



ANNUAL REPORT CEA-LITEN 2021





*François Legalland,
CEA-Liten's CEO*

The climate crisis is here, and the need to introduce and massively deploy alternatives to fossil fuels is more pressing than ever. France is one of many countries taking a firm policy stance to steer its economy to carbon neutrality within the next three decades.

The government's "France 2030" plan will channel substantial funds to driving the cost of new energy technologies down and building the industries that will support the energy transition. And research will of course be crucial to bringing new technologies to an acceptable cost-performance tradeoff—the prerequisite to widespread deployment. According to the IEA, 45% of the technologies needed to achieve carbon neutrality by 2050 are not yet mature enough for the market.

The year 2021 was a particularly dynamic one for CEA-Liten's flagship research areas. These include hydrogen—production by electrolysis, storage, transport, and use—but also Li-ion batteries, carbon capture and recycling, multi-vector energy grids, high-performance PV, and eco-innovation and recycling.

Scientific excellence continues to be a core component of our identity. We hosted more than 150 PhD students, published more than 210 articles, and filed 193 patents in 2021. Having our contributions recognized through publications, patents, and partnerships leaves us more confident than ever in our ability to overcome the technological hurdles on the path to net-zero carbon by 2050 and to help build the industries that will support the energy transition in France and Europe-wide.

Inside you will find the research results and scientific advances that marked the past year at CEA-Liten—now in a single document. Whether it was through building partnerships or breaking new technological ground, we continued to contribute to a more competitive, sovereign, and sustainable economy throughout 2021.

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CEA-LITEN, LEADING THE

CEA-LITEN IS AN INSTITUTE OF THE CEA (THE FRENCH ALTERNATIVE ENERGIES AND ATOMIC ENERGY COMMISSION) AND IS A MEMBER OF THE *INSTITUT CARNOT ÉNERGIES DU FUTUR*, A CONSORTIUM DEDICATED TO RESEARCH PARTNERSHIPS WITH BUSINESSES. CEA-LITEN HAS FACILITIES ON THE CEA-GRENOBLE CAMPUS AND AT FRENCH NATIONAL SOLAR ENERGY RESEARCH INSTITUTE INES IN CHAMBÉRY. CEA-LITEN RESEARCH PROGRAMS FOCUS ON THE ENERGY TRANSITION. SPECIFICALLY, THE INSTITUTE EXPLORES SOLAR ENERGY, GRID MANAGEMENT, AND ENERGY STORAGE, INCLUDING BATTERIES AND HYDROGEN. ENERGY EFFICIENCY AND THE CIRCULAR ECONOMY FORM AN INTEGRAL PART OF CEA-LITEN'S RESEARCH. THE TECHNOLOGIES DEVELOPED ADDRESS SEVERAL MARKETS, FROM POWER GENERATION AND DISTRIBUTION TO TRANSPORTATION, AND FROM INDUSTRIAL PROCESSES TO GREENTECH. CEA-LITEN HAS LEVERAGED ITS POSITION WITHIN THE CEA, ONE OF THE WORLD'S MOST INNOVATIVE GOVERNMENT RESEARCH ORGANIZATIONS, TO LEAD THE DEVELOPMENT OF COMPLEMENTARY, COST-COMPETITIVE, AND MORE ENVIRONMENTALLY-FRIENDLY SOLUTIONS TO SUPPORT AN ENERGY STRATEGY BUILT ON MULTIPLE ENERGY VECTORS AND TIME AND SPACE SCALES.

CEA-Liten's main research programs address:

- The development of high-performance solar photovoltaic components and their integration into innovative, cost-competitive systems
- The design and development of future generations of batteries capable of delivering performance, safety, and long lifespans
- The design of hydrogen and hydrogen-enabling energy production, storage, transmission/distribution, and conversion technologies
- The design and use of digital technology to optimally dimension and manage energy (electricity, gas, heat) systems and grids
- The development of electrical and thermal energy management components for generation, conversion, and storage
- The integration of the circular economy principles of "reduce, reuse, recycle" into all research and development projects to reduce the impact of the energy transition on raw materials supplies
- The development of technologies to convert CO₂ and other sources of carbon into synthetic substances that can be used in the energy and chemical industries



KEY FIGURES 2021


1000
EMPLOYEES


150
PHD CANDIDATES
AND POST-DOCS


150
MILLION: ANNUAL
OPERATING BUDGET


1865
PATENTS


200
PUBLICATIONS
IN 2020

ENERGY TRANSITION



CEA-LITEN, A PILLAR OF CARNOT ENERGIES DU FUTURE

In 2022, *Carnot Énergies du futur* will celebrate its fifteenth anniversary—and fifteen years of R&D partnerships with companies. The Carnot seal is awarded by the French Ministry of Higher Education, Research, and Innovation to research organizations that demonstrate a strong commitment to research partnerships with companies and back that commitment with high-quality research and partnership management practices. Together, CEA-Liten and the ten academic research labs that form *Carnot Énergies du futur* are making it easier for companies to access technologies at a wide range of TRLs. The Carnot seal comes with funding we use for the kind of pump-priming research that will feed our innovation pipeline and respond to the future needs of businesses.

Learn more at www.energiesdufutur.fr



ECOTECH ENERGIE CONFERENCE

The fourth edition of the ECOTECH Energie conference took place on December 14, 2021. The conference, on new local energy solutions for cities and communities, was co-organized with PEXE (a federation of small- and medium-sized companies engaged in the environmental transition), the French government's New Energy Systems Policy Committee, and a Carnot Network consortium made up of Carnot Energies and Extra&Co. This is exactly the kind of event needed to continue to drive France's new energy systems industry forward. The entire innovation value chain (R&D laboratories, start-ups, small- and medium-sized companies, corporations, and financiers) came together around current issues, learning about the latest innovative solutions, networking, and reaching out to new business contacts through one-to-one meetings.

Two of CEA-Liten's innovations were selected for the program:

- DistrictLab-H: A software solution for district heating and cooling network optimization.
- Multi-scale modeling of grid flexibility and prosumer integration.


+200
INDUSTRIAL
R&D PARTNERS


12
PLATFORMS

CEA-LITEN'S PARTNERSHIP ECOSYSTEM

1. INDUSTRIAL R&D PARTNERSHIPS

CEA-Liten is one of the few research organizations in Europe to cover the entire energy technology value chain, from materials synthesis to pilot production runs. CEA-Liten has the facilities and experts needed to bring its R&D partners a decisive competitive advantage in the form of advanced technologies for renewable energy, energy efficiency, and the circular economy.

Testimonial from Bertrand Morel,
Director of R&D at  **orano**

"A project we started with CEA-Liten in 2019 very rapidly evolved into a joint R&D lab on lithium-ion battery recycling. CEA-Liten's developments are inventive, and their people are responsive and proactive—all factors that led us to set up the joint lab. We have successfully completed the traditional phases of R&D and small pilot production runs, and we are now tackling larger-scale pilot production runs. CEA-Liten is making a significant contribution. In 2021 we hit all of our targets despite the pandemic. Ours and CEA-Liten's people worked together seamlessly, helping keep our projects on schedule. Today, our partnership is broadening into magnet recycling and the carbon cycle—both important to the energy transition. We are more than pleased with the results so far and we are very optimistic that they will lead to the commercialization of new solutions."

2. COLLABORATIVE R&D PROGRAMS

One of CEA-Liten's missions is transferring new technologies to companies. And collaborative research with partners in France and across Europe play a key role in our strategy. We actively seek out partnership opportunities by maintaining close relationships with French and EU institutions, industry groups, networks, and other research and technology organizations. This positions us to identify opportunities for new innovation projects and to contribute to R&D roadmaps for the industries we address.



- In France, the government has allocated funding for Priority Research Programs and Equipment (PEPR). CEA-Liten has been working on developing projects under this new program. One of these projects, PEPR-H2, with France's national center for scientific research (CNRS), officially began in early 2022.
- We are also active in European research, as evidenced by our success rate with Horizon



THE CARNOT SEAL IS EVIDENCE OF OUR COMMITMENT TO SUPPORTING THE R&D STRATEGIES OF OUR PARTNER COMPANIES. WE COMPLETED MORE THAN 250 PROJECTS WITH PARTNERS IN 2021.

Testimonial from Olivier Amiel,
Director of the all-solid-state battery program at 

"Saft, a wholly owned subsidiary of TotalEnergies, has been developing advanced batteries for industrial applications for over 100 years. Technological excellence is one of our hallmarks. In 2018 we created a new R&D program on tomorrow's all-solid-state batteries. Our goal is to bring these new batteries to the industrial and automotive markets by 2026-2028 through our joint venture, ACC.

Partnering with the CEA is helping us validate new technologies around different solid electrolyte families to speed up our development work. The CEA's wide variety of equipment and experts in different fields are instrumental to our program."

Europe calls for projects, including:

- **The EU Surpass project** to develop eco-friendly and safe-by-design plastics
- **The EU Batraw project** on battery dismantling and recycling
- **The EU Resilex project** on PV module eco-design and recycled Si reuse
- **The EU Decagone project** on thermal energy storage

3. SCIENTIFIC RESEARCH PARTNERSHIPS

Scientific excellence is vital to our work at CEA-Liten. We build and maintain strong, long-term partnerships with renewable energy research stakeholders at the regional, national, European, and international levels. We conduct research at low TRLs* with academic research laboratories. The purpose of this research is to produce new scientific knowledge and identify breakthrough concepts.

*Technology Readiness Level



Cross testimony of:

Florence LEFEBVRE-JOUD,
Research Director, Head of national
and international academic
partnerships at CEA-Liten



Werner PLATZER,
Head of International
Business Development at
Fraunhofer ISE (Institute
for Solar Energy Systems)

Could you briefly describe the main ambition and the current status of the collaboration?

FLJ: CEA-Liten and Fraunhofer ISE are both focused on low carbon footprint energy technologies and systems. The collaboration aims at joining forces to accelerate the development of technological innovations required for reaching carbon neutrality by 2050.

WP: Fraunhofer ISE already has many fields of investigation. However, the energy transition requires even more competences to contribute to a more energy-efficient and more solarized Europe. Therefore we join forces in the collaboration with CEA-Liten in some very specific topics. CEA seems to be an ideal partner for ISE, as we share the same philosophy regarding industrial product development and applied research.

Is there a significant initiative or result to highlight in 2021?

FLJ: We have launched two parallel PhDs on concentrated photovoltaics, with students working at CEA Liten and at Fraunhofer ISE on complementary approaches. We aim at duplicating this "twin PhD" formula.

WP: We will next concentrate on areas where up to now interest but little cooperation activity has developed in the past : smart heating grids, power electronics for medium voltage grids and EV infrastructure.

In your opinion, what are the strengths of this collaboration between the two institutes?

FLJ: Our two institutes share a common culture of high quality applied research turned towards industry transfer and we both have high level research infrastructures that are often complementary.

WP: Apart from the general synergies of cooperation, both institutes should be more successful with joint applications in the highly competitive European research funding system. Also it may be possible to raise political awareness, that needed energy innovations in both economies could be accelerated by bilateral funding of our cooperation.



PHOTOVOLTAIC (PV) TECHNOLOGY IS EXPECTED TO BECOME A KEY COMPONENT OF THE WORLD'S ENERGY MIX BY ENABLING CHEAP AND LOCAL RENEWABLE ELECTRICITY PRODUCTION. CEA-LITEN IS HELPING PV GAIN TRACTION BY CREATING TECHNOLOGIES—HETEROJUNCTION, PEROVSKITE-SILICON TANDEM—CAPABLE OF PUSHING YIELDS ABOVE THE 30% BAR. OUR RESEARCH ALSO ADDRESSES GROUND-MOUNTED PHOTOVOLTAIC SYSTEMS, WITH PROJECTS TO BOOST PRODUCTIVITY, INTEGRATE PV INTO VARIOUS INFRASTRUCTURES TO REDUCE THEIR FOOTPRINT ON THE GROUND, AND MAKE ALL TYPES OF MOBILE CONNECTED DEVICES—FROM SMART WATCHES TO SATELLITES—SELF-POWERING.



DECARBONIZING ENERGY PRODUCTION

KEY FIGURES

38 PUBLICATIONS

375 PATENTS

32 PhD CANDIDATES

200 EMPLOYEES

1 HIGH-EFFICIENCY PHOTOVOLTAIC TECHNOLOGY

The solar cell is the core component of any photovoltaic system. And the race toward higher yields is on. CEA-Liten obtained a world-record yield of 25% on silicon heterojunction cells, just four points away from the technology's theoretical limit. But because cost is also crucial, our end goal is to find the optimal tradeoff. Module assembly is also vital, and it presents two challenges we are addressing at CEA-Liten. First, we are investigating how to connect cells to produce a component with significant power. We are also developing transparent and weatherproof envelopes to protect the cells from external environmental conditions. Our research here, which supports French and European manufacturers' efforts to build a PV industry that can compete globally, has already resulted in a first successful technology transfer to Enel Green Power.

MANUFACTURABLE MODULES WITH SHINGLE INTERCONNECTIONS

CEA-Liten at Ines is developing a cost-competitive shingle PV cell interconnection technology that offers higher power densities and energy efficiency and lower resistive losses. A test manufacturing run produced 10 shingled high-performance heterojunction (HJT) modules (60-cell equivalent) designed for building-applied PV (BAPV). The modules were made with conventional HJT cells on M2 wafers with

a glass front and back configuration, and some had a non-UV blocking encapsulant, pushing average front-end power to 322.64 W, or 214.15 W/m², (2% more powerful than conventional modules). The average yield of 21.41% and the weight per unit area of 11.8 kg/m², which is one-third less than the conventional type, puts the modules in the top five industrial HJT modules in the world in terms of performance.

This project received funding from the European Union's Horizon 2020 program for research, technology development, and demonstration under Grant Agreement no. 857793.



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CEA-LITEN RESEARCHERS DEVELOPED SHINGLE INTERCONNECTION TECHNOLOGIES FOR HETEROJUNCTION CELLS AND MODULES FOR THE INDUSTRIAL ROOFTOP PV MARKET.”

A RENEWED PARTNERSHIP WITH MONDRAGON ASSEMBLY

Mondragon Assembly and CEA-Liten at Ines signed a new three-year partnership on cell interconnection, the next step in their joint R&D on PV panel assembly. Jean-Philippe Aguerre, R&D Director, Mondragon Assembly, said: “Extending the partnership

is strategically important for our company. It will help us keep our costs competitive by substantially reducing certain expensive materials and increasing module energy yields.”

A GIGAFACTORY IN EUROPE

Enel Green Power's TANGO project won the European Commission's Innovation Fund for large-scale projects. It will increase annual production from 200 MW to 3 GW of bifacial heterojunction photovoltaic modules at the 3SUN plant in Catania, Italy. CEA-Liten has been working in partnership with Enel Green Power on Heterojunction technology at Ines since 2015.



3 GW/YEAR

3SUN PV PLANT ANNUAL
PRODUCTION INCREASE

REDUCING INDIUM CONTENT IN TCOs

Reducing the indium content in transparent conducting oxides (TCOs) is a way to reduce the environmental impact of photovoltaic systems that use heterojunction technology (HJT). We tested a method that involves thinning the TCO layer and covering it with an anti-reflective coating, and were able to produce coatings with satisfactory properties by using low frequency and low-temperature PECVD, processes compatible with HJT's 200 °C thermal limits.

2 NEXT-GENERATION PHOTOVOLTAICS

CEA-Liten is also working on technologies with a longer time horizon like perovskite-silicon tandem cells designed to absorb a larger part of the solar spectrum. We are setting our sights on a cell yield of more than 30% in the lab. We will also develop processes that can be scaled up for volume manufacturing. To achieve this, we must still overcome technological obstacles like increasing the conversion yield on a process with scale-up potential, improving cell stability, and limiting cell sensitivity to heat, UV, and humidity.

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PEROVSKITE-
SILICON TANDEM
CELLS TO REACH
30% YIELD BY 2030.”



RECORD EFFICIENCY FOR FLEXIBLE PEROVSKITE CELLS

Perovskites have some interesting properties: They can be used in liquid form and at low temperatures. In research for the EU APOLO project, CEA-Liten at Ines reproduced results previously obtained on rigid substrate on a flexible substrate. Average performance of about 18% was obtained on a batch of 12 single-junction flexible perovskite solar cells,

with one record-breaking cell (with a surface area of 0.33 cm²) performing at 19.2%. The structure implemented was simple, and the double cation perovskite layer's stability is promising; encapsulated cells retained 90% of their initial yield after an 800h test in humid heat. Additional research is underway to develop larger flexible modules.

Acknowledgement for funding from Institut Carnot Energies du Futur (Si-Premium and LASPV projects) and H2020 APOLO project (No 763989). The APOLO project received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No 763989.



SCALABLE DEPOSITION PROCESS FOR A LARGE-AREA PEROVSKITE LAYERS

CEA-Liten's materials formulation research led to a high-yield perovskite layer using a methyl-ammonium-free perovskite material. The process, which is manufacturable at scale, includes a gas-assisted spray coating step. The resulting low-temperature (< 100 °C) layer was then integrated into 10 cm² active surface modules using laser ablation as the patterning process, keeping

inactive areas to a minimum. A maximum 18% yield was achieved under 1-sun STC exposure. This technology is compatible with tandem module architectures. The time needed (approximately 30 seconds) for the deposition of the perovskite layer onto an M2 wafer makes this process currently the fastest for large-scale, high-volume production.

Special thanks to: CEA, Carnot Energies du Futur Si-Premium, H2020 EU Grant APOLO project N°763989.N°763989.

3 LARGE-SCALE PHOTOVOLTAIC PRODUCTION

CEA-Liten is conducting targeted research to better predict and optimize the productivity of photovoltaic systems through simulation and modeling. We are developing modules and systems for large-scale solar farms, which pose specific challenges in terms of durability, performance, and optimizing energy output. We are also analyzing system monitoring data—with the help of advanced algorithms—to gain insights into performance and identify malfunctions. The goal? To reduce costs over the lifetime of the system.



A MODELING AND SIMULATION TOOL FOR NEW PHOTOVOLTAIC POWER PLANTS

TriFactors, a modeling and simulation tool for power plants made of bifacial photovoltaic panels, was developed by CEA-Liten researchers at Ines. The software uses 3D form factors to calculate the DC output and quantify the side effects of PV power plants—something that today's commercially available software cannot do. TriFactors was developed and verified on CEA test benches and tested on several live power plants. And it scales up well, maintaining reasonable computation time and handling power plant simulations with unusual features, like vertical bifacial plants for agricultural applications.

SOLAR ENERGY IN THE DESERT

CEA-Liten at Ines is working with the ATAMOSTEC Institute in Chile on accelerated aging test procedures for photovoltaic panels in deserts. While deserts are naturally great places for solar power plants, the extreme conditions raise questions about durability. In the Atacama Desert, testing methods used to

guarantee system durability have to factor in wide variations in irradiation, humidity, and temperature from day to night in order to be effective. The procedure included guidelines for selecting the best testing method. The project partners would ultimately like to come up with a "desert-certified" testing procedure.

In partnership with ATAMOSTEC (Chile) with financial and organizational support from the Chilean government agency CORFO.



“EXTREME ENVIRONMENTS REQUIRE ROBUST PV CHARACTERIZATION METHODS.”

4 PHOTOVOLTAICS EVERYWHERE

With photovoltaic technology, systems can potentially be integrated into virtually any structure, generating electricity for the grid without increasing the system footprint. ITE INES 2S has dedicated a number of projects to “photovoltaics everywhere” scenarios. PV integration into mobile devices opens up even more possibilities in fields like aeronautics and space, mobility, and maritime and land transportation. Unlike grid-connected photovoltaics, photovoltaics everywhere places functionality ahead of productivity—an opportunity to invent solutions with even higher added value.

CONCENTRATOR PHOTOVOLTAIC SYSTEMS IN COLLABORATION WITH FRAUNHOFER

PV systems for space must innovate to provide energy to telecommunications, observation, and exploration satellites. Fraunhofer ISE and CEA-Liten signed a partnership to develop concentrator photovoltaic systems, a promising solution that uses very few rare III-V materials, which reduces manufacturing costs and is compliant with most specifications. Their research will deliver the kinds of innovative solutions Europe’s space stakeholders need.

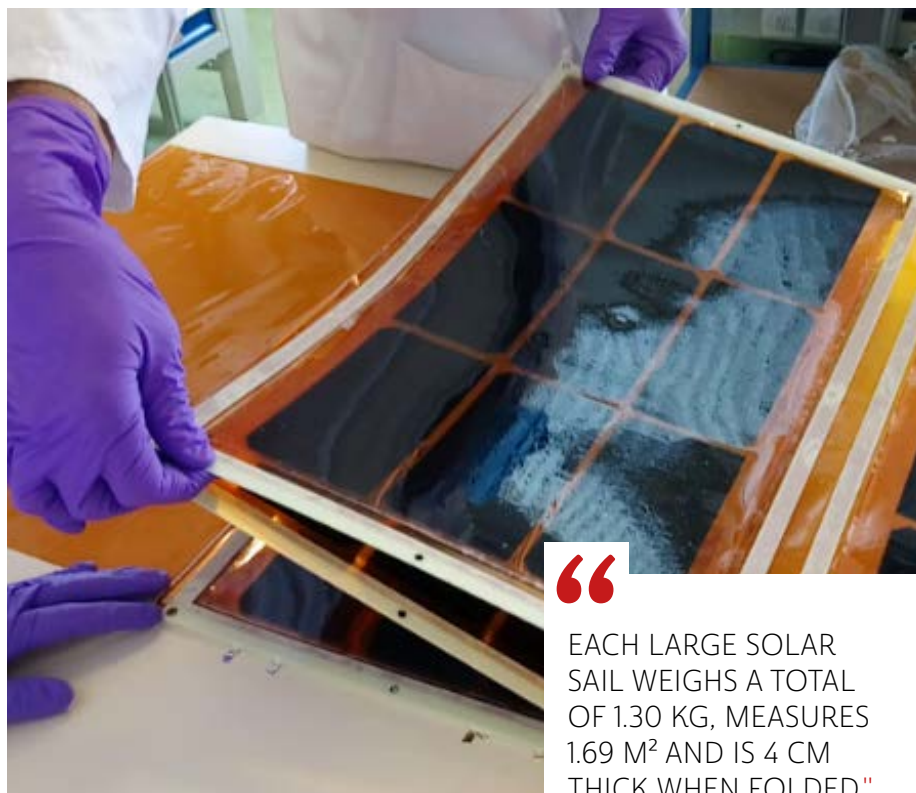
SOLAR POWERED VEHICLES

CEA-Liten is developing a solar retrofit kit for electric vehicles as part of the ITE INES 2S project. This after-factory solution would bring multiple benefits: Vehicles could effectively extend their own ranges and charge less often, lowering the carbon footprint at the end of the vehicle lifecycle.

THE NEW SPACE RACE

The burgeoning new space industry is driving demand for photovoltaic energy. As part of the European ALFAMA project, CEA-Liten produced the first large, thin, and foldable solar sails for space generators. These flexible photovoltaic arrays (PVAs) are an innovative solution and a sustainable alternative to conventional PVAs and their thick and rigid

architecture and lower efficiencies. Two large-scale solar sail demonstrators were built from design through to manufacturing, bringing the technology up to TRL 4 using proven, low-cost processes. At the European Space Technology Centre (ESTEC), a large solar generator passed a vibration test that simulates the launch vehicle environment.



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EACH LARGE SOLAR SAIL WEIGHS A TOTAL OF 1.30 KG, MEASURES 1.69 M² AND IS 4 CM THICK WHEN FOLDED.”

ECO-DESIGN CREATES NEW OPPORTUNITIES FOR INNOVATION IN PHOTOVOLTAICS

BACKGROUND

Any photovoltaic (PV) technologies developed today have to be compatible with the demand for products with low environmental impacts. The lifecycle assessment (LCA), currently the most relevant standard method for measuring a product's environmental impacts, presents some limitations when applied to photovoltaic technologies [1]. This makes some of the choices involved in eco-designing PV technologies difficult. CEA-Liten has developed a more suitable method for integrating environmental impacts into the PV R&D projects conducted for and with the institute's partners. The building blocks of this environmental impact assessment originated with a PhD research project [2], and further development work was completed through a network of experts under the ITE INES2S program.

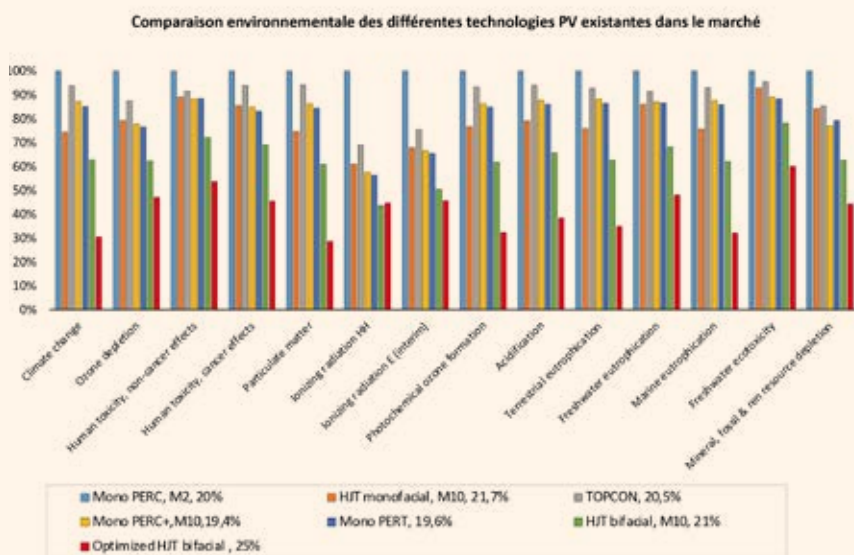
TECHNICAL RESULTS

The assessment method developed integrates environmental impacts into R&D projects across the entire PV value chain, from material to system. It also addresses financial and technical aspects of PV R&D. The LCA is used to assess the environmental benefits of the technology being developed, and the environmental impacts of all current low-TRL PV technologies likely to reach the market in the medium to long term were mapped (Figure 1). Tandem PV technology was recently included in the PV technology database. An inventory of high-performance "top cell" materials compatible with deposition processes that can

be scaled up to volume production was also completed. The results of this environmental, financial, and technical assessment indicate that PK/Si-HJT tandem technology, with its high efficiencies, could generate much lower environmental impacts than standard PV modules [3]. The assessment revealed that adding layers to the top cell does not increase the environmental impacts of the technology. The silicon "bottom cell", sourced from China, turns out to be the major culprit in terms of overall impacts. European manufacturing will be a key factor in reducing tandem PV's greenhouse gas emissions (by more than 80%).

OUTLOOK

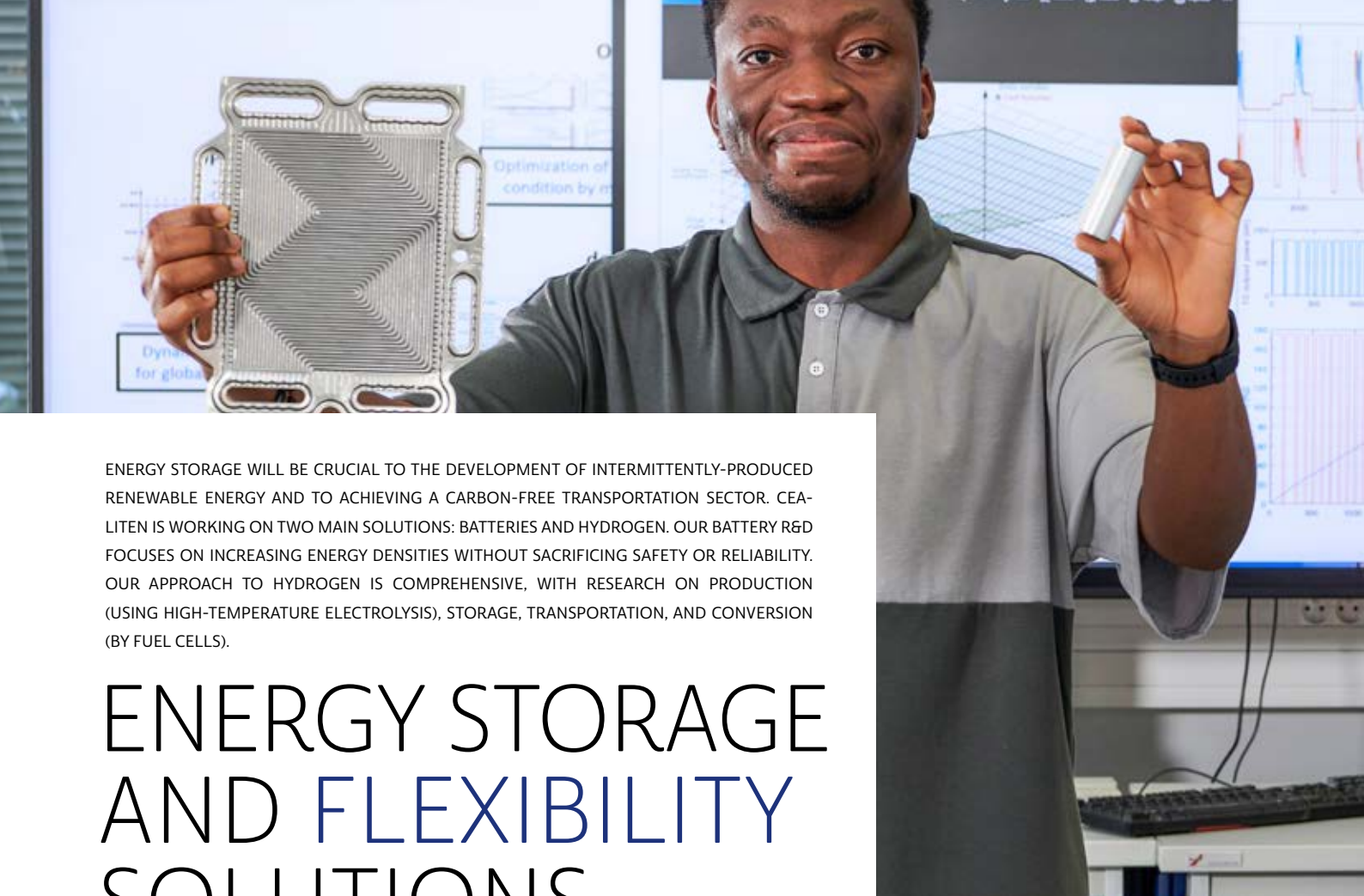
The assessment tool (ECO PV software) developed as a result of this research is now used to help outline technology roadmaps and assist manufacturers in selecting the right technologies. Because the assessment is automated, it can be integrated into R&D projects over the long term. Engineers from a variety of disciplines contributed to the tool, which is organized around discrete technologies. This facilitated knowledge sharing between experts across the value chain. CEA-Liten is now poised to offer its partner institutions and companies a range of eco-innovation services.



[1] N. Gazbour et al., "A path to reduce variability of the environmental footprint results of photovoltaic systems", J. Clean. Prod., vol. 197, p. 1607-1618, Oct. 2018, doi: 10.1016/j.jclepro.2018.06.276.

[2] N. Gazbour, "Systemic integration of eco-design from the R&D phase of photovoltaic technologies," www.theses.fr "x3_," February 14, 2019. www.theses.fr/s183189 (accessed October 22, 2019).

[3] INES, "Perovskite-Silicon Tandem," INES - Institut National de l'Énergie Solaire. www.ines-solaire.org/news/tandem-perovskite-silicium/ (accessed February 2, 2022).



ENERGY STORAGE WILL BE CRUCIAL TO THE DEVELOPMENT OF INTERMITTENTLY-PRODUCED RENEWABLE ENERGY AND TO ACHIEVING A CARBON-FREE TRANSPORTATION SECTOR. CEA-LITEN IS WORKING ON TWO MAIN SOLUTIONS: BATTERIES AND HYDROGEN. OUR BATTERY R&D FOCUSES ON INCREASING ENERGY DENSITIES WITHOUT SACRIFICING SAFETY OR RELIABILITY. OUR APPROACH TO HYDROGEN IS COMPREHENSIVE, WITH RESEARCH ON PRODUCTION (USING HIGH-TEMPERATURE ELECTROLYSIS), STORAGE, TRANSPORTATION, AND CONVERSION (BY FUEL CELLS).

ENERGY STORAGE AND FLEXIBILITY SOLUTIONS

KEY FIGURES

59 PUBLICATIONS

696 PATENTS

54 PhD CANDIDATES

350 EMPLOYEES

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A GOVERNMENT PROGRAM TO SUPPORT FRANCE'S EMERGING HYDROGEN INDUSTRY.”

1 HYDROGEN AS AN ENERGY VECTOR

Hydrogen has the potential to drive the energy transition in two ways: as a zero- or low-carbon fuel for the heavy-duty, long-haul transportation sector, and as an efficient way of storing large quantities of renewable energy over long periods.

HELPING TO DEVELOP A CLEAN HYDROGEN INDUSTRY

The CEA and the French national center for scientific research (CNRS) are leading a government program to support France's emerging hydrogen industry. Known as the Clean Hydrogen PEPR (Programme et Equipements Prioritaires de Recherche), the program will provide funding for the development of high-temperature electrolysis, PEMFC, and energy storage

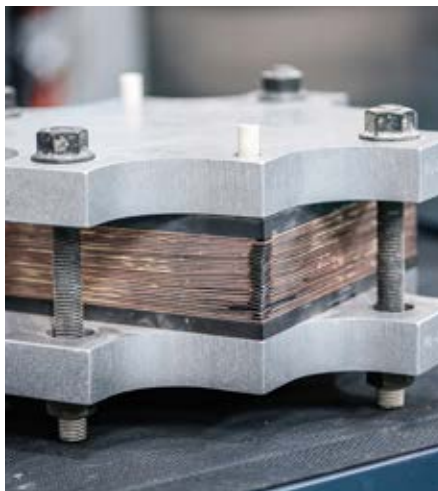
research, and will run until 2030. The aim is to help hydrogen companies conduct early-stage R&D (TRLs 1–4) and meet the targets set out in the national hydrogen strategy. The projects—covering hydrogen production, storage, transportation, and conversion—will be led by teams of top researchers in these fields and run for five to six years.

2 HIGH-TEMPERATURE ELECTROLYSIS

Hydrogen can only be used to decarbonize the transportation sector if it can be produced without excessive greenhouse gas emissions. The CEA has developed a high-temperature steam electrolysis process that converts electricity to hydrogen with an electrical efficiency as high as 85%. The technology is reversible, meaning it can also operate in fuel-cell mode to turn renewable hydrogen into electricity.

OFFICIAL LAUNCH OF THE GENVIA VENTURE

Genvia is a joint venture between the CEA, Schlumberger, and partners VINCI, Vicat, and the strategic investment agency for the Occitanie region (ARIS). Launched in March 2021, the company aims to accelerate the industrial deployment of the CEA's high-temperature solid oxide electrolyzer technology, which is expected to be a game-changer in the production of clean hydrogen. Genvia's R&D team and tech transfer center will work closely with the CEA in Grenoble to get the technology ready for market. Genvia has two other sites: Clamart, responsible for systems engineering, and Béziers, where the electrolyzers will be manufactured.



“ HIGH-TEMPERATURE SOLID OXIDE ELECTROLYZER TECHNOLOGY IS THE MOST EFFICIENT AND COST-EFFECTIVE WAY OF PRODUCING CLEAN HYDROGEN.”

FIRST HIGH-POWER STACK PASSES VALIDATION TESTING

The market for solid oxide electrolyzer cells is expected to grow rapidly in coming years, and larger, more powerful systems will be needed to meet demand. Until recently, CEA-Liten had manufactured “standard” stacks consisting of 25 cells, each with an active surface area of 100 cm². 2021 saw a new milestone, with the production of a “power stack” containing 75 cells, each with

an active surface area of 200 cm². The stack passed validation testing, generating 5 Nm³ of H₂ in an hour—six times more than a conventional stack under similar conditions. This equates to 200 Nm³ of H₂ in 40 hours, with an operating point of 0.9 A/cm² and a steam conversion rate of 55%. The technology was also successfully operated in fuel-cell mode.

STATE-OF-THE-ART R&D FACILITIES

CEA-Liten is going to be ramping up its work on high-temperature electrolysis and collaborating with Genvia to accelerate scaleup of this technology. To support this, the institute has invested in new equipment. Two new activation benches have been installed to allow the institute to produce fuel stacks on a larger scale and carry out the extensive optimization and testing that this entails. Activation, or “break-in,” is the final stage in the fuel cell manufacturing process. Without this step, the fuel cell stack cannot achieve its maximum performance. The high-power solid-oxide cell (SOC) testing platform inaugurated in 2020 has also been adapted for even more powerful modules. All these changes—extra equipment, larger stacks, longer durability tests—mean that the platform is using more gases. To make sure that the hydrogen platform stays reliable as activity ramps up, the gas supply system was upgraded in 2021.



ADVANCED CHARACTERIZATION AND MODELING TOOLS SUPPORT THE BURGEONING HYDROGEN INDUSTRY.

Interview with Jérôme Laurencin, an expert in the modelling and characterization of high-temperature electrochemical converters

How are your activities supporting the hydrogen industry?

Hydrogen production, storage, and transport research is booming. CEA-Liten has been investigating fuel cells and hydrogen production by high-temperature electrolysis since the institute was first set up, accumulating many years of knowledge and experience we are now using to help companies scale up and commercialize fuel cell and hydrogen solutions. And for a solution to be viable on the market, it has to be efficient and durable. Here at my laboratory, we work on high-temperature electrochemical systems, whether that's electrolyzers or fuel cells. We focus specifically on the electrochemical cells at the core of the system, trying to understand how the different mechanisms at work affect performance and how degradation impacts durability. We have access to some particularly advanced modelling and characterization techniques we have developed in partnership with ESRF in Grenoble and PSI in Switzerland.

What were some of your highlights of 2021?

Our work during the year focused mainly on the electrochemical mechanisms at work inside electrodes. We completed analyses that helped us better understand the reaction mechanisms involved [1,2]. We used modelling and cyclic voltammetry tools to improve our ability to detect degradation and analyze it [3].

A PhD research project on the mechanical degradation of materials completed in our labs in 2021 led to the development of tools we can now use to predict damage in complex electrode microstructures (Fig. 1) [4,5].

In terms of the work you are doing, how important are your research environment and your recent fellowship?

Research in our field is moving fast right now, and our lab is at the center of it. The ground for partnerships is particularly fertile. We are working with universities in France (LEP-MI, ICMCB, Insa Lyon) and other countries (DTU in Copenhagen, AIST in Japan, EPFL in Lausanne), which is a great way to share knowledge.

In 2021 I reached a milestone in my research career with my fellowship appointment. This reflects both my work and that of my team, including—and especially—the PhD students and post-docs who have worked in the laboratory over the years.

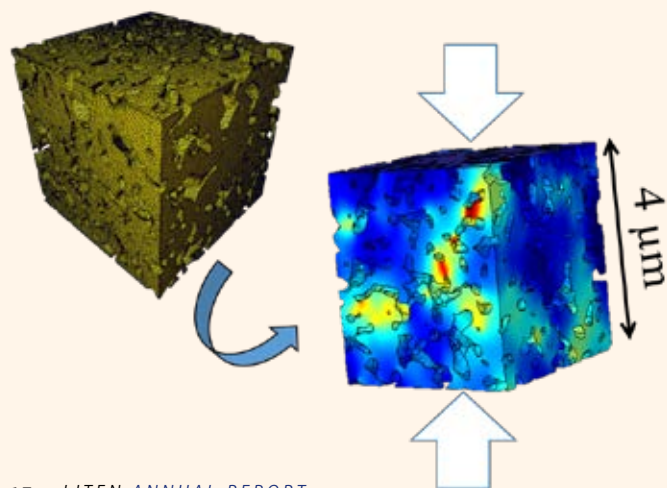


Fig. 1 Simulation of crack initiation and propagation in porous electrode microstructures.

- [1] F. Monaco, E. Effori, M. Hubert, E. Siebert, G. Geneste, B. Morel, E. Djurado, D. Montinaro, J. Laurencin, Electrode Kinetics of Porous Ni-3YSZ Cermet Operated in Fuel Cell and Electrolysis Modes for Solid Oxide Cell Application, *Electrochimica Acta* 389 (2021) 138765
- [2] E. Effori, J. Laurencin, E. Da Rosa Silva, M. Hubert, T. David, M. Petitjean, G. Geneste, L. Dessemond, E. Siebert, An Elementary Kinetic Model for the LSCF and LSCF-CGO Electrodes of Solid Oxide Cells: Impact of Operating Conditions and Degradation on the Electrode Response, *J. Electrochem. Soc.*, 168 (2021) 044520.
- [3] E. Effori, J. Laurencin, V. Tezyk, C. Montella, L. Dessemond, E. Siebert, A Physically-based Modelling to Predict the Cyclic Voltammetry Response of LSCF-type Electrodes: Impact of the Ohmic Losses and Microstructure, *Solid State Ionics* 371 (2021) 115765
- [4] A. Abaza, J. Laurencin, A. Nakajo, M. Hubert, T. David, F. Monaco, C. Lenser, S. Meille, Fracture properties of porous yttria-stabilized zirconia under micro-compression testing, *Journal of the European Ceramic Society*, 42 (2022) 1656-1669.
- [5] A. Abaza, J. Laurencin, A. Nakajo, S. Meille, J. Debayle, D. Leguillon, Prediction of crack nucleation and propagation in porous ceramics using the phase-field approach, submitted to *Theoretical and Applied Fracture Mechanics* (2022)

3 HYDROGEN STORAGE AND TRANSPORTATION

To transport hydrogen safely, we need to know how different materials react to it. This is a key area of research at CEA-Liten. Recently, the institute also started investigating ways of storing hydrogen using organic molecules known as Liquid Organic Hydrogen Carriers or LOHCs.

NEW MATERIALS FOR HYDROGEN STORAGE

Liquid Organic Hydrogen Carriers (LOHCs) store and carry hydrogen in liquid form. Teams at CEA-Liten are seeking to identify new stable non-toxic biosourced molecules that can absorb and release hydrogen as required. The researchers use modeling techniques (in particular Density Functional Theory, or DFT) to predict the thermodynamic properties of the molecules and select the

most promising combinations of molecules and catalysts—those offering the highest hydrogen storage density and the best compromise between cost and availability. CEA-Liten is also developing innovative reactors and conducting carbon footprint and life-cycle analyses to assess the environmental benefits of the new processes.



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LOHCs MATERIALS STORE AND CARRY HYDROGEN IN LIQUID FORM.”



PREPARING GAS GRIDS FOR THE HYDROGEN ERA



A hydrogen exposure testing protocol that mirrors the real-world operating conditions of a gas grid has been set up.

Interview with Tanguy Manchec, Hydrogen R&D Manager at the GRTgaz Research and Innovation Center for Energy (RICE)

"Using existing gas infrastructure to carry hydrogen is a promising solution as it's both cost-effective and good for the environment. To do this, however, we need to know exactly how the metal components of pipelines react when exposed to hydrogen. We decided to work with the CEA because they are experts in the field and have cutting-edge testing capabilities. The partnership has allowed us to compile a database of all the materials used in GRTgaz's gas infrastructure, and set up a hydrogen exposure testing protocol that closely mirrors the real-world operating conditions of a gas grid. The preliminary results are very encouraging as they confirm that we can safely inject gas containing hydrogen into our existing natural gas pipelines."

4 PEMFCs

CEA-Liten has more than 20 years of experience in developing low-temperature proton exchange membrane fuel cells (PEMFCs). This technology is both compact and high-yield, making it ideal for sectors like heavy-duty transportation, where batteries are not a viable option due to their high weight and volume and limited capacity. When combined with international-standard-compliant pressurized (700 bars) storage, hydrogen can compete with combustion-engine-powered vehicles in terms of both range and charging times. CEA-Liten is now looking at how to reduce fuel cell production costs while improving performance and lifespan.



DEVELOPING FRANCE'S FIRST MILITARY HYDROGEN-POWERED UAV

CEA-Liten has partnered with the *École de l'Air**, to develop a hydrogen-powered UAV designed and manufactured exclusively in France. Baptized RAPACE—bird of prey in French—the project is France's first attempt at developing a hydrogen-powered UAV for military use. CEA-Liten's fuel cell technology was chosen for the project thanks to its unique ability to withstand all kinds of extreme environmental conditions.

*The military and aeronautical training school for officers of the French Air Force and Space Agency.

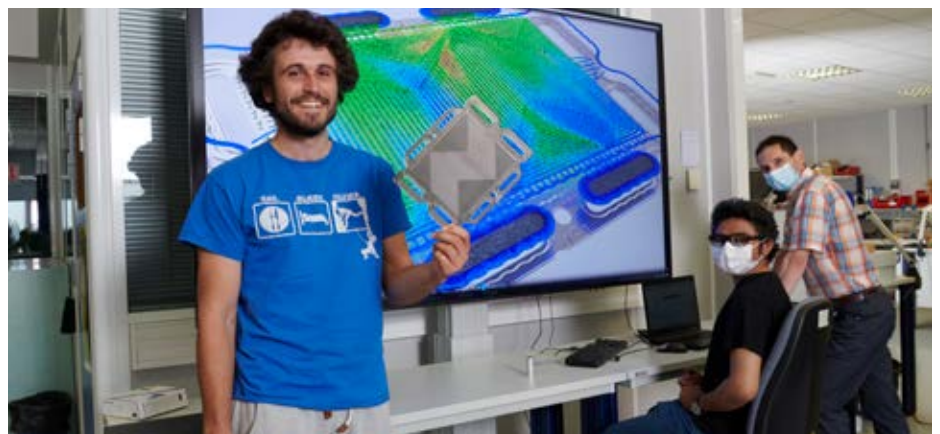
NEW MANUFACTURING PROCESS FOR ACTIVE LAYERS IN PEMFCs

Researchers at CEA-Liten have developed a new process for manufacturing the active layers of PEMFCs. The membranes are mechanically reinforced using microfibers, and then directly coated with catalyst inks. Even when used on an industrial scale, the technology would only require small quantities of platinum, representing significant cost savings.

NEW ADVANCE COULD EXTEND PEMFC LIFESPANS

Membrane degradation is one of the main lifetime-limiting factors in PEMFCs. Membrane degradation can be accelerated by several things, one of which is the presence of metal ions. The origin of these ions, however, is unknown. Researchers at CEA-Liten posited that plate corrosion could be the culprit. To test their hypothesis, they modeled the corrosion-induced emission of iron ions and the diffusion of these ions from the plates and through the cell to the membrane. They also modeled the reverse fluoride transfer

that occurs during membrane degradation and stimulates plate corrosion. Finally, they integrated all these models into CEA-Liten's MePHYSTO fuel-cell simulator. Modeling combinations of degradation mechanisms in this way is unique, as researchers usually look at single mechanisms in isolation from each other. The research will now allow researchers to simulate the interactions between the different phenomena at work in the stack as well as any snowball effects. Ultimately, the insights gained will help extend fuel cell lifespans.



This unique modeling combinations of degradation mechanisms will ultimately help extend fuel cell lifespans.

ARTIFICIAL INTELLIGENCE AT THE SERVICE OF BATTERY AND FUEL CELL MANAGEMENT SYSTEMS

BACKGROUND

Increasing the lifetime and reliability of PEM fuel cells and Li-ion batteries in real conditions of usage is crucial for the electrification of transport. This requires optimizing their operation in real time, which relies on determining the current state of the system (diagnostic) and on estimating its future state (prognostic) to decide how to optimize the system operating conditions. The diagnostic and prognostic algorithms are embedded in dedicated electronics: the battery and fuel cell management systems (BMS and FCMS).

APPROACH

Three approaches are identified to develop diagnostic and prognostic algorithms. The model-based approach consists in integrating the best theoretical expert knowledge to determine the current and future states of the system. This approach is currently the most widely used but requires much data acquisition and analyses in many laboratory conditions to determine and understand the underlying physico-chemical degradation

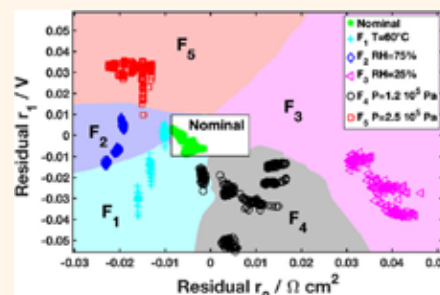
mechanisms that are integrated in the models. The data-based approach, which, despite its promising potential, still exhibits generalization or performance limitations in real applications, uses machine-learning methods to estimate the ageing trend. Hybrid methods combine the principles of the two previous approaches by improving the model by artificial intelligence algorithms trained on databases.

APPLICATION EXAMPLES

We illustrate this hybrid approach on two examples of application.

1 / To detect and classify fuel cell operating faults, we developed a new algorithm based on the analysis of current, voltage and impedance measurements that are easily accessible in real operating conditions. We showed that the differences between the experimental measurements and the outputs computed by the physical model are sensitive to operating faults. Using a database of estimated residuals from various known faults, a classification of faulty operating conditions has been developed by a K-nearest Neighbor algorithm. The classification score depends on the type of fault but is very accurate (>99%) for high pressure and low humidity faults for instance.

2 / To improve the ageing estimation of a Li-ion battery, we developed a model that combines a Kalman filtering method based on specific battery models to estimate the state indicators and a support vector machine learning method to track the cell capacity evolution. This method hybridizing model-based and data-based approaches achieves a high accuracy to estimate the battery state-of-charge and ageing: less than 1% error, which represents a 85% improvement compared to a standard Kalman estimation.



On top: PEM fuel cells test bench

Below: insulation defect in the PEMFC fuel cells stack

References

- [1] Fuel Cells Fault Detection and Isolation for Proton Exchange Membrane Fuel Cell Using Impedance Measurements and Multiphysics Modeling
- [2] IEEE Battery-Aware Optimization of Green Small Cells: Sizing and Energy Management
- [3] IEEE An Adaptive Sigma Point Kalman Filter Hybridized by Support Vector Machine Algorithm for Battery SoC and SoH Estimation

5 BATTERIES

Batteries are a key technology for the energy transition. They enable clean transportation, and in coming years we will also see batteries being used to address the backup power needs of the grid. CEA-Liten is leveraging its expertise in electrode materials and their chemistry to improve two aspects of battery performance: energy density and power density. Energy density determines the range of a battery, and power density determines how fast energy can be delivered. Research is focused primarily on solid-state batteries, although alternative technologies are also being investigated. The goal is to develop new generations of safe, powerful batteries. Last but not least, in terms of sustainability, the battery industry needs to become less reliant on expensive, toxic solvents and critical raw materials like cobalt. CEA-Liten is contributing to this goal by investigating new electrode manufacturing processes and techniques for recovering and recycling raw materials.

TOWARDS MORE DURABLE BATTERY MATERIALS

CEA-Liten's work on lithium-ion battery materials covers multiple aspects. As well as studying safety and performance criteria like energy and power, researchers are looking at how to extend battery lifespans and exploring low-cost alternative chemistries. Environmental aspects are equally important. Goals include eliminating the use of critical raw materials like nickel and cobalt

in cathodes, and developing end-of-life recycling and recovery processes. The latter are of interest because the recovered nickel, manganese, and cobalt salt solutions can be used to produce new materials. This approach reflects two overarching goals: to reduce the environmental footprint of electric vehicles, and to address geopolitical risks relating to the supply of raw materials.

PREPARING FOR ELECTRICAL TESTING OF NEXT-GENERATION SOLID-STATE BATTERIES

Solid-state batteries are so named because they contain solid electrolytes and separators. Because of this, cylindrical cell formats are not suitable. The most promising alternative is a pouch cell format. CEA-Liten has developed a method for assembling, cycle-testing, and dismantling modules comprised of functional Li-ion pouch cells. The electrical testing method proved effective and a high level of reproducibility was achieved. This lays the groundwork for evaluating pouch-type chemical batteries (Li-ion or post-Li-ion) with higher energy densities.

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WORK ON LITHIUM-ION BATTERY MATERIALS COVERS MULTIPLE ASPECTS (PERFORMANCE, SAFETY, LIFESPANS...)”



SILICON ANODES FOR SOLID-STATE BATTERIES

CEA-Liten is working with the Interdisciplinary Research Institute of Grenoble (IRIG), part of the CEA's Basic Research Division (DRF), to develop new types of silicon anodes for solid-state batteries. The first step was to select an electrolyte that is compatible with silicon. The researchers chose to use solid sulfide electrolytes because they offer high ionic conductivity and their mechanical properties make them compatible with cold-pressing assembly procedures. Coupled with micron-scale silicon

particles, the $\text{Li}_6\text{PS}_5\text{Cl}$ electrolyte (LPSCI) exhibited a specific capacity of 3000 mAh/gSi with a coulombic efficiency of more than 97% from the second cycle onward. Further work is being conducted to evaluate different sizes and shapes of silicon-based materials. Nanowires grown at IRIG have shown promising results. The researchers also plan to try combining nanowires with carbon-containing materials, and to explore ways of optimizing the surface area of the active materials.



THE GRENOBLE BATTERY HUB

In 2021, the CEA joined forces with the ESRF and the ILL—two of Grenoble's large European instruments—to form a new battery research hub dedicated to battery characterization. The hub will conduct operando experiments to study the electrochemical processes that take place in batteries in both normal and abusive conditions. Researchers will have regular access to the ESRF's beamline, allowing them to conduct their investigations at the highest possible spatial and temporal resolution. By using multiple characterization technologies and pooling their expertise, the hub's members will be able to obtain valuable quantitative data, gain a better understanding of what happens inside batteries, and develop models that can more accurately predict battery performance, health, and ageing effects. The long-term goal is to develop new battery materials, sensors, and architectures. The Battery Hub will soon be open to other European research institutes and labs, too.

EMBEDDED SENSORS FOR LI-ION BATTERIES

"CEA-Liten is coordinating the INSTABAT project as part of the EU-funded BATTERY 2030+ initiative, which aims to invent the batteries of the future. The INSTABAT solution involves embedding six sensors in Li-ion battery cells: four physical sensors (one electrochemical sensor, two optical sensors, and one gas sensor), and two virtual sensors (based on electrochemical and thermal models). The sensors perform operando monitoring of

internal parameters of the battery, feeding data to the Battery Management System (BMS) with the aim of providing more accurate information about the state of charge, health, power, energy, and safety (SoX). Ultimately, this will allow for the development of safer, more reliable batteries and better end-of-life recycling and recovery processes."

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955930.



AN OPERANDO METHOD FOR STUDYING BATTERIES

Online Electrochemical Mass Spectrometry (OEMS) allows researchers to observe the electrochemical reactions that occur in batteries in real time. In particular, they can study ageing mechanisms by cycling a battery inside a special test cell and using mass spectrometry to continuously sample and analyze the evolved gases.

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PERFORMING IN OPERANDO MONITORING OF INTERNAL PARAMETERS OF THE BATTERY LET US UNDERSTAND REACTIONS THAT OCCUR IN BATTERIES AND IMPROVE THEIR PERFORMANCE, RELIABILITY AND SAFETY.”

A LIGHTWEIGHT SYSTEM TO PREVENT THERMAL RUNAWAY IN BATTERIES

Thermal runaway in batteries is a major safety issue, especially for on-board aircraft batteries, where early detection is crucial. In research for the EU OASIS project*, CEA-Liten, plastics R&D center IPC, and Thales joined forces to develop a new battery cell packaging that is 15% lighter, robust enough to withstand extreme thermal and mechanical stress, and equipped with two kinds of sensors developed at CEA-Liten.

Specially designed temperature sensors are integrated into a new composite packaging developed by IPC to replace the conventional, much heavier metal system. The original flexible piezoelectric sensors, integrated inside the battery core, can detect changes inside the material indicative of malfunctions that can lead to thermal runaway.



* Grant Agreement N° 814581

6 CARBON-FREE MOBILITY

To help accelerate the shift to clean transportation, CEA-Liten is addressing the electric power chain holistically, covering everything from elementary component to complete system. The idea is to effectively dimension and optimize power management according to vehicle operating conditions. Our researchers design and build hybrid battery/fuel-cell drivetrain systems with built-in power and control electronics, which they integrate into prototype vehicles. They also monitor and interpret data from road tests, and look at how their systems interact with charging infrastructure.

BOOSTING HYBRID ELECTRIC VEHICLE DEVELOPMENT

In the future, increasing numbers of electric vehicles will have both a battery and a fuel cell. CEA-Liten improved and updated its dimensioning software for energy chains combining fuel cells and batteries. The new release should help make developing hybrid electric vehicles more efficient. Once the battery and fuel cell have been selected and dimensioned, the next step is to come

up with a control law to determine which energy supply should be used to power the vehicle at any given moment to ensure optimal efficiency. The control law is already part of the MUSE multi-scale multi-physics modeling platform. Here, it was modified to streamline the iterative calculation process. The latest release of the software is three times faster than the previous version.



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THE SOFTWARE DETERMINE WHICH ENERGY SUPPLY SHOULD BE USED TO POWER THE VEHICLE AT ANY GIVEN MOMENT.”

GEN-Z: REVOLUTIONIZING THE HEAVY-DUTY TRANSPORTATION INDUSTRY

The goal of the Gen-Z project is to develop an innovative high-power fuel-cell technology for the heavy-duty transportation industry. Project leaders Mike Horn and Cyril Despres plan to put the technology through rigorous real-world testing by competing in an upcoming rally race in a hydrogen-powered vehicle equipped with Gen-Z technology.

CEA-LITEN SCIENTIST RECOGNIZED AS ONE OF THE WORLD'S MOST CITED RESEARCHERS

Natalio Mingo was named a Highly Cited Researcher by Clarivate Analytics, making him the first researcher at CEA Grenoble to receive this honor. Dr. Mingo's publications focus on theoretical calculations of thermal conductivity and high-throughput computational materials design, and have been widely cited by his peers.

OVERCOMING BARRIERS TO HEAVY VEHICLE ELECTRIFICATION

The nature of heavy vehicles and how they are used mean that the standard electrification technologies used in light vehicles are not suitable. The POWER2024 project, headed up by Actia, aims to overcome these barriers. It leverages multiple innovations: “cell-to-pack” battery technology, multi-level miniaturized power converters, and advanced battery monitoring and management systems. Together, these innovations will help reduce greenhouse gas emissions and pollution in urban areas.



BATTERIES

Develop lithium-ion batteries and future generations, including "all-solid" batteries that are more compact, more efficient, and safer.



GREEN CHEMISTRY AND PROCESSES FOR THE ENVIRONMENT

Promoting long-term growth through improved materials and processes in an eco-circular manner



STRUCTURAL ELECTRONICS

Functionalize flat or 3D surfaces with electronics



CARBON CONVERSION

Convert CO₂ and its derivatives into energy carbon products



MODELING AND INTEGRATION FOR MOBILITY

Using a systemic approach to the energy chain, dimension and optimize energy management based on usage conditions.



POWDER METALLURGY, PLASTICS PROCESSING AND ASSEMBLY

Develop and manufacture high-value-added components from powders, solid metallic or ceramic parts.

12 PLATFORMS FOR TECHNO



NANOCHARACTERISATION

Probe the structure and behavior of materials on a unique platform with over 50 advanced characterization instruments.



NANOSAFETY

Supervising the use of nanomaterials and controlling emerging risks

Propose a unique approach to the design and optimization of PEMFC batteries



FUEL CELL



HYDROGEN PRODUCTION & STORAGE

Exploiting hydrogen as an energy source, producing it by electrolysis of water vapor.



SOLAR PHOTOVOLTAICS



MULTI-ENERGY SMART GRID

Put energy management solutions on complex networks (electricity, gas, and heat) to the test in real-world scenarios

Accelerate the deployment of high-efficiency photovoltaic solutions

ADVANCED LOGICAL RESEARCH

OUR DIGITAL AND TECHNOLOGICAL PLATFORMS COMBINE MEANS AND SKILLS, AND ALLOW TO INNOVATE BOTH IN PRODUCT AND PROCESS R&D. CONVINCED THAT COMPETITIVENESS REQUIRES, AMONG OTHER THINGS, THE DEVELOPMENT, TESTING AND VALIDATION OF INNOVATIONS ON PRE-INDUSTRIAL EQUIPMENT, LITEN CONTINUOUSLY INVESTS TO KEEP ITS PLATFORMS AMONG THE BEST IN THE WORLD.



NEW SCENARIOS LIKE THE INTRODUCTION OF INTERMITTENTLY-PRODUCED RENEWABLE ENERGY INTO GRIDS; EMERGING MODES OF CONSUMPTION LIKE ELECTRIC VEHICLES, ELECTROLYZERS TO PRODUCE HYDROGEN, AND SELF-CONSUMPTION; AND THE COUPLING OF DIFFERENT ENERGY VECTORS LIKE ELECTRICITY, HEAT, COLD, AND GAS ARE ALL HALLMARKS OF THE ENERGY TRANSITION. CEA-LITEN LEVERAGES MULTI-ENERGY-VECTOR TEST PLATFORMS AND DEEP KNOWLEDGE OF ENABLING TECHNOLOGIES TO DEVELOP ITS OWN SOFTWARE TO OPTIMIZE THE DIMENSIONING AND CONTROL OF ENERGY SYSTEMS AND GRIDS. CEA-LITEN ALSO DEVELOPS ELECTRICAL AND THERMAL ENERGY MANAGEMENT COMPONENTS FOR GENERATION, CONVERSION, AND STORAGE TO MAKE ENERGY SYSTEMS AND GRIDS AS EFFICIENT AS POSSIBLE.

SYSTEMS, GRIDS, AND ENERGY EFFICIENCY

KEY FIGURES

47 PUBLICATIONS

335 PATENTS

24 PhD CANDIDATES

170 EMPLOYEES

1

ENERGY SYSTEMS AND GRIDS

The energy transition presents new technical challenges. Energy systems and grids must be adapted to handle new modes of consumption and allow for the efficient integration of renewable energy into the energy mix. Researchers at CEA-Liten are working closely with partner companies to design multi-energy-vector systems that are cleaner, more efficient, and—crucially—smarter and more connected. These automated, connected systems—such as smart grid technologies that automatically monitor and manage energy production, use, and storage—will help the energy industry respond to new use cases and meet energy efficiency and carbon emissions targets.

MULTI-ENERGY SMART GRID PLATFORM

The PISE technology platform has a comprehensive suite of equipment for developing complex energy systems. 2021 saw the start of renovation work to extend the platform's existing infrastructure and install

new heating and cooling equipment. Upon completion, the revamped facility will provide a unique environment for testing complex heating, cooling, electricity, natural gas, and/or hydrogen networks.



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PISE, A UNIQUE ENVIRONMENT FOR TESTING COMPLEX HEATING, COOLING, ELECTRICITY, NATURAL GAS, AND/OR HYDROGEN NETWORKS.”

One of the components of the PISE Platform, based at Ines, allows the study and optimization of heat and cold management solutions

DISTRICTLAB-H: A DIGITAL SOLUTION FOR HEAT NETWORKS

CEA-Liten and its partners have been looking at ways to optimize the management of urban heat networks for many years. Recently, they developed innovative algorithms and integrated them in a suite of software called DistrictLab-H. The software has two interoperable modules. The first is a simulation tool for testing new configurations, like connecting additional end users to a heating network. The second is an online mode that helps operators optimize energy production and distribution and make their heating networks greener and more efficient. The software was scaled up to cover large urban networks as well as neighborhood-scale microgrids and has been successfully rolled out in the French cities of Grenoble and Metz.

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DISTRICTLAB-H IS A VALUABLE TOOL FOR ENERGY STAKEHOLDERS BECAUSE IT CAN BE ADAPTED TO GRIDS AND CITIES OF ALL SIZES. THE PLAN NOW IS TO HAND OVER THE DEVELOPMENT WORK TO A STARTUP, WITH THE AIM OF HAVING A COMMERCIAL VERSION READY FOR MARKET BY 2023.”

BUILDING DESIGN: REDUCING CALCULATION TIME FOR SIMULATION AND OPTIMIZATION STUDIES

Buildings account for about one third of global energy demand, but we can reduce this by adopting a more holistic approach to energy systems. Building envelopes, connected systems, and renewable energy sources all have to be studied and optimized in connection with one another. However, researchers seeking to model such complex systems are faced with a dilemma. Full-scale simulations are too costly and time-consuming, but using simplified models is not a viable option, because the results are not sufficiently representative.

Researchers at CEA-Liten's facilities at the French national solar energy research institute (INES) may have found a solution. They have developed a new algorithm called TypSS (Typical Short Sequence) that uses a shorter simulation period. In tests on a detailed building model, the algorithm obtained much faster results with no loss of accuracy compared to an annual model.

The software suite DistrictLab-H™ assists the designer in getting an optimized layout



COUPLED HEAT AND MOISTURE STORAGE FOR COOLING COLD SPOTS IN THERMODYNAMIC CYCLES

BACKGROUND

The cooling of thermodynamic cycles is a crucial factor in electricity production, as it directly and significantly impacts conversion efficiency [1]. Wet cooling offers the highest efficiency, but at the cost of very high water consumption [2]. Conversely, the efficiency of dry cooling decreases sharply as ambient temperature increases [3]. With pressure on water reserves mounting and a climate that is only expected to get hotter, alternatives to wet and dry cooling are needed.

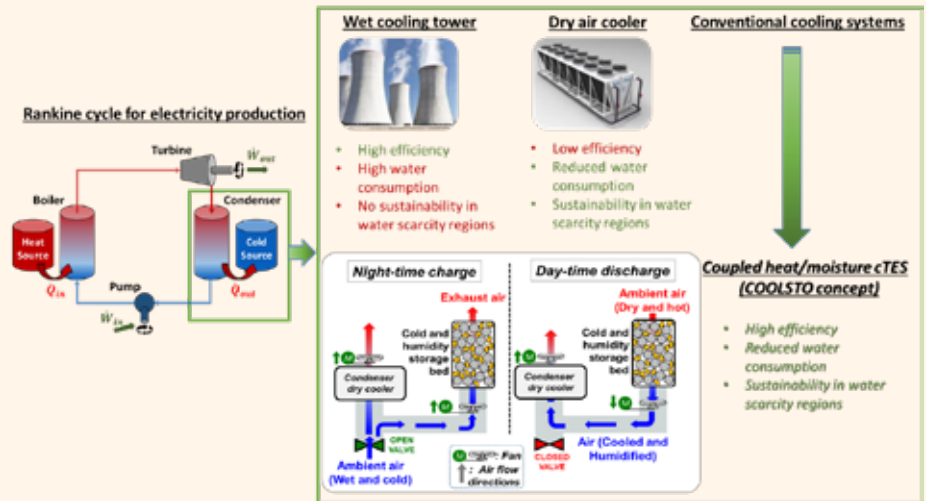


Figure 1: The COOLSTO coupled storage concept and advantages.

RESULTS

As part of CEA-Liten's energy efficiency strategy and the institute's efforts to support more efficient, sustainable electricity production, a coupled heat and moisture storage concept was developed under the COOLSTO project (Figure 1). This new concept offers the advantage of offsetting the performance losses observed in dry cooling systems, but without the excessive water consumption of wet systems. It is based on convection and sorption: A storage medium filled with sensitive and sorbent materials stores heat and moisture at night to cool the ambient air during the day.

The COOLSTO project led to the validation of this concept. Testing and simulation using purpose-built equipment and new numerical models provided an excellent understanding of the physical mechanisms that underpin the

process, and the data produced was used to calculate the system's performance at various sites and in different regions. Figure 2 shows a typical example of the system's efficiency. On a typical night (n), the cold and moisture in the ambient air are stored by adsorption, "filling up" the system. The following day, the hot ambient air is cooled by convection and desorption in the tank. Only then is it sent to

the dry air cooler, limiting the performance losses seen with dry cooling alone. The experimental measurements (temperature and adsorbed/desorbed water) aligned closely with the numerical simulations.

CONCLUSION

The results of the research conducted under the COOLSTO project were validated by two scientific publications, one on the experimental research [4], and one on the numerical model [5]. An additional vote of confidence for this concept came in the form of funding for a PhD candidate to pursue the development of the system. This has already led to the development of an innovative hybrid material (for which a patent has been filed) [5] and to additional articles.

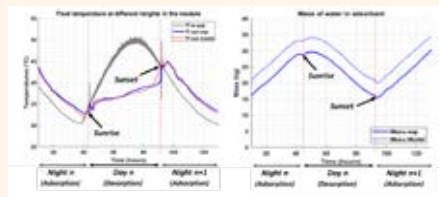


Figure 2: Typical experimental and simulated cooling effect on the ambient air (left) and changes in the mass of water in the sorbent (right).

[1] DOE, Concentrating Solar Power Commercial Application Study: Reducing Water Consumption of Concentrating Solar Power Electricity Generation. DOE, 2008.

[2] Carter, N., & Campbell, R., Water Issues of Concentrating Solar Power (CSP) Electricity in the U.S. Southwest (No. R40631), 2009.

[3] Turchi, C. S., Wagner, M. J., & Kutscher, C. F., Water Use in Parabolic Trough Power Plants: Summary Results from Worley Parsons' Analyses (No. NREL/TP-5500-49468). NREL, 2010.

[4] S. Rougé, O. Soriano, A. Bruch, G. Largiller, and J. Bentivoglio, 'Experimental characterization of coupled sensible heat and moisture storage for dry cooling enhancement', Appl. Therm. Eng., vol. 192, p. 116922, Jun. 2021, doi: 10.1016/j.applthermaleng.2021.116922.

[5] Grégory Largiller, Igor Correa Ferreira, Adsorbent composite material for humidity control devices, heat exchange and storage devices, Patent application (in deposit).

2 THERMAL ENERGY MANAGEMENT

Heating and cooling account for a significant proportion of total energy demand in buildings, averaging 40% depending on building type (residential, commercial, or industrial). Optimizing these systems is thus an important step towards a carbon-free energy future. CEA-Liten's R&D work addresses two key challenges in this field: developing thermal storage to provide flexibility for energy systems and grids and improving thermal systems to make them more efficient and cost-effective, including for waste-heat recovery.

MORE AFFORDABLE COOLING

CEA-Liten recently developed a machine that combines an absorption-cooling-type system and power turbine to generate cold and electricity simultaneously, using waste heat (80 °C –200 °C) from industrial processes as an energy source. The new machine uses between 10 and 20 times less energy than conventional air conditioning

systems, which rely on mechanical vapor compression. The researchers used numerical models to develop a high-purity ammonia vapor generator that is particularly efficient and compact. The vapor produced can be used in two ways: to run the cooling cycle, and/or to run the system's integrated turbine to produce electricity.



“ ABSORPTION-BASED TECHNOLOGY USES WASTE HEAT FOR HEATING SYSTEMS OR TO GENERATE COLD AND ELECTRICITY SIMULTANEOUSLY.”

USING SUGAR AS A STORAGE MEDIUM IN URBAN HEAT NETWORKS

Scientists at CEA-Liten have developed a thermal storage demonstrator that uses sugar, of all things! The sugar in question was xylitol, a naturally occurring sugar alcohol. Xylitol has the advantage of being non-toxic and inexpensive. However, it remains liquid even below its theoretical freezing point. The researchers overcame this issue by adding seed crystals to initiate crystallization, then producing air bubbles to speed up the process. Combining the two techniques allowed them to recover all the energy stored in the sugar.



This thermal storage demonstrator uses... sugar, of all things!

ABSORPTION TECHNOLOGY FOR HEATING SYSTEMS

CEA-Liten has developed a new absorption-based technology for domestic hot water systems. The project is funded by the Auvergne-Rhône-Alpes EasyPOC program, which finances proof-of-concept (POC) development and testing. CEA-Liten's solution uses waste heat or heat from a renewable energy source, and natural working fluids that do not release any CO₂. It is 70% more efficient than using the same energy directly. The institute has filed two patents to protect the technology and hopes to have it ready for market in the near future.

3 HIGH-PERFORMANCE POWER CONVERTERS

With electricity consumption rising rapidly, and pressure to efficiently integrate renewables into the energy mix increasing, there is urgent demand for new and improved power electronics devices. Teams at CEA-Liten are leveraging the latest innovations to design power converters that are smaller, more powerful, and more efficient. Most of the solutions under development use wide bandgap silicon carbide (SiC) and gallium nitride (GaN) components because these can deliver the high current densities and operating frequencies required in the key target markets.

GaN COMPONENTS FOR THE MOBILITY SECTOR: TOWARDS HIGH-POWER APPLICATIONS

The EU has set tough emissions targets for the automotive industry, pushing car manufacturers to make their vehicles more energy efficient. CEA-Liten formed a joint team with CEA-Leti to take part in a European project aimed at improving electric vehicle drivetrains by using high-performance materials and design techniques. The team's key innovation was the use of wide bandgap gallium nitride (GaN) components in a six-phase inverter. Initial tests on commercially available 650V/240A GaN prototype modules yielded very encouraging results, with conversion efficiencies exceeding 99% and a maximum power output of 80 kW. Researchers used a digital twin of the inverter to show that optimizing the thermal properties of the packaging would increase the power output to over 120 kW. The demonstrator confirms that GaN components are a promising solution for high-power (> 10 kW), low-frequency applications (< 50 kHz).

A GaN-BASED PHOTOVOLTAIC MICRO-INVERTER

Photovoltaic (PV) generators are usually coupled with a static converter to keep them operating at their Maximum Power Point (MPP) and send the harvested energy to collectors (AC or DC). Alternatively, a Maximum Power Point Tracker (MPPT) converter can be installed in the junction box of each PV module. This helps overcome the problem of mismatch losses that occur due to conditions like partial shading, so that the maximum power can be harvested from each module

individually. Two types of MPPT converter exist—DC/AC (micro-inverters) and DC/DC (power optimizers). CEA-Liten at INES has produced a high-temperature dynamic characterization bench and a first prototype of a 400 W photovoltaic micro-inverter using GaN components produced by CEA-Leti's components department. A second-generation micro-inverter is in the pipeline for late 2022. It will use GaN-based switches that have been optimized for use in PV modules.

HIGH-EFFICIENCY COMPACT TRANSFORMERS FOR ON-BOARD CHARGERS IN ELECTRIC VEHICLES

In R&D conducted with Renault, the CEA developed a dimensioning method for the design of compact magnetic components like transformers and inductors. These components account for between 30% and 40% of total converter volume, so the ability to make them more compact without negatively impacting efficiency is a key issue. We did a thermal analysis of the magnetic components, which resulted in a better understanding of the thermomecha-

nical limitations to reducing component size when ferrite-type materials are used. Pot core components do limit electromagnetic emissions, but are more prone to thermal gradients than EE core structures. The thermal management of this type of component can be improved by integrating thermally conductive materials as close to the windings as possible, limiting thermal gradients.

ECO-INNOVATION GAINS TRACTION ACROSS CEA-LITEN LABS IN 2021

LEARN MORE ABOUT OUR ECO-INNOVATION STRATEGY FROM THE PEOPLE BEHIND IT!

At CEA-Liten, we are purpose-driven. And that purpose is to develop technical solutions—for the energy industry in particular—to lighten our environmental footprint. To fulfill our mission, we consider the economic, environmental, and societal dimensions of the technologies we develop. It is crucial for our researchers to be able to assess the environmental and financial performance of the systems they are developing in light of the use cases that will be addressed. This approach allows us to make the necessary adjustments to our R&D and market intelligence work. Our eco-innovation processes ensure that we

have the insights and indicators we need to monitor and measure the environmental impacts of our technologies so that we can take specific steps to reduce them. We are also making sure that our researchers are empowered through initiatives tailored to each research area's unique culture and needs. New knowledge and best practices from our departments are shared organization wide. Our team's strong commitment to eco-innovation is backed by a broad range of know-how and more than a decade of experience using LCA and technical and financial assessment tools.



WHAT WAS YOUR TOP ECO-INNOVATION MOMENT OF 2021?

“

“I was able to apply the results of environmental impact studies of additive manufacturing processes. Addressing environmental concerns gives my work meaning.”

Emmanuelle COR

“

“I was involved in a project to model a 100% renewable national energy mix. Not only was it rewarding to contribute to the team's success, but I also learned a lot personally.”

Julie CREN

“

“Helping set up the EU Surpass project. We addressed all three sustainable development pillars to develop this eco-innovation project on safe, durable, and recyclable plastics.”

Stephanie DESROUSSEAUX

“

“One of the highlights for me was participating in the French government working groups on the electric road. People are becoming more and more aware of the benefits the solution can bring.”

Fabien PERDU

“

“We were able to share our insights on the technical, economic, and environmental limitations of different energy mixes.”

Didier BLOCH

“

“We released a more flexible and user-friendly version of our EcoPV tool that will support future technology development projects.”

Nouha GAZBOUR

“

“Improving the economic and environmental performance of our technologies also creates new opportunities to innovate, and that's important to remember.”

Isabelle MAILLOT



CIRCULAR ECONOMY CONSIDERATIONS WILL NEED TO BE A MAJOR FACTOR IN TECHNOLOGICAL INNOVATION IF THE IMPACT OF THE ENERGY TRANSITION ON RAW MATERIALS CONSUMPTION IS TO BE LIMITED. AT CEA-LITEN, OUR RESEARCH SUPPORTS A CIRCULAR ECONOMY APPROACH TO MATERIALS. TO EFFECTIVELY “REDUCE, REUSE, AND RECYCLE,” WE ARE ROLLING OUT AN ECO-DESIGN APPROACH TO NEW ENERGY TECHNOLOGY—ONE THAT INCLUDES RECYCLING AND RECYCLABILITY. WE ARE USING INNOVATIVE, MORE ENVIRONMENTALLY FRIENDLY METHODS LIKE ADDITIVE MANUFACTURING, COMPLEX ASSEMBLIES, BIO-BASED MATERIALS, AND STRUCTURAL ELECTRONICS TO EMBED FUNCTIONS DIRECTLY IN MATERIALS. THE INSTITUTE ALSO DEVELOPS MATERIALS, PROCESSES, AND SYSTEMS FOR THE CIRCULAR CARBON ECONOMY, I.E., THE CONVERSION OF CARBON-CONTAINING RESOURCES INTO MOLECULES OF INTEREST FOR ENERGY OR CHEMISTRY.

CIRCULAR ECONOMY



1 ADDITIVE MANUFACTURING

KEY FIGURES

67 PUBLICATIONS

461 PATENTS

47 PhD CANDIDATES

230 EMPLOYEES

We have been working on 3D printing since 2014, partnering with 3D printing equipment manufacturers to prepare for the future growth of this industry. Our additive manufacturing (or 3D printing) research focuses on new materials and the detailed characterization of parts made using additive manufacturing. The idea is to understand the relationships between process parameters, the microstructures within the 3D-printed materials, and their mechanical properties. We are also working on solutions to integrate additive manufacturing into use cases in a wide range of industries and, with CEA-List, on non-destructive testing methods to inspect 3D-printed parts.

FUNCTIONALIZED COMPOSITE POWDERS FOR HIGH ADDED VALUE

We developed a laser powder-bed fusion process for structural aluminum alloys. We functionalized the metal powders using electrostatic grafting of nanopowders, a pre-treatment that minimizes the abnormal grain growth that can cause hot cracking

during cooling. A new high-shear mixer, which can also be used for other materials, was used in this process. This is just one of the CEA-Liten material-saving innovations developed for the manufacture of high added value parts.

HP AND CEA PARTNER TO BRING METAL BINDER JET 3D PRINTING TO MANUFACTURERS

HP and the CEA—partners since 2018—set up an HP Metal Jet printer at the CEA in Grenoble so that their respective partners can learn about this new additive manufacturing solution. The powder-bed fusion binder jet technology offers a throughput that qualifies it as a volume manufacturing tool. Even better, costs are predictable and competitive, and the quality of the parts manufactured satisfies industrial specifications.



The objective is to disseminate this HP metal binder jet technology and to confront it with the requirements of the different application sectors

2 COMPLEX PROCESSES AND ASSEMBLIES

CEA-Liten also conducts research to support the manufacturing of high added value near-net-shape parts (that require little to no post-manufacturing machining) from powders using plastics processes, hot isostatic pressing (HIP), and sintering, for example. We are also looking at how to manufacture complex, multi-material components by combining different manufacturing processes.

AN INNOVATIVE ASSEMBLY SOLUTION FOR THE METALLURGICAL INDUSTRY

CEA-Liten is engaged in the CALHIPSO project, coordinated by the University of Burgundy Franche-Comté, which won an EQUIPEX+ 2020 grant from the French government. The project partners are using a holistic approach that includes experimentation, modelling, and simulation to develop turnkey hot isostatic pressing (HIP) solutions for the metallurgical industry. CEA-Liten purchased a state-of-the-art R&D HIP press for the project.

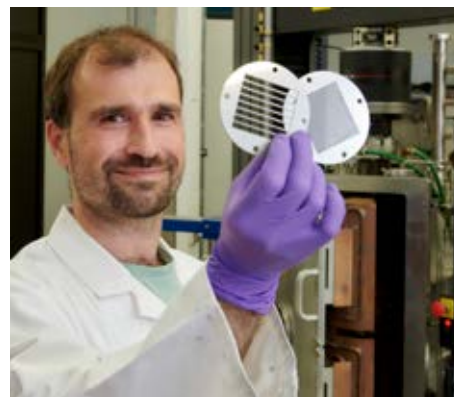
This work is being funded in part by the French National Research Agency (ANR-21-ESRE-0039) as part of France's national economic stimulus program.

NUCLEAR ASSEMBLY PLATFORM

CEA-Liten has been developing a diffusion welding assembly technology for the past 20 years. Originally for nuclear fusion, diffusion welding is now being used for low-carbon energy solutions. For example, we are bringing our knowledge of heat exchanger construction to projects targeting a variety of use cases. In one project, IDNES, we are designing heat exchangers and studying the technical and economic feasibility of recovering waste

process heat for use in heat networks or water electrolysis for hydrogen production, for example. We are also engaged in a project called Nuward alongside EDF, Framatome, NavalGroup, and TechnicAtomes, where we are comparing HIP* and UHP** to assemble the plates in a power reactor. These projects align with the strategic objectives of the "France 2030" program by supporting the development of small modular reactors (SMRs).

*Hot isostatic pressing **Uniaxial hot pressing



3 STRUCTURAL ELECTRONICS

In structural electronics, enabling technologies are used to integrate electronics into the material of an object. It is a natural extension of CEA-Liten's fifteen years of research and development in the field of printed electronics. We are working on new ink formulations, of course. But we are also developing printing, forming, and assembly processes involving flexible and stretchable substrates. The potential applications span energy, health, and transportation.

PRINTED ORGANIC ELECTRONICS REACH MATURITY

Printed organic electronics could lighten the environmental footprint and lower the cost of IoT sensors. In research for an EU-funded project, CEA-Liten is working with Arkema and Arjowiggins to develop a smart, autonomous paper label capable of detecting impacts, even tiny ones. A combination of component transfer and printing technologies for the tracks, antennas, and

piezo sensors were used to create the device on a paper substrate. It can measure vibrations and impacts as light as a touch, sending the data to the chip via an antenna. It is ideal for tracking fragile objects and parcels. Later, temperature and humidity sensors could be added, further augmenting this 100% recyclable smart paper label's capabilities.



“

THIS SMART TAG WAS
DESIGNED ON A PAPER
SUBSTRATE.”

FLEXIBLE ELECTRONICS HELP COMPANIES INNOVATE

The European SmartEEs cascade funding program supports the integration of flexible electronics into innovative products and services, specifically to help startups and small to medium-sized businesses go digital. SmartEEs is an extension of the European Digital Innovation Hub (EDIH) project of the same name, which will end in 2022. “We are offering an integrated, pan-European innovation service,” said CEA-Liten's Jérôme Gavillet, coordinator of SmartEEs. “Companies can come to us for digital technology, a wide range of know-how and partners, plus business development support.”

ISORG'S FINGERPRINT SENSORS NOW FBI-APPROVED

CEA spinoff Isorg, created in 2010 to develop polymer sensors and organic photodetectors, recently obtained FBI certification for its fingerprint sensor. Isorg is already active on the growing smartphone market. The FBI certification is crucial to accessing another high-growth market: security.

SYMBIOSE RAISES FRESH CAPITAL FOR NEW PLANT

Symbiose raised €6.5 million in 2021 to build a new plant in Pugnac, near Bordeaux. The plastronics startup developed its IME technology in partnership with the CEA. The technology can be used to create 3D objects with integrated circuits and waveguides of varying degrees of complexity by printing patterns or circuits onto conformable surfaces.

4 GREEN CHEMISTRY AND RECYCLING

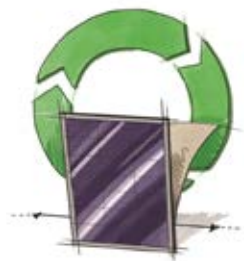
CEA-Liten has set its sights on solutions to make the technologies being developed for tomorrow's low-carbon energy systems more sustainable. We have earned a reputation for our capacity to develop more environmentally friendly recycling processes specific to spent renewable-energy components. However, the institute is also investigating new recycling channels for secondary materials. At the same time, we are developing ecodesign approaches for components that enable the best possible use of recycling processes.



BETTER RECYCLING OF END-OF-LIFE PHOTOVOLTAIC PANELS

CEA-Liten has developed an energy-efficient, minimally polluting end-of-life recycling method for solar panels. A diamond wire is used to cut through the PV cells, separating the front face, made from glass, from the back face, made from a mix of polymers. The technique was successful at separating the two faces, which are just a few hundred microns apart. The lab equipment was able to separate a module with a surface area of one square meter in half an hour. The glass recovered can be recycled

into new products. The metals present in the cutting residues can be recovered and separated using hydrometallurgical processes, and then recycled.



PILOT BATTERY RECYCLING PROJECT WITH ORANO

Orano is joining forces with high-profile partners Paprec, MTB Manufacturing, Saft, and the CEA under the RECYVABAT project to give a second life to the recoverable materials in spent batteries. The project consortium has developed a process to purify and recover the metals (lithium, cobalt, nickel, etc.) contained in electric vehicle batteries separately, so that they can be recycled into new battery components. CEA-Liten is helping bring new innovations into the entire cycle. Two full-sized pilot lines will be built for technical and process testing.

THE SERENADE LABORATORY OF EXCELLENCE (LABEX) FOR SAFE, FRUGAL, INNOVATIVE NANOMATERIALS

BACKGROUND

The eight-year, thirteen-partner Serenade (Safer Ecodesign Research and Education applied to Nanomaterial Development) Laboratory of Excellence (Labex) addressed the challenge of how to design nanomaterials that are safer for people and the environment. With a consortium of partners spanning research and business working together in a coordinated manner, Serenade provided a unique opportunity to tackle safe-by-design nanomaterials holistically using real-world use cases. Together, the partners were able to investigate use cases in several industries at different stages of the lifecycle and at different TRLs [1].

TECHNICAL RESULTS

The research showed that titanium dioxide nanoparticles (nanoTiO_2) could be a promising solution for the mineralization of gaseous pollutants like volatile organic compounds in photocatalytic paints. To control the potential risks associated with the use of nanoTiO_2 , the paint design strategy addressed risks to people and the environment throughout the material's lifecycle [2]. Different variations of nanoTiO_2 were synthesized [3],[4] and incorporated into the paint formulations. The paints were then applied to standardized substrates so that their performance and behavior could be studied under controlled stressors. The painted substrates were artificially aged in a climatic chamber, and a TABER® abrasimeter was used to study particle emission due to erosion, for example.

The research demonstrated the usefulness of a holistic and product-oriented approach integrating performance, risk analysis, and health and environmental impacts. Products containing nanomaterials can be studied over the entire lifecycle based on realistic

use and end-of-life scenarios. Products that do not comply with the target specifications can be eliminated during the process. Although this approach is complex, it does constitute an effective design and assessment strategy [5].



On top: climatic chamber

On the right: TABER® abrasimeter

OUTLOOK

The development of safe, sustainable photocatalytic paints in partnership with France-based manufacturer Allios is a prime example of the advantages of this kind of holistic approach to eco-design. The research also led to several EU projects involving CEA-Liten to support the development of safe-by-design nanomaterials (SAByNA, SBD4Nano, ASINA) and to new European roadmaps for a safe, sustainable, competitive nanofabrication industry (SUSNANOFAB).



[1] J. Rose et al. "The SERENADE project; a step forward in the safe by design process of nanomaterials: The benefits of a diverse and interdisciplinary approach," NanoToday, 37 (2021), 101065.

[2] A. Rosset et al. "Towards the development of safer by design TiO_2 -based photocatalytic paint: impacts and performances," Environmental Science Nano, 8 (2021), 758.

[3] J. Laisney, " TiO_2 nanoparticles coated with bio-inspired ligands for the safer-by-design development of photocatalytic paints," Environ. Sci.: Nano, 8 (2021), 297.

[4] D. Musino, "CNC/AgNP hybrids as safer-by-design biocides in paints," Environ. Sci.: Nano, 8 (2021), 12, 3673.

[5] J. Rose et al. "The SERENADE project - a step forward in the Safe by Design process of nanomaterials: Moving toward a product oriented approach," NanoToday, 39 (2021), 101238.

5 CIRCULAR CARBON ECONOMY

Technological breakthroughs that align with circular economy principles are needed if we are to transition to a carbon-neutral economy.

Producing carbon-containing molecules from recycled or renewable carbon to avoid releasing additional CO₂ into the atmosphere is one of the challenges that need to be addressed. One of the avenues we are exploring at CEA-Liten involves capturing carbon emissions, like those from industrial sources, and transforming them into molecules of interest for the energy and chemical industries. Another alternative is the thermoconversion of bioresources.

BIOCHAR COULD HELP SHRINK THE STEEL INDUSTRY'S CARBON FOOTPRINT

Non-ferrous metal (Zn, Cu, etc.) production is a major source of greenhouse gases. Biochar, a substance obtained by burning agricultural and forestry waste, is currently in the running to replace fossil-based coal as a fuel and reducing agent in metallurgical processes. The CEA is investigating biochar production in research for two European projects. In the first project, CIRMET, a biochar manufacturing process was developed and optimized in the laboratory before being transferred to the CEA's pilot furnace, where a ton of biochar was produced from poplar tree biomass. The biochar was tested in project partners' metallurgical furnaces with copper recovery rates close to those obtained with fossil coal. In the second project, DIGISER++, laboratory and pilot scale experiments were completed on two types of agricultural biomass. The optimal operating conditions for the production of 250 kg of biochar with characteristics similar to those of fossil coal were determined.

Given the performance obtained on low-cost biomass, the process offers excellent scaleup potential.



SYNTHETIC FUELS: A POTENTIAL SOLUTION FOR SUSTAINABLE MOBILITY?



Synthetic fuels, produced from CO₂ and low-carbon electricity, allow the CO₂ emitted by industrial processes to be recycled to synthesize non-fossil hydrocarbons. Used in addition to biofuels, these e-fuels are garnering increasing interest as a way to limit net CO₂ emissions from transportation. Their carbon footprint over their entire manufacturing cycle is at least 70% smaller than that of fossil fuels. Heavy and long-haul transportation, difficult to decarbonize through electrification or hydrogen, could benefit from these alternative fuels. The main downside is that it takes a lot of energy to produce e-fuels. So, the time to start thinking about where to find massive amounts of low-carbon electricity and heat is now. The CEA has set up a cross-disciplinary circular carbon economy research program to help researchers (CEA, CNRS, INRAE, and the Universities of Paris-Saclay, Grenoble Alpes, and Aix-Marseille) break new scientific and technological ground and get closer to producing competitive synthetic fuels. The program will also support the CEA's R&D partner companies.

CEA-LITEN: EDUCATING

EDUCATION—FROM SCHOOL OUTREACH PROGRAMS TO STUDENT INTERNSHIPS, PhDs, AND POSTDOCS—HAS LONG BEEN A PRIORITY FOR THE CEA. EVERY YEAR, AT CEA-LITEN ALONE WE HAVE AROUND 250 STUDENTS WORKING IN OUR LABS AND SUPPORT DEPARTMENTS. ALL THE STUDENTS WE HOST ARE GIVEN THE OPPORTUNITY TO WORK ON MEANINGFUL PROJECTS THAT WILL ACCELERATE THE ENERGY TRANSITION AND TRANSFORM THE WORLD WE LIVE IN.

"In 2021 we took a step further in our commitment to putting young people first by getting involved in a French government program introduced in 2020 to help match young jobseekers with training or employment opportunities. Together with the other CEA institutes, we provided placements for 1,000 students on work-study programs.

It's important to underline that we would not be able to support young people in this way if it weren't for our employees, many of

whom regularly supervise student research projects and theses or provide training. 2021 also saw the creation of a new role—that of "CEA ambassador". These ambassadors liaise closely with schools, colleges, and universities, and help students find a suitable placement or supervisor and settle into their new environment.

Students who come to CEA-Liten have the chance to hone their skills and gain valuable experience by working alongside pioneering researchers in a state-of-the-art R&D environment."

P. Berruyer, Human Resources Director, CEA-Liten

EDUCATION AT CEA-LITEN: SOME KEY FIGURES



1/3

OF OUR STAFF MEMBERS
SUPERVISE STUDENT
PROJECTS OR THESES
OR PROVIDE TRAINING



+200

INTERNS, PhDs, AND
POSTDOCS WORK
AT THE INSTITUTE
EVERY YEAR



60

HIGH-SCHOOLERS
DID WORK
EXPERIENCE
PLACEMENTS AT
CEA-LITEN IN 2021



1200H

TEACHING STUDENTS
BY EXPERTS FROM
CEA-LITEN IN
SCHOOLS, COLLEGES,
AND UNIVERSITIES



THE NEXT GENERATION

"I chose CEA-Liten because the project on offer was all about innovation, and I was excited about working on a brand new idea. The best thing about working here is that most of the staff teach or supervise interns and PhDs as well as carrying out their research, so they have a lot of experience and know how to explain things clearly."

Alek GUEDEGBE, PhD student



"CEA-Liten seemed like a great place to do my PhD because of its focus on climate change and its close partnerships with companies. I'm based at the Fuel Cell Platform and love how varied my work is, covering everything from materials through to system integration."

Marine CORNET, PhD student

"I decided to do my thesis at CEA-Liten because the institute is doing a lot to shape the energy transition in France and has specialists in so many different fields. I can discuss my thesis with highly qualified researchers who are experts in their field, which is a fantastic way of learning about new topics."

Colette GARRON, PhD student



"I applied to do my thesis at CEA-Liten because it's one of the top institutes in France for hydrogen research. The projects I work on cover lots of different aspects—experimentation, modeling, characterization, and so on—and I've had chance to use all kinds of tools and equipment. Sometimes I work independently, and other times I work with other members of my lab."

Amandine JAY, PhD student



"I chose CEA-Liten because it's known for its pioneering R&D and focuses on the biggest challenges of the 21st century. Doing a thesis here gives you a real sense of purpose, and you learn a lot because the standard of research and technical expertise is so high."

Gatien Baccheta, PhD student

"I'd already done two internships at CEA-Liten before coming back to do my thesis. I chose this lab because it is very much focused on finding concrete solutions to topical issues like climate change and clean energy. I also enjoy the fact that I get to work on projects that draw on knowledge from so many different disciplines, because that helps broaden my understanding of the world of science."

Simon TOINET, PhD student

"I'm studying big data and am convinced that data science has a huge role to play in creating a carbon-free future. I applied to do my work-study program at CEA-Liten to see first-hand how I can contribute to the energy transition and put my knowledge of data science to good use. I learn something new every day—not just technical skills, but also things like communication and teamwork. It's proving to be a really great experience!"

Ludovic Desmeuzes, student on internship



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