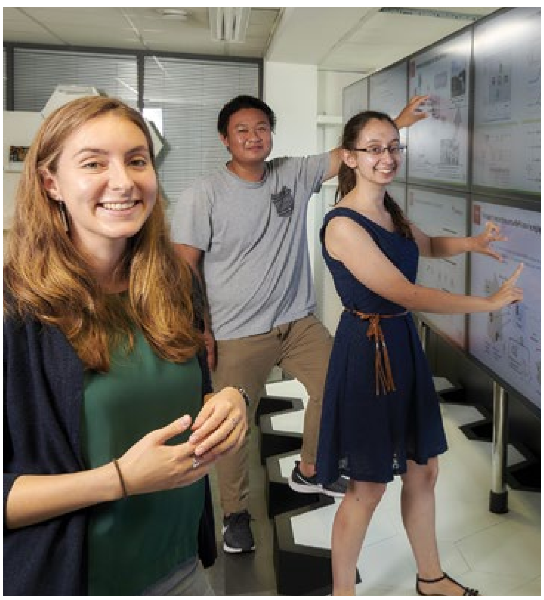
cea liten

ANNUAL REPORT 2022

INSTITUT CARNOT
Energies du Futur



Foreword

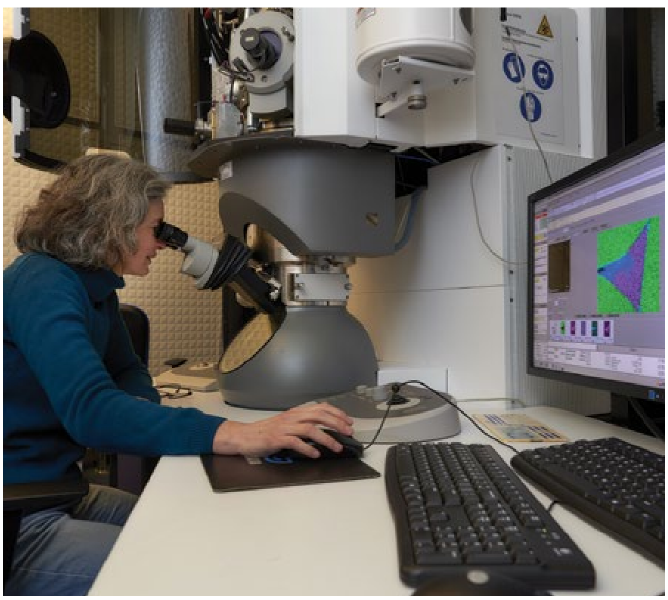
François Legalland
CEA-Liten's CEO

France and Europe are faced with two crises, a climate change crisis and an energy crisis. Against this backdrop, we must leverage any and all low carbon footprint technologies in order to rapidly – and drastically – reduce our fossil fuel energy use. It's therefore critical to continue to innovate, to support French and European industry in their efforts to get to grips with the value chains of new energy tech that's cost-competitive and environmentally friendly. This is exactly the role and the vocation of institutes of research and development such as Liten.

To successfully fulfil its objectives of technology transfer to industry, Liten plays to its strengths: the expertise of its teams, its close relationships with scientific and industrial ecosystems, its intellectual capital and its research facilities. The year 2022 provided excellent examples of these strengths: the joint Liten-CNRS Priority Research Programme and Infrastructure (PEPR) focusing on hydrogen, batteries and advanced energy systems technologies, a 20-million euro investment in new equipment and facilities, and active participation in the European Union's Horizon Europe programme.

This strategy has enabled us to build on our main fields of interest such as batteries, hydrogen and photovoltaics. It has also allowed us to expand into other areas, for example, the circular carbon economy and magnets – as well as to apply an eco-innovative approach to all our new developments. The end result has been a vote of confidence from several of our longstanding industry partners, the establishment of ambitious programmes with new partners, start-ups which have emerged out of our research projects and lastly, a higher public profile in major trade fairs and conferences, not to mention in the media.

This document offers an introduction to the most noteworthy achievements of 2022, a year marked by scientific partnerships, technological progress and events around which the whole research community - and others - can gather, such as the first 'Liten Days' event. It reflects how our expertise and our spirit of innovation enable us to furnish French and wider European industry with cutting-edge solutions to take on the challenges presented by the energy transition.



Executive summary

LITEN

DECARBONIZED ENERGY PRODUCTION

STORAGE AND GRID FLEXIBILITY SOLUTIONS

SYSTEMS, NETWORKS AND ENERGY EFFICIENCY

CIRCULAR ECONOMY

CEA-LITEN, LEADING THE ENERGY TRANSITION

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, costcompetitive 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 CO_2 and other sources of carbon into synthetic substances that can be used in the energy and chemical industries

KEY FIGURES 2022

1,000 EMPLOYEES

180 PhD STUDENTS

160 MILLION EURO ANNUAL BUDGET

›1,900 PATENT FAMILIES IN OUR PATENT PORTFOLIO

›200 PUBLICATIONS EACH YEAR

›200 INDUSTRIAL PARTNERS

›200 INSTITUTIONAL PROJECTS

12 TECHNOLOGY PLATFORMS

RESEARCH AND INDUSTRY COME TOGETHER ON THE VERY FIRST 'LITEN DAYS'

These conversations continued in a more relaxed atmosphere during a networking evening.

Lastly, this event provided an opportunity to celebrate, along with various colleagues in the academic world, the 15th anniversary of the awarding of the 'Carnot Energies du futur' label recognizing the capabilities of CEA-Liten and other Grenoble-based research facilities for driving industry-focused innovation.

Held on 30th November and 1st December 2022 at Minatec, the Liten Days event brought together over 200 very satisfied participants who were particularly impressed with the breadth and depth of the discussions and the quality of the speakers at this inaugural event.

Leading figures from the worlds of science and industry and state actors were all present at the Liten Days event, which seeks to boost innovation, foster relationships and inspire new projects which will smooth the transition towards a more sustainable future.

Being convinced that research and innovation have a crucial role to play in solving issues relating to climate change and the environment, we devised a programme on the theme of 'Accelerating the transition to sustainable energy through innovation'. The opening session consisted of a round table comprising partners who gave their perspective on the radical changes needed to grasp hold of openings in the market and break down barriers to speed up the energy transition. Seminars on the mass electrification of energy, zero carbon industry and new electrochemistry for clean mobility provided attendees with the chance to discover the most recent technological advances supported by the CEA.

The tour of the Grenoble site's research facilities, the discussions with researchers and face-to-face meetings with the CEA-Liten's partnership development team leaders combined to make the event an extremely interesting one.

TESTIMONIALS FROM OUR PARTNERS

Some of CEA-Liten's key partners tell us about their work with the institute's research teams:

Yves Van Rompay
Senior Vice President corporate R&D at Umicore

Our collaboration with the CEA lasts for roughly 12 years, and is mainly based on battery materials development. This has become a very functional collaboration going beyond battery materials. In the Umicore's RISE 2030, Umicore's ambition is to be a true transformation partner for our customers, guiding them on their journey in sustainability and circularity. Umicore is moving ahead to accelerate the global transition to carbon free mobility, and has inaugurated a giga plant for cathod materials in Poland, a first of its kind in in Europe! We will continue cooperate with CEA to overcome the challenges on the scarcity of materials, on developpment of new materials, but also new systems. I believe CEA is a good partner for that also in the future.'

Cosimo Gerardi
Head of innovability, CTO – 3SUN gigafactory, Enel Green power

We have a very long and strong collaboration with the CEA. Since 2015, the CEA at INES has been supporting us in industrializing and making competitive very innovative technologies. The perspectives are very good because we want to increase the development of new solar cells with greater efficiency. Indeed, Enel is investing a lot, not only in Europe but we are also thinking of expanding into the United States. The good results obtained thanks to the strong technical support of the CEA teams are very promising and allow us to be seen as competitor of photovoltaic field giants.'

Gavin Rennick
President - SLB New Energy

The CEA has been an excellent partner for us. We are invested together in Genvia, which is unique joint-venture, that has enormous potential. I think the match between pure research, smart talented people and then industrial organization that can turn that into something that's very impactfull is an excellent match. Working with the CEA has really been a pleasure, and we are only early in that journey, with a lot of exciting things ahead.'

As a Research and Technology Organisation, one of our principal goals is to help our partners make advances in the technological and industrial spheres.

PEPR: HYDROGEN AND KEY TECHNOLOGIES FOR THE GREEN TRANSITION AT THE CENTRE OF NATIONAL STRATEGIES

The *France 2030* investment plan will direct huge sums of money to innovative technologies to support the green transition. As part of this effort and through the Strategic Investments Fund, the most important fundamental research is funded by the Priority Research Programme and Infrastructure (PEPR).

As a major research institution, CEA-Liten participates actively in several projects in a coordinating or contributing role including PEPR Hydrogen, PEPR Batteries, PEPR Advanced Energy Systems Technologies (TASE), PEPR Decarbonization of Industry and PEPR Recycling. The CEA is the co-lead on the first three projects.

PEPR: key objectives

At the heart of national and European-wide strategies, the goal of PEPR programmes is to establish or consolidate a leading position in key scientific fields, representing a transformational leap forward in the technological, economic, societal, healthcare or environmental sectors.

How? The French state has launched a comprehensive, coordinated national strategy encompassing standards, funding and taxation measures – and PEPRs will help overcome scientific barriers and obstacles currently standing in the way.

***France 2030* funds two types of PEPR:**
• **PEPRs backing national acceleration strategies,** promoting a process of transformation that has already been started.

• **PEPRs that are exploratory in nature,** funding and nurturing transformations at a very early stage.

In the PIA4 – the fourth 'Investments for the Future' programme – the French state agreed upon several strategies relating to technologies that are key to the energy transition: hydrogen, batteries, the electric grid, photovoltaic power and the decarbonization of industry.

Putting hydrogen-based solutions into widespread use by removing technical and socio-economic obstacles

For example, the Hydrogen PEPR aims to support a hydrogen sector in France with the help of leading industrial players who would be able to export their products and expertise and ultimately, create jobs. To this end, the PEPR has a budget of 83.1 million euros.

More specifically, research is underway into:
• the production of decarbonized hydrogen through electrolysis and photoelectrocatalyic production

• storage of hydrogen as a liquid (cryogenic, LOHC, ammonia), as a solid or in gaseous form

• conversion of hydrogen into electricity in fuel cells.

One project will also be focused on social, technical and economic analyses and life-cycle assessments of all these hydrogen-based systems.

CEA-Liten's involvement in the Hydrogen, Batteries and TASE PEPR projects

• The **Hydrogen PEPR** encompasses a portfolio of nineteen projects. CEA-Liten coordinates three of these projects and is involved in five others.

• **The Batteries PEPR** is jointly managed by the CNRS and CEA and has a 45.66 million euro budget. It includes five projects of critical importance and two infrastructure-related projects. Liten coordinates two projects (one infrastructure project) and contributes to the other four projects of critical importance.

• Lastly, the **CEA**, alongside the **CNRS**, jointly manages the **TASE PEPR** (Advanced Energy Systems Technologies) and is involved in other programmes in a non-lead role, such as the Decarbonization of Industry PEPR.

INVESTMENTS 2022-2023

As an RTO (Research and Technology Organization), we can count on solid foundations: our expertise, our patents and our world-beating technological facilities. Ensuring these facilities are constantly at the cutting-edge, both in terms of general infrastructure and equipment, is therefore crucial. With this in mind, CEA-Liten has established a multi-year investment plan tailored to our key avenues of research. Funds invested in 2022 enabled the launch of several promising projects, including:

- **Hydrogen:** the creation of a demonstration 'High temperature electrolysis module'

- **Batteries:** the commissioning of key equipment relating to 'solid-state' batteries in an anhydrous environment (dry room). These batteries are designed to replace lithium-ion batteries

- **Cutting-edge scientific equipment:** CALHIPSO was funded through the Equipex scheme and will provide an environment for the use of Hot Isostatic Pressing (HIP) technology for the aeronautical, defence and nuclear industries.

- **The circular carbon economy hub:** establishment of infrastructure for the gasifiers of the future

20 million euros invested in 2022 into major research programs

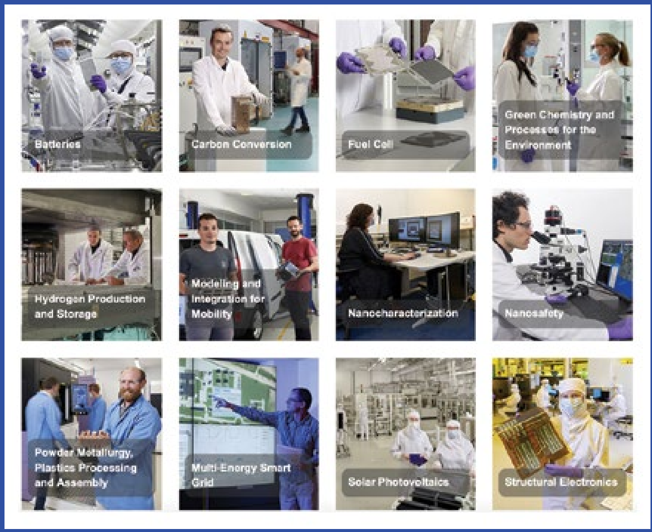
Investments 2023: gearing up our focus on key R&D avenues

In line with our aim to fund research which will have a real impact on reducing carbon emissions, investment in 2023 will focus on:

- Energy networks and smart grids
- Powder Metallurgy
- Fuel cells and the large-scale production of hydrogen through high temperature electrolysis technology
- The characterization facility, supporting all our research, in partnership with Large Scientific Instruments and our other partners in the Grenoble-based 'Scientific Polygon'.

These investments will be part-funded by our own resources and part-funded by our public partners, the Auvergne-Rhône-Alpes Region and the France 2030 investment plan.

Explore Liten's 12 technological platforms on our website: https://liten.cea.fr/



- **Batteries**
- **Green Chemistry and Processes for the Environment**
- **Carbon Conversion**
- **Structural Electronics**
- **Modeling and Integration for Mobility**
- **Nanocharacterization**
- **Nanosafety**
- **Fuel Cell**
- **Powder Metallurgy, Plastics Processing and Assembly**
- **Hydrogen Production and Storage**
- **Multi-Energy Smart Grid**
- **Solar Photovoltaics**

DECARBONIZED ENERGY PRODUCTION

Photovoltaic (PV) technology is expected to become a key component of the world's energy mix as it will facilitate low-cost, low-carbon electricity production at the local level. CEA-Liten is helping PV gain traction by creating technologies – heterojunction, perovskite-silicon tandem – capable of pushing conversion efficiencies 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.

1 High efficiency photo-voltaic technology

The solar cell is the core component of any photovoltaic system. And the race toward higher yields is on. But because cost is also crucial, our end goal is to find the optimal trade-off. 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 manufacturers' efforts to build a strategic value chain which will contribute to French and wider European energy independence, has already resulted in a first successful technology transfer to Enel Green Power.

KEY FIGURES

20 PUBLICATIONS

400 PATENTS

30 PhDs

200 EMPLOYEES

Industrial surface HET cell sets conversion efficiency record

Achieving high levels of efficiency for heterojunction cells requires very high quality silicon wafers, the preferred choice being N-type wafers obtained by Czochralski (Cz) pulling Type-P wafers, the most widely used in the world, benefit from lower cost but suffer from poorer performance caused by light degradation phenomena. A new manufacturing method using gallium (Ga) was recently deployed on a large-scale. This means these wafers are no longer affected by light degradation: as a result, P-type heterojunction cells could become competitive with N-type cells!

In the framework of the partnership between the CEA at INES and Enel Green Power regarding the mass production of Heterojunction cell technology (HET) in Europe, the use of Ga doped wafers has led to a new milestone: a world record of 24.47% for a P-type silicon HET cell with an industrial surface, certified by ISFH Caltec. This was achieved using the same manufacturing processes as the N-type.

Certified efficiency

24.47%

World's record

The quest for very low carbon photovoltaic panels

The CEA is committed to reducing the environmental impact of the photovoltaic industry. A Life Cycle Assessment study (LCA) was carried out in relation to heterojunction technology, resulting in improvements being made to the aspects of this technology which were most relevant to its carbon footprint: the reduction of the thickness of silicon wafers, the optimization of the metallization and interconnection processes to reduce the consumption of indium and silver, using a thinner glass frontsheet, the replacement of its aluminium frame by a frame made of wood. This approach encourages the use of components manufactured in Europe. The choice of fluorine-free thermoplastic encapsulants and backsheets will facilitate recycling. The demonstration PV module made at CEA after this study achieves a very low carbon footprint of 317 $kgCO_2eq/kWp$ (compared to the norm of 700 to 800 $kgCO_2eq/kWp$ delivering 566 Wp), a result that ranks amongst the very best in Europe.

Eco-designed demonstrator panel, 317 kg CO_2 eq/kWp, made by the CEA teams

2 Next generation photovoltaics

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 cell conversion efficiencies of more than 30% which can be scaled up for volume manufacturing. To achieve this, we must still overcome technological obstacles like increasing conversion efficiency via a process capable of overcoming industrial constraints, improving cell stability, and limiting cell sensitivity to heat, UV and humidity.

11.6 cm^2 encapsulated flexible perovskite solar modules

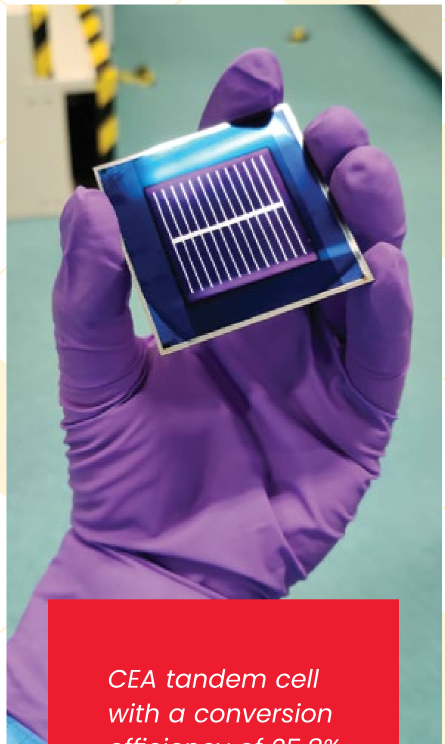
The use of flexible substrates for perovskite solar technology (PK) opens the way to high-speed, low-temperature printing processes. The real challenge is to make larger area devices with sufficient stability. As part of the APOLO European Union project, the CEA at INES made flexible PK modules with a surface area of 11.6 cm^2 and a power conversion efficiency of 18.95% on a low-cost substrate (PET), with a structure composed of just 5 layers.

Under damp heat conditions, these devices achieved long-term stability of several hundred hours - 400 to 800 hours depending on encapsulation method - considering a standard objective of 1000 h. Tested at the Fraunhofer Institute for Solar Energy Systems for indoor applications, the modules achieved power conversion efficiencies of up to 24.5% at very low levels of illumination (500 lux).

Tandem Si/PK technology: a new conversion efficiency record for PIN-architecture

The CEA at INES, in partnership with Enel Green Power and its subsidiary 3SUN in Catania, are developing two-terminal Si/PK (Perovskite-Silicon) tandem technology with the aim of achieving high conversion efficiencies on traditional PV formats using processes suitable for mass production. Work begun in 2021 on PIN-architecture achieved a new conversion efficiency record of 25.8% over 9 cm^2, with shading correction. The race towards higher efficiency (over 30%) PIN architecture Si/PK tandem cells on large textured surfaces, ready for mass production, will require more work in the years to come.

The development of the characterization of tandem cells is also a pre-requisite to improve the accuracy of the measurement of the device's optical performance. It will then be a matter of replicating these results using deposition methods suitable for use on larger-scale applications.



CEA tandem cell with a conversion efficiency of 25.8% on 9 cm^2

3 Large-scale photovoltaic production

The CEA is conducting targeted research to better predict and optimize the productivity of photovoltaic (PV) systems through digital simulation. We are developing modules and systems for large-scale solar farms, specifically in desert regions. This poses 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.

Advanced diagnostic technologies for solar power plants

In a growing photovoltaic market, plant diagnostics using intelligent and efficient methods is a very active research area. In partnership with Ener-Pacte, the CEA has developed a complete advanced diagnostics software solution combining imaging and electrical measurements. It embeds the results of work initiated as early as 2014 in the framework of the ITE INES.2S*. It uses thermographic images acquired by drone for defect inspection and estimating photovoltaic string losses. The two software prototypes now have a degree of maturity enabling their efficient operational use by Ener-Pacte.

A better way to study solar panel ageing

Solar panels must have an operational life of at least 25 years. Within the framework of the ITE INES.2S*, the CEA is developing an accelerated - combined ageing method which makes it possible to identify PV modules' degradation mechanisms by means of a smaller number of tests over a shorter period of time. This method allows for the testing of various degradations - which the current IEC 61215 standard fails to flag up – in a shorter time-frame.

** The ITE INES.2S energy transition institute operates under the umbrella of the CEA at INES and is part funded by the French Government under the Investment for the Future Programme (ANR-10-IEED-0014-01).*

An 'electronic shepherd' for solar panels

Enel Green Power and the CEA are developing high efficiency bifacial PV panels, intended mainly for large-scale ground-mounted power plants. With a view to improving these power plants' energy efficiency, the two partners developed a DC/DC MPPT (Maximum Power Point Tracker) electronic solution with a maximum power of 500W, at module level. It allows the number of panels in a string to be increased in order to increase the overall power, whilst remaining in the low voltage range (< 1500 Vdc). It also reduces the impact of production imbalance between panels connected in series (*photo*).

36 prototypes of DC/DC MPPT converters were installed on a CEA demonstrator site in Cadarache to carry out tests in real operating conditions

4 Photovoltaics everywhere

One advantage of photovoltaic technology is that it 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.

Photovoltaic technology working hand-in-hand with the rail sector

The SNCF and SNCF Réseau (the French national railway company and railway infrastructure manager) have established a partnership with the CEA at INES to develop PV systems capable of operating at voltages up to 9,000 Vdc. The aim is dual: to provide an innovative technical solution with dedicated photovoltaic panels to address a DC network (3kVdc, 6kVdc and 9kVdc), optimizing installation (particularly with regard to cables), operation and maintenance costs and improving the service life of these systems.

There are currently no panels on the market which can operate at voltages above 1,500 Vdc. The SNCF project will therefore benefit from the CEA’s expertise in this field as the CEA has already developed photovoltaic panels for the 3,000 Vdc range. An experimental 3,000 Vdc power plant is also being installed at INES as part of the European Union’s H2020 Tigon project.

This project is based on the work of the ITE INES.2S energy transition institute, which is part funded by the French Government under the Investment for the Future Programme 2030 (ANR-10-IEED-0014-01).

Solar powered vehicles

The CEA has been developing cutting-edge concepts over the past few years aimed at embedding photovoltaic technology in electric vehicles. One of these projects resulted in a prototype for a solar hood, which was presented at CES 2023 in Las Vegas. Its composite panels feature high-efficiency heterojunction silicon cells. These panels are light, weighing less than 5 kg/m^2, mould to the shape of the vehicle just like any body part and have a low environmental footprint, being made from recyclable thermoplastics. They are manufactured using thermocompression technology which is suitable for mass production.

Interconnection technology for n-type solar cells with reduced Ag consumption

Context

Historically, the increase in module power has largely been driven by improving cell efficiencies. In the last 3-5 years novel interconnection technologies and module materials changed the game. As the deployment of PV has reached the TerraWatt scale, sustainability considerations such as critical raw material usage are recently emerging as complementary key metric for PV modules. More specifically, the reduction of Ag consumption is critical to ensure a sustainable growth as already 10% of the global supply has already been dedicated to PV in 2020 [1].

Approach & Results

CEA-Liten has presented its latest research on n-type high-power modules, at the intersection of material – process and equipment development on low temperature interconnection process based on electrical conductive adhesive (ECA) and Pb - free ribbons. To avoid significant deterioration of the surface passivation, the metallization and interconnection processes of heterojunction cells (SHJ) are limited to temperatures below 200°C, and two-terminal tandem devices with a perovskite subcell impose further reduction of the process temperature below 130°C.

First, demonstration of stencil printing based ECA deposition with improved accuracy down to 100 µm width precision has been showcased on a pilot scale tool. This level of accuracy is one of the critical means to further reduce the amount of ECA deposited, and scale down Ag usage [1,2].

Additionally, exploring the material compatibility of novel type of ECAs and interconnection ribbons with low Ag content or mixed Ag/Cu content enabled to lowered the overall Ag consumption while maintaining device performance and reliability.

Last but not least, upon extracting the cross-linking thermal budget from a Differential Scanning Calorimetry (DSC) analysis of novel ECAs analysis that we could demonstrate interconnection at temperatures below 130°C with sufficient adhesion (> 0.8 N/mm) of the ribbon to the cell.

Conclusion

These recent advances enable to define technical roadmap towards < 25 mg/Wp of Ag consumption on short-term and pushing to a sustainable level of < 5-10 mg/Wp Ag usage on mid-term[3].

Additionally, the diversification in module technologies represents a paradigm shift that is set to continue. A Review of the state-of-the-art of advanced inter-connection technologies and its combinations is presented in soon be published book[4] .

References

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[2] R. Monna et al., "Latest advances of ECA-based tabbing and stringing at CEA-INES", Photovoltaics International, E. 48 (2022)

[3] E. Voroshazi et al.,"Sustainable Silicon PV Cell and Module Materials and Technologies", 48th IEEE PVSC, plenary invited presentation (2022)

[4] V. Barth et al., "Chapter 4.4: Advanced module concepts", n-Type Crystalline Silicon Photovoltaics:Technology, applications and economics, EIT, ISBN 978-1-83953-176-7 (2022)

STORAGE AND GRID FLEXIBILITY SOLUTIONS

Energy storage is a major challenge with regard to the development of renewable energy sources and their use in various fields (transportation, industry, construction). Liten is working on two main solutions: batteries and hydrogen technology. Our battery R&D focuses on increasing energy densities without sacrificing safety or reliability. Liten's approach to hydrogen is a wide-ranging one, taking in the production of hydrogen by electrolysis, storage, transportation and its conversion into electricity by fuel cells.

1 High temperature electrolysis

The large-scale development of hydrogen as an energy carrier requires a decarbonized hydrogen production process using methods that produce minimal greenhouse gases. The CEA has spent more than 15 years working on a high-temperature steam electrolysis process based on SOC (solid oxide cell) technology. This technology can achieve conversion efficiencies that are up to 15 percentage points higher than conventional electrolysis technologies. What's more, this technology is reversible, meaning it can also operate in fuel-cell mode to produce electricity (and heat) from different fuel sources including gases that produce little or no carbon dioxide when consumed, such as ammonia.

KEY FIGURES

50 PUBLICATIONS

750 PATENTS

70 PhDs

400 EMPLOYEES

Increasing the size of cell stacks

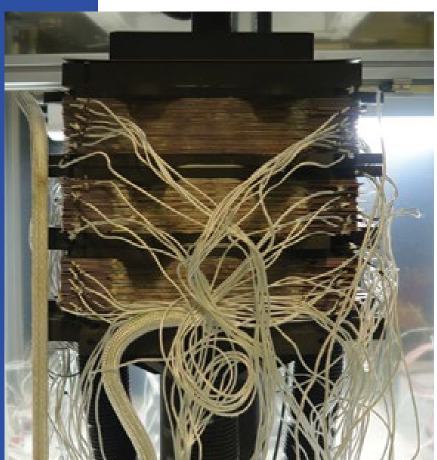
Europe aims to produce massive quantities of hydrogen by 2030 to achieve its decarbonization and energy sovereignty objectives. Hundreds of GW of installed electrolyzer capacity will be needed, requiring work to be done on how these enabling technologies are to be matured and deployed on a larger scale. Increasing the size of individual components is a key consideration. In the framework of its partnership with Genvia, CEA-Liten has successfully produced larger cells with an active surface area of 200 cm^2, twice the size of standard cells (100 cm^2), in standard-sized stacks composed of 25 cells. Two approaches to developing stacks composed of a larger number of cells were considered. To begin with, a 'monolithic' stack made up of 50 cells, each measuring 200 cm^2 was assembled and tested. A current density of 0.9 A/cm^2 at 1.3 V and 700°C was achieved, similar to the results from standard 25-cell stacks (100 cm^2 active surface area).

A second approach was to assemble substacks composed of 25 cells (200 cm^2 active surface area) to create a 75-cell stack using interconnecting plates between the substacks.

Delivering greater fuel cell stack durability

As part of the European Union MULTIPLHY project, which aims to develop and operate a Solid Oxide Electrolyzer with a capacity of several Megawatts (~2.4 MW), a harmonized test protocol was developed with a view to comparing the performance of two types of high-temperature electrolysis stack technology: CSS (cathode supported) and ESS (electrolyte supported). A durability test was performed on a 25-cell CSS stack (100 cm^2 active surface area) at the CEA. We succeeded in achieving the hydrogen production objectives we had set ourselves for the entire duration of the test without any drop-off in performance.

A 75-200 stack formed from putting together three 25 -200 substacks



Conference

Julie Mougin, Head of the Hydrogen Technologies department at Liten, and Jérôme Laurencin, senior scientist specializing in SOC at CEA-Liten, chaired the 15^{th} European SOFC and SOE forum. Held in Lucerne, Switzerland from July 5^{th} to July 8^{th}, 2022, the conference focused on Solid Oxide Fuel Cells (SOFC) and Solid Oxide Electrolyzers (SOE). This is the most high-profile conference on the international stage to be devoted to Solid Oxide technologies and helps bridge the gap between scientific research and potential applications in electrolysis (SOE), fuel cells (SOFC) and reversible (rSOC) technology.

2 PEMFC fuel cells

The CEA has been working on the development of Proton Exchange Membrane Fuel Cells (PEMFC) for 25 years. This technology is particularly suited to certain types of heavy and intensive-use transportation where the weight and bulk of batteries remains problematic. Combined with a storage solution (700 bar tank pressure) that meets international norms, PEMFC technology is starting to rival thermic vehicles, both with regard to range and refuelling time. Research is ongoing to further reduce fuel cell manufacturing costs, whilst improving performance and extending service life.

PEMFC for heavy transportation

The current maximum operating temperature for commercial PEMFCs of 80°C acts as a brake to the wider use of this technology in the decarbonizing of the heavy transportation sector. In the framework of an ANR-funded collaborative project between the CEA and CNRS, Liten has been tasked with developing a Membrane Electrode Assembly (MEA) for PEMFC fuel cells able to operate at a rated temperature of 95°C. The research teams began the tests using commercially available materials, improved the formulation and application of cathode inks and the composition of the cathode. Tests performed with 25 cm^2 cells in operational conditions show that the CEA MEA performs up to 30% better at 95°C than the best commercially available MEAs and at efficiencies of 60%.

inocel
Hydrogen powered solutions

A new player in the very high-power fuel cell field

The original GEN Z project, headed up by CEA and Mike Horn, aimed to develop a full drivetrain for a rally raid vehicle featuring cutting-edge PEMFC technology. This project reached a watershed moment in 2022 with the founding of INOCEL. This business seeks to mass-produce high-performance solutions for the global market in the shape of turn-key electric propulsion systems powered by hydrogen, specifically, innovative low-temperature fuel cells. The company is targeting the heavy transportation sector, both in the marine and land categories, high-performance sports vehicles and power generation. To continue to introduce innovative technology to real-world applications, INOCEL is pursuing a long-term partnership with the CEA.

PEMFC fuel cell research laboratory

Investigation of liquid water heterogeneities in large area proton exchange membrane fuel cells using a Darcy two-phase flow model in a multiphysics code[1]

Context

Effective management of the liquid water and heat produced in proton exchange membrane fuel cells is essential to increase its performance and durability. Water is present in all the layers[2] of the cell because of humidification of the inlet gases, production by the electrochemical reaction and water transport inside the cell. The equilibrium between membrane drying (lowering electrical conductivity) and cell flooding (lowering reactants concentration) is a challenging task for a proper water management.

Approach and results

A two-phase flow and multicomponent model, called two-fluid (2-F) model, is developed in the commercial COMSOL Multiphysics® software to investigate the liquid water heterogeneities in large area PEM fuel cells, considering the real flow fields in the bipolar plate. Indeed, a full-3D model is still not appropriate for the simulation of a complete cell of a realistic stack design for transport applications, due to the computation time required for such large cell dimensions. Consequently, a macroscopic pseudo-3D multi-layers approach has been chosen.

A one-fluid (1-F) model was previously developed and validated by comparison with temperature, current density[3] and liquid water quantity obtained from neutron imaging measurements[4]. It combined a single-phase flow transport formulation with a condensation model in a post-treatment process. Good numerical results were observed for several low power automotive conditions, but a poor prediction capability was observed for higher power operating conditions.

The new 2-F model required the development of specific local volume-average method and pseudo-3D formulation of the conservation equations (Fig. 1). The numerical results are compared to 1-F model results and liquid water measurements for several operating conditions, and the numerical results are examined in each component of the cell, exhibiting very heterogeneous water thickness over the cell surface.

Conclusion

While the numerical results of the 1-F model greatly overestimate the quantity of liquid water and cannot correctly represent its distribution, the new 2-F model fits the measurements more accurately. In addition, the 2-F model can identify flooded and dry areas in each PEMFC layer (channels, gas diffusion electrodes, etc.), information which is not accessible experimentally. For instance, the model predicts a dry air outlet (hydrogen inlet) only in the gas diffusion electrodes and in the anode gas channels (Fig. 2).

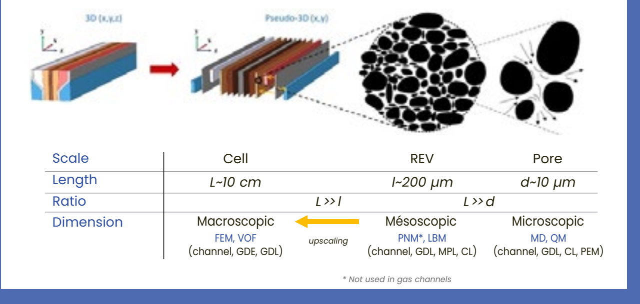


Figure 1 : From full 3D to pseudo-3D model and the different modeling scales in PEM fuel cell.

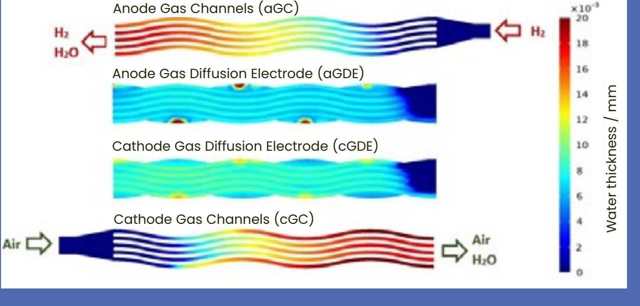


Figure 2 : Water thickness distribution in the anode and cathode gas channels and gas diffusion electrode

References:
[1] E. Tardy et al., Int J Hydrogen Energ, vol. 47 (91), 38721-38735, 2022
[2] G. Zhang et al., J Power Sources, vol. 391, 120-133, 2018
[3] F. Nandjou et al., Int J Hydrogen Energ, vol. 41 (34), 15573-15584, 2016
[4] E. Tardy et al, Int J Heat Mass Tran, vol. 45, 118720, 2019

3 Hydrogen storage and transportation

Liten carries out research into hydrogen transportation and storage, analyzing how different materials react to hydrogen. Recently, the institute also started investigating ways of storing hydrogen using organic molecules known as Liquid Organic Hydrogen Carriers (LOHCs).

Molecules for the storage of hydrogen in the liquid state

The CEA is developing liquid organic hydrogen carriers, or LOHCs, that leverage certain innovative compounds' reversible chemical reactions. As part of a Carnot Network project, CEA researchers identified a particularly promising molecule-catalyst pair: GBL-BDO*. The catalysts developed for the hydrogenation-dehydrogenation reactions performed better than commercial catalysts in laboratory batch reactor tests. The models developed — a kinetic model describing the reactions plus additional studies of the GBL-BDO reactions on a continuous reactor test bench developed to validate the overall reactor model — were used to design an innovative reactor technology for which one patent was filed.

Storage of hydrogen by means of hydrogenation-dehydrogenation reaction

The development of underground storage of NG-H_2

Given the increasing extent to which hydrogen is being used as an energy carrier in industrial applications, STORENGY (a subsidiary of Engie) is interested in using its natural gas (NG) underground storage facilities to store NG-H_2 blends. This partner asked CEA-Liten for help in understanding and classifying the behaviour of the steel components used in its network when they come into contact with various NG + H_2 blends. Testing devices have been adapted to perform tests in test environments simulating the conditions found in NG underground storage facilities, evaluating fracture toughness, fatigue crack growth rate and oligocyclic fatigue. Initial results have enabled trends to be identified regarding the impact of water vapour on hydrogen embrittlement susceptibility in different steels.

Lisa Blanchard received the Young Scientist Award for her work on gaseous hydrogen embrittlement of metallic alloys at CEA-Liten, during the Hydrogen Week in October in Brussels.

*gamma-butyrolactone (GBL)-1,4-butanediol (BDO)

How advanced characterization techniques can aid technological developments

The development of new materials with enhanced functionalities suited to the energy transition as well as the shift towards new digital and medical technologies requires increasingly sophisticated characterization tools that really push the limits of spatial and temporal resolution. The CEA's Conseil Scientifique de la Direction de la Recherche Technologique (Scientific Committee of the Technological Research Division) meets annually to assess developments in a specific field, comparing them to the most stringent international standards. 2022's topic was about the use of advanced characterization techniques to boost the performance and lifespan of systems developed in the CEA's laboratories. The report was drawn up in partnership with the CEA-Leti and CEA-List institutes and helped highlight not just the very high standard of work carried out using the Nanocharacterization platform (PFNC) and large scientific instruments, but also developments in instruments and methodologies which are currently pushing the boundaries in terms of scientific measurement in these fields.

Located in the Presqu'île district of Grenoble, the Nanocharacterization platform (PFNC) features around fifty high-tech characterization devices. With the help of large scientific instruments, these are working to open up new opportunities.

The front cover of the DRT's scientific report for 2022

The committee with the responsibility of assessing both the report and the presentations arising out of the report (14^{th}–17^{th} November 2022) is composed of leading academics and industry figures. It highlighted world-class research into the characterization of energy systems through operando techniques and the use of electron microscopy. The committee drew attention to a number of strong points, in particular, our researchers' skills, the high quality of characterization which has greatly assisted current research projects, the PFNC's ability to cope with the challenges posed by the fields of application in question and our awareness of the difficulty of managing the enormous amount of data generated by characterization.

1 - Dr. Paul Friedel (Directeur de IMT Atlantique), Dr. François Monnet (Président de l'association de chimie Plant), Prof. Subashish Mitra (Université de Stanford), Dr. Patrick Gros (INRIA), Dr. Gema Martinez Criado (Directeur de recherche ESRF), Dr. Delphine Le Cunff (Ingénieur principale STMicrolelectronics), Prof. Kristina EDSTROM (Université d'UPPSALA), Prof Rafal Dunin Borkowski (FZ Jülich), Dr. Emmanuel Dubois (Directeur de recherche CNRS-IEMN), Dr. Mickaël Dolle (Directeur Technique SAFT).

4 Batteries

Batteries are crucial for the development of decarbonized transportation and also play a role in delivering improved grid flexibility. Building on its expertise across the entire battery value chain (materials, cells and systems), Liten's research aims to bring improvements to several key aspects, specifically, performance (energy density and power density), durability, safety, environmental footprint and cost. It's working on the development of next generation batteries which will be safer and deliver better performance, focusing particularly on solid-state batteries, as well as, in the longer-term, looking at alternative solutions.

K-ion batteries: the prospect of batteries that are entirely critical metal-free!

Liten is to the fore in early-stage research on technological alternatives to Li-ion batteries, primarily with a view to doing away with the need for critical materials required by these batteries (nickel, cobalt, copper, lithium). As part of a PhD thesis on the development of a potassium-ion battery, the use of the precipitation method to synthesize Prussian White ($K_2Mn[Fe(CN)_6]$) cathode materials was researched and improved. Adding a chelating agent to precursors helps slow precipitation kinetics and improve Prussian White crystallinity. Initial trials using a half-cell configuration and KPF6 based electrolytes achieved a reversible capacity of 125 mA h g^{-1} at 3.9 V vs K/K^+.

Battery materials synthesis laboratory

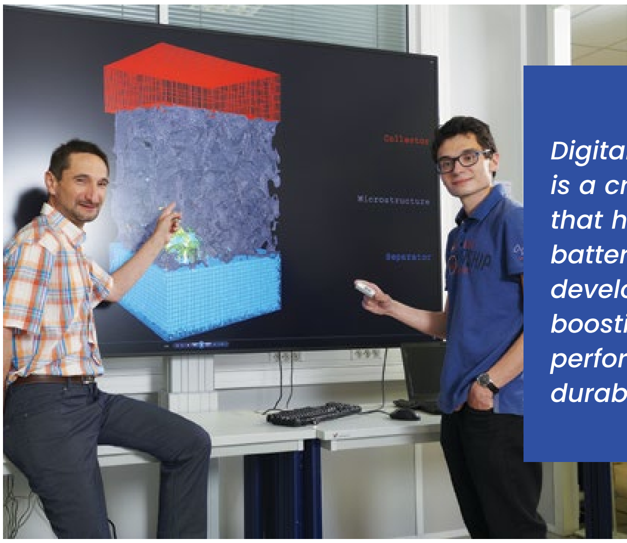
A Strategic Planning Committee for battery materials

In 2022, as part of an assessment carried out by the 'Energies du Futur' Carnot Institute's Strategic Planning Committee, CEA-Liten and the LEPMI (UMR 5279) gave a presentation on their work on battery materials to a committee of external experts divided equally between academics and industry professionals. The aim is to draw up recommendations about the lines of research that should be focused upon in the future, funded by the Institut Carnot. The committee highlighted the relevance of the methodology used, thus demonstrating the timeliness and relevance of this research, thanks to a wealth of advantages (technical resources, access to large scientific instruments, characterization facilities, advanced modelling tools, complementary expertise at all TRLs and more).

Stellantis and the CEA are co-operating on digital battery modelling

In the spring of 2022, teams from Stellantis and the CEA presented the first fruits of their partnership in the area of digital battery modelling. These models make it possible to analyze battery charging and battery degradation mechanisms with a view to reducing battery charging times, extending battery lifespan for clients and reducing the environmental impact of a range of battery technologies over the next 5 years.

> *The CEA is proud to offer Stellantis its technological expertise and our partnership will span all stages of the product life-cycle from design to end-of-life'* stated Stéphane Siebert, CEA's Director of Technological Research in 2022.



Digital modelling is a crucial tool that helps speed battery technology development by boosting battery performance and durability.

Partnership between CEA experts and the Fire Department of Savoie-France (SDIS 73) relating to stationary battery safety

On the initiative of the French Directorate General for Civil Security and Crisis Management (DGSCGC) and the Fire Department of Savoie-France (SDIS 73), an interdisciplinary group of experts was formed to better understand the possible risks related to the use of stationary energy storage batteries in confined spaces and to provide an understanding of the phenomena observable during accident situations to enable the fire and rescue services to adapt their operational responses. CEA-Liten took part in this 4-year-long research project and helped write a report which has now been made available to the relevant stakeholders.

Supporting innovation in order to develop the next generation of batteries

Managed by the CEA and the CNRS on behalf of the French state, the Priority Research Programme and Infrastructure (PEPR) 'Soutenir l'innovation pour développer les futures générations de batteries' (Supporting innovation in order to develop the next generation of batteries), was launched on 10th January 2023. Funded through the France 2030 investment plan, it's part of a wider national strategy to accelerate battery development and help stimulate battery supply and demand.

> *This PEPR is an excellent opportunity to strengthen links between researchers working in the field of battery innovation. We've been entrusted with the task of coordinating working groups and research initiatives, which will encourage synergies between different projects, generating as much new knowledge as possible in a short time frame. We will strive to transmit this knowledge to professionals in this field who can then pass it on to the wider business community.'* Hélène Burlet, CEA lead on the PEPR.

In 2022, CEA's batteries were in the media spotlight!

Industrie & technologies, N° 1056, October 2022

'CEA-Liten tackles the challenge of solid-state batteries'

At least 80% of our programmes relate to solid-state batteries to some degree. About 20% of these programmes are focused on the development, production and end-use of materials for solid-state electrolytes,

said Sébastien Patoux from CEA-Liten.

Sciences & Avenir, N° 908, September 2022

'Solid-state' batteries are the way forward

40 million euros will be allocated to state-owned laboratories towards the development of new batteries under the France 2030 investment plan,

said a delighted Hélène Burlet, an expert in new energy tech at the CEA.

TF1

Le Journal de 20 heures

'02/11/2022, news feature on the transportation systems of the future and the CEA'

The main issue with electric cars is their batteries. They're very heavy and their manufacturing processes aren't yet environmentally friendly enough. But here [at CEA], they're working to resolve these problems!

explains Florence de Juvigny, a journalist working with French TV channel TF1, in the introduction to her special report filmed in the laboratories of CEA-Grenoble.

Sciences et Vie, N° 1262 November 2022

'Tech: the promise of next-gen batteries'

In the field of batteries, you need to allow about ten years from the time that a solution is successfully developed in the lab to its arrival on the marketplace,

remarked Fabien Perdu from CEA-Liten.

L'usine nouvelle, May 2022

'Why are so many start-ups and large companies interested in batteries with silicon-based anodes?'

Graphite has a theoretical specific capacity of 372 milliampere-hours per gram, compared to 3,579 mAh/g for silicon. This means that silicon's storage capacity is 10 times that of lithium, enabling an increase of battery energy density and therefore range by 20 to 50%!,

points out Cédric Haon, a materials science researcher at CEA-Liten.

Isotope tracing of lithium from mine to cathode materials manufacturing

Context

The ban on the sale of new ICE vehicles by 2035 is going to lead to an increase in annual lithium demand (a 44-fold increase between now and 2030)[1] resulting in an upsurge in mining, along with all the environmental impacts that this activity entails. To increase transparency around lithium provenance and the environmental impact of lithium extraction and purification, a way to successfully trace lithium based on isotope tracing has been described in a joint BRGM, EDF and CEA publication[2].

Methodology & Results

The supply chain of the Li-ion industry involves many different companies engaged in a wide variety of activities, based all over the world. This makes it hard to guarantee compliance with all relevant ethical and legal considerations with regard to critical materials in the supply chain. To help mining companies take a responsible, accountable approach and to prevent fraud, a way to trace lithium based on isotope tracing has been developed.

Lithium's isotopic composition (δ^7Li) is expressed in parts per thousand, with the ^{7}Li/^{6}Li ratio of a sample expressed relative to the international standards ratio

$$(\delta^7 \mathrm{Li} = \left[\frac{(^7\mathrm{Li}/^6\mathrm{Li})\ sample}{(^7\mathrm{Li}/^6\mathrm{Li})\ standard} - 1\right] \times 1000).$$

Specialist literature shows that natural samples have an δ^7Li value of between -15‰ and +45‰ and this value depends on where it was extracted (figure 1). Four samples of lithium precursors from different locations were delivered to the CEA by the BRGM with a view to synthesizing cathode materials *(figure 2)*.

The results of isotope analysis carried out by the BRGM on the materials synthesized by the CEA demonstrate an exact match between the isotope composition of lithium precursors and the cathode materials derived from these precursors. The lamellar oxide synthesis process (calcination) does not change lithium's isotope ratio. Mass spectrometry analysis will make it possible to identify/confirm the provenance of the lithium contained in a battery.

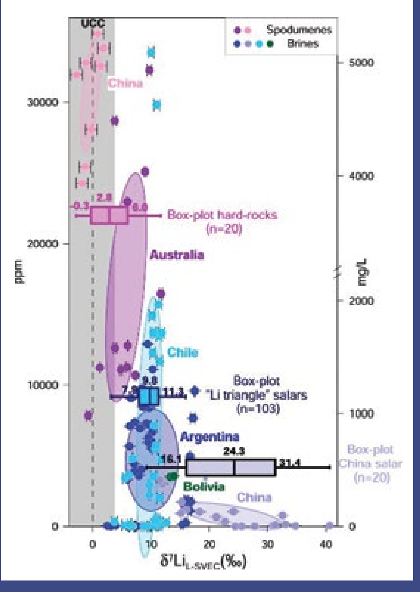


Figure 1 : Lithium content and isotope compositions (δ^7Li) in different deposits. gisements

Future developments

The large-scale use of critical materials in Li-ion batteries creates a need for tools to be developed which are able to track materials from the mine all the way through to the end of the fuel cell's lifespan. Results show that lithium's isotope ratio does not change regardless of the stages it has to go through - extraction, purification, processing and calcination – to be synthesized into cathode material. Further research will explore this concept with regard to cobalt and nickel.

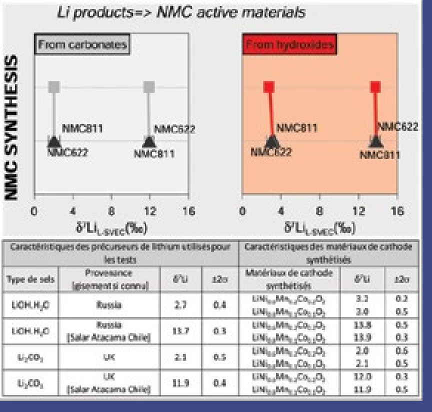


Figure 2 : Comparing isotope compositions in Lithium precursors and synthesized cathode materials

References :
[1] C. Thies, K. Kieckhäfer, T.S. Spengler, M. S. Sodhi, Assessment of social sustainability hotspots in the supply chain of lithium-ion batteries, Procedia CIRP 80, 292–297 (2019)
[2] A.M. Desaulty, D. Monfort Climent, G. Lefebvre, A. Cristiano-Tassi, D. Peralta, S. Perret, A. Urban, C. Guerrot, Tracing the origin of lithium in Li-ion batteries using lithium isotopes, Nature communication, 13, 4172 (2022)

SYSTEMS, NETWORKS AND ENERGY EFFICIENCY

Above and beyond improving key technological components (photovoltaic, batteries, electrolyzers, fuel cells etc.), a major challenge with regard to the energy transition lies in how to integrate these components efficiently to design systems able to meet exacting standards in terms of energy efficiency, reduction of greenhouse gas emissions and cost. With this in mind, Liten is developing digital solutions to facilitate the planning and management of energy systems of different sizes (vehicles, buildings, industrial estates, energy networks), as well as components that are critical to managing electrical power (power electronics) and heat (solar power generation, storage, heat transfer and conversion).

1 Managing thermal energy

Heating and cooling are a very significant proportion (ca. 50%) of energy end-use in industry, the tertiary sector and residential sectors. Our research focuses on generating heat through solar thermal energy to cater to the needs of industrial processes, for thermal energy storage to offer flexibility to energy systems and networks and heat exchangers and heat engines to put waste heat to use.

KEY FIGURES

70 PUBLICATIONS

350 PATENTS

30 PhDs

180 EMPLOYEES

New absorption heat pump for domestic hot water

In the framework of the EasyPOC project supported by the Auvergne-Rhône-Alpes region, CEA-Liten and industrial refrigeration specialist Clauger developed a proof-of-concept for an absorption machine that produces heat for domestic hot water applications. The machine uses ammonia as a refrigerant and water as a carrier, these being naturally CO_2 emissions-free liquids. Heat at temperatures of above 65°C can be produced by low-temperature (around 30°C) waste heat. The primary energy sources in question derive from waste process heat or renewables. The prototype performed 50% better than machines that use thermal energy directly and required 30 times less electricity than conventional mechanical vapour compression.

Toward industrial carbon-free power generation

European project DECAGONE started mi-2022, with main objective to overcome considerable reduction in performance of ORC (Organic Rankine Cycle) technology for waste heat-to-power conversion during their lifetime, and propose innovative approaches to maintain high-performance over 15-20 years of operation. A demonstrator integrating of an ORC and a thermal energy storage will be installed in Trinec iron and steel works site. The viability of the solution will be studied in different use cases, such as iron & steel, natural gas sector, glass industry, etc. In the project, CEA-Liten is mainly involved in identification of potentially relevant fluids and mixtures to be used as working fluid for the ORC, definition of the instrumentation of the DECAGONE prototype, and development of the thermal energy storage system.

A compact, modular heat storage solution

CEA-Liten and GRIMS have developed a latent heat storage solution as part of the EasyPoc project. The solution comprises a lattice heat exchanger and a bio-based Phase Change Material (PCM) (*photo*). This solution, which is called GRIMSBOX®, is three to four times more compact than water-based thermal storage solutions. It is also modular in shape and size – ideal for the limited space available in district heating network substations. The next step is a 1:1 scale demonstrator, which will be tested in real-world conditions on a district heating network managed by Energies du Sud in greater Montpellier, France.

The metal honeycomb matrix which is moulded around the heat transfer fluid tubes is the main innovation of this heat exchanger.

2 Energy systems & networks

In order to integrate renewable energy sources into the energy mix and decarbonize a variety of sectors, energy systems and networks must be redesigned. Teams from the CEA are working alongside their industry partners to develop multi-vector energy systems capable of meeting criteria in terms of energy efficiency and carbon footprint, whilst also meeting the specific requirements of the uses for which they are designed. With this in mind, Liten has been developing tools designed to improve the planning and management of systems and networks, taking an approach the combines digital simulation, semi-virtual testing in a representative environment and demonstration testing and monitoring in a real-world environment.

Improving energy system design to improve electricity generation

To integrate renewable energy into the energy mix as efficiently as possible, CEA-Liten has developed and tested a more realistic method of managing the district heating and electrical power supply for the Cambridge district in the French city of Grenoble. After having modelled energy use in the area hourly over the course of an entire year, the next step was to establish the extent to which the new methodology would enable the introduction of models that provided a more accurate representation of the system's short-term operational constraints whilst enabling it to run more efficiently over the course of the year without undermining the usefulness of the simulation with overly complex models.

When conventional methodologies are used, electricity generation and storage systems appear inadequate and excessive use of fossil fuels can be noted (in this case, heating oil). The new methodology proposed by CEA-Liten makes it possible to manage the system almost as efficiently as if energy demand for the whole year were known in advance (accurate to within 1 to 2%) whilst at the same time maintaining the capability to adapt to changes in actual demand when this deviates from forecasted demand.

Bringing solar power onboard to get electric transportation moving

Electric vehicles recharging at the CEA's Cadarache site

RTE and the CEA have tested an electric vehicle (EV) charging management solution at the CEA's Cadarache site. The goal was to hook up 24 charging points to a solar power plant and to an intelligent management system developed by the CEA at INES with a view to increasing the role played by solar energy in electric mobility. Some of the electricity for the charging points was supplied by the Mégasol solar power plant located near the CEA and the amount of self-produced electricity generated using the management solution and without using the management solution was compared over a 5 month period. The study demonstrated that the share of solar power-generated electricity used by the charging points can increase from 34 to 90%, thanks to this charging management software. This confirms that combining solar power generation and intelligent charging management solutions represents a really promising opportunity!

Liten's expertise helps reduce energy consumption at CEA sites

For the last two years I've been working on the Synergie Liten Centre programme, developing joint projects bringing together CEA centres in France and Liten in the fields of energy efficiency, renewable energy integration and decarbonization.
The CEA's leadership team identified major challenges in relation to energy use in its various sites and saw that Liten could have a part to play in boosting energy efficiency here. Liten's expertise is to be applied to the CEA's various sites, improving employee comfort and reducing CO_2 emissions. Several labs are working together to try to develop practical solutions which can be quickly implemented. Research focuses mostly on installing photovoltaic panels and district heating systems. The project is making good progress and the results in terms of energy savings are promising. Initial studies looked at 4 sites, but we are now going to expand this to include other centres. This will enable us to make further progress in applying the solutions that we have been developing for our industry partners to our own sites'.

Bernard Thonon, Energy Systems and Energy Network programme manager at CEA-Liten

3 High-performance power converters

With a growing proportion of the energy mix being supplied by electricity, power electronics is becoming an increasingly important component in the drive to efficiently integrate renewable energy into the electrical grid and to the large-scale electrification of our transportation sector. At CEA-Liten, the teams are developing innovative solutions to make power converters more efficient, smaller and more powerful. 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.

Compact magnetic cores for bidirectional electric vehicle charging

The SMARTIE project is focused on developing compact magnetic cores capable of performing at least two functions (i.e. transformer, inductor). This type of core makes it possible to transfer energy both to and from an electric vehicle's battery. The CEA-Liten teams at Grenoble and RENAULT redesigned the traditional magnetic component to achieve significant improvements in terms of size and mass. In addition to the basic function of a transformer, this magnetic core features two primary inductors and two secondary inductors. This design enables automated coil winding, simplified assembly and improved thermal management thanks to surfaces specifically developed for this purpose and the addition of encapsulation to help with coil cooling. The solution that was devised has now been sent to a components manufacturer for testing. If these tests are successful, this component will go into large-scale production.

A power convertor integrated with a PEMFC fuel cell

CEA-Liten has developed a sophisticated technological solution which integrates the DC-to-DC converter unit to the bipolar end plate of a PEMFC stack, using a cooling circuit that is integrated into the mechanical side of the solution (*photo*).

As part of the European Flhysafe research project, an electric power converter with a max input current of 175 A was developed by taking into account all of the requirements of the of the multi-physics system (power electronics and driver electronics, automation, mechanical, cooling) in a very confined space. This converter achieves between 96% and 97% efficiency over a wide output power range (between 7.5 kW and 30 kW) at a high cooling temperature (65°C). The stack/converter subsystems were able to supply approximately 6 kW electrical power on the CEA test bench. The process of integrating this into the full system is in progress.

Integrated converter and stack.

This project has received funding from the Clean Hydrogen Partnership under Grant Agreement No 779576. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

Optimal design and operation of multi-energy systems at district level

Context

In France, about 40% of the energy consumption is used for heating buildings[1]. While shift from fossil fuels to electricity is considered as a priority[2], several challenges arise regarding the pace of building renovation, the availability of low-CO_2 electricity, and the overall energy efficiency. Indeed, realistic scenarios require not only electrification but also increased sector coupling, in particular between the electric and thermal network, which can bring more robustness and flexibility.

Approach & Results

The study[3] compares two alternative systems for providing energy to a residential district.

System A is driven only by electric power, with decentralized heat pumps providing heat to each building separately. System B considers district heating with centralized units for heat production. The comparison is based on technical-economic/environmental multi-objective optimization, which computes the optimal sizing and costs of the system under an optimal control assumption. The case study is inspired by a real district in Grenoble (France), and comprises 13 residential buildings, totaling 500 dwellings approximately. Relevant data has been collected from various sources, so as to be representative of a real case.

La figure 1 (left) illustrates the Paretofront obtained when optimizing the cost for both systems, under a varying CO_2 emission constraint. While the cost is almost equivalent without constraint (rightmost case), the cost of the electricity-driven system A increases exponentially for an increasing constraint.

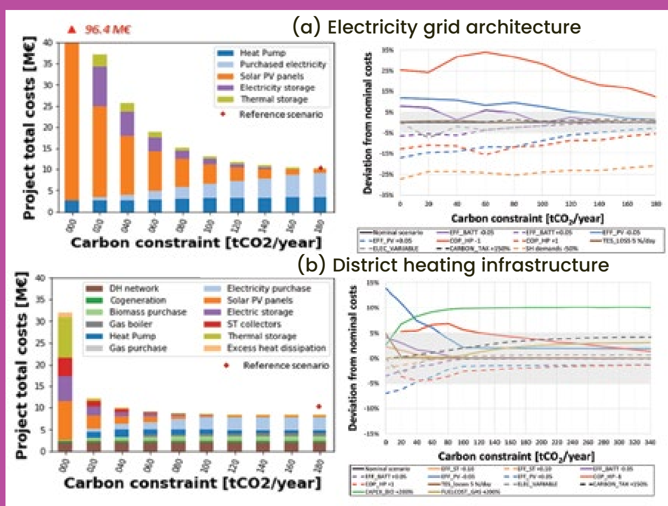
Figure 1 (right) illustrates the sensitivity of the obtained results to the variation of several parameters, and outlines the stronger sensitivity and lower resilience of the power-only system A especially regarding the heat pump COP*, which is indeed a very uncertain factor (a large discrepancy between design and operation is often observed in practice).

**Coefficient Of Performance*

Conclusion

This study illustrates two properties common to many studies conducted at Liten. First, an optimal combination of energy vectors has a strong potential for decreasing overall system cost, especially when additional constraints are applied. Second, and not surprisingly, combining energy vectors provides more flexibility and robustness to uncertainties. To tackle these more complex systems, the TRILOGY platform developed at CEA provides key software tools to design and operate multi-energy systems efficiently. On-going research aims at integrating more LCA** criteria.

***LCA : Life-Cycle Analysis*



***Left:** Pareto-front costs/CO_2 emissions for the two systems (a) (a) Electricity grid architecture; (b) District heating network. For each scenario, the multi-coloured columns show the cost of each technology used.*

***Right:** sensitivity of the two systems to the chosen parameters*

À droite : sensibilité des deux systèmes aux paramètres sélectionnés

References :
[1] Ürge-Vorsatz et al., "Heating and cooling energy trends and drivers in buildings," Renewable and Sustainable Energy Reviews, vol. 41 (2015)
[2] RTE, "Energy pathways 2050 - key results" (October 2021)
[3] Fitó et al., "Robustness of district heating versus electricity-driven energy system at district level: A multi-objective optimization study," Smart Energy, vol. 6 (2022), doi: 10.1016/j.segy.2022.100073

CIRCULAR ECONOMY

To minimize the impact of the energy transition upon the consumption of raw materials, an environmentally friendly circular economy model must be central to technological innovation. Liten is carrying out research into the materials circular economy ('Reduce, Reuse, Recycle'), with particular emphasis on eco-design and recycling as applied to new energy tech. Liten is also developing eco-innovative materials and processes such as the manufacturing of near-net-shape items, complex assemblies and bio-based materials. Liten also designs materials, processes and systems for the circular carbon economy which facilitate the conversion of carbon-based energy sources into molecules of interest to the fields of energy and chemistry.

1 The materials circular economy

With the energy transition in mind, it's vital to adopt a circular economy model based on the 3 Rs (Reduce, Reuse, Recycle) in order to reduce consumption of raw materials and add value to secondary materials, reduce environmental impacts and ensure a substantial degree of sovereignty over the supply of these materials. R&D is currently focusing on finding substitutes for critical materials such as silver or indium for the photovoltaic industry, cobalt or nickel in batteries and platinum in PEMFCs. Research is also being conducted into emerging industrial sectors in France and the rest of Europe which are key components of the energy transition, specifically in the field of permanent magnets.

KEY FIGURES

50 PUBLICATIONS

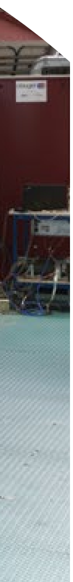
450 PATENTS

50 PhDs

230 EMPLOYEES

Boosting electric car battery recycling in Europe

The RESPECT project, coordinated by Orano Mining, a subsidiary of Orano, is funded by the European Union (EU) and Horizon Europe. It brings together 18 international partners around a shared goal: consolidating Europe's strategic independence with regard to the materials used in making batteries. The focus is on developing an innovative closed-loop recycling procedure that is flexible enough to be applicable to any Li-ion battery, covering everything from logistics, sorting, materials recovery and reuse, not forgetting safety issues relating to the opening and deactivation of cells and hydrometallurgy. CEA-Liten has been working for over ten years on developing hydrometallurgical and electrochemical methods of recycling and is responsible for the technical and scientific coordination of the project.



Its teams have been closely involved at every stage of the development of these recycling processes, especially direct recycling, involving active materials being reused.

PV technology: reducing the quantities of silver used in solar cells

One of the ways in which the photovoltaic industry can reduce its environmental impact is to reduce its consumption of materials like silver, which is deposited during the cell metallization stage. CEA-Liten's experts have succeeded in reducing the metal line width using screen printing mesh with smaller openings than normal, whilst transferring the silver paste successfully and achieving low line resistance.

Pilot system for recycling batteries

The M2 size 6BB (busbar) heterojunction cells that are produced as a result possess a ratio of silver consumed per watt of 19.2 mgAg/W instead of 24.58 mgAg/W (ITRPV 2022). This corresponds to the 2026 target for silver consumption for this kind of technology that scientists worldwide have been aiming for!

Recycling multi-layer plastic packaging

The MERLIN European project aims to design innovative recycling and upcycling processes for plastic materials. Its goal is to develop processes to reuse low-quality polyethylene (rPE) derived from rigid and flexible food packaging, as well as recycled PET (rPET), from flexible packaging. The CEA's role is to improve the materials' mechanical properties and stability so that they can be reused by adding specific additives such as fillers and antioxidants using reactive extrusion. The increase in rPET/rPE multi-layer adhesion and affinity would enable the use of more environmentally friendly adhesives, or even for adhesives to be dispensed with entirely.

Bringing magnet manufacturing back to France

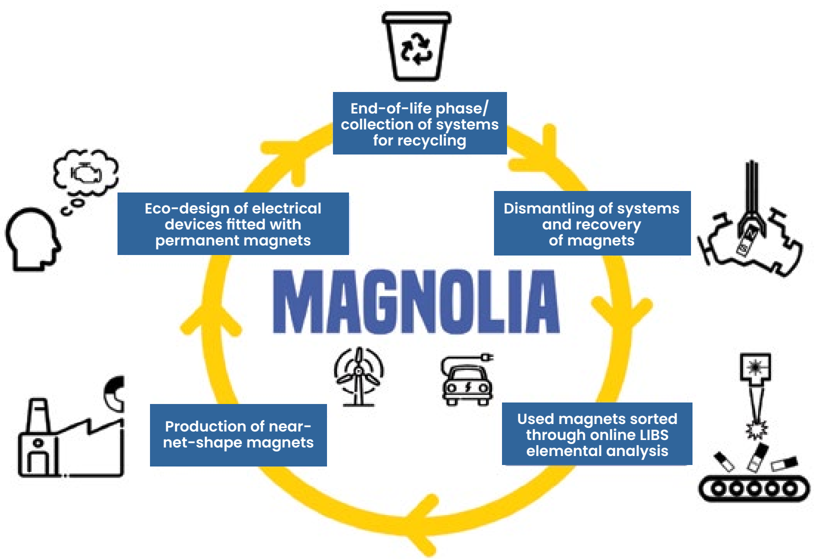
Permanent magnets are key components of the energy transition. They contain rare-earth metals (more than 30% of their content), which are viewed as critical materials due to China's near monopoly on their production. Consequently, reducing dependency on foreign suppliers for rare-earth metals is now a major strategic challenge for all of Europe, including France. The MAGNOLIA project brings together 5 industrial and institutional partners in the high-performance permanent magnet field: Orano, Valeo, PAPREC, DAIMANTEL France and the CEA. Their main goals between now and 2025 are to:

• Develop technologies to manufacture sintered magnets in France and scale these technologies up on pilot and small-run production lines. A decision on whether to start large-scale production will be made in 2025.

• Lay the groundwork for an electric motor collection, dismantling, and recycling industry in France. This nascent industry will have to ensure stable and economically competitive prices and a secure domestic permanent magnet supply chain and manufacturing operation.

• Reduce the environmental impacts of all processes by recycling magnets, limiting manufacturing waste, recycling rare-earth metals, and eco-designing electric machines for easy dismantling.

CEA-Liten will be tasked with increasing the current capacities of the pilot line at the Powder Metallurgy Platform to 4 tons and bringing the technologies needed to reduce or replace critical raw materials to maturity. This will include solutions to use critical raw materials more efficiently, optimizing formation processes to boost material yields and examining the circular economy angle, most notably in the form of the recycling of spent sintered magnets through an innovative powder process.



This project is funded by the 'France relance' initiative

The partnership between CEA-Liten and Orano was already a fruitful one. Now, with the MAGNOLIA project, it's discovered a new outlet in the shape of scaling up processes for the recycling and manufacturing of sintered NdFeB magnets. Orano embarked on this long-term development plan two years ago and its first tangible results can be seen in this project.

2022 was an important year. It saw the establishment of dedicated teams at Orano and Liten, the assessment of the technical readiness level of every process being developed as part of the MAGNOLIA project, and the drawing up of the specifications for the facilities required at CEA-Liten to implement an ambitious R&D programme. This work will ensure that in time we will have access to research facilities boasting cutting-edge technology.

For Orano, the technical expertise acquired by CEA-Liten is of critical importance. It lends weight to our bid to position ourselves in this growth industry and also speeds up this process. Despite the numerous challenges we face, the excellence that characterizes this multi-year partnership means we can be confident of achieving our ultimate goal of greater economic sovereignty for Europe.'

Benoit Richebé, Head of the Magnets and Rare-earth metals projects at Orano

2 Eco-innovative materials & processes

Liten is faced with a challenge – to design more sustainable technological solutions for decarbonized energy systems, both in terms of the materials used in their construction and in the processes required in their implementation. Liten is currently developing processes that are designed to make more efficient use of materials in the manufacture of high added-value components. This involves near-net-shape items and is feasible thanks to power metallurgy and additive manufacturing, not to mention assembly processes for complex multi-material components. More recently, it has been exploring the use of bio-based materials. Technological developments now adopt an ecological design-based approach which encourages taking environmental criteria as well as fundamental economic issues into account when making design choices.

Developing more eco-friendly approaches to photovoltaic panel design

CEA at INES is currently working on making photovoltaic panels lighter by replacing the glass used on the front sheet and the fluorinated polymers on the back sheet. Several combinations of eco-friendly composite materials would help reduce the environmental footprint of this technology. To compensate for highly variable data and the relatively recent nature of state-of-the-art reviews of these types of materials, the CEA's teams have developed a standardized tool to perform environmental analysis of a photovoltaic panel's value chain.

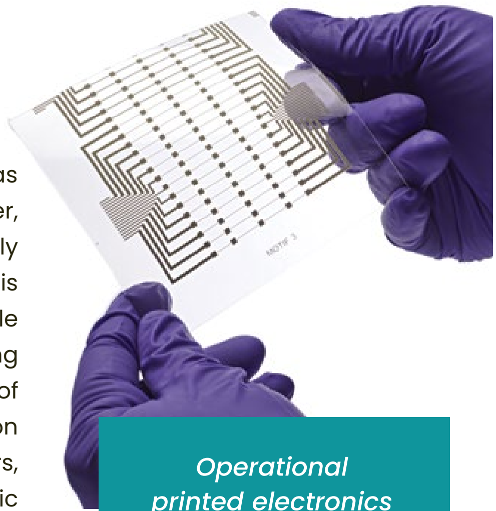
A dedicated composite materials data base has been created. Earlier studies have identified materials not widely known in the field of photovoltaics which hold out a lot of promise as alternatives to traditional materials, including resins of the bio-based thermosetting type and polypropylene-type thermoplastics, glass, flax and basalt fibres.

Analysis demonstrated, amongst other things, that in the case of all of the criteria studied, the environmental impact of composite materials depended mostly on the choice of resin, fibre and the quantity of these materials used to manufacture each panel. The environmental benefit ranges from 5% to 15% depending on the combinations and proportions in use. The most promising solution will be subjected to a full Life-Cycle Assessment (LCA) to confirm its suitability from an environmental point of view.

This research was carried out within the framework of the ITE INES.2S, part funded by the French government under the Investment for the Future programme (ANR-10-IEED-0014-01). Launched in 2019, INES.2S is an Energy Transition Institute which operates under the umbrella of the CEA at INES.

Bio-based polymer films for flexible electronics

Thin bio-based or biodegradable films have started to emerge as a substitute for some petroleum-based flexible thin films. However, most of these are currently produced and sold in Asia, creating supply challenges for the European market. The supply of these products is therefore an important element in the long-term development of flexible bio-based organic electronics in Europe. With the goal of securing supply chain sovereignty in this field, the CEA, in the framework of the Europe-wide INN-PRESSME project, has invested in a film extrusion manufacturing line. Following improvements to process parameters, substrates of a very specific thickness were produced using polylactic acid (PLA). A pilot operational flexible electronics demonstrator was created from this bio-based, biodegradable substrate, using screen printed conductive tracks. Embedding components (LEDs) was the final step in creating the prototype.



Operational printed electronics demonstrator using bio-based substrates produced at CEA-Liten

Plastronics drives innovation in automotive industry

Symbiose, a startup founded in 2014 to develop and commercialize plastic films for printed electronics, is working with the CEA to help make plastronics — electronics embedded in plastic materials using printing and other techniques — the go-to solution for the automotive industry.

Developing the technologies required for overmoldable plastic touch interfaces is one of the company's priorities. And CEA-Liten has know-how that could help. The institute possesses a winning combination of innovative technologies that enable piezoelectric and capacitive sensors to be printed on thermoformable films onto which additional components can then be bonded. The plastronic touchpads made using these technologies deliver excellent optical performance.

CEA-Liten printed electronics R&D plateform

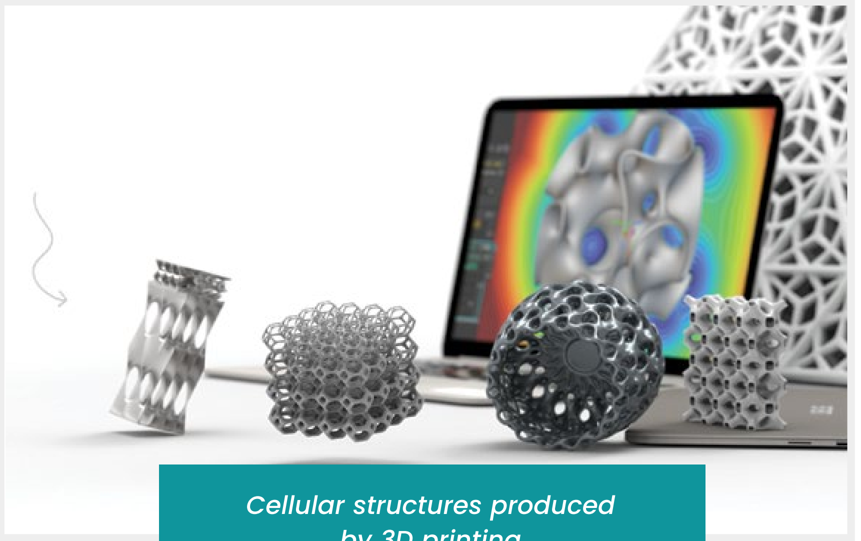
Symbiose would also like to make its components more environmentally-sustainable by integrating circular economy principles into its development and manufacturing processes. Research on new, more environmentally-friendly materials for the automotive industry being done by CEA-Liten for an EU project that kicked off in September 2022 will support this objective. Specifically, CEA-Liten is improving the plastronic component manufacturing processes for these new materials and developing performance tests for the final components.

Symbiose raised €6.5 million in 2021 and moved into its new factory in Pugnac, France in May 2022.

3D printing: an innovative approach using cellular structures

As part of the HUB3D print initiative, CEA-Liten and its industry partners are experimenting with 3D printing in order to tackle challenges in a wide variety of markets. One example of this is the development of cellular structures for mechanical energy dissipation purposes or for creating structures that exhibit very precise mechanical behaviours. Additive manufacturing makes it possible to create complex structures by means of printing, thus both reducing the weight of these structures and saving on raw materials. The mechanical properties of these cellular structures are excellent, delivering high specific strength in a wide range of scenarii. With this in mind, advanced design techniques like algorithmic design and implicit modelling are used in conjunction with DFAM (Design For Additive Manufacturing) rules in an innovation through design approach. This allows for the creation of angles and shapes hitherto impossible to produce. Lastly, the automation of some software components offers an effective way of identifying structure models and process parameters to improve the design of components with specific, desired mechanical properties.

These projects have borne fruit in the shape of working demonstrators. These were produced as pre-production models in very short time-frames to speed up the ongoing development process with a view to making the product commercially available.



Cellular structures produced by 3D printing

A long expertise in Hot Isostatic Pressing (HIP)

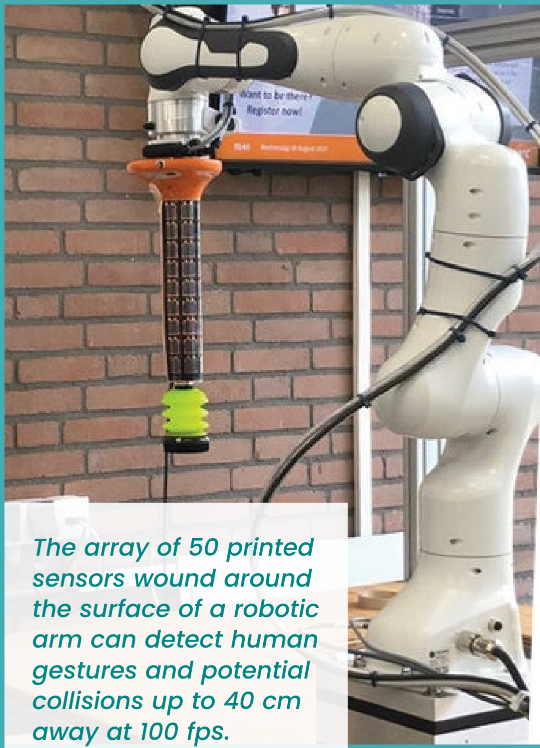
Whether it is assembling solid parts or compacting metal powders, the CEA has been using Hot Isostatic Pressing (HIP) to manufacture complex parts for nearly 40 years. In addition to producing parts with excellent mechanical properties, HIP also stands out for its ability to produce parts with complex geometries and parts made from multiple — and sometimes incompatible — materials. It can also be used on parts of many different sizes. And, because HIP can reduce the number of machining and welding steps needed, it also saves on raw materials. CEA-Liten is currently engaged in the EQUIPEX+ CALHIPSO* project, coordinated by the University of Burgundy Franche-Comté (UBFC). This project is developing custom HIP processes to meet the needs of manufacturers through a holistic approach that encompasses experimentation, modeling, and simulation. The goal is to develop a network of French HIP technology providers and create high-added-value jobs in the aeronautics, automotive, rail, energy, defense, and other strategic industries.

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

Robot proximity sensors could benefit from new printed pyroelectric sensor arrays.

Context

Cobots — robots designed to interact directly with human operators — are packed with integrated sensors. Making these sensors in a wide variety of form factors and ensuring they are compatible with the kinds of use cases they are likely to encounter is a challenge. An approach known as structural electronics provides an alternative to thick, rigid conventional sensors with their many connectors. Devices like pyroelectric sensors that detect heat and the associated control electronics can be printed directly on very thin, flexible, and conformable substrates. In addition to being easy to integrate, these printed electronic devices possess all the qualities needed to develop smart skin for tomorrow's robots [1,2].



The array of 50 printed sensors wound around the surface of a robotic arm can detect human gestures and potential collisions up to 40 cm away at 100 fps.

Methodology & Results

The Eindhoven University of Technology, which has been working with CEA-Liten on flexible circuits for years, evaluated a flexible motion detection and gesture recognition sensor made using printed electronics. The research, published in *Nature Electronics*[3], focused on the integration of sensors made from PVDF-TrFe* organic polymers, known for their piezoelectric and pyroelectric properties. There is no lack of prior research on this kind of sensor. Not so common is research on multi-pixel integration, which is particularly challenging due to the many interconnections required and the impact not only on integration, but also on the quality of the signals measured.

To address these limitations, the research team co-integrated printed organic thin-film transistors (OTFTs**) under the sensors' flexible surface. This type of OTFT was developed by CEA and partners for the EU H2020 ATLASS project completed in 2019 and a system-level prototyping line was built. In-pixel active circuits amplify the signal for an improved signal-to-noise ratio and a detection range ten times longer. The approach also enables multiplexed sensor arrays for human gesture recognition at a range of 40 cm at 100 frames per second.

**PVDF-TrFE: polyvinylidene fluoride-co-trifluoroethylene*

*** OTFT Organic Thin Film Transistor*

Future developments

The electrical performance and high yields obtained by the technology developed and the circuits manufactured by the CEA and its partners have established a new state of the art benchmark. These results illustrate the potential of structural electronics in terms of innovation and confirm not only the CEA's leadership in organic thin film transistors, but also CEA-Liten's capacity to nurture a technology from concept to complete system prototype.

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[1]-https://www.equip-prod.com/equipement/rapprocher-les-robots-de-lhomme-en-leur-offrant-une-peau-aux-pouvoirs-etendus/

[2] - Y. Dai and S. Gao "A Flexible Multi-Functional Smart Skin for Force,Touch Position, Proximity, and Humidity Sensing for Humanoid Robots" IEEE SENSORS JOURNAL, VOL. 21, NO. 23, DECEMBER 1, 2021

[3] - Fattori, M., Cardarelli, S., Fijn, J. et al. "A printed proximity-sensing surface based on organic pyroelectric sensors and organic thin-film transistor electronics." Nat Electron 5, 289–299 (2022).

3 The circular carbon economy

A great many key industries are unable to do without organic compounds, these being at the very heart of their activities (heavy transportation, chemicals etc). For these sectors, the energy transition will require the implementation of a circular carbon economy which will enable them to put an end to fossil fuel-based CO_2 emissions. Liten's strategy revolves around the developing of complex '*power-to-X*' and '*power-and-biomass-to-X*' systems to convert CO_2 and other carbon-based resources into organic compounds of interest thanks to hydrogen produced from low-carbon electricity. This approach applies not just to gases (methane), but also liquids (methanol, synthetic aviation fuels etc.)

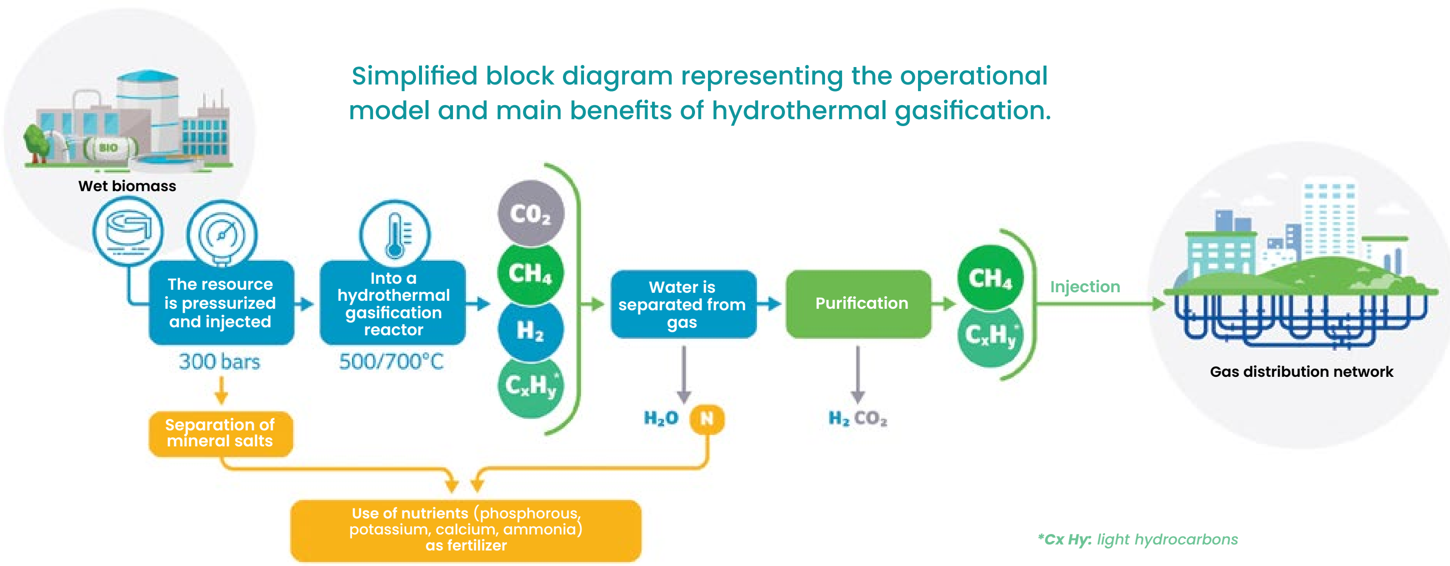
The CEA and GRDF: supporting the nascent hydrothermal gasification sector

As part of the Gazhyvert 2 project, launched in January 2022, the CEA and GRDF have joined forces to work towards a shared goal, that of developing the key technologies and know-how needed to nurture the emergence of a French hydrothermal gasification (HG) industry for the production of biomethane - without competing for inputs. This technology makes it possible to produce renewable, high energy content natural gas from wet biomass which is either viewed as a waste product or which cannot be disposed of in landfill.

A preliminary study carried out by the two partners in 2021 demonstrated the feasibility and commercial viability of producing methane through HG from sewage sludge. This new phase in our research aims to identify the adaptations required to bring the process to a stage of greater maturity so as to design one or more large-scale demonstrators. The goal is to implement the process on a mass scale by 2025.

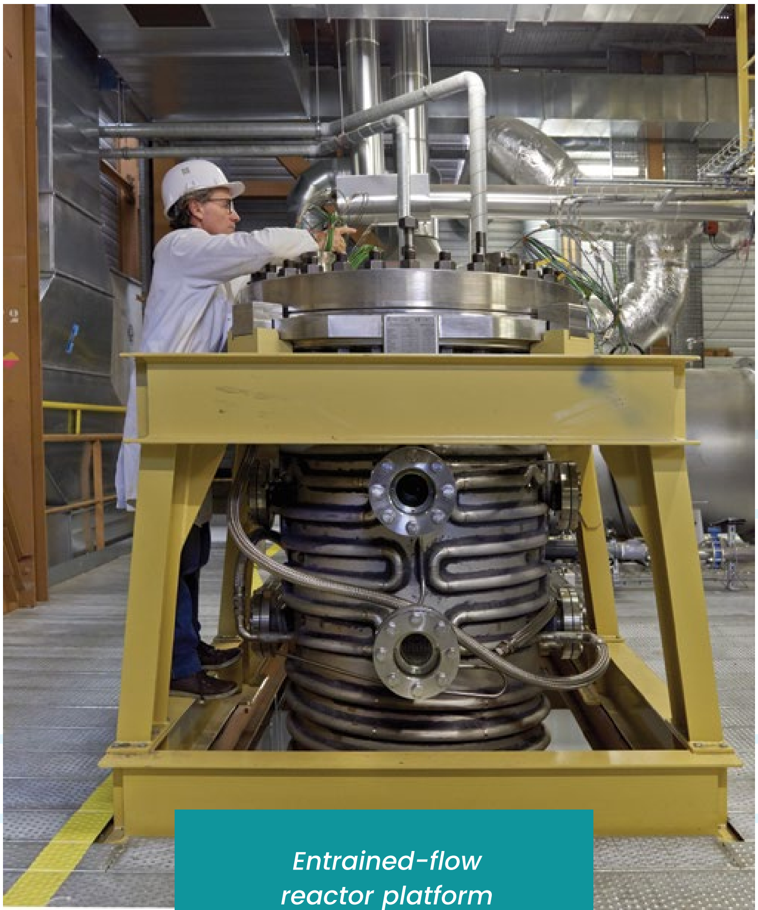
Backed by more than ten years of expertise in this field, the CEA team can count on its experimental hub with test benches operating in batch mode or continuous mode, its physico-chemical testing facilities and its simulation tools to help drive the success of this project.

Simplified block diagram representing the operational model and main benefits of hydrothermal gasification.



An alternative use for old tyres: gas production

GRDF, the French natural gas distributor, has conducted research into various fields with a view to synthesizing methane and decarbonizing its business model. One technique, pyro-gasification, would make use of old tyres. Meanwhile, ALIAPUR, a tyre recycling business, is interested in finding alternative ways of reusing tyres that does not involve burning this waste product. These two partners asked the CEA to carry out trials involving the gasification of rubber powder from waste tyres in its entrained-flow reactor experimental platform. By creating an optimal operating environment in terms of both temperature and pressure, 96% of the carbon in the tyre is converted to gas and the production of hydrocarbons (with the exception of methane) is limited. Gasification's potential for converting used tyres into methane is clear and it is estimated that as of 2022, the cost of methane produced using this method is close to that of biomethane.



Entrained-flow reactor platform

Developing an innovative approach to biomethane production

The EU's METHAREN project brings together 17 different partners. Its primary objective is to significantly increase the profitability of biomethane production at existing biogas plants. The project aims to develop an innovative biomethane production solution using household waste. This will valorize biogenic CO_2 and waste material that up to now has ended up on the scrapheap. This innovative procedure is underpinned by a number of valorization and conversion technologies. This potentially very promising approach could deliver a 150% increase in biomethane production and a 20% reduction in production costs. CEA-Liten is working on two technological components of the METHAREN process. The first relates to hydrothermal carbonization. The second is the process of methanation, the end goal of which is to create a demonstrator featuring an innovative reactor developed at CEA-Liten and to test it in real-life conditions.

Carbon Capture and Usage: a CEA-organized workshop to promote the development of the sector and bring together actors from industry and institutional bodies

On November 30th 2022, CEA-Liten held a workshop focusing on Carbon Capture and Usage (CCU). There were 60 attendees, most of whom were from industry and public bodies rather than the CEA.

The morning was given over to keynote speeches on the role Carbon Capture and Usage has to play in tackling climate change, the challenges associated with CCU, an overview of the current regulatory environment and reports on the implementation of concrete CCU solutions by major industry players Technip Energies and GRDF.

The afternoon provided an opportunity to work in sub-groups in three different workshops:

The first workshop was called 'How do we tailor our goals to our available resources?'

Currently, ambitious plans are afoot to eliminate fossil fuels from industry and transportation, sectors which, for the time being, seem hooked on organic compounds. The regulatory environment in this field is becoming ever more complex. Meanwhile, questions are being asked about resource availability. Participants noted that there were insufficient resources to meet all needs and suggested it would be necessary to implement ways of assessing key performance indicators like LCA (Life-Cycle Assessment), cost or even national self-sufficiency to help inform future roadmaps. The usefulness of multi-criteria (technical, economic and environmental) studies was highlighted.

The second workshop was called 'Is State involvement required in order to create an influential, collaborative CCU sector in France?'

Although numerous CCU-related projects in France are at an advanced state of technological readiness (TRL 6 to 7), the uncertainty over future regulatory developments in the field currently makes transitioning to large-scale, commercial-level operations look like a complex and potentially risky proposition in France. Participants identified the 'National Hydrogen Strategy' as being a model to emulate in terms of opening a dialogue with politicians, drawing up roadmaps and cooperating on initiatives. They expressed a desire to create a similar body for CCU with the specific aim of establishing a constructive dialogue with the public authorities to help promote the development of this sector in France.

The third workshop was called 'Technological barriers – an opportunity for industrial symbiosis?'

The workshop's goal was to list the technological barriers still to be overcome with regard to the different processes so crucial to the Carbone capture and usage (catalytic reactors, thermal conversion, the Fischer-Tropsch process etc.). The issue of a joint French/European solution involving a partnership between different actors in the sector to overcome these barriers was discussed. The CEA identified RWGS (converting CO_2 into CO) as a key building block which features in many approaches/applications/products. The development of cutting-edge, high-performance RWGS reactors is now firmly in the CEA's CCE roadmap.

The event generated lots of interest and enthusiasm. The CEA has put forward concrete initiatives to act upon the conclusions reached by the various workshops. Some of these initiatives have already got underway.

“ We give the floor to entrepreneurs ”

DistrictLab Digital twin for energy grids

*‘ **DistrictLab** (https://www.districtlab.eu/) has developed a computer-aided engineering solution which aims to improve the design and functioning of urban district heating systems (heat networks). We're offering software to help clients achieve greater energy efficiency and make better investment decisions. This is based upon R&D programmes developed at the CEA between 2010 and 2020, in partnership with district heating operators and alongside initiatives to scale up undertaken through the CEA-MAGELLAN start-up accelerator scheme.’*

Roland Bavière (CEO and CTO)
& Abdelhamid LARBI (CCO)

Heliup

' **Heliup** *aims to facilitate the rapid, large-scale roll-out of electrical generation solutions through the development of lightweight solar panels to cover the roofs of large buildings (commercial premises, industrial facilities, farm buildings). At present, conventional solar panels weigh too much to be installed on the large majority of these kinds of buildings. We founded Heliup to tackle this problem by devising lighter solutions that are competitively-priced and which perform consistently well over periods of 25 years and more. Our goal is to become a major player in this European industry and reach a one gigawatt per annum electricity generation target within five years...'*

Yannick Veschetti & Julien Gaume

SolReed

'The idea behind Solreed *emerged from the fact that huge numbers of photovoltaic panels are currently sent to landfill even though they're still working. We asked ourselves the question: how can we re-use this supply of panels and create an industry, firstly based in France, then Europe-wide, to give these panels a new lease of life? This led us to look at creating a business driven by a three-fold vision based on a sound business model, care for the environment (100% zero-carbon products) and social inclusion (we have decided to entrust the process of refurbishing the panels and ensuring they are compliant with all relevant regulations to those generally excluded from the labour market).'*

Luc Federzoni

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