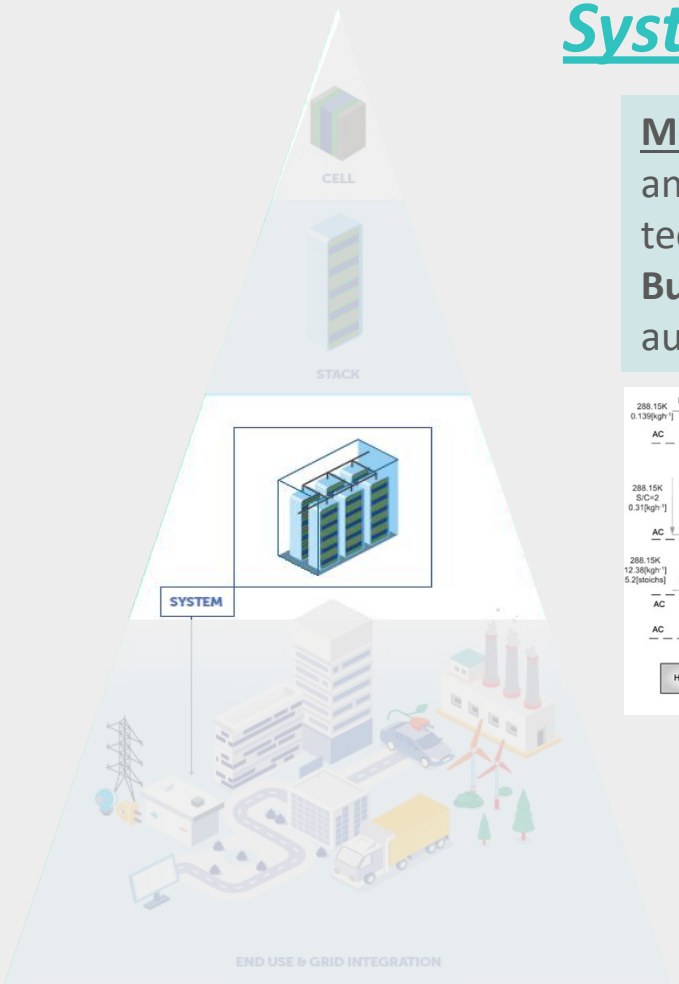
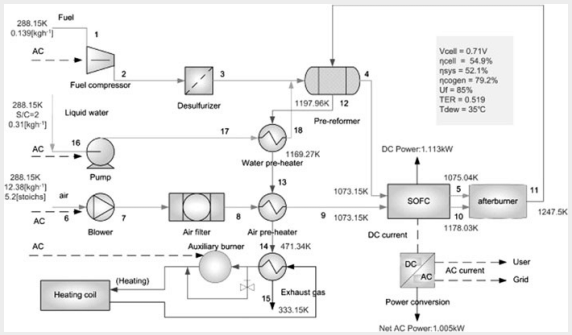


System engineering

Modelling of integral systems to obtain the **Balance of Plant**, optimizing energy and water requirements of electrolysis/fuel cell systems and evaluate their techno-economic feasibility.

Building of prototype electrolysis systems integrating fabricated stacks with auxiliary equipment (based on modeled BoP)



50 kW SOFC-based system *for integration in H_2-based micro-grids (ongoing work)*

Back (Research Lines)

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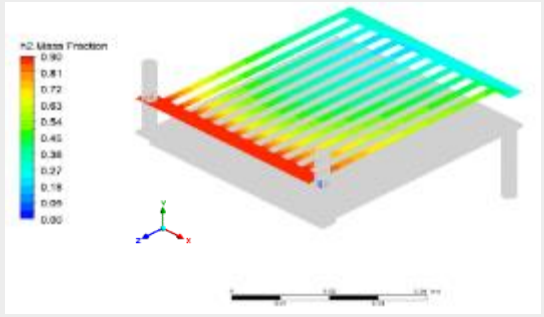
Modelling hub

This area specializes on **modelling of electrochemical systems** at any scale (from cells and stacks, to integrated systems based on renewable energies and including such devices).

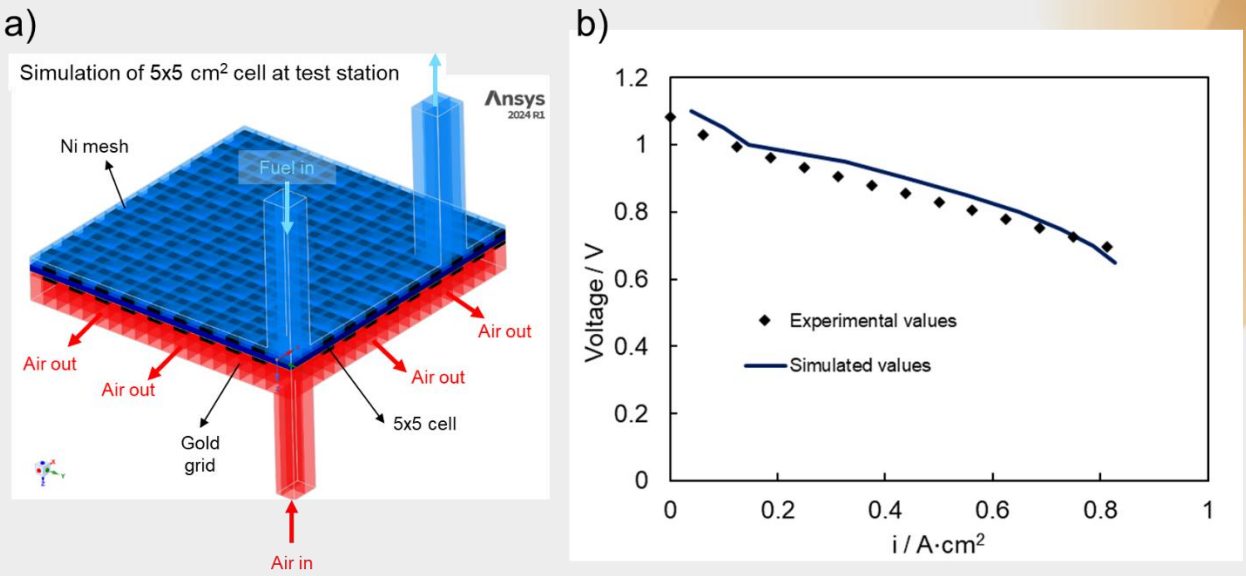
MODELLING OF CELLS AND STACKS

It aims at optimizing material properties and cell design (electrode thickness, porosity, gas channels, interconnectors, etc) to **imitate the response of cells and stacks within several operation scenarios**. This allows optimizing the performance of cells/stacks, thus minimizing experimental, temporal and economic efforts.



H_2 concentration contours

Modelling of electrochemical conversion and storage systems is carried out by applying **Computational Fluid Dynamics (CFD)** together with system modelling (Ansys). High capacity computers and specific simulation software are used for this purpose.



a) 3D representation of a 5x5 cm² commercial cell within the test station, and b) obtained i-V curves with CFD simulation (continuous line) and experimentally (dots).

Back (Research Lines)

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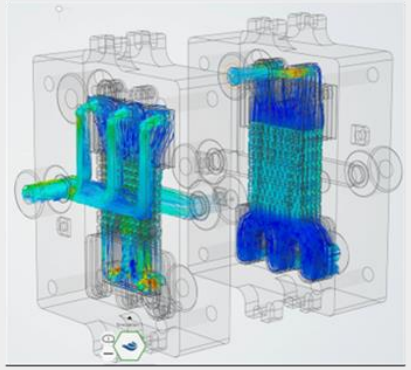
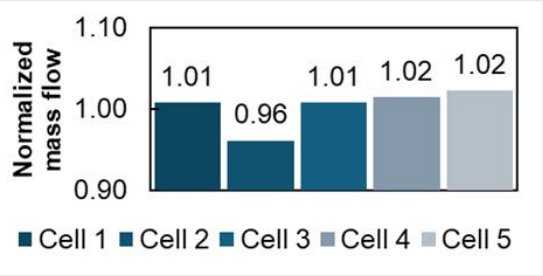
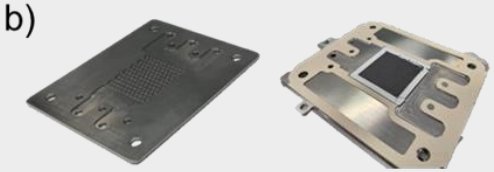
MODELLING OF CELLS AND STACKS

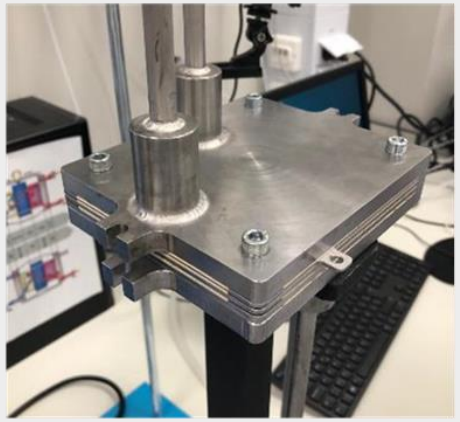
a)





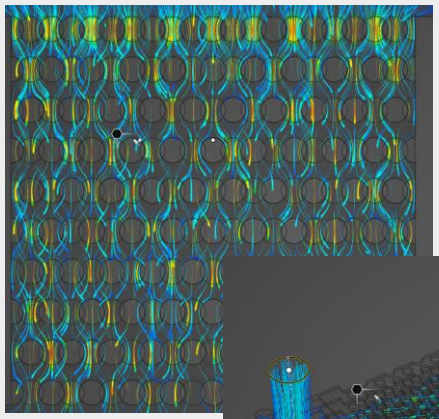
b)

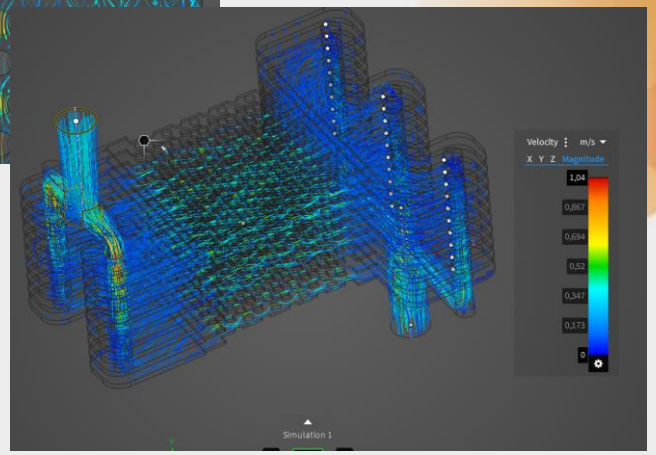




Ansys Discovery simulation of flow distribution over a 5 cell stack, along with normalized mass flow plots in the different cells. b) Images of fabricated IP plates, IP/sealant cell assembly, and complete stack [Judez et al., 2024]

Gas distribution within interconector





Gas distribution within stack

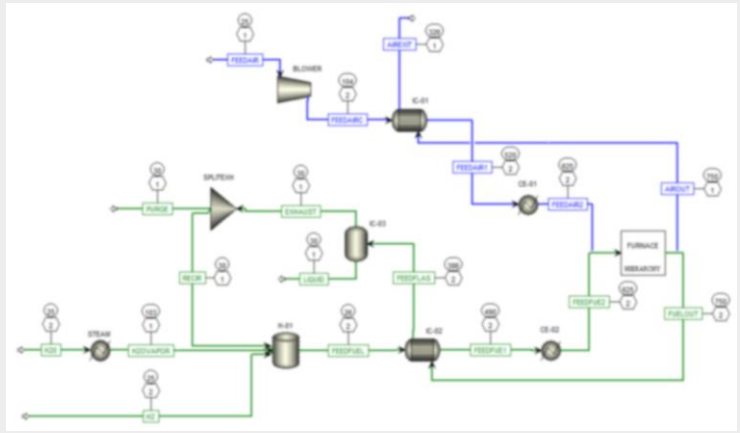
Back (Research Lines)

Modelling hub

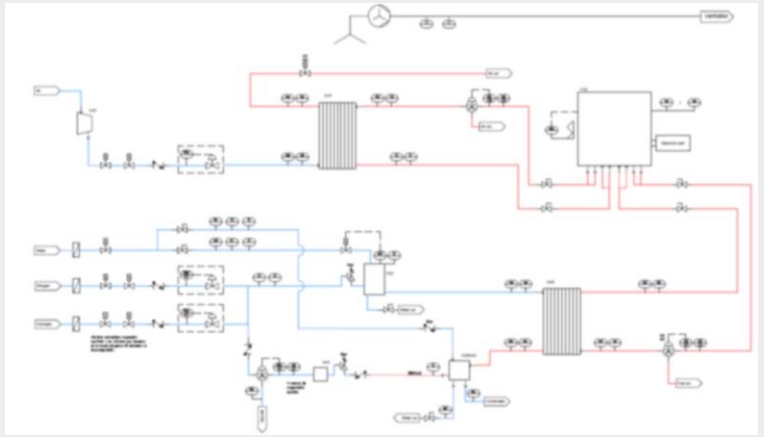
This area specializes on **modelling of electrochemical systems** at any scale (from cells and stacks, to integrated systems based on renewable energies and including such devices).

SYSTEMS MODELLING

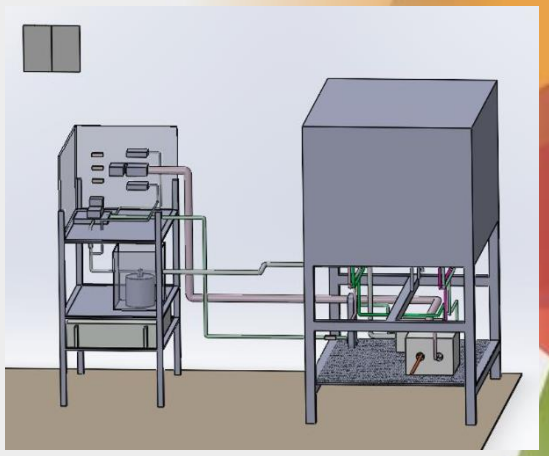
It allows to obtain their "plant Balance", that is, to calculate energy and water requirements of electrolysis/fuel cell/storage systems and therefore evaluate their techno-economic feasibility.



Preliminary P&ID (Aspen Simulation)



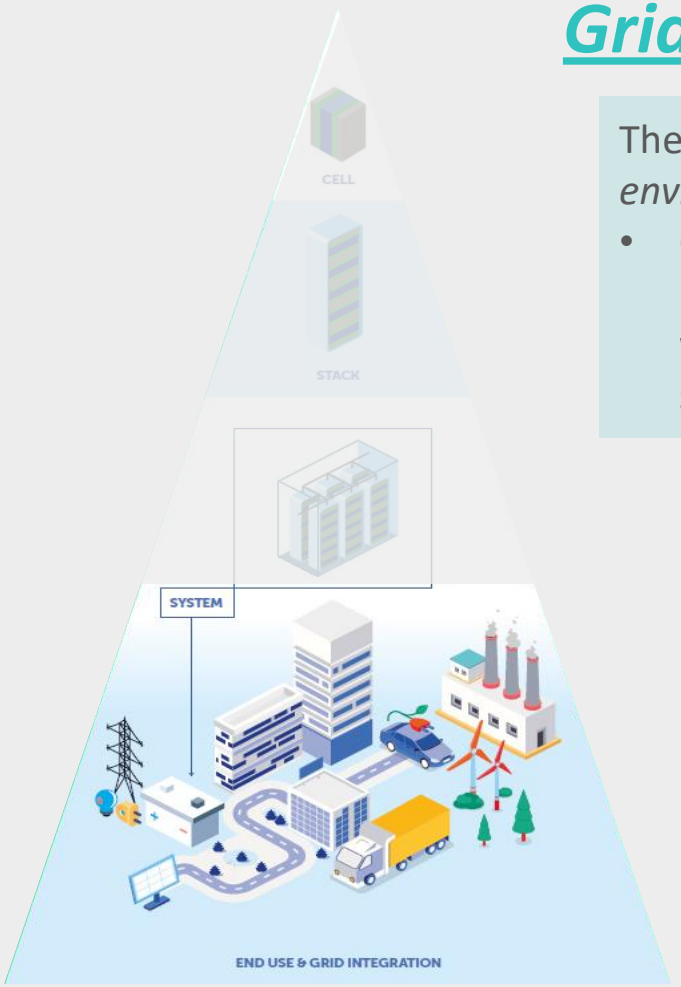
Detailed P&ID



Lay out

Back (Research Lines)

Grid & micro-grid integration



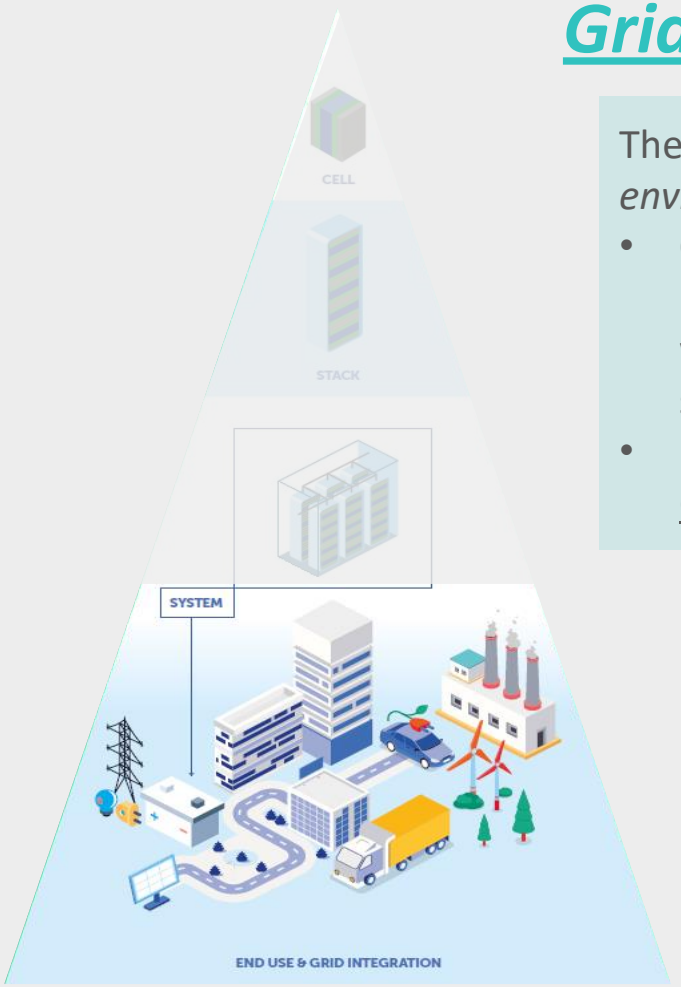
The importance of **TRL7** – *system prototype demonstration in operational environment*

- CENER owns a **versatile microgrid**, where different renewable energy production systems (photovoltaic, wind power, etc) can be combined with conversion and electrochemical storage devices (batteries, supercapacitors, and of course, fuel cells).

- Testing of energy storage & conversion prototypes (e.g. electrolyzers) **up to 1 MW**
- **Coupling** with renewables (wind, PV) and other storage technologies

Back (Research Lines)

Grid & micro-grid integration



The importance of **TRL7** – *system prototype demonstration in operational environment*

- CENER owns a **versatile microgrid**, where different renewable energy production systems (photovoltaic, wind power, etc) can be combined with conversion and electrochemical storage devices (batteries, supercapacitors, and of course, fuel cells).
- Furthermore, CENER has developed an **Energy Management System (EMS)** that can be adapted to any set or combination of technologies.

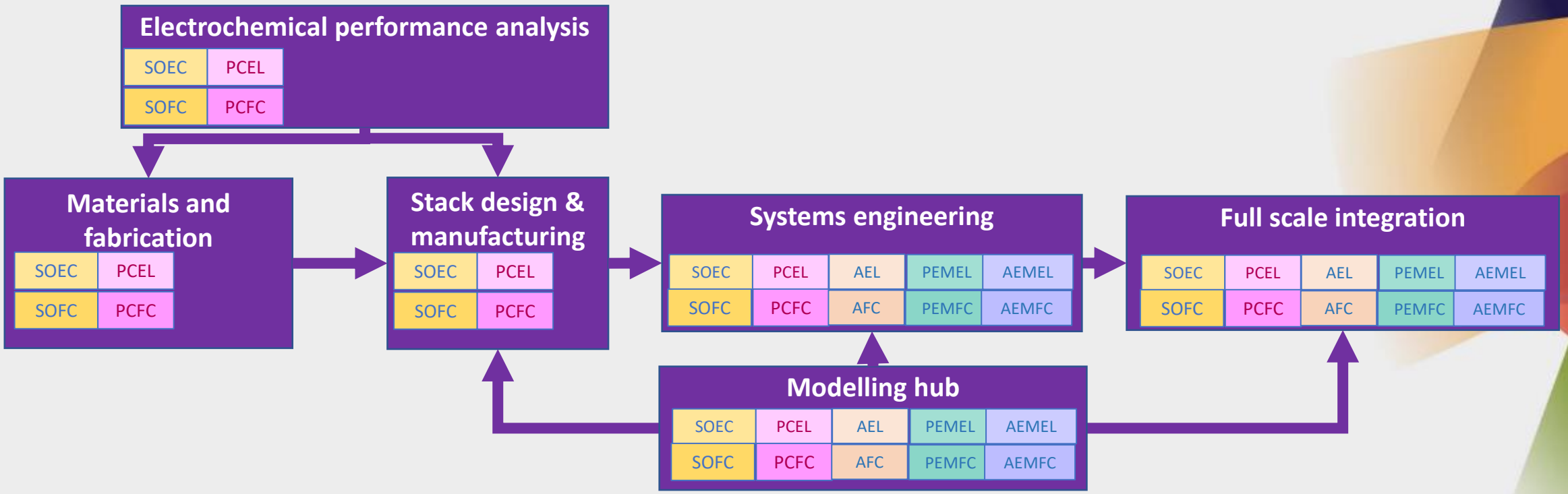
EMS with:

- Integrated Standardize Industrial comm protocols
- Advanced smart strategies for power plant optimization
- SCADA

Back (Research Lines)

HyGrIn Lab in summary…

Hydrogen Area is equipped with **all the necessary assets to produce cells and stacks until reaching preindustrial scale (up to 2 kW).** Complementary capabilities (modeling, engineering, characterization) are available to complement and foster the development of advanced cells and stacks.



While materials area is focused on solid state technologies, **CENER offers unique installations for testing, designing and scaling all kind of technologies for electrolysis (SOEC, PCEL, PEM, AEM, etc.) and fuel cells (SOFC, PCFC, etc)**

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HyGrIn Lab external services and expertise

Electrochemical performance analysis

SOEC	PCEL
SOFC	PCFC

Electrochemical testing of SOEC/SOFC cells and stacks, including degradation studies and postmortem analysis

Systems engineering/Modelling

SOEC	PCEL	AEL	PEMEL	AEMEL
SOFC	PCFC	AFC	PEMFC	AEMFC

Technical studies for full systems engineering:

- Process Flow Diagrams (PFD).
- Piping and Instrumentation Diagram (P&ID).
- Identification of suppliers for auxiliary equipment.
- Security studies and operation guidelines.

Full scale integration

SOEC	PCEL	AEL	PEMEL	AEMEL
SOFC	PCFC	AFC	PEMFC	AEMFC

Testing of prototypes (up to 500 KW) in ATENEA microgrid:

- Validation of prototypes in controlled environment, prior to industrial setting.
- Emulation of grid events (voltage peaks, power interruption, etc) and dynamic load (linked to renewable feed).
- Determination of real flexibility parameters (load flexibility, warm and cold start-up, heat-up ramp, load gradient, etc).
- Analysis of best control strategies for protecting systems against degradation, improving overall performance and flexibility, etc.

Others

SOEC	PCEL	AEL	PEMEL	AEMEL
SOFC	PCFC	AFC	PEMFC	AEMFC

- Training courses about hydrogen value chain, electrolysers, fuel cells and SOEC/SOFC technology.
- Technical assessment of electrolysers/fuel cell technology.

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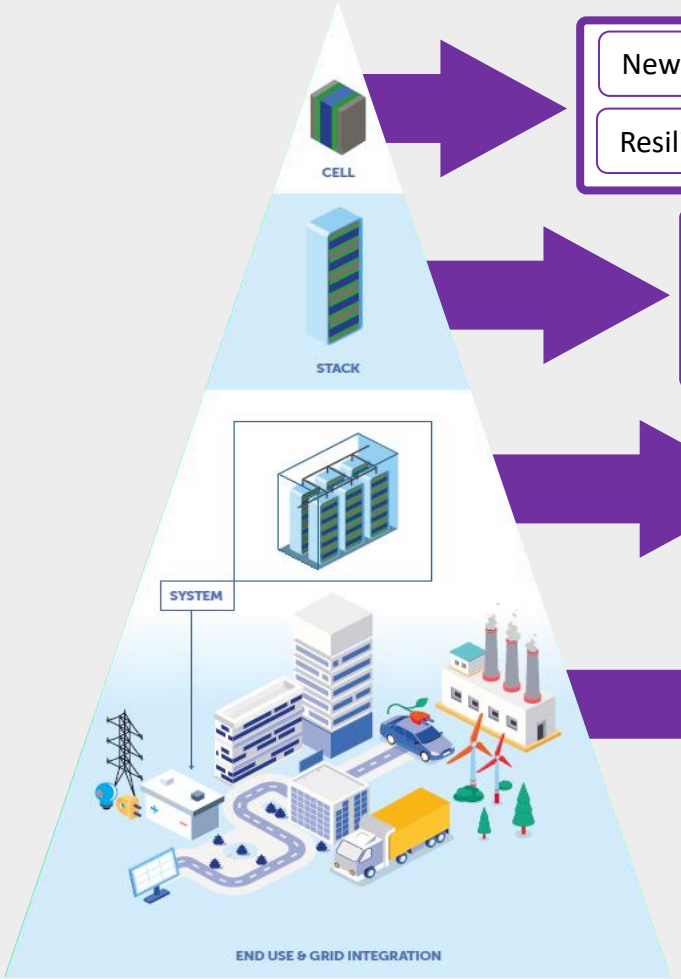
Some research lines of interest



- New electrode materials & integration
- Larger cell sizes (> 10x10 cm^2)
- Resilient cells to non-conventional waters
- Co-electrolysis for syngas production

- New and optimized components (interconnects plates, seals)
- New fabrication technologies
- ~10 kW-scale modules
- Protective coatings for enlarging lifetime
- New stack designs adapted to fuel cell and/or electrolysis operation

- BoP design and fabrication of ~50 kW systems
- Thermal management of SOC systems
- SOEC for green fuels production
- Integration of SOC systems with relevant processes (e.g. energy-intensive industries, direct use of gH_2
- H_2-integrated EMS

- Testing capabilities of electrolyzers and fuel cells in a controlled environment (ATENEA)
- H_2 systems coupling with renewables and/or storage technologies (batteries)
- TEA and LCOH analysis in different scenarios

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Calls and topics of interest (Europe)

National scope*

Financiado por la Unión Europea
NextGenerationEU

PERTE ERHA-Cadena de Valor: Programa de incentivos 4: retos de investigación básica-fundamental, pilotos innovadores y la formación en tecnologías habilitadoras clave

TransMisiones

Proyectos de Generación de Conocimiento

Cooperación Público-privada

European scope

Clean Hydrogen Partnership

- TC1-02 Improved lifetime and cost of high temperature electrolysers by introducing innovative materials and components in stacks and BoP
- TC1-04 Efficient electrolyser coupling with Dynamic electricity source and improved heat integration
- TC1-05 Innovative co-electrolysis systems and integration with downstream processes
- TC4-01-Stationary fuel cells for resilience of remote energy communities

Horizon Europe

- Integrated use of renewable energy carriers in industrial sites (Processes4Planet partnership)
- Solving issues in carbon-neutral iron and steel making processes with diverse input materials of varying quality (Clean Steel Partnership)
- Innovative solutions for energy conversion and safety of low and zero-carbon fuels in waterborne transport (ZEWT Partnership)
- Using captured CO_2 as a resource to replace fossil fuels in industrial production

**Mainly as subcontracted entity*

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