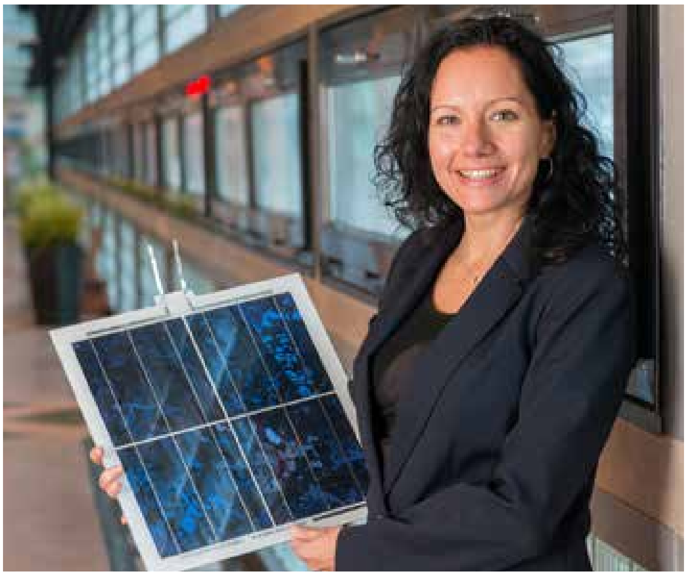
liten
cea tech

# ANNUAL REPORT 2018

Growing collective awareness of climate change is pushing governments around the world to step up their energy transition policies in much the way France has. France's energy transition strategy, overhauled in late 2018, contains some ambitious targets. The first is to implement energy-efficiency measures to reduce the total energy consumption of all sectors by 14% by 2028; the second is to achieve carbon neutrality by 2050. To make these objectives a reality, the priorities must be to integrate renewable energy into existing energy grids for 100% carbon-free electricity production and to curb residential, industrial, and transportation-related energy consumption. Intermittent energy sources are gaining traction. At the same time, our natural resources are being depleted and the environment is in crisis. The resulting technological and economic hurdles must be addressed. Liten possesses broad knowledge of all energy carriers—electricity, heat, and gas—encompassing production, storage, and management. We are developing breakthrough technologies like heterojunction photovoltaics and high-temperature electrolysis for carbon-free hydrogen production, to name just two. Our systemic approach to adress energy challenges makes us a major provider of energy solutions that our partners can take from our labs to their plants and, ultimately, to the market.
This annual Activity Report offers up a review of some achievements that marked the year 2018 and that illustrate our ambition of providing the technologies that will power a sustainable future. ■

**Florence Lambert,**
Director, Liten



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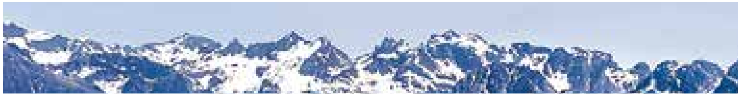





Editorial: CEA Liten / Translation: Sarah Freitas Graphic design: DEUXPONTS Manufacture d'Histoires © Photos Crédits : P. Jayet, Drone Savoir, P. Avavian, D. Guillaudin, Jakub Rupa Fotolia, Chamois constructeur, Fotolia, T. Delaplagne, A. Navin-Puthod CEA, L. Godart, Stratobus E. Briot, J. Gaume CEA, S. Boivin, #almabte, Sylvain Ramadier CEA, F. Pattou, Francillon, CEA/Production Perig - Fotolia, DR.

# LITEN: SOLVING CLIMATE, ENERGY,

Liten, the Laboratory for Innovation in New Energy Technology and Nanomaterials of the French Alternative Energies and Atomic Energy Commission, is the leading research organization in Europe to focus exclusively on solutions for the energy transition.

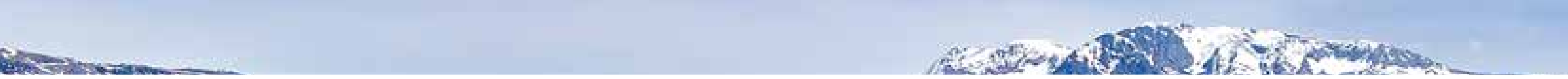
With facilities in Grenoble and Chambéry, at the center of France's number-one energy-producing region, Liten has carved out a position as a major provider of technological research in the field of energy over the past fifteen years. Today, Liten is developing solutions that address our energy and environmental challenges while supporting economic growth.

Liten's research activities are underpinned by a strong belief that a successful energy transition will be built on the convergence of renewable energy, smart grids, and overall energy efficiency. The institute's research strategy is to develop solutions and innovations that position our partners to:

- Control the production of energy from intermittent renewable sources
- Develop energy grids that integrate various flexibility solutions through digital dimensioning and management tools
- Guarantee a satisfactory overall energy footprint

Liten draws on its thirteen technology platforms, a portfolio of more than 1,600 patents, and the knowledge of a thousand scientists, technicians, and support staff to reach these goals.

All of these strengths combined make Liten a powerful R&D provider poised to resolve complex technological challenges and create the products, processes, and components of the future. □



# AND ENVIRONMENTAL CHALLENGES

## LITEN PLAYS KEY ROLE IN CARNOT NETWORK ENERGY ACTIVITIES

The Carnot seal was established by the French Ministry of Higher Education, Research, and Innovation to encourage direct partnerships between research and industry through a network of research institutes, *Instituts Carnot*. Liten, along with ten academic research labs, is a member of the *Institut Carnot Energies du Futur* consortium. Together, the members of the consortium offer innovation services targeting a variety of technology readiness levels.

For more than twelve years, the resources available through the Carnot network have supported Liten in maintaining a state-of-the-art technology portfolio and expanding its pump-priming research—vital to delivering innovation and scientific excellence over the long term and positioning Liten as a key player in tomorrow's energy landscape. Learn more at: www.energiesdufutur.fr □

www.liten.cea.fr

# LITEN: INDUSTRY'S TECHNOLOGICAL

## ELISABETH AYRAULT, CEO, CNR

*"At CNR, innovation is a major pillar of our strategy. Our partners' know-how is crucial to helping us speed up the transition to a different world. We established a significant partnership with Liten to address three topics: managing the intermittency of renewable energy, reducing it, and developing the energy of the future. One example is our work with Liten within an entire consortium of partners on the Jupiter 1000 power-to-gas demonstrator plant in Fos-sur-Mer in the south of France. We are developing systems to manage the injection of synthetic methane into the grid and the production of hydrogen. Liten is also supporting our efforts to develop the energy of the future, with research on linear solar energy systems capable of making more efficient use of surfaces like embankments and railroad tracks. Liten really stands out for its capacity to apply its key technologies to projects of all scopes."* □

## LAETITIA BROTTIER, CO-FOUNDER, DUALSUN

*"Our partnership with Liten began four years ago on the Dualplas+ project to develop a hybrid photovoltaic-thermal (PVT) solar module. It has received French public funding. We wanted to maintain our technological leadership, so we turned to Liten to help identify the best solution. Liten drew on its solar energy and module integration know-how to help us select the best options and, ultimately, complete our project. Liten's researchers demonstrated a high level of engagement. They were also flexible and proactive throughout the project. Later, Liten asked us to join the Horizon 2020 SunHorizon project consortium, where we incorporate our innovative PVT technology. Without Liten's support, we would have missed this opportunity to work with researchers and industrial companies from several European countries."* □

## A TAYLOR-MADE

**Industrial research agreement:**
Covers a given time period and clearly-identified R&D topic; can be coupled with a collaborative R&D project (like those funded by the French National Research Agency, French Single Interministerial Fund, or EU programs).

**Affiliate programs:**
Multipartner R&D programs with simplified administrative procedures; especially suited to SMEs.

# RESEARCH PARTNER OF CHOICE

## FRANCK ROGEZ, R&D MANAGER, ENTREPOSE

*"Since 2015 Entrepose Group, a subsidiary of Vinci Construction, has been working on a large-scale electricity storage solution that entails storing hydrogen in salt caverns. In 2017, thanks to a partnership between Vinci Construction and its subsidiaries, a new collaboration has been established with Liten which had been developing a reversible fuel cell. This resulted in the ERMES project, a high-capacity solar power plant in North Africa with its own energy storage system. By combining our know-how with Liten's mastery of high-temperature electrolysis, we were able to complete a technical feasibility study and a technical and economic analysis, comparing several technology bricks to come up with the best possible compromise between efficiency and economic performance. This successful first collaboration spurred us to work with Liten again, this time on a power-to-liquid project to transform $CO_2$ into a synthetic fuel using high-temperature electrolysis powered by carbon-free electricity."* □

## ERIC NOTTEZ, CEO, SNAM*

*Société Nouvelle d'Affinage des Métaux

*"Our partnership with Liten began more than ten years ago when we were seeking ways to improve our battery recycling processes and adapt to new battery chemistries. Liten brought us expertise we didn't have in house—especially in materials science, electrochemistry, and electronics—and impressed us by providing a coordinated response. The project was a success. Today, we have secured 95% of the electric vehicle battery recycling market. Little by little, the knowledge this partnership has brought us has positioned us to open a new-battery manufacturing plant where the products are made from 80% recycled components. We have also built a pilot line for the purification of metal salts using a hydrometallurgical process developed in close cooperation with Liten."* □

## OFFERING

**Joint R&D lab:**
Joint research team under a reciprocal agreement. Shared goals, technology milestones, and joint management mechanisms.

**Technology transfer:**
Partners can license our technology under certain conditions. Liten's technical support to transfer mature, patented technology.

# IMPROVED PERFORMANCE, NEW PROCESSES

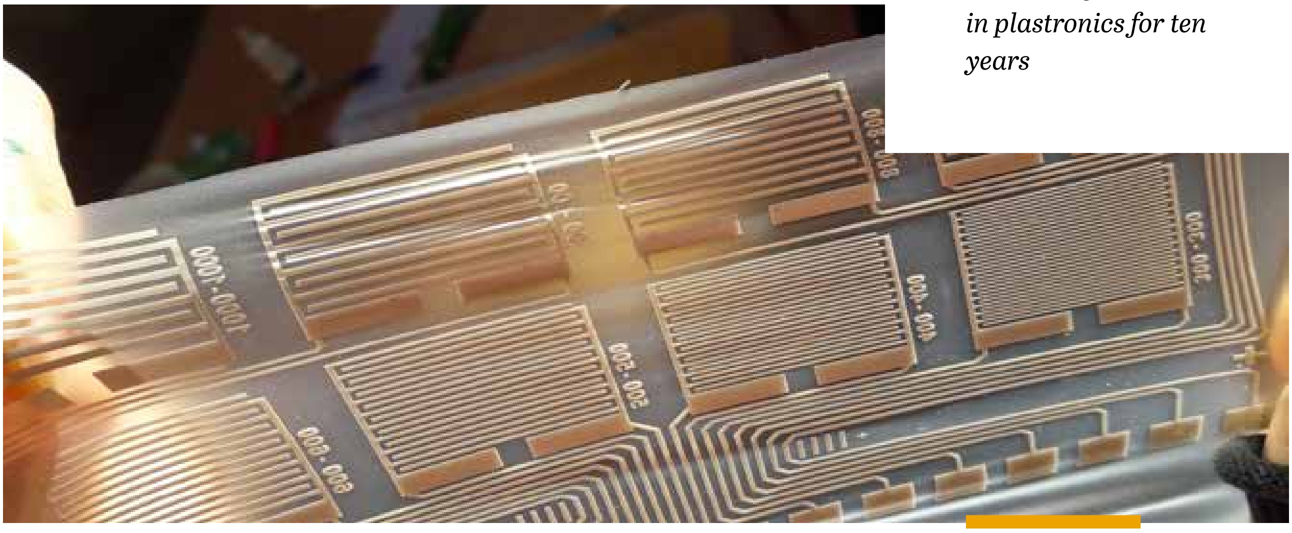
At Liten, we are working to improve the performance of materials used in energy. Our researchers are coming up with innovative solutions that structure materials to exacerbate given properties, or that combine several different materials when no single material can meet an application's specifications. We are also developing more sustainable alternatives to critical materials like rare-earth elements, lead, or hazardous substances like carcinogenic solvents.

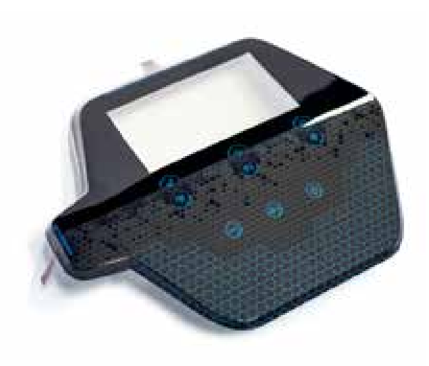
We are also investigating new processes to achieve three objectives: make more economical use of material, for instance through additive fabrication processes; shrink the environmental footprint of materials (by addressing process energy efficiency and eliminating substances like solvents); and integrate greater proportions of recycled material. Furthermore we are transitioning our work on large-area printed electronics towards structural electronics with some initial applications in plastronics.

# STRUCTURAL ELECTRONICS PLACES INTELLIGENCE INSIDE OBJECTS

With the advent of structural electronics, a single part can be attractive, user-friendly, and connected all at the same time—a boon to manufacturers. Structural electronics uses complex assembly processes to combine objects functionalized through printed circuits and then thermoformed, with more conventional components from the silicon industry. The cross-cutting field of structural electronics is right at home on Liten's R&D roadmap. The institute has been conducting research in plastronics for ten years, and has gradually branched out into new substrates like textiles. The institute is now building on these experiences to improve assembly processes. One example is Liten's collaboration with Leti on the integration of thin silicon chips onto conformable substrates. □

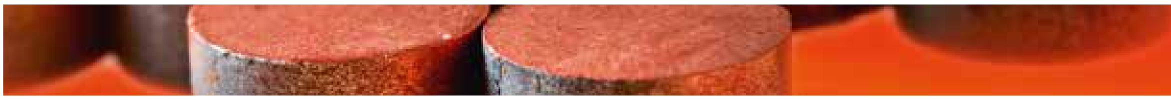
*The institute has been conducting research in plastronics for ten years*





# INTEGRATING ELECTRONICS INTO COMPONENTS' STRUCTURES

Liten built several haptic demonstrator systems in partnership with SE2D in research conducted under the EU Horizon 2020 INSCOPE project. The demonstrators are evidence of Liten's expanding know-how in structural electronics. The first is a slider that includes capacitive components and actuators that were screen printed onto flexible substrates at the PICTIC platform, laminated onto decorative films, and then overmolded using plastic injection. The system, designed to be integrated into a dashboard, uses LEDs for visual rendering. Liten's partnership with SE2D is ongoing, with a focus on more complex types of components like LED drivers. At the same time, the institute is working on parts that integrate new features like transparent capacitive systems and pressure sensors. □



# COMPLEX COPPER PARTS MADE USING STEREOLITHOGRAPHY

Liten demonstrated the feasibility of making complex-shaped copper parts using stereolithography (SLA), an additive manufacturing technique. A paste made of 60% copper powder and resin that can be reticulated by exposing it to UV rays was formulated to produce rheological behavior compatible with the spreading system used. The part was manufactured by depositing a series of layers at around 50 µm/s to 100 µm/s. It was then exposed to UV rays to obtain the desired geometry. The thermal cycle of the debinding process was improved to effectively eliminate the resin present in the printed part. The parts were then consolidated using natural sintering. The resulting parts presented a relative density in excess of 90% with very low light element content, very similar to that of the initial copper powder. ☐

# 3D PRINTING GAINS TRACTION AT THE POUDR'INNOV PLATFORM

**Liten's 3D printing capabilities, housed at the Poudr'Innov 2.0 platform, encompass a range of equipment that can shape polymers, ceramics, metals and magnetic materials using direct and indirect methods.**

The market for additive manufacturing techniques is growing exponentially. Liten signed its first 3D printing partnership agreements with 3DSystems and Prodways and today has three laser beam melting machines. The institute is currently setting up a partnership with AddUp, France's leading metal 3D printing company, and the partners have already made a major investment in a fourth LBM machine. The machine was purchased under the FAMERGIE project, which is backed by the Auvergne Rhône-Alpes regional government and Feder funds, and which will focus on applications for the energy industry.

Poudr'Innov 2.0 also possesses another indirect additive manufacturing technique that can be applied to metals and ceramics: a Prodways stereolithography (SLA) machine that Liten is using to develop advanced metal components.

In terms of polymers, the platform has a Prodways machine compatible with advanced materials like particle-loaded, fiber-enhanced, and multimaterial polymers. In addition, Liten, with a partnership with Hewlett Packard around HP's 3D polymer printing equipment (MJF), is putting in place and animates an ecosystem of complementary industrial and academic partners around the common issues of 3D printing.

Liten is also contributing to research and development at the Additive Factory Hub on the CEA Saclay campus. ☐

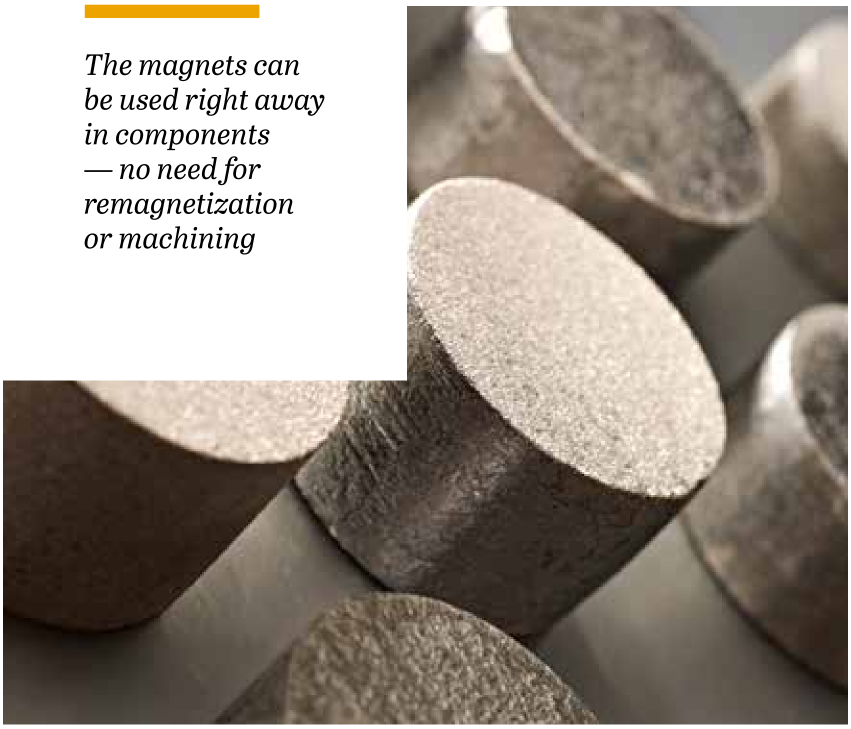
# NdFeB PERMANENT MAGNETS PRODUCED USING LASER BEAM MELTING

The performance of magnets made from rare-earth minerals is closely linked to the conditions in which the magnets are produced. This is due to the influence of production methods on the magnets' microstructures. Liten made good-quality NdFeB isotropic permanent magnets using laser beam melting (LBM), a type of 3D printing. But first, the researchers made adjustments to manufacturing parameters like the power of the laser, scanning speed, and beam trajectory, and analyzed the relationships between these parameters and the magnetic properties obtained. Dense magnets were produced using the process without negatively impacting the initial magnetic phase. And, the magnetic properties of the magnets produced are comparable with those of the initial powder. Additional research is underway to further improve the machine's parameters and thus the resulting properties. 3D printing offers the advantage of being able to produce complex shapes without subsequent machining and the associated material waste. ☐

# PLASTIC POWDER INJECTION MOLDING USED TO PRODUCE MAGNETS

Magnets were produced directly in the desired shape using a conventional plastic injection process called powder injection molding (PIM) and an innovative mold. The mold contains spools that produce a field in the mold cavity that directly magnetizes the material during injection. The magnets produced using this method can be used right away in components—there is no need for additional remagnetization or machining. Finally, these parts were integrated into an energy harvesting system, where they were tested and validated on a configuration where commercially-available magnets were simply switched out for the injection-molded ones. □

*The magnets can be used right away in components — no need for remagnetization or machining*

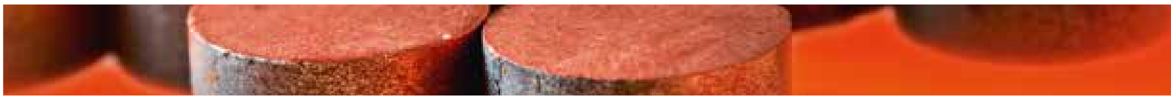


# NATALIO MINGO WINS STARS OF EUROPE AWARD FOR ALMA PROJECT

Liten researcher and coordinator of the Alma project Natalio Mingo was one of twelve French scientists to win Stars of Europe (Etoile de l'Europe) awards at the 5th Horizon 2020 Forum. The Alma project is investigating the hotspots that can occur in nanostructured materials and that cannot be predicted using the equations that govern macroscopic systems. Mingo developed AlmaBTE, the first-ever publicly-available heat-exchange simulation software that applies to multi-scale systems. The software is used as a tool in the predictive design of complex micro and nanostructured materials, with applications in GaN power electronics, as well as in any other new technology where heat transfer is a major issue. □

# LUMINESCENT NANOPARTICLES SYNTHESIZED AT SEMI-INDUSTRIAL SCALE

Luminescent particles were synthesized in a 20-liter reactor at Liten. The synthesis process, developed in the lab on around 100 ml of solution, was scaled up to 15 liters and around 100 grams of luminescent nanocolloids were obtained. The purification step, which presents the biggest challenge at this scale, was completed by transferring the reaction medium to dialysis membranes. The development was achieved in research with Sealock SARL, a northern-France-based SMB that formulates and manufactures industrial adhesives. The purpose of the project was to mark an initial 20-kg batch at the pilot scale at Sealock's plant. Invisible to the naked eye, the optical code can only be "seen" by a specially-designed reader. A volume-manufacturing prototype of the markers—used to authenticate materials—is now available. □





## PROCESS FOR EXTRACTING RARE-EARTH MINERALS FROM STEEL-INDUSTRY WASTE

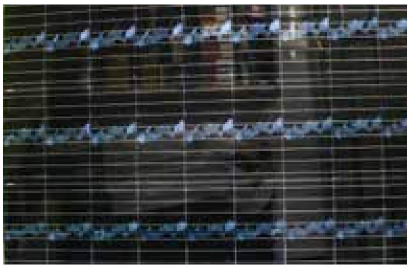
A process for extracting critical metals from steel-industry waste (slag) was developed under EU project Reslag. Liten teamed up with Seprosys to develop a continuous purification process using Sequential Simulated Moving Bed Chromatography (SSMB) on a pilot scale. The process, which takes place in solution, requires a preparatory step: the slag must first be treated with acid to extract the metals of interest. The leachate thus obtained then flows through an ion-exchange resin that collects the material to be recycled. When tested on a leachate from smelted NiMH batteries, the process was able to recover a 99.5% pure blend (Nd, Ce, La) with a process yield of 94%. An economic assessment of the process is in progress to determine whether it is advisable to transfer the technology. ☐

## AN INNOVATIVE HYDROMETALLURGICAL PROCESS FOR BATTERY RECYCLING

Battery recycling company SNAM now has a new hydrometallurgical processing unit following research and development work completed by Liten. The company specializes in the recycling of NiCd, NiMH, Li-ion, alkaline, and saline batteries. The batteries are first refined by thermolysis, a process that produces a substance called black mass. Selective dissolution is used on the main substances—in this case, cobalt, nickel, and manganese—in the black mass, which are then extracted one by one using precipitation. The substances recovered are pure enough to be recycled in industrial processes. ☐

*The substances recovered are pure enough to be recycled in industrial processes*

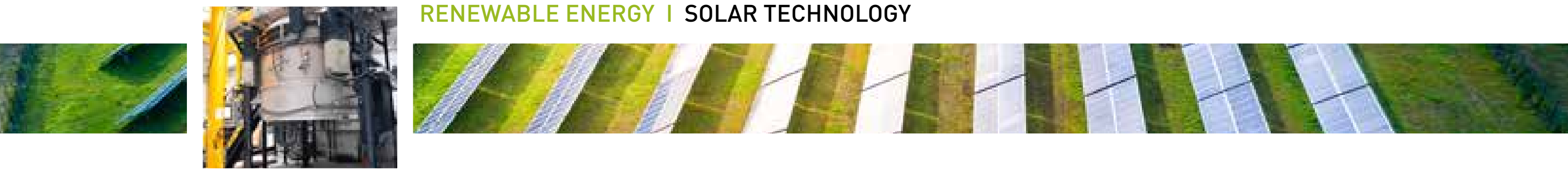
## FIRST-EVER ECO-DESIGNED PHOTOVOLTAIC MODULE WITH CELLS MADE FROM RECYCLED MATERIAL



The first-ever eco-designed PV module with cells made from recycled PV waste was built at Liten. The module is made up of 60 Al-BSF cells fabricated 100% from silicon recycled from spent modules under EU Horizon 2020 project CABRISS, also coordinated by Liten. The recycled module delivers similar performance to what is generally seen with this kind of technology: 252 Wp power and a cell-to-module performance ratio of 99%. The most hazardous materials were also replaced with the more environmentally-friendly ones recommended as a result of the Ecolabel project. For example, the glass used on the front and back sides of the module is antimony-free, the welding process used is guaranteed lead-free, and a new thermoplastic encapsulation material is easily destroyed to facilitate subsequent recycling. ☐

# RENEWABLE ENERGY PRODUCTION OF CARBON-FREE SOLAR ENERGY

Liten’s renewable energy research focuses on solar photovoltaic and solar thermal energy and covers the entire value chain from materials to grid-connected systems. Liten’s technology platforms are used to build prototypes to meet the needs of manufacturers. Our photovoltaic research addresses premium modules with very high yields and communications and self-diagnostic capabilities, as well as integrated modules for space and other specific applications. Our equipment development work is designed to support French manufacturers’ export sales.



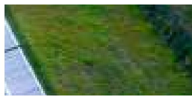
## FIRST G8 MONOLIKE INGOT PRODUCED

A first G8-format quasi monocrystalline (monolike) silicon ingot was produced using directional solidification equipment developed with ECM-Greentech. The ingot produced was satisfactory in terms of defect rates, compatibility with diamond cutting, and crystalline quality for PV yields. The compatibility of the furnace with the Crystalmax® process of directional growth from mono-seeds was also validated. Further improvements will be made to the process to increase ingot quality and size; the first ingot produced weighs 1.2 tons. The quality of the G8 monolike ingot will also be validated at each step in the value chain (diamond cutting, conversion yields, aging, etc.). The advance was achieved in research conducted under the CrystalMega20 program co-funded by French energy agency ADEME. □

*A first G8-format monolike silicon ingot was produced using directional solidification*

## BORON-DOPED POLYSILICON WITHOUT DELAMINATION NOW POSSIBLE

Liten's Solenna doping technology was used to boron-dope a layer of polysilicon integrated into the passivated contact of a photovoltaic cell. The process entailed PECVD-depositing the boron-doped oxide (SiON:B) onto a layer of amorphous silicon, and then annealing the stack. The silicon was crystallized and the boron diffused without the addition of hydrogen and the associated risk of bubbling. The stack was undamaged by the process, which is compatible with higher thicknesses. The doping is equivalent to what can be achieved using conventional methods. The photovoltage potential of the passivated contact, at 720 mV, is excellent. The research is now focusing on validating the technology implemented on cells to improve the electrical contacts. □



## HETEROJUNCTION CELLS WITH FIVE BUSBARS DELIVER EXCELLENT PERFORMANCE

In research and development conducted in partnership with Enel, excellent performance was obtained on five-busbar heterojunction cell modules. Advances in cell fabrication resulted in average yields of 23.1%; the highest yield measured was 23.3%. In terms of improvements to the modules' integration, advanced ribbons to build string of cells were used to reduce the amount of shade and increase intensity. Finally, the encapsulation materials were carefully selected to boost the optical performance and current. The cell-to-module ratio was 100% for power and 105.2% for current. A 60-cell monofacial module achieved power of 341 Wp, the equivalent of 409 Wp for a 72-cell module. A bifacial module achieved power of 388 Wp. The research is ongoing, with the goal of achieving 350 Wp for a 60-cell module format. □

## 412 WP PV MODULE, A WORLD FIRST

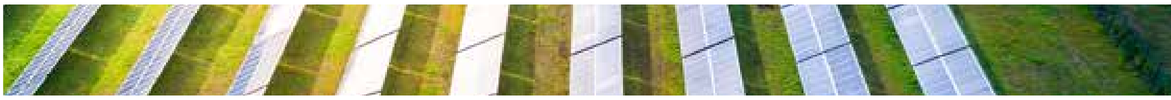
A PV module with 72 heterojunction cells with wired interconnections (SWCT) was built and measured at 412 Wp, the 60-cell equivalent of 344 Wp. The performance measured sets a new world record for silicon technology. The modules were manufactured on equipment made by Meyer-Burger, a partner on the project. Since the project was completed, Meyer-Burger has sold a 600 MW production line that uses the same technology. All available means were employed to optimize the module: a nanocrystalline layer was used on the front side of the cells; modelling and simulation were used to determine the resistivity of the substrate; SWCT was used to minimize resistive losses; and specially-developed encapsulation were used on the front and back sides. Additional improvements are currently on the way with a view to achieving 500 Wp module power by 2021. □

*The performance measured sets a new world record for silicon technology.*

## HET CELLS DELIVER 23% YIELD

Silicon heterojunction cells measuring 15.6 x 15.6 $cm^2$ were certified at conversion yields in excess of 23% by an independent lab in Germany. The cells were produced at Liten using high-throughput (2,400 cells per hour) Meyer-Burger equipment. The research resulted in improvements to the PECVD deposition of nanometric layers of amorphous silicon and to the deposition of the transparent conductive oxide. Metallization with six busbars with very thin (around 50 microns) gridlines was selected to reduce the impact of shading with regard to the electrical charge collection. The research is ongoing, with a view to scaling up the technology for manufacturing. The objectives are to lower manufacturing costs, improve quality, increase productivity, and bring the cell yield to 24%. □





## PEROVSKITE SOLAR MODULES WITHIN REACH

Perovskite photovoltaic systems were fabricated on surfaces that allow the technology to be scaled up from individual cells to modules. The thin layers were first produced at the scale of a single cell; the process was then expanded to mini-modules, ultimately resulting in active surfaces of 10 cm². The photovoltaic system obtained delivered a maximum yield of 16.9%. Its active surface was more than 93% of the total surface of the substrate. The excellent performance achieved can be attributed to a finely-tuned deposition process that resulted in a homogeneous layer over the entire surface and the development of three laser structuring steps to connect the cells in series with no resistive losses. The process used is compatible with the development of tandem cells built on the heterojunction technology developed at Liten for high-yield photovoltaic products. ☐

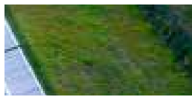
## ADVANCES TOWARD LIGHTWEIGHT PERSONALIZED PHOTOVOLTAIC MODULES

**Liten has been developing lightweight and ultra-lightweight photovoltaic modules to meet the needs of its partners since 2014. The institute has reduced the standard module weight of around 12 kg/m² by up to tenfold or more depending on the target application.**

Liten developed its first lightweight rigid modules for the Solight (for partner Photowatt) and Operasol (for 2CA) projects. Weighing in at less than 6 kg/m² and less than 4 kg/m², respectively, these modules were designed for installation on commercial building rooftops and military tents. The institute later responded to requests for airborne vehicles like the Sunbirds 100% solar drone and, more recently, the Thales Alenia Space France Stratobus™ stratospheric balloon, for which Liten developed a module that weighs less than 800 g/m² and that delivers power in excess of 190 Wp/m² (STC). To bring the weight of the modules down, the front side glass and aluminum frame used on conventional modules were eliminated. Instead, lighter and, in some cases, flexible materials (thin polymer films, thin glass, composites) were used. The encapsulation material and the cells themselves were also made thinner. Each module is designed to meet the target application's robustness and weight specifications. However, the designs—size, weight, thickness, and even mounting systems—also facilitate integration into the target object. ☐


## SIMULATION IMPROVES MODULE ARCHITECTURES

Liten developed a tool to simulate the power of a PV module depending on the module's architecture (ribbons or wires, half or whole cells). The model used leverages an expansive characterization database and also factors in optical losses (due to shading on the metallization and the optical properties of the layers that make up the module) and resistive losses in the interconnections. A simulation on 72 heterojunction cells revealed that an architecture comprising 144 half-cells and wire interconnections delivered 4.4% higher maximum power than a 72-cell and ribbon architecture. The simulation tool will be used to improve yields while reducing the amount of lab testing. Further developments will be made, including the integration of new shingle-type architectures. ☐



## NPC VOLTAGE CONVERTER DELIVERS 99.2% YIELD

Prototypes of a static high-yield converter with a Neutral Point Clamped (NPC) topology of more than 100 kW were fabricated using silicon carbide power modules and tested. The combination of an “old” topology and new material delivered excellent results in the form of 99.2% peak yield, optimal switching frequency of 30 kHz, and a compact form factor. The performance obtained was substantially better than what silicon-component-based switches can provide, and could meet the needs of 700 V to 1,500 V solar power plants hooked up to three-phase 230 V/400 V industrial electrical installations. The converter could also be suitable for grid-connected storage. Characterization work on the models is ongoing so that specifications can be drawn up for an initial prototype and, later, a test manufacturing run. □

## TEST BENCH REPLICATES MODULE FOULING

A prototype of a test bench that replicates photovoltaic module fouling phenomena was developed and commissioned. The bench can generate a controlled flow of dry air containing contaminants like ground dust, ocean salt, volcanic ash, soot, and more. A homogeneous deposit of the contaminants can be made on PV modules up to 40 cm x 40 cm; moisture and temperature can also be fine-tuned. The system is designed to mimic the most commonly-occurring natural module fouling cycle, which can lower production by 50% in arid and desert climates. Development work is ongoing, with additional adjustments to the temperature parameters used. Ultimately the test bench will be used to evaluate protective layers and cleaning methods and to come up with testing protocols for standardization purposes.□

*The converter will be installed at two sites each with 20 kWp of building-integrated photovoltaics*

## PV CONVERTERS: SILICON CARBIDE CURRENT SWITCH

A preindustrial mockup of a 5 kW photovoltaic converter with a three-phase current switch topology was developed and patented in research conducted under an EU-funded project. Its silicon carbide components resulted in high switching frequency (150 kHz) with one conversion stage instead of two. The converter’s other unique feature is that the switching cells are made with anti-series transistors, which limit conduction losses in the diodes. The maximum yield is 97.8% and the component cost is €0.10/Wp, for a total weight of 13 kg. The converter will be certified by Bureau Veritas in 2019. Eight units will be manufactured and installed at two demonstrator sites, each with 20 kWp of building-integrated photovoltaics. □

ENERGY STORAGE

# FOR STATIONARY AND MOBILE APPLICATIONS

Liten's electrochemical storage research targets stationary applications and mobile applications, from the high power capacities required for electric vehicles down to portable electronics like medical devices, watches, and more. Our researchers are addressing technologies already on the market like lithium-ion, as well as potential breakthrough technologies like lithium-sulfur and sodium-ion. Our work covers the entire value chain, from materials and batteries to battery management and monitoring systems. In this last area, we are working on instrumentation and supervision solutions to make storage systems more reliable (thermal, critical thresholds, etc.) and lengthen their lifespans.

## BATTERY 2030+: CONSOLIDATING RESEARCH TO SUPPORT EUROPE'S BATTERY INDUSTRY

To keep pace with competition from Asia, in 2018 the European Commission rolled out a strategic plan to develop Europe's battery industry. The Commission's goal is to simultaneously boost European production capacities while implementing initiatives to support research and innovation. One of these initiatives is BATTERY 2030+, a far-reaching early-stage research program. The program's partners include Uppsala University, DTU, CNRS, and industry organizations EMIRI, RECHARGE, and EASE. Liten and IRIG, two institutes of CEA, are helping to define research priorities and develop a ten year BATTERY 2030+ roadmap. The European Commission will launch the first wave of calls for research projects in July 2019. Among the disruptive technologies supported by the program are high-throughput new material discovery platforms and the integration of smart functions (sensors and self-repair) into battery cells.

## PILOT LAMINATION MACHINE FOR LITHIUM-METAL

Lithium-metal chemistry has been a topic of research at Liten for years now. It is deemed to be one of the most promising candidates for post-lithium-ion batteries. In research conducted under the EU ALIM project, Liten helped develop a pilot lamination machine that could reduce the thickness of the lithium-metal layer—currently 50 microns—by half. A thinner layer would increase the amount of energy that can be held by an equivalent volume.

The flexible lamination machine developed features rolls whose materials were selected for their capacity to flatten the lithium without sticking. It is set up in an anhydrous chamber at Liten, where it will be used to make further improvements to the lamination process and determine key parameters (roll diameter, speed, tension, lubrication, etc.) to overcome the technology-related barriers to developing a future solid-state battery.



## PRELITHIATION EXTENDS BATTERY LIFESPANS

A prelithiation process was developed to increase the silicon content of the negative electrode in 0.5 Ah, 5 mm x 40 mm x 70 mm cells. The process produced electrodes with a silicon content of 15%. With just 0.001% capacity losses per cycle at a 70% discharge and 0.01% per cycle at full discharge, the cells' cyclability performance was better than the current state of the art. This excellent performance indicates that the cells could ultimately deliver the 2,000 cycles required for electric vehicle applications. Cells of 1 Ah give similar performances. The patented process removes some of the hurdles associated with working with metal lithium and is ready to scale up. The researchers' next challenge will be to improve prelithiation process yields. □

## ESTOR DATABASE PROBES LITHIUM-ION CELL PERFORMANCE

Liten's Estor database contains comprehensive data—manufacturer specifications and initial, aging, and thermal stability test results—on a large number of energy storage systems and, especially, some 200 lithium-ion cells built on LFP, NMC, LCO, and other technologies. All tests follow standard protocols so that the resulting data can be compared reliably. Estor, which is growing by 20 to 30 new products per year, also includes test results for CEA prototypes and commercially-available products selected to ensure coverage of a wide range of manufacturers, battery chemistries, and manufacturing plants. To date, Estor is the only database of its kind in the world. It is used in projects with partners from industry to assist them in selecting the most appropriate batteries for their needs. □

## PROGRESS TOWARD HYBRID POLYMER AND SOLID ELECTROLYTES

Liten's research on innovative electrolyte chemistries took off in 2018. One of the institute's projects, carried out under a multi-year R&D contract with Solvay, is focusing on a hybrid polymer electrolyte. In addition, four PhD research projects are underway on solid polymer or oxide electrolytes. Finally, the institute patented a new polymer electrolyte. Hybrid polymer and solid electrolytes are expected to make batteries safer and enable performance-boosting higher energy densities. Liten's research encompasses materials synthesis and characterization, some of which is carried out at ESRF and ILL. Until recently, the main goal has been to understand the behavior of these new chemistries, especially during charging/discharging. These advances will now make it possible to build functional prototypes. □

*Liten's research on innovative electrolyte chemistries took off in 2018.*

## BATTERIES TAKE TO THE SKIES

Some notable advances were made for three all-electric airborne vehicle development projects at Airbus. Liten worked with Airbus DS to develop a 1 kWh lithium-ion battery for the Skyway urban parcel delivery drone, which completed its first flight in Singapore. The second advance—for the Vahana single-seat flying taxi tested for the first time ever in California—came in the form of two battery packs delivering a total of 38 kWh. Finally, Liten supplied the 115 kWh batteries used to power the four-seater CityAirbus flying airport taxi. Weight and safety were major concerns for all three projects. The batteries Liten supplied are at the state of the art in terms of energy density with flight accreditation (160 Wh/kg for the Vahana, and 170 Wh/kg for the CityAirbus). The CityAirbus battery includes a liquid cooling system that enables faster charging on the ground. □

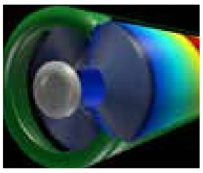
## ADVANCES TOWARD BETTER DIMENSIONING OF HYBRID POWER-ENERGY BATTERIES

A combination of three simulation tools developed at Liten for the institute's own research was used to dimension a pack of two hybridized lithium-ion batteries, one for power and the other for energy. The first tool completes multicriteria power/energy optimization; the second focuses on serial/parallel dimensioning depending on voltage requirements; the third assesses aging over time and during cycling. This innovative approach pointed to several battery couplings whose aging performance was better than the reference battery. Optimal use strategies were also developed, especially concerning charging. □

*Three simulation tools developed at Liten were used to dimension the battery pack*

## SIGMA CELLS: MOBILE, RECONFIGURABLE ENERGY STORAGE

An energy storage demonstrator system with a reconfigurable architecture was built and validated on a use case in collaboration with Leti. A regular household electrical supply was used to charge the system, which successfully powered a 1 kW coffee maker. The system includes control electronics and 32 reconfigurable modules made from four commercially-available 18650 cells each. It adjusts battery topology in real time to deliver all types of voltages, including 230 V-50 Hz, without the need for a converter or switch. Each cell is independent, and the cells are dynamically managed, with the system switching them to ensure optimal use for increased battery life and lifespan. It directly generates a motor-command signal and can operate with different types of cells (second life, multi-chemistry). The technology, called Sigma Cells, is protected by fifteen patents. □



## LI-ION BATTERY SHIPPING: RESEARCHERS LOOK TO OVERDISCHARGING AS A SOLUTION

A total of four battery technologies were subjected to repeated overdischarging to assess the impact on performance. Discharging batteries to 0V could potentially reduce electrical hazards during shipping and, in the process, free up industry stakeholders from stringent shipping regulations. The tests showed that Li-ion batteries with copper negative collectors lost their capacity, in some cases after just 150 hours at 0V. The capacity of cells with aluminum collectors (LFP/LTO and Na-ion) was barely impacted by full discharging. However, the impact on the Na-ion was significant. Therefore, and contrary to what the scientific community was expecting, staying at 0V can in fact degrade the active materials used in this technology. Research on the mechanisms that underpin the degradation of the active materials in Na-ion will be conducted in the very near future. □

## LITHIUM-ION BATTERY SAFETY A STRATEGIC RESEARCH TOPIC

**Liten is working not only to increase Li-ion battery energy density and lifespans, but also to improve battery safety.**

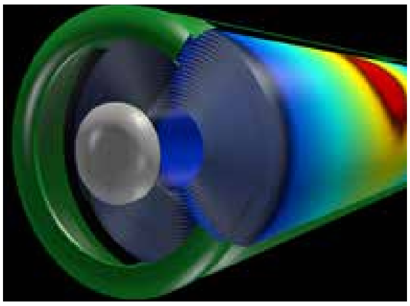
With numerous phenomena spanning several disciplines occurring in combination, battery physics is complex, and researchers still have much to learn. Liten and Serma technologies have created a new battery abuse-testing platform. It completes more than a hundred tests each year to measure, study, and modify batteries subjected to extreme conditions, from overheating and short circuits to puncturing and crushing. The results of the tests are analyzed to identify the sequence of events resulting in degradation, as well as the underlying mechanisms. Liten tests cells up to 1 kWh, while higher-power batteries are tested at the DAM* center in Le Ripault.

Multi-scale (material, electrode, cell, and pack) and multi-physics (thermal, electrical, electrochemical, and mechanical) modelling and simulation are used to determine the critical parameters to factor into battery behavior analysis. When combined with safety analyses inspired by the nuclear industry, the approach can be used to generate design rules that optimize battery performance, lifespans, safety, and costs. The research resulted in around ten patents. □

*A battery abuse-testing platform has been created*

* CEA Military Applications Division

## THERMAL RUNAWAY IN LI-ION BATTERIES MODELLED



Liten developed a tool to simulate the ignition reactions that occur in certain conditions and that can lead to thermal runaway in Li-ion batteries—the main cause of incidents on this type of battery. Cells were heated in an adiabatic chamber in the lab and tested to identify the overall reaction kinetics responsible for thermal runaway. The resulting data was used to build a model, which was resolved on 3D cell models, and then integrated into Comsol Multiphysics software. The impedance characteristic of an internal short circuit is used to reproduce the signature of the thermal runaway likely to occur. The tool was partially validated up to around 150 °C to 200 °C and is now available on the MUSES multi-physics modelling platform. □

# TOWARD ENVIRONMENTALLY-FRIENDLY MOBILITY AND ENERGY STORAGE

Hydrogen—as an energy carrier—is mainly used at Liten to extend the range of clean vehicles to enable interurban use. Our research focuses on developing better-performing, more cost-effective fuel cells and optimized, self-regulating hybrid battery-fuel cell systems.

We are also investigating hydrogen's capacity to provide flexibility on electricity grids amid the growing integration of renewable energy sources. We have developed effective power-to-gas solutions that leverage high-yield high-temperature-electrolysis hydrogen production with systems to deliver the hydrogen directly to industrial users or to convert it into syngas via a catalytic reaction with $CO_2$.

## A HYDROGEN-ENERGY INDUSTRY IS EMERGING

**From policymakers to businesses, everyone is looking at hydrogen energy, and Liten is positioned as a major stakeholder in this emerging industry.**

In 2018, Nicolas Hulot, then France's Environment Minister, announced the government's hydrogen strategy, which was subsequently incorporated into the multi-year energy master plan issued at the end of the same year. Public policies like these are evidence of the vital role hydrogen will play in the energy transition.

In terms of hydrogen-powered mobility, fuel cells have already been implemented in captive vehicle fleets. The next step will be to expand fuel-cell rollout to public transportation (buses and water shuttles), "last-mile" urban delivery vehicles, and heavy trucks. The aeronautics and rail industries are also beginning to show an interest in hydrogen.

To respond to these new needs, Liten is pursuing its research programs with projects to adapt PEMs to the unique specifications of these uses, all of which will require substantial R&D to improve fuel-cell lifespans and performance and lower costs.

At the same time, Liten is working to scale up the high-temperature electrolysis of water vapor as a means of producing clean hydrogen for industrial rollout. The institute's horizon for scaling up the technology from the tens of kW to 300 kW is three years. A number of demonstrator systems will be built to illustrate the technology's potential for producing carbon-free, cost-competitive hydrogen for industrial consumers, for hydrogen-powered mobility, and for electricity storage and grid flexibility. □

*Liten and Safran created a hybrid energy source that combines a fuel cell and a small lithium-ion battery*

## HIGH-YIELD REUSABLE HYDROGEN CARTRIDGES

Liten and Safran joined forces to create a hybrid energy source that combines a fuel cell and a small lithium-ion battery. The system offers power of 10 W to 30 W, an operating temperature range of -20°C to 44 °C, a 72-hour life, and half the mass of a battery alone. The researchers improved the sodium borohydride hydrolysis, which allows hydrogen to be released on demand. A more effective borohydride formulation and an optimized catalytic system increased hydrogen yields from 3% to 4%. A new reusable—rather than single-use—cartridge concept was also developed. The electronics used for the energy source also manage the release of hydrogen. The institute is also working on new materials that would leverage thermolysis to achieve 10% mass hydrogen yields. □

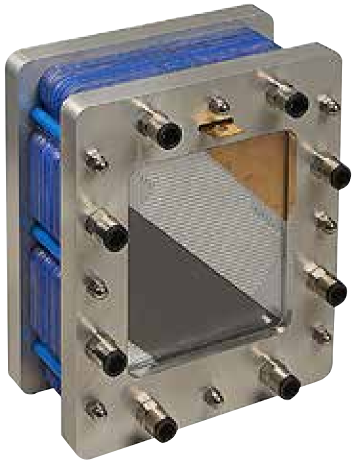
## LOW-PLATINUM-LOAD MEA OPERATING LIFESPAN TESTED

When it comes to PEMFC technology, reducing the amount of catalyst is a prerequisite to lowering dependency on platinum. This will entail using very thin layers (<5 µm) as well as thinner and thinner components. Therefore, the active layers must be homogeneous and free from agglomerates to maintain PEMFC operating lifespans. Liten interrogated the formulation of the inks used to deposit the active layers. Modifications to the insertion and dispersion of the components resulted in reduced granulometry. The researchers built MEAs with a geometry representative of a power stack (160 cm²) and achieved performance levels of 1 W/cm² in European-standard automotive conditions with 0.25 $mg_{Pt}/cm^2$ overall. A 25 cm² single-cell version offered an operating lifespan of more than 1,000 hours. However, at such low platinum loads, extending fuel-cell lifespans remains a substantial technological and scientific challenge. □

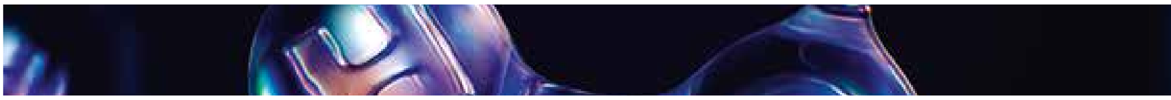
## IMPACT OF HYDROGEN POLLUTANTS ON FUEL CELLS STUDIED

A study of the impact of various pollutants present in hydrogen on fuel-cell performance and lifespans was conducted with the goal of determining the best compromise between cost and performance. Tiny amounts of the pollutants studied ($NH_3$, HCl, and $C_4Cl_4F_6$) were voluntarily added to hydrogen, which was then used to power fuel cells. The fuel cells' performance was then measured on test benches developed specifically for the experiment. The influence of the pollutants on fuel-cell lifespans was calculated by extrapolation, using the data gathered from 900 hours of testing. Finally, post-mortem analyses on the MEAs delivered insights into the impact of the different pollutants on the mechanisms that underpin material degradation. The results obtained were factored in to new standards on the acceptable levels of impurities in hydrogen. □

## IMPROVED MANUFACTURING AND EXTENDED LIFESPANS TO REDUCE THE COSTS OF PEMFC BIPOLAR PLATES



In order for PEMFCs (proton-exchange membrane fuel cells) to reach the market, they must be cheaper and last longer. In research conducted under the EU COBRA project, new plate coatings were tested to replace the gold habitually deposited on the plates to boost their electrical conductivity and corrosion resistance. MaxPhase®, a low-cost coating sold by Impact Coatings, was selected from among several potential products. The processes used to manufacture the bipolar plates were also improved. Specifically, the hydroforming step was enhanced and cutting was made more efficient, bringing manufacturing costs down. These innovations were tested on an actual plate and on a 5 kW fuel-cell prototype used to power a vehicle. □



## AN INNOVATIVE POWER-CONVERTER DEMONSTRATOR SYSTEM

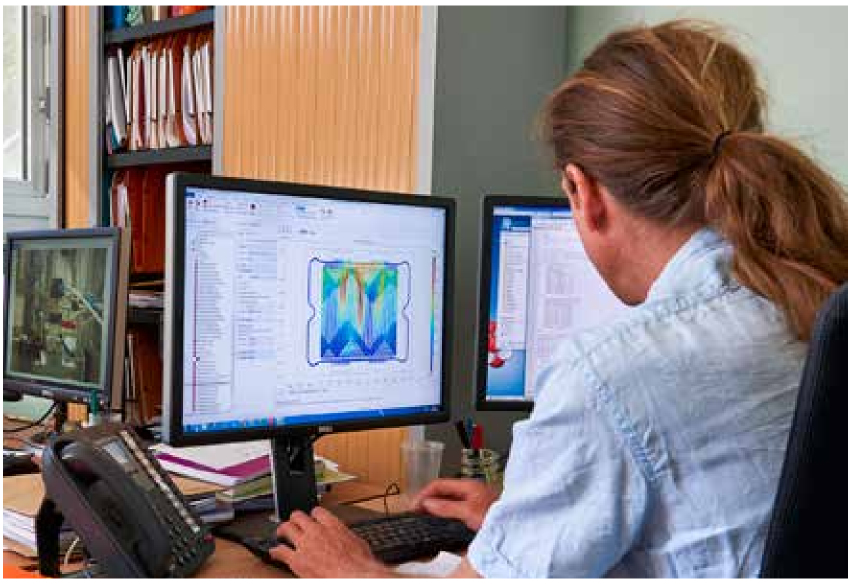
In research conducted under the European 3CCAR project, Liten designed, simulated, built, and tested a power converter integrated into a hydrogen fuel cell. The 10 kW to 15 kW DC/DC converter is used to prepare the energy produced by the fuel cell so that it can be stored by a battery. It is designed to be mounted on top of the fuel cell so that the coolant inside the fuel cell can also circulate in the converter. The system's architecture addresses the fact that power transistors produce heat and must be cooled, usually by a separate fan. By pushing the integration of these components to new levels, the researchers reduced the size and energy consumption of the system. They also used another innovation—digital rather than analog power transistor management—to increase switching precision. □

## MODULAR FUEL CELLS FOR LOW-POWER APPLICATIONS

A public fund has been dedicated to the development of a fuel cell whose nominal power is between 100 W and 1,000 W for mobile applications, mainly in aeronautics. The concept selected is comprised of a modular fuel-cell composed with 1 to 12 stacks; the stacks are made up of between 10 and 30 cells and are held between two terminal plates. The architecture is electrically modular: the stacks can be connected in series or in parallel to obtain the desired voltage. It is also geometrically modular: the fuel-cell's height-to-width ratio can be configured as needed. An innovative stamped sheet metal bipolar plate with a small active surface (16 $cm^2$ instead of the minimum 100 $cm^2$ previously) was designed and validated using fluidics simulations. Experimental tests are running on mono-cells to validate performance. □

## PSEUDO-3D MODEL OF A BIPOLAR PLATE-MEA ASSEMBLY TO VALIDATE NEW CELL DESIGNS

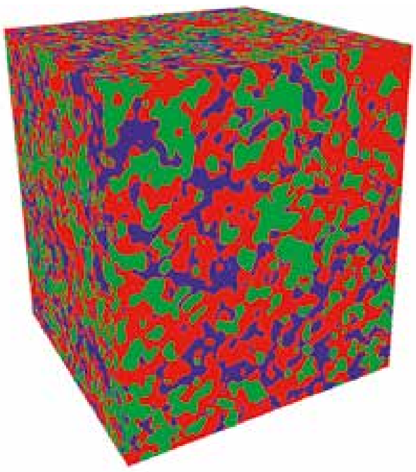
Liten developed a cell simulation model to determine the influence of new bipolar plate designs on fuel-cell performance. It models thermal, fluidics, and electrochemical combinations between the membrane-electrode assembly (MEA) and the liquid and gas flows in the channels of the bipolar plate. Rather than explicitly representing the system geometry in 3D, which would make computing times prohibitively long, the researchers treated the cell like a stack of layers, each of which is simulated in 2D. The model developed was integrated into the MUSES platform, where it was used on new designs in research conducted with an industrial partner. The single-cell operation simulations revealed non-uniform operation of the MEA, and, as a result, new operating conditions were recommended. □



# VIRTUAL MICROSTRUCTURES REPRESENTATIVE OF SOLID-OXIDE CELL ELECTRODES GENERATED

Advanced characterization of the porous electrodes used in solid-oxide fuel cells is crucial to gaining a better understanding of fuel-cell performance and degradation mechanisms. Liten developed a numerical method leveraging 3D stochastic models to create a virtual reconstruction of the electrodes' three-dimensional microstructure. They then compared this theoretical microstructure with a microstructure obtained using the reconstruction of X-ray nanotomography (synchrotron) images of commercially-available electrodes. The comparison showed that the method developed generates microstructures that are highly representative of actual electrodes. The virtual models can be used to improve existing microstructures: Individual parameters can be modified on the virtual model so that the impacts of the modifications on performance can be measured using electrochemical models. □

*The method creates a virtual reconstruction of the electrodes' three-dimensional microstructure*



# SYLFEN SMART ENERGY HUB PASSES TESTS

Sylfen and Liten announced that they designed, assembled, and successfully tested the first-ever demonstrator of Sylfen's Smart Energy Hub. The system, built on the CEA's r-SOC reversible technology, can produce hydrogen when operating in electrolyzer mode, and then reuse the hydrogen produced to generate electricity when operating in fuel-cell mode. The demonstrator, now officially out of the lab, has been hooked up to conventional energy (water, gas, electricity) grids and is operating in real-world conditions. It includes hydrogen storage and hybridization with batteries. It can also be used to produce domestic hot water through CHP. These features make the system ideal for supplying buildings and eco-neighborhoods with energy from local and renewable sources. In addition, it is completely automated and managed by an embedded software application. □

# REVERSIBLE SOEC/SOFC STACK PILOT PRODUCTION LINE

The CEA is conducting more and more research on reversible SOEC/SOFC technology, spurring an increase in the number of demonstrator systems being built. And more demonstrator systems require more stacks. To respond to demand, Liten has put into operation a pilot stack production line that brings together in a single location around a dozen machines (chemical, mechanical, testing) used to manufacture and assemble the stacks. The equipment used aligns with industrial reproducibility and throughput requirements and can be upgraded or modified for R&D purposes, as new stack designs emerge. Ultimately, the pilot line will raise Liten's capacity from the current one stack per month to two per week. □

# RECOVERING, STORING, AND REDISTRIBUTING ENERGY

The capacity to effectively manage the intermittence of renewable energy is crucial to integrating renewables into the grid. At Liten, our research focuses on storing energy from various sources so that it can be used when it is needed—whether it is in several hours or several months. Our research targets three markets: buildings and construction, with models to predict energy performance; industry, where the goal is to recover lost and waste heat from processes to reuse it or transform it into other forms of energy; and energy grids, with work on simulation and optimization designed to right-size energy storage systems and determine suitable management strategies.

We are also investigating how electricity, gas and heat carriers can be combined to boost flexibility. Finally, we are researching a variety of hydrogenation mechanisms for the conversion of $CO_2$ into useable substances.

## COMEPOS PROJECT SHAPES TOMORROW'S ENERGY-PLUS HOME

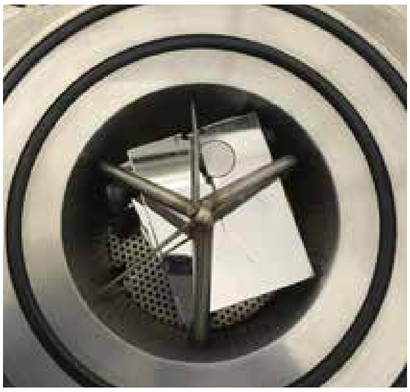
Around 20 energy-plus houses were designed as part of the COMEPOS project, which is financed in part by French energy agency ADEME and coordinated by Liten. These prototype houses, built in various locations across France, will be monitored for two years following a specific protocol that encompasses equipment management, measurement, and data collection. The objective is to test the houses' energy impact and carbon footprint in real-world use scenarios so that the underlying models can be optimized and other improvements can be made. The houses, which boast very efficient envelopes, appropriate technical equipment, and integrated PV systems (in some cases combined with storage systems), delivered positive energy performance over the course of a year. The entire set of houses is being managed with a view to developing an innovative intuitive building concept called "0-énergie," which will guarantee comfortable indoor temperatures and indoor air quality. ☐

## MONITORING OF HYBRID PHOTOVOLTAIC-THERMAL THERMODYNAMIC BOILER

*An innovative hybrid photovoltaic-thermal (PVT) sensor is coupled with an evaporator*

As part of a comparative study of the seasonal performance of innovative domestic hot-water production solutions, Liten assisted Edilians, a subsidiary of leading French roof tile manufacturer Imerys, with the implementation of a solar thermodynamic boiler prototype with an innovative hybrid photovoltaic-thermal (PVT) sensor coupled with an evaporator. The boiler is based on a heat pump, which collects heat from the outdoor air and from rooftop PV solar panels. The tests completed—domestic hot water production was compared to the primary energy used—revealed that the hybrid model developed by Edilians offered the best performance of the four solutions tested. PVT could ultimately be used in building-integrated photovoltaic (BIPV) solutions. ☐

# EFFECTS OF HYDROGEN ON PRESSURIZED GAS PIPE NETWORKS

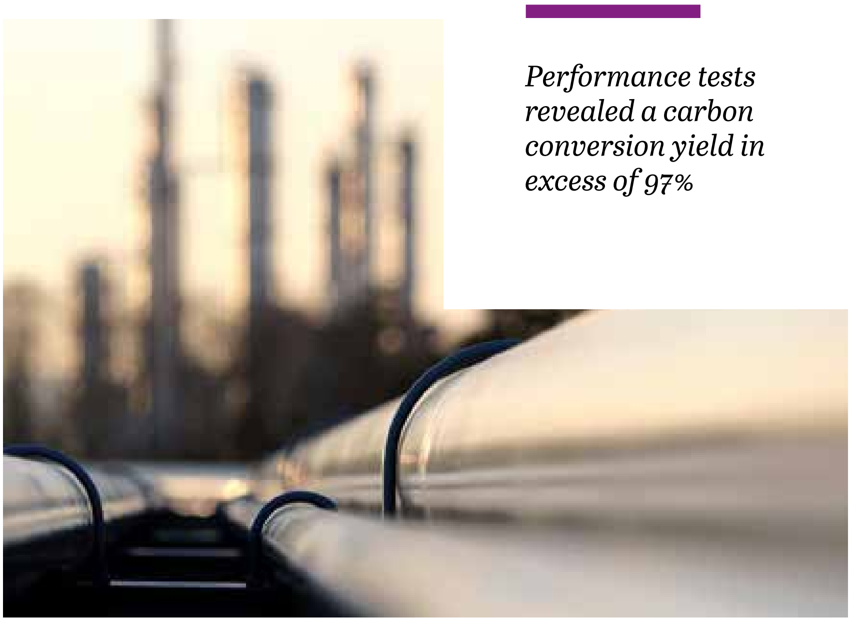


In research designed to measure the effects of injecting hydrogen into natural gas grids on pipe materials, Liten completed tests on several metal alloys provided by GRTgaz. The propagation of cracks and fatigue and the robustness of three types of steel representative of the pipes that make up gas grids were placed in an autoclave and exposed to natural gas/ $H_2$ blends containing 2%, 25%, and 100% $H_2$ under pressure of 85 bars. The tests revealed that the energy necessary for the propagation of cracks diminishes as hydrogen content increases. The data from the tests will be used by GRTgaz to determine how much $H_2$ is acceptable in terms of grid safety. Special testing samples will be assessed in real-world conditions (actual gas blends) on the Jupiter 1000 demonstrator grid. At the same time, a PhD research project is looking at the mechanisms that cause hydrogen to weaken steel. □

# FIRST POWER-TO-GAS DEMONSTRATOR PLANT BASED ON CEA TECHNOLOGY COMMISSIONED IN POLAND

The first-ever syngas production demonstrator plant was commissioned in September 2018 at a facility operated by Polish energy company Tauron. Like Jupiter 1000, another large-scale power-to-gas demonstrator located in Fos-sur-Mer, France, the Polish demonstrator leverages a compact reactor with millistructured plates developed by Liten. The methanation reactors, designed with the assistance of models developed and validated in the lab, convert hydrogen and $CO_2$ into syngas. The reactors, developed especially for this project, were manufactured by Atmostat using a hot isostatic pressing process. Several of the large-suitcase-sized reactors can be assembled to achieve the desired power output. Performance tests revealed a carbon conversion yield in excess of 97%. □

*Performance tests revealed a carbon conversion yield in excess of 97%*



# HYDROTHERMAL GASIFICATION OF MICROALGAE IN SUPERCRITICAL WATER

A process for the hydrothermal gasification of microalgae in supercritical water was developed as part of a study for gas grid operator GRTgaz. The high-carbon-conversion-yield process offers the advantage of being able to treat algae without drying it first. The tests were carried out at temperatures ranging from 500 °C to 700 °C at 300 bars of pressure on a solution containing 11% dry material. The syngas produced was clean. In terms of process yields, the carbon-to-gas conversion rate observed was at least 85%; the overall energy conversion rate was 70% or more. The $CH_4$ produced can be injected into the gas grid; the $H_2$ provides energy used in the process; and the recycled $CO_2$ can be used to feed an algae production unit. An economic sensitivity study was completed and revealed that the process can be profitable even if only the renewable natural gas produced is sold. □

# CALORIE MICROGRID: ELECTRICITY AND HEAT GRIDS COUPLED FOR THE FIRST TIME EVER

A reversible-type heat pump was installed on Liten's experimental Calorie micro heating and cooling grid. The pump, which produces both heat and cold from electricity, will be used to test the algorithms employed to manage power-to-heat technologies developed on the PEGASE platform under the EU Pentagon project. The goal is to make the best possible use of surplus electricity by converting it into heat (or cold), factoring in grid parameters (electricity rates, $CO_2$ content, demand for heat, etc.). This unique experimental system will also provide opportunities to measure the effectiveness of the system in different operating configurations and to study the effects of the configurations on energy converter ageing. ☐

# TOOLS FOR THE MECHANICAL OPTIMIZATION OF SOLID-MATRIX HEAT STORAGE SYSTEMS

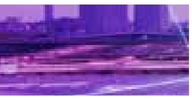
Liten developed the first-ever tool for the study of granular material growth on the walls of the tank containing the material. The tool will be used to make improvements to dual-thermocline solid-matrix heat-storage tanks, which use a mix of heat-transfer fluid and solid granular material (rock or ceramic beads). A numerical model of a cylindrical tank filled with sphere-shaped beads subjected to heating and cooling cycles was developed. It can be used to assess strain on the tank wall related to interactions with the granular material. At the same time, an experimental tank was built to validate the model. These tools will be used to more effectively size tanks, taking into account the strain on the tank walls that builds up during cycling. ☐

*The first-ever tool for the study of granular material growth on the walls of the tank containing the material*

# ORGANIC RANKINE CYCLES IMPLEMENTED WITH A BLEND OF FLUIDS

Organic Rankine Cycle (ORC) machines use an organic fluid to convert heat into electricity. The fluid cycles through evaporation, relaxation, condensation, and compression. Liten compared the performance of a blend of non-azeotropic fluids with that of pure fluids. A blend was chosen based on screening for environmental, thermodynamic, energy, mechanical, and market criteria and was implemented on an existing machine. The chosen blend* performed better than the pure fluid. With conversion yields 10% higher and high pressure 10% lower than pure fluid, the blend is good in terms of cost and machine safety. Other compositions will also be tested, taking into account the needs of the target applications. ☐

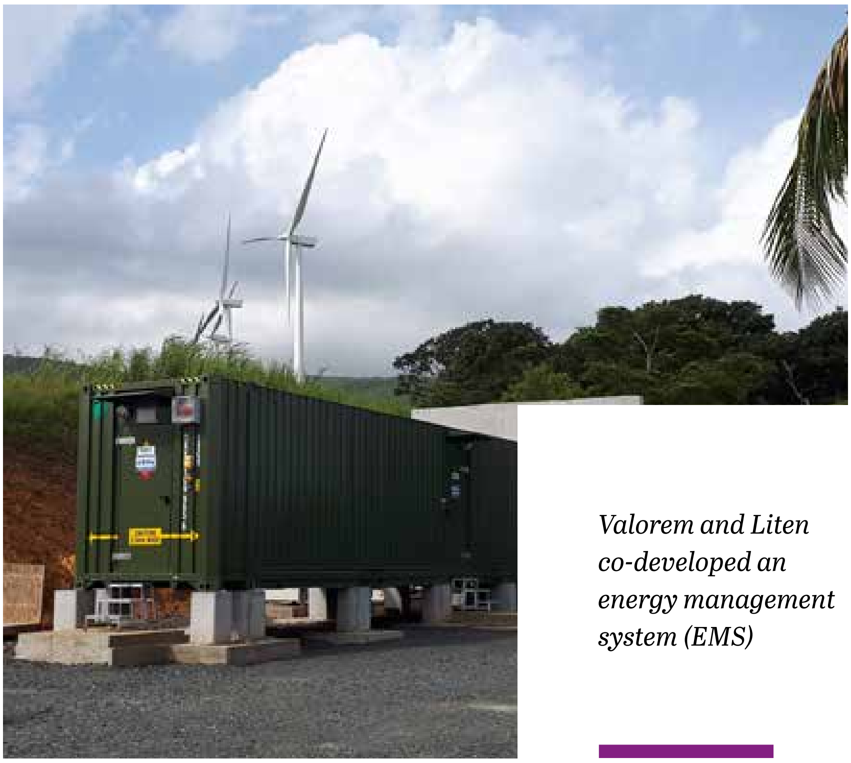
*80% $CF_3CF_2C(O)CF(CF_3)_2$ / 20% $C_3F_7OCH_3$





## ENERGY MANAGEMENT SYSTEM IMPLEMENTED ON WIND FARM WITH BATTERY STORAGE IN GUADELOUPE

Valorem, which operates the Sainte-Rose wind farm in Guadeloupe, turned to Liten for help developing management tools. The institute assisted Valorem with dimensioning the battery-based storage system associated with the wind farm. In addition, Valorem and the CEA co-developed an energy management system (EMS) to manage the wind farm and battery system in real time in a way that takes into account the unique demands of island communities. Decisions are made in real time taking into account economic data. The solution was tested at France's national solar energy institute (INES) on a laboratory model at INES's PRISMES platform. It was then successfully implemented at the Sainte-Rose wind farm, which has eight 2 MW wind turbines and two batteries for a total of 5.2 MWh. ☐



*Valorem and Liten co-developed an energy management system (EMS)*

## DIGITAL TECHNOLOGY GETS GAS, HEAT, AND ELECTRICITY COMMUNICATING

**New simulation and data processing capabilities are making it possible to combine several energy carriers—gas, heat, and electricity—and optimize the local energy supply.**

Today's multi-energy grid convergence projects are being led by energy companies seeking ways to expand their products and services and by local government agencies in charge of energy. The projects tend to cover relatively small geographical areas—from single neighborhoods to entire urban areas to regions—mainly because combining energy carriers is simpler at these smaller scales.

Liten is developing digital technologies and methods for the design and operation of these systems. The institute's solutions encompass tools to effectively dimension systems; feasibility and advisability studies; and energy management, control, analysis, and scheduling algorithms. The major challenges lie in the number of very different technologies that must be combined. Some energy sources, such as solar and wind, are intermittent, while others are continuous. This creates a need for energy storage and conversion between different energy carriers. For instance, hydrogen produced by electrolysis could be converted into gas, heat, or electricity. In addition to research on the digital tools themselves, Liten is also testing prototypes of integrated energy systems on a dedicated testing platform. Moreover, Liten researchers are active in operational implementation projects involving industrial facilities or local heating networks. Several algorithms and software applications developed as a result of this research have been patented or filed with France's software protection agency, APP*. ☐

*APP : Agence pour la Protection des Programmes

## FUEL CELLS: AGEING STUDIED IN THE FIELD

The HyWay project's fleet of 40 Renault Kangoo electric utility vehicles equipped with fuel-cell range extenders was monitored for two years and a total of 280,000 kilometers logged. One of the goals of the research was to determine fuel-cell health and maintenance indicators. Real-world data (current, voltage, temperature) was recorded, filtered, and then used for statistical analysis. Specifically, data clustering was used to pinpoint distribution changes that could be interpreted as indicators of fuel-cell degradation. A set of three indicators was developed, showing that degradation is not linear and that it can differ from one vehicle to another. A patent was filed to protect these new fuel-cell diagnostic algorithms. □

## PV PLANTS GEAR UP FOR FREQUENCY REGULATION

In research conducted under the FlexyPV project, Liten developed a control chain that would allow PV plants to contribute to electricity grid primary frequency regulation. The overriding objective is to prepare for the massive rollout of PV production. The control chain includes operating reserve algorithms. The tools developed were tested and validated using laboratory simulations, and then implemented at an actual plant. The operating reserve for different plants is calculated for the following day based on PV power forecasts. Then, depending on the operating reserve calculated, PV production can be reduced in real time if the frequency increases above its nominal value. Tests are being run on 25 PV plants in France, and will continue through 2020. □

## NOVEL HEAT NETWORK TESTED IN GRENOBLE

An innovative heat network demonstrator system was rolled out in Grenoble's Flaubert neighborhood, following the completion of studies and simulations. The demonstrator system is partially powered by the heat sources (household waste, biomass, etc.) used by CCIAG, Grenoble's urban heat network operator. It will soon also be connected to a rooftop solar thermal plant on the Bifurk building, also in Grenoble—a world-first. Storage solutions leveraging phase-change materials were also implemented to improve profitability and limit the production of heat during peaks in demand. Finally, the demonstrator system is managed by a program that integrates the optimal use of resources according to demand and sunlight forecasts. A first building has been hooked up to the demonstrator system; two more will be hooked up within two years. □



## BATTERY PLATFORM

This platform focuses on lithium-ion batteries in particular, from materials and components through to pack assembly, systems integration, and testing. The platform targets both stationary and mobile applications from high-power equipment down to small mobile devices. Unlike any other R&D center in Europe, the battery platform possesses advanced semi-industrial equipment and know-how. ☐

## FUEL-CELL PLATFORM

The fuel-cell platform takes a unique approach to PEMFC-type fuel-cell design and optimization, addressing materials, membrane-electrode assemblies, stacks, and testing in representative conditions. The platform's mission—backed by an aggressive intellectual property strategy—is to speed up the transfer of technology from lab to market. ☐

## ELECTRIC MOBILITY PLATFORM

This platform integrates battery and fuel-cell prototypes developed by the CEA into land, air, and sea vehicles and vessels and tests them in real-world conditions. The tests provide valuable feedback on battery and fuel-cell performance, cycling, and aging. ☐

## PHOTOVOLTAIC SOLAR PLATFORM

The mission of this platform is to support the expansion of France's solar-energy industry by developing all of the components that make up PV solar energy systems. The platform innovates in materials, processes, and equipment to enable high-yield PV solutions. It also has a pilot manufacturing line capable of producing heterojunction cells with a throughput of 2,400 wafers per hour and with high reproducibility. ☐

## SMART-GRID SYSTEMS PLATFORM

This platform uses a mix of emulators and actual components to size, manage, and optimize energy systems that include fluctuating production sources and electricity storage. Specifically, the platform is designed to study a variety of configurations, test components, and develop and evaluate management strategies. ☐

## BUILDINGS & ENERGY PLATFORM

This platform optimizes the integration of solar energy into buildings and addresses the convergence between residential buildings and transportation systems. This 1:1 scale testing facility provides builders and equipment manufacturers with the resources they need to assess innovative solutions likely to boost building energy performance. ☐

## HYDROGEN PRODUCTION AND STORAGE PLATFORM

This platform focuses on the use of hydrogen as an energy source, most notably through research and development on reversible high-temperature electrolysis technology and coupling the technology with renewable-energy production sources. A special prototyping workshop enables Liten to develop and test large demonstrators, from stacks up to complete systems. ☐

## THERMAL TECHNOLOGY PLATFORM

The thermal technology platform is unique in Europe, in terms of both its size and the scope of its R&D activities, which span technologies to produce thermal energy (concentrated solar power), store it for later use, and use it efficiently for industrial applications. ☐

## POUDR'INNOV 2.0 POWDER METALLURGY PLATFORM

The platform develops and produces high-added-value components from metal, ceramic, semiconductor, and magnetic powders. Complex-shaped parts can be made directly from these powders using additive manufacturing techniques without the need for subsequent machining processes. ☐

## LARGE-SURFACE PRINTING PLATFORM

This platform develops smart plastics, papers, and textiles made by printing electronics directly onto these materials' flexible surfaces, for dimensions of 320x380mm². The potential applications for these printed electronics include human-machine interfaces, smart lighting, interactive displays, and environmental monitoring. ☐

## BIOMASS PLATFORM

The purpose of this platform is to convert waste to energy, achieving high process yields. R&D at the platform covers grinding, torrefaction, pyrolysis, hydrothermal liquefaction, and gasification at a scale that can be extrapolated to industrial processes. ☐

## NANOSAFETY PLATFORM

The nanosafety platform investigates protection, health, and safety issues related to the handling and the use of nanomaterials. The platform conducts R&D and can take on operational assignments such as on-site measurement campaigns, audits, emergency response personnel, and training. The platform's broad range of activities makes it a unique resource in Europe. ☐

## NANOCHARACTERIZATION PLATFORM

The development of nanomaterials and components requires in-depth knowledge of the underlying morphology and chemical and physical properties. The platform provides these insights through around 40 research equipments capable of generating 2D and 3D images approaching the atomic scale. Some of the equipment is only available at a handful of other facilities worldwide. ☐

For more info: http://liten.cea.fr/technologyplatforms

# KEY FIGURES

## BUDGET

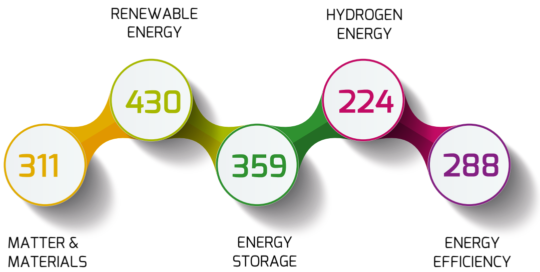
**138**

MILLION € - OPERATING BUDGET


## BREAKDOWN OF INTELLECTUAL PROPERTY

**1612**

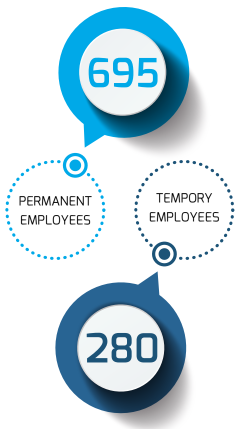
PATENTS IN PORTFOLIO AS OF END-2018



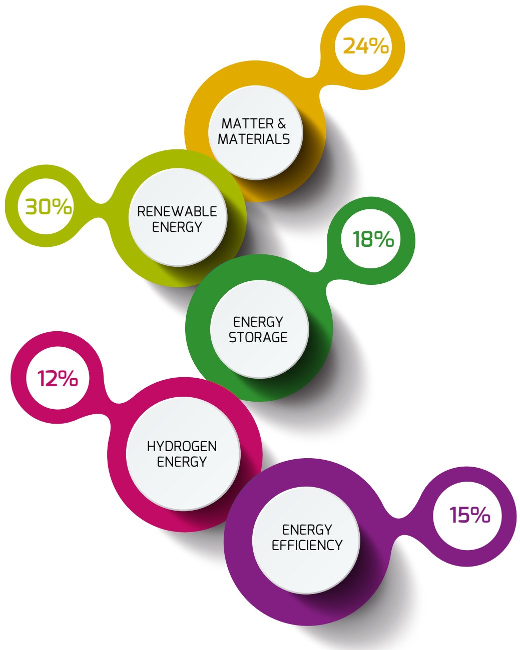

## STAFF

**975**

TOTAL STAFF




## R&D STAFF BY PROGRAM

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