liten
cea tech

ANNUAL REPORT 2017

DIRECTOR'S FORWARD

LITEN, A LEADING CENTER FOR RESEARCH IN RENEWABLE ENERGY

Research institute Liten supports France's energy transition strategy through the following research and development programs:

- Renewable energy production, with a particular focus on solar energy and bioresources. Our programs encompass the entire value chain, from component manufacturing and integration into basic systems through to implementation in vastly more complex energy systems like microgrids, neighborhoods, and—just over the horizon—entire communities.
- An active contribution to lowering greenhouse gas emissions and, especially, carbon dioxide, with research and development on electric mobility and various CO_2 conversion technologies.
- Controlling the energy consumption of buildings and industrial processes.
- Finally, an increasingly sharp focus on the efficient use of materials; research topics include the synthesis of new generations of materials and the development of new processes, like 2D and 3D printing, that use less material.

This year's Activity Report includes the many results of our work in these key fields. At end-2017 Liten possessed major technologies covering several energy carriers, including electric, thermal, and hydrogen.

In 2017, our research and development activities benefitted from an international climate in which renewable energy—and, especially, solar—grew exponentially around the globe; the electric vehicle truly took off; and the Hydrogen Council was founded, evidence of major corporations' interest in this energy carrier. In France, the government's Climate Plan was established, with the target of achieving a net zero carbon footprint by 2050; the French government also announced that it would be looking more closely at the role of batteries and hydrogen in the energy transition.

Liten's activities align closely with the policies of the government ministries that oversee the institute. The energy transition cannot happen without the support of the digital transition that is already well underway. Several years ago, Liten shifted its strategy, leveraging its extensive know-how in modelling to drive the development of software to enable the efficient dimensioning and agile management of complex energy systems.

Liten's capacity for innovation was once again evident in 2017, with a significant number of patents that helped maintain the CEA's position as one of the world's most innovative research organizations. The year was also marked by shortages of certain materials (like the cobalt used in electric vehicle batteries), which confirms the relevance of Liten's work to find new materials and processes to support sustainability and the circular economy.

Last, but not least, Liten signed several international partnership agreements, including with ITRI in Taiwan on materials, NISE in India on PV solar, and with ENEL Green Power in Italy for the transfer of heterojunction PV solar technology. ■

Florence Lambert,
Director, Liten

CONTENTS

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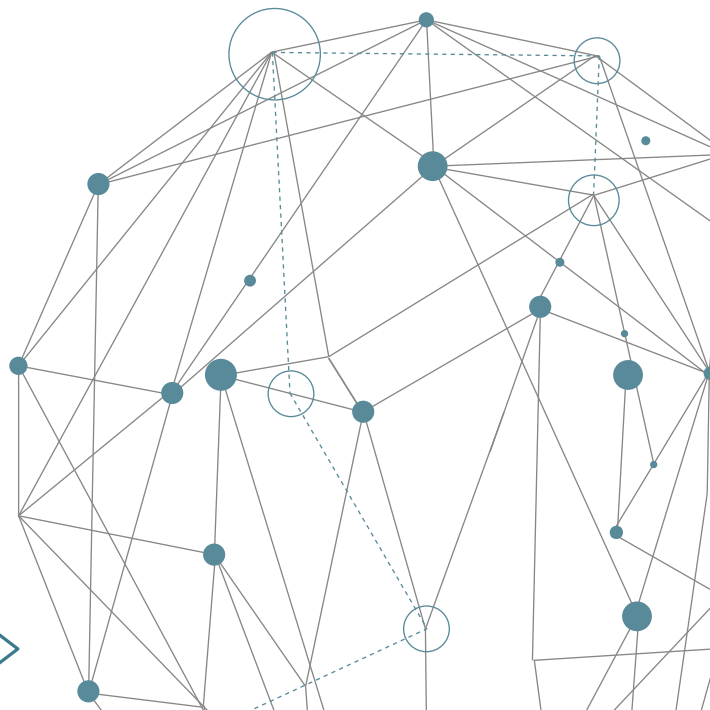

LITEN INSTITUTE

LITEN: INNOVATING FOR THE ENERGY TRANSITION

Liten (the Laboratory for Innovation in new Energy Technologies and Nanomaterials) is Europe's largest research institute entirely dedicated to new energy technology. Its main facilities are located in Grenoble and Chambéry, France. As an institute of the French Alternative Energies and Atomic Energy Commission (CEA), for more than a decade Liten has been conducting advanced technological research to respond to climate change and support a circular economy that will protect our environment for future generations.

WHO WE ARE ?

Liten is one of the few research institutes in Europe to cover the entire energy value chain, from materials synthesis to scaling up processes for industrial rollout, positioning the institute to bring its partners a crucial competitive advantage on their markets.
With fourteen technology platforms, a portfolio of more than 1,500 patents, and the know-how of a thousand research scientists, technicians, and support staff, Liten is a powerful R&D resource capable of overcoming complex technological challenges and developing tomorrow's products, components, and industrial processes.

LITEN, A MEMBER OF THE INSTITUT CARNOT ÉNERGIES DU FUTUR

The Instituts Carnot seal, which is granted by the French Ministry of Higher Education, Research, and Innovation, facilitates and encourages direct partnerships between research institutes and businesses. Liten, along with ten academic research labs, is a member of Énergies du futur, which offers a range of innovation services addressing technologies at various degrees of maturity.
The Filières Carnot programs, in which several Instituts Carnot participate, address a specific industrial issue, helping facilitate access to research and technology by SMEs in particular. The Énergies du futur institute, of which Liten is a member, coordinates the Carnot program on renewable energy and energy efficiency (EnergICs) and is a member of the programs on mechanical industries and processes (IMP) and automotive technologies (Carnauto). The Carnot seal provides access to additional resources that have enabled Liten to finance 21 PhD and post-doc positions and several pump-priming research programs to prepare for tomorrow's technology transfer programs and respond to tomorrow's energy challenges.

The institute's activities focus on three main fields:

1/Materials synthesis and implementation:
- Find alternatives to critical materials for sustainable growth,
- Develop materials- and energy-efficient components and processes,
- Invent the materials of the future for greater performance, safety, and sustainability.

2/Low-carbon renewable-energy production and storage:
- Make solar energy (PV, thermal, and thermodynamic) and bioresources more efficient,
- Reduce the carbon footprint of renewable energy by using hydrogen for production, storage, and conversion,
- Develop carbon-free applications (mobility, industrial processes, and buildings).

3/Energy efficiency:
- Address energy management at system-level to improve overall efficiency,
- Design and test solutions to manage intermittent resources,
- Work with our partners to explore economically feasible solutions compatible with new usages and territories.

INSTITUT CARNOT Energies du futur

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WORKING WITH LITEN

LITEN, INDUSTRY'S TECHNOLOGICAL RESEARCH PARTNER OF CHOICE

1,512 ACTIVE PATENTS (220 PATENTS FILED PER YEAR)
350 PARTNERSHIPS WITH INDUSTRIAL COMPANIES
100 EUROPEAN PROJECTS

A TRUSTED PARTNER WITH EXTENSIVE CONTRACT R&D EXPERIENCE

- 30% of our researchers have worked in industrial R&D.
- Project management and benchmarks are aligned with each partner's unique needs.
- We commit to project deadlines and deliverables.
- ISO certified.
- Partnerships with companies of all sizes, from SME to corporate.

KNOWLEDGE OF A BROAD RANGE OF INDUSTRIES AND A COMPLETELY INTEGRATED APPROACH

- Liten has deep knowledge of a broad range of industries (transportation, energy, food manufacturing, manufactured goods, etc.) in France and internationally.
- Our integrated approach (from component to system) lets us focus on your area of interest while ensuring that your project remains relevant with regard to the entire value chain.

UNRIVALLED INNOVATION RESOURCES AND KNOW-HOW TO SUPPORT YOUR STRATEGY

- Advanced technical capabilities, unrivalled know-how, and a substantial portfolio of patents that we can leverage for your project and transfer to you as needed.
- We constantly research the latest international tech news and advances and are active on several national committees on the energy transition.
- Our fourteen technology platforms provide key R&D resources to address your products and processes.

HIGH ADDED VALUE FOR INDUSTRIAL COMPANIES

Leverage innovation to grow your business:

- For companies operating in the energy industry: Secure your core business for the long term.
- For industrial companies whose products and/or processes are directly affected by changes in the energy landscape (like the spread of electric vehicles): Differentiate your products and services on your existing markets or penetrate new foreign markets.
- For industrial companies seeking ways to transform the energy transition into business opportunities: Diversify by creating a new line of business.

Save time:

- Develop and scale up new technologies faster: Benefit from immediate access to Liten's know-how and patents to overcome technical hurdles to new product development.
- Boost your image as an innovative company and test the feasibility of new projects: Develop innovative proof-of-concept prototypes and demonstrator systems to use at trade shows.
- Increase your know-how quickly through the transfer of skills and tools from Liten to your company.

Secure your R&D investments:

- Confidentiality guaranteed.
- Exclusive licenses to results may be granted for given markets/products.
- Test new ideas, and benchmark and analyze the market before investing in R&D.

MATTER & MATERIALS

NEW PROCESSES, IMPROVED PERFORMANCE

At Liten, we are working to improve the performance of materials used in energy applications. 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 alternatives to current materials—rare-earth elements, indium, gallium, lead, and solvents—that could become difficult to procure or use for geopolitical, economic, or regulatory reasons. 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. Flexible and printed electronics becomes gradually structural electronics with a first stage in plastronics.

MATERIALS SYNTHESIS

TRANSPARENT HEATING POLYMER FILMS

Liten patented the world's first 100% PEDOT polymer film that is both heating and transparent. The material, which was developed in partnership with CEA institute INAC as part of a thermoelectric materials research and development program, is conductive enough to ensure very low electrical resistance, even when it has been thinned to the point where light can pass through it. In addition, the material is flexible and easy to implement on large surfaces at a low cost using different processes, from spraying and dipping to flow coating and printing. When an electrical current of 12 V is applied, the film's temperature can rise to more than 120° C, making it ideal for uses like defrosting and defogging. A motorcycle-visor prototype was built to demonstrate the feasibility and advantages of the concept, garnering interest from several manufacturers. ■

CAROLINE CELLE

"Liten has been studying silver nanowires since 2010 to meet the emerging flexible optoelectronics market's need for industrially-manufacturable transparent, flexible electrodes. The institute conducted research on materials synthesis and electrode manufacturing processes, and then completed initial proof-of-concept testing on organic solar cells. Silver nanowires offer very good optoelectronic properties and—given the tiny amount of material used—are affordable. These advantages make the nanowires a credible alternative to indium titanium oxide for these new markets.

Today, Liten addresses the entire silver nanowire value chain, from synthesis to integration. The technology has matured, resulting in our first contracts with industrial partners in 2015 for heating films for defrosting applications.

We were also approached by French chemical company Protavic International to help integrate metal nanowires into its products. Liten responded by setting up a test reactor at the company's plant. The synthesis process was transferred to the company in 2017, and Liten continues to work with them to personalize their products for tomorrow's consumers." ■

> *"Today, Liten addresses the entire silver nanowire value chain, from synthesis to integration."*

MAGNETIC MATERIAL

A STEP TOWARD COMPLEX-SHAPED NdFeB MAGNETS

A technique to protect neodymium-iron-boron powder from oxidation was validated, paving the way toward powder injection molded (PIM) NdFeB magnets. The process would enable the manufacturing of complex-shaped magnets to optimize the yields of electric motors. It also eliminates the need for machining and is compatible with high manufacturing throughputs. The powder is blended with a solution of stearic acid and a solvent under neutral atmosphere. The blend is then heated under vacuum to evaporate the solvent. Once treated in this way, the powder can be manipulated in the open air for two hours to make the feedstock, a powder-polymer blend, required for PIM. At this stage, the material's oxygen and carbon content is low enough not to affect magnetic performance. Additional research is underway to optimize debinding of the parts obtained. ■

A PLANAR TRANSFORMER FOR ULTRA-COMPACT CONVERTERS

Two transformer prototypes with very low heat loss for ultra-compact converters (1 MHz, 100 W) were dimensioned and built. They are made up of a ferromagnetic oxide molded onto a traditional printed circuit. The transformers' planar architecture means that they can be integrated into an electronic circuit board without the need to add coolers. They can also be manufactured using powder injection molding (PIM), a technique that is compatible with industrial-scale manufacturing. The first prototype was characterized at 60 W; the rise in temperature remained within a range that is compatible with the use of the material. The losses of 300 mW/cm^3 observed are three to five times lower than those of commercially-available solutions. The results (from a PhD research project) have been protected by several patents and could also be used for other planar converter components like inductors. ■

SPARK PLASMA SINTERING WORKS ON FERRITES

To make high-performance magnetic cores from spinel ferrites, Liten researchers used spark plasma sintering rather than traditional sintering. The process requires flash heating (up to 1,000° C per minute) for a very short period. It proved to be very beneficial for magnetic materials, which, compared to control samples, gained 5% magnetization intensity at 7 teslas. The process was modelled with the ultimate goal of developing a tool to optimize operating conditions, which would pave the way for the manufacturing of complex parts. Spinel ferrites, which are characterized by low magnetic losses, are prime candidates for high-switching-frequency (1 MHz to 5 MHz) power converter inductors. ■

PHILIPPE EMONOT

"At Liten, we are developing our know-how in metallurgy, with a focus on specific component manufacturing and assembly processes and, in particular, hot isostatic pressing and brazing. Hot isostatic pressing is a high-temperature (1,000° C), high-pressure (1,000 bars) process used in the lab to assemble components by diffusion welding. Our work resulted in a major advance in 2017. After more than fifteen years in development, the process was used to manufacture a first 1:1 panel for the lining of the ITER reactor. Another of our advances in 2017 was the compact exchanger manufacturing process developed for the energy conversion system of the future ASTRID nuclear reactor, which also opened the door for applications in renewable energy with the manufacture of methanation reactors. Brazing is a technique that creates a bond between two parts. Brazing material placed between the two parts is fused and solidified. In 2017 the lab started development work on a technology for repairing the silicon carbide mirrors in space telescopes. The technology is based on a soldering process outside the furnace using an appropriate brazing material developed at the lab." ■

> *Our work resulted in a major advance in 2017"*

THERMOLYSIS OF METAL BOROHYDRIDES PRODUCES PURE HYDROGEN

For the past several years, Liten has been investigating the potential of metal borohydrides and their derivatives for high-capacity hydrogen storage. Thermolysis of the compounds, which triggers a larger release of hydrogen than the hydrolysis-based processes previously developed, was tested for the first time ever in the lab. Specifically, a new metal borohydride synthesized from $NaBH_4$ that could produce yields of 10% pure hydrogen at temperatures compatible with fuel-cell operation is under development. The new compound, which could be regenerated in a plant after use, would be suitable for non-reversible storage applications. The research is ongoing with the goal of improving hydrogen desorption and, ultimately, obtaining a reversible process. ■

ADDITIVE FABRICATION

ADDITIVE FABRICATION USED SUCCESSFULLY ON 316LN STAINLESS STEEL

In research conducted under a partnership with Naval Group, an additive manufacturing (3D printing) process using powder bed laser fusion was applied for the first time ever to 316LN stainless steel, a material that is employed for certain applications that require specific mechanical properties. The printed parts offered densities of 99% of the material's theoretical density and presented characteristics superior to those of parts manufactured in the same conditions from other stainless steels like 316L or 304L. Tensile and impact-resistance tests completed on various samples revealed mechanical performance superior to the minimum values set forth in the standard for parts forged from the same grade of stainless steel. The process used to manufacture the parts consumes 39% less energy than the minimum in the literature. ■

STEREOLITHOGRAPHY TO MANUFACTURE COMPLEX-SHAPED PARTS FROM SILICON CARBIDE

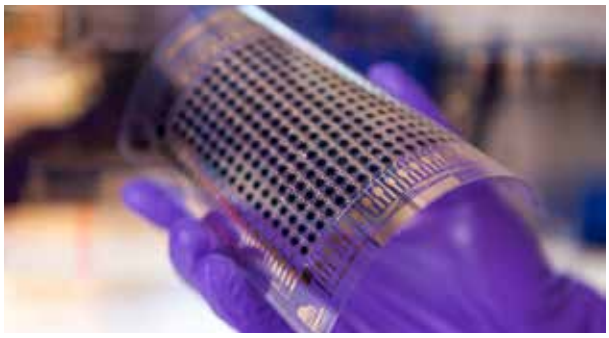
Complex-shaped (honeycomb, hollow, mesh, etc.) silicon carbide (SiC) parts are currently manufactured using powder metallurgy and machining. Due to the cost of the machining process, the applications for these kinds of parts are limited. Additive manufacturing is currently being investigated as a way to expand the technical possibilities and bring costs down. Researchers at Liten are studying a technique that has received little attention until now: the stereolithographic printing of preceramic polymers. Complex-shaped centimentric sized components were made at a layer-printing rate of around 500 µm/s. Pyrolysis was then used to obtain the final ceramic. At this stage, some of the structures were healthy and did not present any internal cracks. However, their oxygen content (5% to 8%) must be reduced further. A PhD research project to determine the relationship between polymer composition, pyrolysis conditions, and final part performance began in early 2018. ■

Fe-Si ALLOYS READY FOR ADDITIVE MANUFACTURING

Liten is conducting research to use selective laser melting (SLM), an additive manufacturing technique, to 3D print complex-shaped parts made from an iron-silicon alloy. Two formulations of the alloy, one with 3% silicon and one with 3.9% silicon, were selected, and raw parts with no cracks were obtained. However, after SLM, the parts must undergo a heat treatment at 1,350° C under hydrogen to give them state-of-the-art magnetic properties. The research is now focusing on making adjustments to the process and the silicon content of the alloy to obtain the expected magnetic properties. Lowering the temperature of the heat treatment is also being investigated to optimize the parts' microstructures and, therefore, their mechanical resistance while reducing costs. The parts being investigated would be used for electric motor rotors, for example. ■

PRINTED ELECTRONICS: FIRST-EVER ACTIVE MATRIX

A 256-pixel active matrix with a pixel pitch of 5 mm was printed at Liten's PICTIC platform. This is the world's first active matrix demonstrator representative of a printed system that integrates electronic addressing functions and sophisticated sensors. The pixel fabrication process (each sensor is run by its own transistor) consists of a series of around ten steps, including gravure printing for the transistors and screen printing for the sensors. The demonstrator system was built with light sensors (photodiodes) and pressure sensors (resistive strain gauges). The research is ongoing to further increase the size of the matrices and reduce the size of the components—and thus the pitch—to improve resolution. ■



INSTALLATION OF PIXORG PILOT FABRICATION LINE UNDERWAY

Liten has been a partner of startup ISORG since 2010. In 2017 the partners dimensioned and selected the equipment for the future Pixorg test organic photodetector fabrication line. The project, led by ISORG, was awarded funding under the French Directorate General for Enterprise nanoelectronics program. Acceptance testing of the first pieces of equipment has begun at the nearly 900 sq. m of cleanrooms at ISORG's future manufacturing facility in Limoges. The pilot line is the first of its kind in France, and will contribute to building the nation's organic electronics industry. Liten is working with ISORG to transfer the process developed at the Pictic platform in Grenoble to the company's manufacturing facility and make the necessary optimizations before beginning sample runs in 2019. The generic process developed will position ISORG to address the smartphone, biometric identification, medical imaging, and, more broadly, industrial (sensors for Industry 4.0 and connected devices) markets. ■

EMMANUELLE VÉRAN

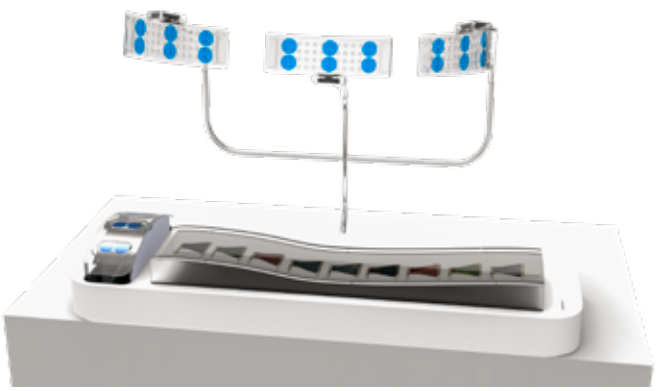
"We presented an innovative switch prototype at CES 2018 in Las Vegas. The switch combines printed piezoelectric components for haptic applications and a plastics process. It is flat and smooth and vibrates in response to pressure to confirm that it has been activated. The technology has garnered interest from automotive industry designers, who tend to prefer smooth surfaces. However, the technology has many other potential applications in home automation, healthcare, sports, video games, virtual and augmented reality, and more.

We leveraged our know-how in printed electronics, materials, thin-layer deposition, and plastics to make the plastronic components in conjunction with two other CEA institutes and with IPC*, an industrial R&D center. To be compatible with in-mold labelling, the components must be able to withstand temperatures of several hundred degrees and pressure of several hundred bars.

We are moving ahead by iteration, adjusting the materials, the design of the component, and the temperature and pressure as we go along. In the longer term, when the processes are more mature, we would like to move to 3D printing." ■

> *"We presented an innovative switch prototype at CES 2018 in Las Vegas."*

*Innovation Plastic Composite



RENEWABLE ENERGY

FROM SOLAR TO BIO-BASED ENERGY

At Liten, our renewable energy research encompasses solar photovoltaic, solar thermal, and bioresources and covers the whole value chain, from materials to grid-connected systems. Our technology platforms are used to build prototypes to respond to the needs of manufacturers in the renewable energy industry. Our solar photovoltaic research focuses on premium—very high yield, communicating, self-troubleshooting—modules as well as integrated modules designed for specific applications, such as space. Our solar thermal research responds to the needs of French companies developing solutions for international markets. The purpose of our bioresource research is to develop methods to convert liquid and solid waste to energy, from wastewater treatment sludge to solid recovered fuel (SRF).

SOLAR PHOTOVOLTAICS

ETIENNE PIHAN
ET GAUTIER FORTIN, ECM GREENTECH

"We made several major advances in the development of monolike silicon technology in 2017. First, we produced 650-kilogram (G6) ingots with controlled crystalline orientation. We achieved a level of homogeneity compatible with industrial standards. The quality of the material was evaluated on several thousand photovoltaic cells by several manufacturers around the globe. Performance was somewhere between that of high-performance multicrystalline materials and monocrystalline Cz, which confirms the relevance of this kind of material. Following the performance assessment, our partner ECM-GT began selling G6-sized furnaces and associated processes to leaders in the field. The next step will be to confirm the potential of the process on 1.4-ton (G8) ingots. We are currently working on this under a research project spearheaded by French energy agency ADEME and contract research with our partner ECM-GT. Our goals are to once again obtain a material of excellent quality and achieve high process efficiency. Once we reach these milestones, the cost of monolike silicon will become even more attractive to manufacturers." ■

> *"Monolike silicon will become even more attractive to manufacturers"*

CUTTING THE BOTTOMS OF G6 MONOLIKE INGOTS NOW POSSIBLE

A new closed-loop diamond-wire cutting machine was tested on a G6 monolike silicon ingot in contract research with our partner BEA. A similar machine smaller in size had previously been validated on a G5 ingot. However, scaling the machine up to G6 ingots created several challenges, including how to hold the 650-kilogram ingots and control oscillation of the diamond wire's mechanical drive system and vibration of the diamond wire loop, which is more than five meters long. Once these issues had been resolved, a complete cut-off was made in fifteen hours. The research is currently focusing on improvements that could reduce cutting time by at least 50%. The layer of seed crystals was recovered, and could be used to grow a new monolike ingot, lowering costs. ■

COMPENSATED SILICON: SIMPLER MEASUREMENT OF DOPANT CONCENTRATIONS

Our researchers developed a simpler method for measuring the dopant concentrations of "compensated" silicon made from recycled waste silicon. Rather than the conventional method—a chemical analysis using mass spectrometry—the researchers opted for a measurement method based solely on the material's electrical properties. The silicon's resistivity is measured at 70 K (-203° C) and at 20 K (-253° C). A mathematical processing method—developed and patented by Liten—then calculates the dopant concentrations. The method, much less costly and time-consuming than mass spectrometry, is accurate enough for routine testing. It will be tested on a larger statistical sample to validate its robustness and reduce uncertainty. ■

FIRST-EVER RECYCLED SILICON SOLAR CELLS

In the EU H2020 CABRISS project frame coordinated by Liten, Al-BSF cells were made from recycled silicon from various sources. The purpose of the CABRISS project is to enable a "circular economy" approach to PV materials. All stakeholders, from the recovery of manufacturing waste and spent modules to the manufacturers of new modules from recycled materials, are involved in the project. The best results were obtained from 60-kilogram (G2) ingots grown using a monolike process. The average yield of the cells produced from the recycled material was 17.5%, with the best-performing cells reaching 18.1%. These cells were used to make a 100% recycled silicon module.

At 252 Wp and with a cell-to-module performance ratio of 99%, the module is comparable to those commercially available. The results exceeded the initial objectives and could pave the way toward a viable recycling industry. ■

PEROVSKITE-SILICON CELLS AIM FOR 30% YIELDS

Our researchers began work on perovskite-silicon tandem cells, validating two junctions connected in series. The tests revealed that, as a top priority, further improvements will have to be made to the perovskite's thermal stability and the control of the metal deposition process. Additional work to ensure that the perovskite layer's absorption range is complementary to that of the silicon layer must also be completed to ensure that the two junctions deliver the same current. Research on this topic, still in its very early stages, is intensifying with two PhD dissertations and the transition from active surfaces of 20 mm^2 to 50 mm x 50 mm and, subsequently, 156 mm x 156 mm. Perovskite-silicon technology could one day achieve yields of more than 30% while offering the advantages of using low-cost materials and simple processes. ■

HETEROJUNCTION TECHNOLOGY

DELPHINE CHERPIN ET PIERRE-JEAN RIBEYRON

"ENEL Green Power announced that it would invest in its Catania, Italy plant with the goal of launching production in 2019 of PV modules of more than 400 W leveraging heterojunction technology developed at Liten. At around 22.5%, current cell-efficiency, combined with low temperature sensitivity and potentially-high manufacturing throughputs, could result in lower LCOE (€/kWh) than the most advanced technologies currently on the market. The modules, which are competitive on the global market, will target solar power plants in India, South Africa, Latin America, and other regions. We are working with ENEL to develop their new cell and module production lines and commission the lines using procedures that meet the company's specifications. Around ten employees of ENEL's Catania site are receiving training at INES on our Fablab equipment. At the same time, our researchers are pursuing their work to improve our heterojunction technology to obtain average yields of 24% by 2020."* ■

*LCOE: Levelized Cost of Energy

> *ENEL Green Power invests in our heterojunction technology.*

HETEROJUNCTION CELLS READY FOR PRODUCTION

EU FP7 project Hercules, coordinated by INES, won a "Stars of Europe" award for the excellence of the results achieved. More than 100,000 bifacial amorphous/crystalline silicon heterojunction cells were produced in test batches. The average cell efficiency is in excess of 22%, with the best cell delivering 22.9%. The module solution, certified at more than 380 W, was also tested successfully. Hercules also resulted in 76 publications and involved eight PhD dissertations, two of which were completed at INES. The processes were scaled up for industrial manufacturing and a study of all factors impacting costs was completed, which means that high-yield cells can now be manufactured in Europe. Technology transfer projects are underway with manufacturers in Russia and Italy, and three new EU projects on innovative heterojunction cells have begun. ■

60-CELL MODULE DELIVERS RECORD POWER

A 324 Wp PV module made from 60 bifacial heterojunction cells was built at Liten. The module, which offers efficiency of nearly 20%, is made of solar cells connected to each other by textured ribbons to trap light and assembled using a conductive adhesive. The module also features a new antireflective glass and encapsulating material that lets more light through. An aluminum foil was integrated into the backsheet of the module to reflect unused infrared light to the back side of the cells, further increasing yield. Finally, the distances between the cells were calculated to capture maximum light. These improvements reduce the losses caused when cells are integrated into modules and create optical gains that, together, result in a 9.6 A current for the module vs. 9.1 A for the cell. ■

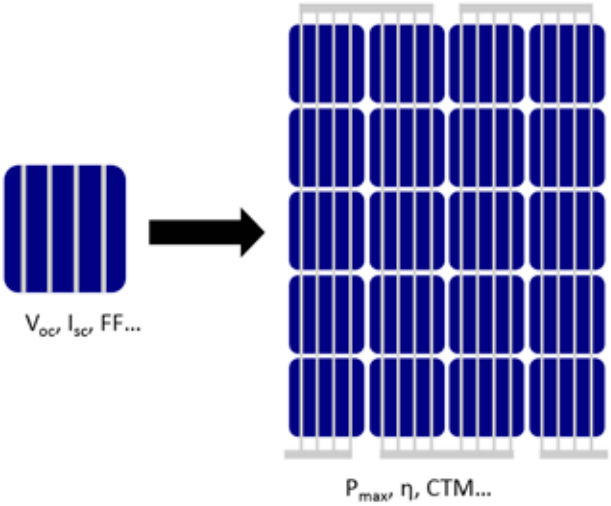
PHOTOVOLTAIC MODULES

ULTRA-LIGHTWEIGHT PV MODULE FOR HIGH-ALTITUDE BALLOONS

In research conducted under the Stratobus project with Thales Alenia Space France (TAS-F), Liten developed a flexible, ultra-lightweight PV module for high-altitude balloons. The module weighs in at less than 800 g/m² (compared to 12 kg/m² for conventional modules) and offers power in excess of 180 Wp/m². It has the potential to respond to the specifications of high-altitude balloons in terms of heat and wind resistance, extreme exposure to light, and lifespans. The module is made of high-yield (>24%) interdigitated back contact (IBC) cells. The aluminum frame was eliminated and the front glass was replaced with a much lighter thin polymer. Another prototype, which is even lighter and which offers higher W/kg performance, was also made using HET cells produced at INES on wafers thinned to less than 120 microns. ■

A CELL INTERCONNECTION TECHNOLOGY SELECTION ASSISTANT

A tool to forecast the performance of photovoltaic modules was developed at Liten. A database containing the characteristics of different types of existing silicon cells was developed specifically for the tool. A model predicts the performance of the target module, taking into account resistive losses at the interconnections. The losses are estimated according to the size and geometry of the interconnect ribbons. A comparison of the losses predicted by the tool with losses actually observed on a module revealed a gap of less than 0.5%. Ultimately, the tool could also supply a detailed analysis of optical losses, which could provide insights useful to selecting the best encapsulation material for a given module architecture. ■



GOPV INVENTS LOW-COST SOLAR ENERGY

The EU GOPV project brought together a consortium of around a dozen partners to develop a photovoltaic system for large plants in southern Europe. The goal is to produce electricity for €0.02/kWh. Operation and maintenance costs must be lowered and equipment costs must be brought down. At the module level (bifacial heterojunction modules on thin wafers will be used for optimal efficiency), an innovative interconnection technology is implemented to make more economical use of materials. The technology requires less silver and soft bonding makes the assembly more reliable. Furthermore, an advanced power inverter architecture eliminates chemical condensers, lengthening module lifespans. The approach will be tested on a complete 100 kW system (PV module, 1-axis tracker, power inverter) in a real-world environment for one year. ■

HERVÉ COLIN

"Here at INES we have developed a platform to evaluate the economic performance of bifacial PV modules. The platform is made up of seventeen 3 kWp photovoltaic systems. It can be used to determine the energy production gains between a bifacial system and a monofacial reference system, for example. Because the platform leverages data from PV plant monitoring systems, its models can predict system performance taking into account the impact of terrestrial albedo, irradiation, module height and direction, and other factors. In 2017, the platform was used for the BISUN project to compare bifacial modules made from n-type monocrystalline homojunction cells with a commercially-available monofacial reference module in different configurations. It was also used for the CHIC project to study different versions of SWCT heterojunction modules (monofacial and bifacial) manufactured by MeyerBurger and compare them to equivalent commercially-available reference modules used in similar conditions." ■

> *The CHIC/BISUN demonstrator system evaluates bifacial systems.*

TRANSFORMERLESS PV SOLAR PLANTS COULD BE JUST OVER THE HORIZON

A 3,000 V photovoltaic solar power plant prototype was built and initial tests were completed. The prototype has two 1,500 V chains made up of 36 modules with reinforced insulation and static converters suited to high DC voltages. The electrical devices and safety equipment were designed specifically for the prototype or were already in use in other industries where 3,000 V is the standard. For PV plants, the capacity to operate at high voltages generates savings on cabling and reduces electrical losses. The ultimate goal is to feed electricity directly into the grid without the need for converters. Tests of the prototype will continue in 2018: a measurement chain for PID (potential induced degradation) specific to high voltage configurations will be implemented. ■

INNOVATIVE POWER ELECTRONICS FOR PV CONVERTERS

Liten developed three power electronics prototypes for PV systems, each of which responds to the specifications of specific target applications. The first is a 200 W DC-DC converter for solar road projects. It features a wireless energy transfer system for easier integration of the modules into road surfaces and replacement. A 5 kW power inverter for building-integrated PV systems was also developed using silicon carbide (SiC) components to reduce the size of the inverter to where it can be installed by a single person. Finally, a compact, high-yield 125 kW power inverter, also built using SiC components, was developed to meet the needs of terrestrial solar power plants. The three lab prototypes will be tested in real-world conditions in 2018. ■

SRF GASIFICATION OUTPUT ANALYZED

Leroux et Lotz Technologies turned to Liten to develop and build a complete sampling and analysis system to measure and identify the particles, condensable substances, and gases produced by its SRF (solid recovered fuel) gasification reactor. The system was designed and tested in the lab, and then installed on the test reactor at the company's Nantes, France site. The gas coming out of the reactor is drawn through removable filters kept at 300°C. Once the particles have been removed, the gas is carried through a heated line to a unit where tars are trapped, and then tested in the lab. Finally, the permanent gases (CO, H_2, CO_2, N_2, CH_y, C_xH_y, etc.) are measured in line. The sampling and analysis system can be used for gasifier mass balances and yield calculations. ■

A MULTI-SCALE, MULTI-CRITERIA SIMULATION TOOL FOR BIOMASS TRANSFORMATION

A digital simulation tool to evaluate the economic and environmental performance of biomass-to-energy transformation systems was developed at Liten. It leverages modelling and simulation at several scales and based on several criteria, factoring in resource availability, transformation process yields, economic performance, and, finally, greenhouse gas emissions. The tool, developed in conjunction with EPFL (Ecole Polytechnique Fédérale de Lausanne), uses physical, economic, and environmental models and the associated databases. It delivers reliable information that can be used to make informed decisions about how to best integrate biomass into an energy mix. ■

GENEPI CONVERTS DRY HOUSEHOLD WASTE INTO LIQUID FUEL

The GENEPI platform, initially designed to study high-temperature, high-pressure thermochemical conversion of biomass to syngas ($CO+H_2$), was used for the first time ever to convert solid recovered fuel (SRF) from household waste into gas. The SRF powder is gasified in just a few seconds at 1,350° C and 1.5 bars. The ash is trapped on the furnace wall in liquid form and then solidified by vacuuming the water droplets out in the lower part of the reactor. The process efficiently separates undesirable particles and produces a very clean syngas (with tar content of just a few mg/Nm^3) ready to be converted into liquid fuel by catalytic synthesis. This first-ever experiment opens the door to the conversion of other types of waste like treated wood and tires into fuel. ■

ENERGY STORAGE

FOR STATIONARY AND EMBEDDED 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 design, 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.

PROTOTYPES

FRENCH DIRECTORATE-GENERAL FOR ARMAMENTS WON OVER BY THE PERFORMANCE OF LITEN'S BATTERIES

The French Directorate-General for Armaments pitted several battery technologies against one another to compare their performance under the French National Research Agency's "Défis Descartes" program. Three teams, all of which were completely or partially made up of Liten researchers, worked on different types of batteries: lithium-ion, sodium-ion, and nickel-zinc. The batteries were used to power a small commercially-available land robot for the test. The three batteries responded to the specifications, successfully completing the most difficult circuit several times. The batteries were also evaluated for toxicity, cost, safety, and performance. In terms of battery life, the lithium-ion prototype vastly outperformed the robot's factory battery. The lithium battery won out for its energy performance and cobalt-free composition. ■

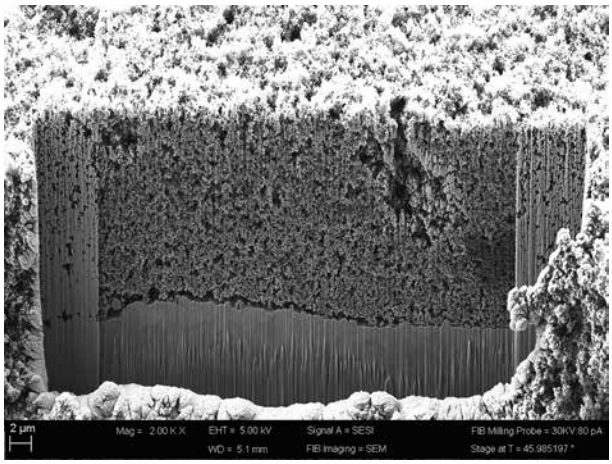
BIDIRECTIONAL CONVERTERS

In research conducted under the EU Esprit project to make urban car-sharing systems economically viable, strategies to redistribute vehicles using "road trains" are being investigated. These strategies would require new solutions for exchanging energy between batteries. For example, when vehicles are parked, only the first would be plugged in to a power supply, and the energy would need to be transferred to the other vehicles. Advances will also be needed to balance the charge of vehicles connected to each other when parked and during transit. Liten made adaptations to existing equipment to develop chargers capable of running off of AC (plugged in to an outlet) and DC (plugged into another vehicle). Researchers are also developing innovative solutions to exchange energy between batteries with very-low-power chargers that only compensate for differences in voltage. ■

OBSERVING BATTERIES

SILICON ELECTRODES: THE REAL CAUSES OF AGING

Liten researchers completed observations combining several imaging and spectroscopy techniques to gain insights into the mechanisms that underpin silicon electrode degradation. Silicon electrodes are in the race to replace graphite electrodes in lithium batteries which would theoretically increase battery life tenfold. The observations were completed for the first time ever in actual operating conditions and revealed that the main degradation mechanism is related to a lack of lithium due to the fact that the lithium is trapped in parasite reactions. These results contradict previous research that indicated that the negative influence of the solid electrolyte interface was one of the main causes of degradation of these kinds of electrodes. The observation of complete cells was made possible by the novel combination of imaging and spectroscopy techniques. ■



Mg^{2+} ION TRANSFER MECHANISMS OBSERVED USING XPS

Liten is conducting research on magnesium batteries, which are safer and offer higher energy densities than lithium-ion batteries. One of magnesium batteries' weak points is the low mobility of Mg^{2+} ions. The mechanisms that underpin the insertion of magnesium into a Chevrel phase material (Mo_6S_8) used at the positive electrode were observed using XPS*. The research revealed a two-stage reversible charge transfer process that involves the structure's axial sulfur atoms, and then the redox centers of the Mo_6 clusters. A better understanding of these phenomena will aid in the development of cathode materials that facilitate the magnesium insertion and deinsertion process, so that the charge transfer is faster and, above all, reversible. ■

*XPS: X-ray photoelectron spectroscopy

BATTERIES' CHEMICAL COMPOSITION OBSERVED OPERANDO

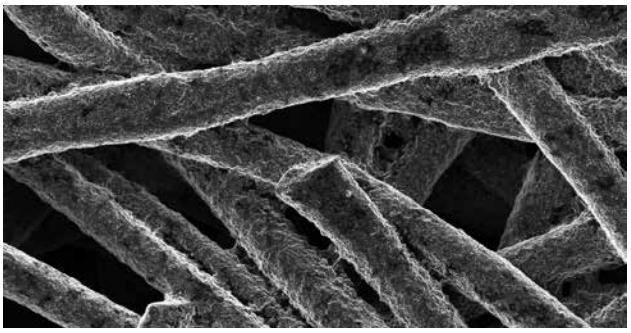
Changes in the chemical composition of lithium-ion batteries were observed during battery operation for the first time ever. Until now, this type of observation required stopping the cycling test and disassembling the battery several times during operation. A holder was developed to connect a lithium battery to a potentiostat to directly monitor the changes in chemical structure at the electrolyte-electrode interfaces. The protocol, called OXPS, was tested on micro-batteries. The results obtained were corroborated by a direct-observation testing campaign conducted in parallel. OXPS will provide insights into the relationship between chemical structure and the degradation mechanisms at work at the interfaces between the electrolytes and the electrode materials. The ultimate goal is to improve the efficiency of the energy-conversion materials. ■

LITEN'S LITHIUM BATTERY KNOW HOW EXPORTED TO BOLIVIA

After months of work, a brand-new pilot line for the manufacturing of cathode materials for lithium-ion batteries for Bolivian company COMIBOL went online in 2017. COMIBOL had turned to ECM Greentech, which partnered with Liten, to design and build a production line for high-added-value materials like LMO and NMC. Liten provided theoretical and practical training for local engineers in Bolivia, and also synthesized and characterized the materials produced. The commissioning of the pilot line marks a major step forward in the development of Bolivia's lithium industry. The performance of the materials synthesized met the specifications. The partners are currently in talks about working together on a much larger plant. ■

ELECTROLYTE GELIFIED IN POLYMER

Growing demand for safer batteries for the automotive and electronics markets is spurring manufacturers to investigate gelified electrolytes, which are less volatile than liquid electrolytes. A gelified electrolyte was produced from a fluorinated polymer (PVDF) specially developed by Solvay. The PVDF is first solubilized, and then blended with the electrolyte. It is then reticulated at the coating stage, effectively "trapping" the electrolyte in a network of polymer chains. Gelified electrolytes work at ambient temperature and can be implemented on equipment in traditional anhydrous environments. The results of the first electrochemical tests completed showed that the electrolytes offer the same performance as lithium-ion batteries at low to moderate operating cycles. ■



FABIEN PERDU

"Lithium-ion batteries are currently reaching their limit, and Liten is investigating new battery concepts. Our work focuses on lengthening battery lifespans, adjusting the energy density to the requirements of the application, and reducing the amount of critical materials like cobalt in the batteries. Lithium-sulfur is one of the battery chemistries we are studying—sulfur is abundantly available and minimally polluting. When used with a metal lithium negative electrode, sulfur at the positive electrode substantially increases the electron exchange capacity. However, because the lithium is not in ion form, there are some real scientific hurdles to overcome for the concept to be feasible. At Liten, we are also looking at other alkalines to replace lithium. We have developed sodium cell prototypes and modules that deliver performance similar to that of today's lithium-ion batteries. Magnesium, which can cycle in metal form without generating dendrites, is also on the drawing board, with the goal of creating a complete electrochemical system. Finally, we are also looking at other candidates like calcium and potassium." ■

> *"What comes after lithium-ion?"*

MODELLING APPROACH

MODELLING AND SIMULATION OF LIFE BATTERIES PACK

Liten developed software that automatically calculates the ideal configuration and size of electricity storage systems made of lithium-ion batteries. The software ensures that the batteries deliver the expected performance and lifespan depending on the target application. The software simulates the changes in various parameters and battery-pack performance over time, factoring in the number of modules and the system use profile. A dynamic electrothermal model can simulate the temperature of and current passing through each cell and the aging of each component at any time. Finally, the software can predict the impact of dimensioning (the number of modules, temperature, and oil flow, for example) on battery-pack lifespans. ■

PSEUDO-2D SIMULATION OF LITHIUM-ION BATTERIES' ELECTROCHEMICAL BEHAVIOR

A pseudo-2D model simulating the electrochemical behavior of lithium-ion batteries was developed at Liten. It describes the local conditions inside the electrode and in the particles of active material in real time at the scale of a basic collector-electrode-separator stack, providing insights into lithium heterogeneities during the operation of the graphite electrode. The model, based on the physical parameters of the materials used, can easily be transposed to other battery chemistries. Ultimately, it will be rounded out with an innovative aging model that combines changes in the passivation layer at the solid electrolyte interface and the appearance of lithium plating. This new model will be used to develop optimized architectures and usage strategies to improve battery performance and slow aging. ■

ESTIMATING THE LIFESPAN OF RECONDITIONED BATTERIES

A method for estimating the lifespan of spent Li-ion batteries was developed in partnership with SNAM. The goal was to use both lab testing and simulation to confirm the potential of new batteries manufactured from 80% recycled materials and evaluate the associated business model. Cells were removed from a battery pack that had been used to power an electric vehicle. The cells had lost 15% of their performance. The cells underwent a battery of fifteen different aging tests. The model created from the lab results shows that, depending on how the spent batteries are reused, it is realistic to expect an additional 4,000 cycles. Liten is continuing to work with SNAM to improve battery management to achieve these levels of performance. ■

HYDROGEN ENERGY

TOWARD ENVIRONENTALLY-FRIENDLY MOBIITY AND ENERGY STORAGE

At Liten, research on Hydrogen focuses primarily on its capacities as an energy carrier to extend the range of clean vehicles, ultimately making them a viable option for inter-city transportation. Liten's programs aim to bring the cost of fuel cells down and to develop optimized, self-regulating battery-fuel cell systems. Our researchers are exploring hydrogen as an alternative to batteries for storing excess renewable energy. The institute is also developing efficient power-to-gas solutions that leverage high-temperature, high-yield electrolyzers and transform the hydrogen produced into a usable source of energy. This can take several forms, from delivering the hydrogen directly to industrial customers to converting it into substitute natural gas (SNG) by adding CO_2, or directly producing syngas via CO_2-H_2O co-electrolysis.

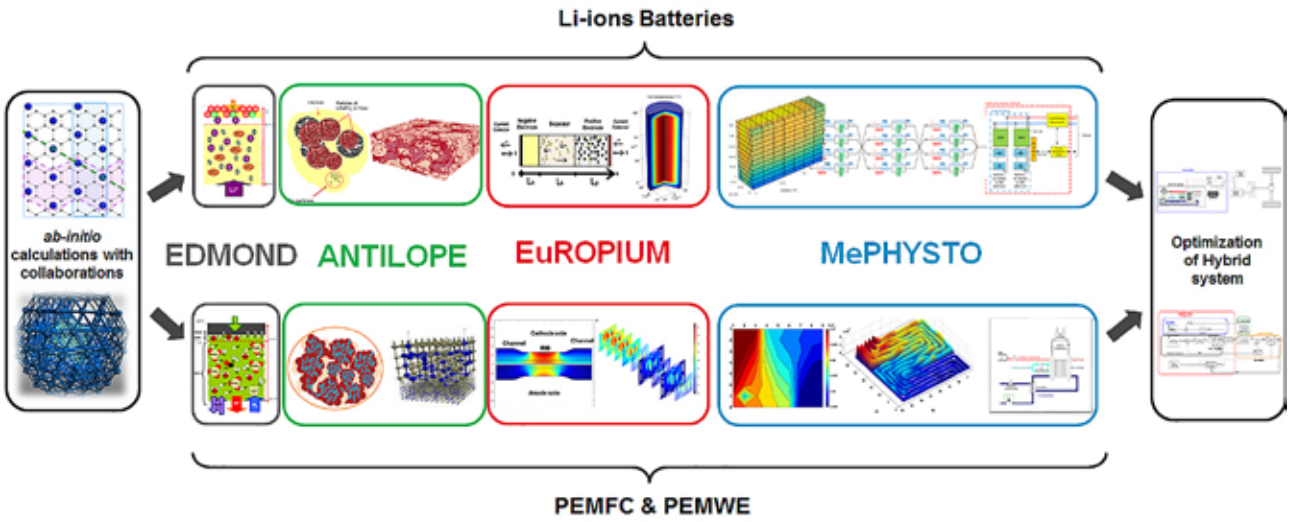
PEM FUEL CELLS

MUSES PLATFORM SIMULATES ELECTROCHEMICAL GENERATOR OPERATION AT ALL SCALES

The physico-chemical phenomena at work in low-temperature proton-exchange membrane fuel cells (PEMFC) and lithium-ion batteries are by nature multi-physics and multi-scale. Liten created the MUSES simulation platform to investigate these systems in detail. MUSES includes five development environments organized by spatial scale, from the active material up to the entire system. Because the models' structures are homogeneous, they can be more easily upgraded as new experimental data becomes available. The numerical simulation models are a crucial addition to the platform, providing insights into the phenomena at work that can be used to improve materials' properties, optimize designs, estimate performance, and predict system aging. ■

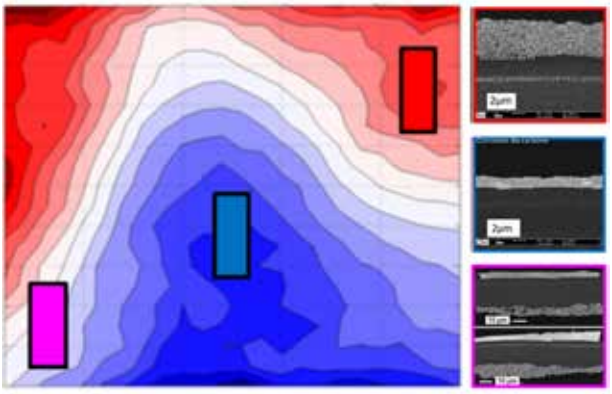
REAL-TIME DIAGNOSTICS OF OPERATING CONDITIONS IN PEM FUEL CELLS

The mechanisms that underpin degradation in PEM fuel cells are highly dependent on the operating conditions such as temperature, pressure, and moisture. Liten developed a diagnostic algorithm to help maintain these parameters at levels that ensure good performance and minimal degradation. The algorithm compares actual pressure and resistance measurements to theoretical values precalculated by a module available on the MUSES platform. Gaps could indicate a malfunction; the nature of the malfunction is determined by a more detailed analysis of the results. Currently, around 90% of faults are correctly classified. The model is robust and requires little memory, making it suitable for real-time diagnostics. ■



PHENOMENA RESPONSIBLE FOR LOCAL DEGRADATION IN MEA IDENTIFIED

Liten researchers investigated the phenomena that cause degradation in the membrane-electrode assemblies (MEA) of proton-exchange membrane fuel cells during rapid forced start-stop cycles. They completed three types of analyses: local in situ current density measurements, electrochemical measurements, and post-mortem observations of modifications of the microstructure. Combining characterization at three different levels revealed the mechanisms that are most likely involved in local degradation—such as corrosion of the carbon in certain areas. Determining which phenomena cause degradation and to what extent will provide the information required to modify electrodes locally to mitigate degradation and lengthen fuel cell lifespans. ■



MICRO-COGENERATION DOES NOT IMPACT FUEL CELL AGING

Liten researchers conducted experiments to confirm whether micro-cogeneration (combined heat and power) in fuel cells impacts fuel cell aging. They simulated the energy needs of a household for one year, alternating operation at different power levels to create cycling characteristic of real-world conditions. This operating profile was then applied to the EPICEA system for 1,000 hours, delivering maximum power of 4 kW and equivalent thermal power. The experiment was monitored regularly, with various measurements taken to make sure that the equipment was in good condition and that the system was operating as intended. The experiment indicates that micro-cogeneration does not speed up fuel cell aging. The results will be used to develop an algorithm to predict fuel cell lifespans for this type of use. ■

DIDIER BOUIX

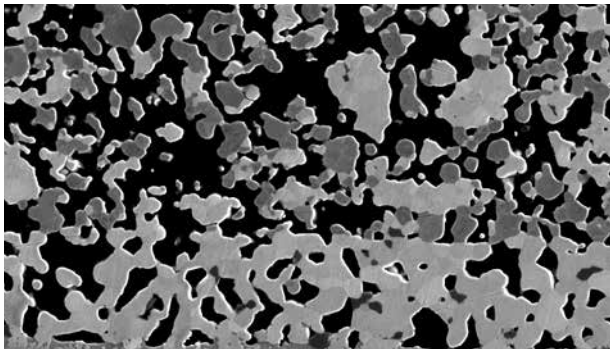
"We have been developing the entire energy system for the Energy Observer catamaran since 2016. The vessel has already sailed around France, and is gearing up to sail around the world, providing its own energy for zero greenhouse gas or fine particle emissions. Liten developed a complete energy architecture that consists of two vertical-axis wind turbines, a smart traction sail, heterojunction photovoltaic modules spread out over 140 sq. m, and two electric motors. However, what makes the vessel truly innovative is that it uses hydrogen for long-term energy storage in addition to the on-board batteries. The excess energy produced by the solar panels and wind turbines powers an electrolyzer to produce hydrogen from desalinated seawater. If there is no sun or wind, the fuel cell reconverts the hydrogen into energy to power the vessel's electric motors. The heat generated is also used to heat the cabin." ■

> *"The Energy Observer is a floating energy lab."*

HIGH-TEMPERATURE ELECTROLYSIS

SOC FUEL CELL DEGRADATION MECHANISMS FINALLY UNDERSTOOD

The degradation of ceramic SOC (solid oxide cell) fuel cells is more intense in electrolysis mode than in fuel cell mode. However, 3D reconstructions of electrodes produced using tomography at ESRF (European Synchrotron Research Facility) revealed that the formation of nickel aggregates is equivalent in both modes. Microdiffraction and microfluorescence were used to complete additional characterization work to determine the mechanisms that explain the difference in degradation. The results showed that a strontium diffusion phenomenon and the formation of $SrZrO_3$ occur mainly in electrolysis mode. The instability of lanthanum strontium cobalt ferrite (LSCF) could therefore explain the higher degradation rates observed in electrolyzer mode. These results will provide insights into how to improve electrode microstructures to lengthen fuel cell lifespans. ■



A REVERSIBLE ELECTROLYZER FUEL CELL ENERGY PROCESSOR FOR RENEWABLE ENERGY STORAGE IN BUILDINGS

A prototype of an automatic reversible system that operates as both electrolyzer and fuel cell was designed and built by Liten. The system is based on solid oxide technology, which operates at high temperatures (>700° C) for unrivalled yields.In electrolyzer mode, the system converts electricity into hydrogen from water vapor. In fuel cell mode, it provides electricity from the previously-produced hydrogen that has been stored. The major advantages of fuel cell mode are that it can be powered by fuels other than hydrogen (natural gas or renewable natural gas) and it produces heat, which can also be recovered and used. The system is the core technology in startup Sylfen's Smart Energy Hub, a solution to enable buildings and eco-neighborhoods to produce more of their own energy. Liten's technology was hybridized with batteries in a dedicated system run by smart management strategies developed by Sylfen. ■

CO-ELECTROLYSIS: FIRST-EVER DURABILITY TESTS UNDER PRESSURE

The co-electrolysis of water vapor and carbon dioxide produces a syngas that could potentially be used as a source of energy for a variety of applications. Liten, which had previously demonstrated the benefits of adding pressure to increase the efficiency of the process, has now reached a major milestone with the first-ever 1,600-hour laboratory test of co-electrolysis under pressure.

The purpose of the test was to assess the impact of operating pressure on electrolyzer durability. The results show that, while performance decreases initially, the apparent degradation of the solid oxide cell later stabilizes at a level equivalent to what is observed under atmospheric pressure. Based on these encouraging results, the researchers are now conducting tests to assess material aging in co-electrolysis mode under pressure. ■

ENERGY EFFICIENCY

RECOVERING, STORING, AND REDISTRIBUTING ENERGY

The capacity to effectively manage the intermittence of renewable energy is crucial to integrate 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 according to occupant needs and building components (walls, doors and windows, air conditioning, etc.); 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.

BUILDINGS

BIPV PANELS PUT TO THE TEST ON FACT

In research conducted under the EU CONIPHER project, building façade panels that integrate PV energy production and thermal insulation were evaluated on the FACade Tool (FACT) at INES's Building Energy Systems platform. The BIPV (Building-Integrated Photovoltaics) panels combine bifacial heterojunction cells laminated onto a twin-glass module mounted on a concrete frame designed to facilitate maintenance. The panel's thermal characteristics (temperature and thermal flows) were measured before and after installation; the production of electricity using the building-integrated modules is currently being evaluated. At the same time, the Homeskin project is developing thin insulating panels made from silica aerogel. The thermal characteristics of panels, which are five times thinner than conventional insulating panels, are also being measured on FACT and could be combined with the CONIPHER panels for a more complete solution. ■

COMBINING ENERGY EFFICIENCY AND AIR QUALITY

Designed to reduce heat losses, ultra-airtight building envelopes often have a negative impact on indoor air quality. Liten developed an algorithm to run building ventilation systems to achieve a good balance between energy efficiency and indoor air quality. The fuzzy-logic algorithm requires an acceptable concentration range for each pollutant measured. A special algorithm adjusts ventilation speeds according to the concentrations measured. The maximum trigger thresholds were all optimized to reconcile thermal insulation and indoor air quality while limiting the number of starts and stops of mechanical fan drives. ■

RAPHAËL COUTURIER

"In a context where fossil-based energy prices are low, we are developing two types of thermal energy storage systems that can store energy from a few hours to a few days. The first, which is very competitive, uses water as a storage material. The second uses phase-change materials and delivers very high storage densities of around 100 kWh/m3 or more. Both types of systems require heat exchangers: we determine the geometry, select the materials, and dimension the heat exchangers to control the power curve during charging and discharging. We have made a lot of progress with the phase-change materials-based systems. In 2018 an initial 120 kWh demonstrator will be implemented in an eco-neighborhood served by Grenoble's urban heat network. For very-high-density systems, we have identified high-potential materials that react chemically with water or water vapor. The next step is 1:1 testing of systems of several hundred liters. The changes in phase alter the materials' physical properties (like granulometry) and their thermal storage capacity. So, we are investigating different ways to maintain or restore these properties." ■

> *We plan to test a 120 kWh thermal storage demonstrator in 2018."*

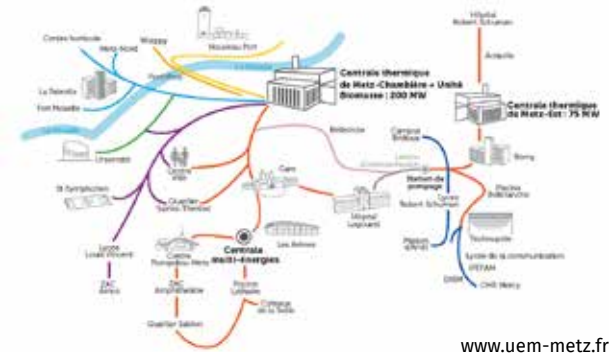
ORC FOR LOW-TEMPERATURE WASTE-HEAT RECOVERY

Liten designed and built an ORC* machine for low-temperature heat sources in partnership with Enogia. The machine was tested in actual operating conditions, where it delivered maximum power of 630 We from heat sources between 90° C and 110° C . The heat-transfer fluid was chosen for its very low environmental impact. Work to improve the machine is ongoing with a PhD dissertation on the optimal zeotropic mixture. The goal is to reach 1 kWe. The compact, lightweight (0.1 m^3, less than 80 kilograms) ORC machine could open the door to new opportunities to recover waste heat from road vehicles and maritime vessels, isolated homes with solar thermal systems, and other sources. ■

*Organic Rankine Cycle

ADVANCED MANAGEMENT OF METZ URBAN HEAT NETWORK EVALUATED

Liten completed a feasibility study for UEM, which operates the urban heat network in Metz, France, to look into the potential benefits of an advanced management system. The thermal and hydraulic performance of 50 substations representative of the network was monitored during the 2016-2017 heating season. Liten then developed a simplified dynamic model and used the Pegase simulation platform to estimate the most economically-beneficial temperature-management point that factors in the cost of the renewable energy sources used. The study showed that advanced management could reduce heat losses on the network and make more efficient use of heat production resources with an attractive return on investment. Savings would be generated on day-to-day management, equipment maintenance, and CapEx planning. ■



www.uem-metz.fr

THE BENEFITS OF ELECTRICITY STORAGE FOR CORSICA

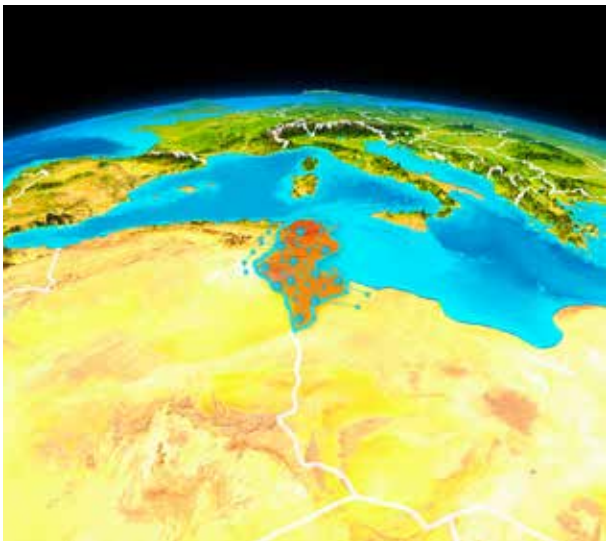
The Smarthyles study conducted in conjunction with French energy agency ADEME evaluated the technical and economic benefits of combining energy storage solutions (like batteries or hydrogen-based systems) with renewable energy production in Corsica, where local micro-grids are connected to the main grid. The study covered three use cases: maximizing self-consumption at a marina; maintaining the voltage stability in an isolated village; and simulating load shedding during ship-to-shore connection of ferries at berth. Simulations completed using the Odyssey and Spider platforms showed that storage, when combined with a source of renewable energy, can enable a broad range of services whose value (estimated roughly due to the changing regulatory landscape) would limit cost increases in an island context. ■

MULTI-DOMAIN MODELLING OF CONCENTRATOR SOLAR POWER PLANTS

Liten's research includes advanced modelling for the development of technologies for concentrated solar power plants. Due to rapid fluctuations in sunlight, solar processes are characterized by complex dynamics. Multi-domain modelling, which covers command-control, optical, and thermohydraulic components, can be used to test different plant management scenarios virtually in different operating conditions. Each domain is addressed with an ad hoc simulation tool; the models are then assembled and co-simulated on the Pegase platform.These dynamic modelling capabilities have already been used to evaluate several regulation strategies during periods of passing clouds when up to 100% of sunlight can be blocked out. The researchers plan to experiment with other uses, including advanced regulation strategies and testing in accidental situations. Ultimately, the tools could be used for operator training and to fully automate future plants. ■

STEG SETS SIGHTS ON SMARTGRIDS

STEG, Tunisia's gas and electric company, now has a road map to increase the contribution of renewable energy to the nation's energy supply tenfold in twelve years. A joint CEA-STEG team supported by several energy-industry professionals looked at the Tunisian national grid's needs, limitations, and unique features and came up with recommendations to implement 38 smart grid technologies according to a specific schedule. Liten also offered to support STEG with the installation of 400,000 smart meters, which will provide access to consumption data in real time, as well as forecasting and scheduling tools to constantly balance supply with demand, factoring in the integration of renewable energy. ■



NEW FEDERATIVE PROJECTS

SUPREME

BRINGING THE CIRCULAR ECONOMY TO POWDER METALLURGY

The SUPREME project aims to make powder metallurgy more efficient (energy, water, yields) across the entire value chain, from mining/extraction and powder manufacturing using grinding and atomization through to implementation (3D printing, sintering). Demonstrators will be developed for several applications: automotive (CRF), cutting tools (DELLAS), aeronautics (PRISMADD), prosthetics (MBA), and machine tools (IPC/MOO). Liten is contributing in particular to the use of high-carbon and 316L stainelss steels for 3D printing for the automotive and energy industries, respectively, and 17-4PH steel for injection molding for the medical industry.

START DATE 01/09/2017 ▮ DURATION 3 YEARS ▮ FINANCED BY HORIZON 2020 ▮ TOTAL PROJECT BUDGET €7.9 MILLION ▮ COORDINATOR LITEN ▮ PARTNERS 17

NENUFAR

NEXT-GENERATION ENERGY STORAGE FOR "MORE ELECTRIC" AIRCRAFT

NENUFAR is an EU H2020 project that is part of the Clean Sky 2 sub-program. The main objective of the NENUFAR project is to help reduce the environmental footprint of airplanes in flight and on the ground. Specifically, the project aims to lower noise and CO_2 and NOx emissions. Making aircraft "more electric" requires increased energy storage capacities. The solutions currently on the market do not meet the needs of aircraft, mainly due to high system-level specific energy, especially when all of the safety-related components required for Li-ion batteries have been integrated. The scope of the NENUFAR project extends beyond energy storage, however. The project also addresses charging and system architecture. The four-year objective is to build two TRL5 demonstrator battery systems of different voltages integrating battery modules, a BMS, a charger, and a communication system. The planned research will leverage existing technologies and modelling/simulation capabilities to support development work and gain a greater understanding of the mechanisms that underpin aging, thermal runaway, degassing, and—in extreme situations—fire at every stage of the project. Specifically, the CEA will contribute know-how in battery degradation modelling and mechanisms.

START DATE 01/01/2018 ▮ DURATION 4 YEARS ▮ FINANCED HORIZON 2020 ▮ BY TOTAL PROJECT BUDGET €5 MILLION ▮ COORDINATOR LITEN ▮ PARTNERS 4

JUPITER 1000

A POWER-TO-GAS DEMONSTRATOR SYSTEM FOR THE PORT OF MARSEILLE

The main goal of the JUPITER 1000 project is to build a 1 MWe power-to-gas demonstrator unit that feeds hydrogen and SNG into the natural gas grid at the Marseille-Fos industrial port. The project unites France's major power-to-gas stakeholders. Upon completion of the project, a business plan will be developed and regulatory recommendations will be submitted to policymakers to facilitate the emergence of power-to-gas technology at the European level. The project supports the energy transition by developing an additional large-capacity energy storage solution that does not require new infrastructure. The primary challenge for the CEA is to implement its compact CO_2 methanation reactor-exchanger technology on the demonstrator system. Liten is also contributing to the technical, economic, and environmental assessments of the technology and to developing management strategies for this type of unit.

START DATE 01/03/2016 | DURATION 5 YEARS | FINANCED BY ADEME | TOTAL PROJECT BUDGET €30 MILLION | COORDINATOR GRT GAZ | PARTNERS 9

OSMOSE

COMBINING FLEXIBILITY ASSETS FOR MAXIMUM INTEGRATION OF RENEWABLES INTO THE GRID

The OSMOSE project will identify, test, and evaluate the different flexibility solutions required for tomorrow's electricity grids, where renewables (and, especially, PV and wind) will account for an increasing proportion of production. Storage, demand management, and grid operation solutions will be investigated and the optimal combination of flexibility assets will be determined based on simulations. The framework necessary for the appropriate development of flexibility solutions will also be examined. What makes the OSMOSE project unique is its comprehensive approach—the project effectively breaks down silos and encompasses all aspects, from assessing needs to testing (via four demonstrators) various combinations of flexibility assets to power shared services. The CEA will coordinate the transfer of results to support implementation of the appropriate flexibility assets on electricity grids.

START DATE 01/09/2017 | DURATION 4 YEARS | FINANCED BY HORIZON 2020 | TOTAL PROJECT BUDGET €28.3 MILLION | COORDINATOR RTE | PARTNERS 33 INCLUDING 6 TSOS

NEW PARTNERSHIP WITH TAIWAN'S ITRI

ITRI originally focused on microelectronics. Today, the institute is ramping up its R&D in energy and the environment, with programs, facilities, and human resources comparable to Liten's. The two institutes' complementary know-how, approaches, and ecosystems led them to join forces to innovate for industry. A Memorandum of Understanding was signed on June 7, 2017, marking the start of a partnership that has already generated two joint research topics (3D printing of metal powders and solid-state batteries). The partners are also discussing potential joint projects on fuel cells, PV cells, and smart grids.

ITRI
Industrial Technology Research Institute

TECHNOLOGY PLATFORMS

BIOMASS PLATFORM

Our biomass platform—unlike any other research facility in France—is exploring ways to achieve high-yield energy production from waste. R&D at the platform covers grinding, torrefaction, pyrolysis, hydrothermal liquefaction, and gasification at a scale that can be extrapolated to industrial processes. The platform works with around fifteen industrial and manufacturing corporations, including CMI, Valoneo, Leroux & Lotz and more recently Vinci Envirommement.

PHOTOVOLTAIC SOLAR PLATFORM

This platform was set up to support French and European solar-energy industry by conducting R&D on PV materials, processes, and equipment. The platform's signature asset is its Heterojunction LabFab, a pilot production line capable of manufacturing heterojunction PV cells with yields of over 20%. The platform has partnerships with more than 100 companies, from small- and mid-sized businesses Semco Technologies, Thermocompact, B.E.A., Sunpartner, CNR, ECM Greentech, Armor...) to large corporations (Enel, EDF-PWT, Arkema...).

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 like heat pumps, boilers, and thermal exchangers. Around 50 industrial partners, including Total, Engie, CCIAG, Safran, Alfa Laval and Roquette are currently engaged in R&D projects with the platform.

SMART-GRID SYSTEMS PLATFORM

This platform looks at how to scale, operate and optimize energy systems connected to intermittent power sources and electricity storage systems. The platform has all of the necessary equipment to study a variety of grid configurations, manage system components, and determine effective operation strategies. Around 50 industrial partners, including corporations like RTE, Valorem, Socomec, Cap Vert Energie and UEM are conducting R&D with the platform.

BUILDING ENERGY PLATFORM

Our building energy platform is available to homebuilders and building materials manufacturers seeking ways to improve building energy performance and occupant comfort. Focus areas include new construction methods and approaches, opaque and glass wall solutions, materials, insulating coatings, smart windows, innovative ventilation systems, solar sensors, BIPV, system and heat storage. The platform has a staff of 40 people and five instrumented test buildings including a new building envelope component testing unit.

HYDROGEN PRODUCTION AND STORAGE PLATFORM

This platform is developing hydrogen production and storage technologies for energy applications. It is one of the world's leading patent filers in the fields of high-temperature electrolysis and solid oxide fuel cells. The platform tests demonstrator systems like storage tanks, for example, and works with around ten industrial partners including Vinci Entrepose, NGK, PSA, Vicat and startup Sylfen.

ELECTRIC MOBILITY PLATFORM

Our electric mobility 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, conducted either at a closed site or in the open, provide valuable feedback on battery and fuel-cell performance, cycling, and aging. Around ten industrial partners—battery, fuel-cell, and combustion-powered or electric vehicle manufacturers—use the platform.

BATTERY PLATFORM

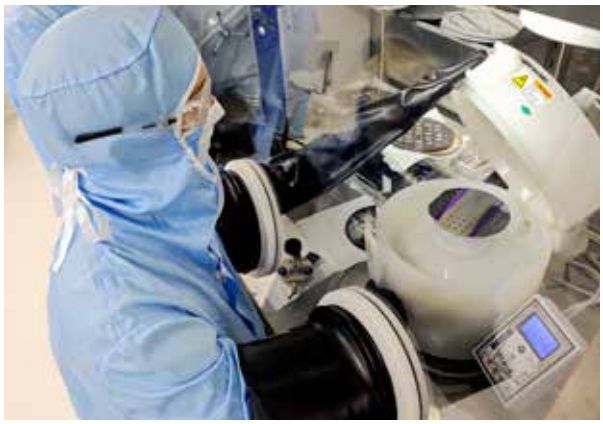
The battery platform develops and manufactures small series of lithium-ion batteries, covering the entire value chain from materials and components through to pack assembly, integration into systems, and testing. The platform's work targets applications ranging from hearing-aid to electric buses. The platform is the largest and most technologically-advanced battery R&D center in Europe. More than 30 industrial partners are using the platform, from small businesses to corporations like Renault, Umicore, and Solvay.

FUEL-CELL PLATFORM

This platform conducts research to improve PEMFC performance and lifespans while reducing costs. The platform's integrated approach covers materials, membrane-electrode assemblies, stacks, and testing in real-world conditions. The R&D conducted at the platform is at the international state of the art and results in between 10 and 20 patents filed each year. Around ten industrial partners, including Michelin, Faurecia and Safran, conduct R&D at the platform.

MICRO-ENERGY-SOURCE PLATFORM

This platform is developing micro fuel cells to power mobile devices like smart cards, sensors, and laptop computers. The platform possesses equipment for industrial process scale-up and focuses on optimizing materials, using techniques like screen printing and PVD-CVD (physical/chemical vapor deposition).



LARGE-SURFACE PRINTING PLATFORM

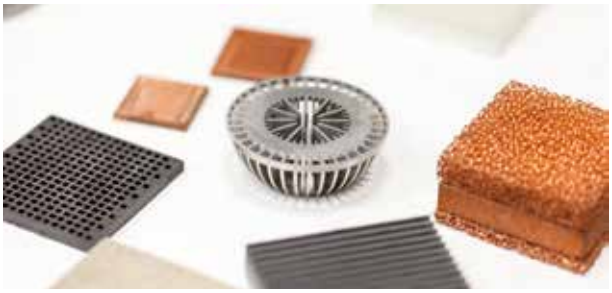
The Pictic large-surface printing platform enhances plastic, paper, and textile substrates by enabling them with electronics like sensors, optics, logic circuits, and display systems. The applications for these flexible circuits include human-machine interfaces, smart lighting, interactive displays, and environmental monitoring. The platform has partnerships with several companies based in France and further afield, including startups Isorg and Symbiose, Japanese chemists and paper manufacturer Arjowiggins.

NANOSAFETY PLATFORM

The nanosafety platform investigates protection, health, and security 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. No other facility in France—or probably Europe—offers such a broad range of services.

POUDR'INNOV 2.0 POWDER METALLURGY PLATFORM

The POUDR'INNOV 2.0 platform develops and produces high-added-value components from metal, ceramic, semiconductor, and magnetic powders whose properties have been enhanced—in some cases surpassing the properties of the traditional material. The platform's work targets the energy, power electronic, healthcare, fine chemicals, and other markets. Around 50 people staff the platform. Facilities : powder injection, compaction, sintering, additive fabrication, brazing and diffusion bonding.



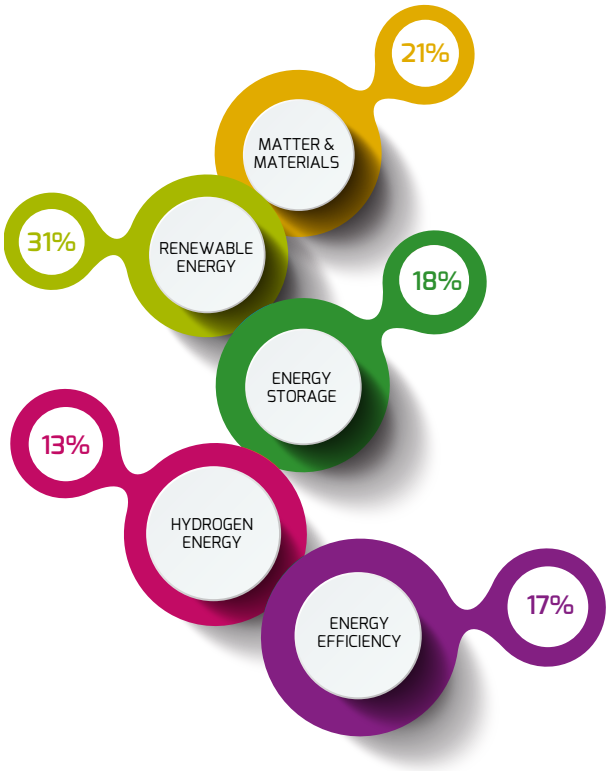
NANOCHARACTERIZATION PLATFORM

The development of nanomaterials and components requires in-depth knowledge of the underlying morphology and chemical and physical properties. The nanocharacterization 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. The platform works with around 20 characterization equipment manufacturers and industrial partners.

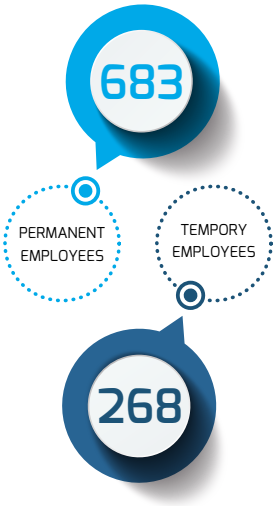
KEY FIGURES

WWW-LITEN.CEA.FR

R&D STAFF BY PROGRAM



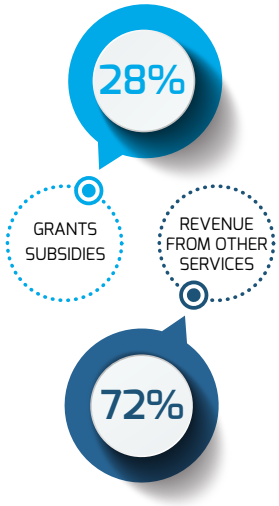
TOTAL STAFF



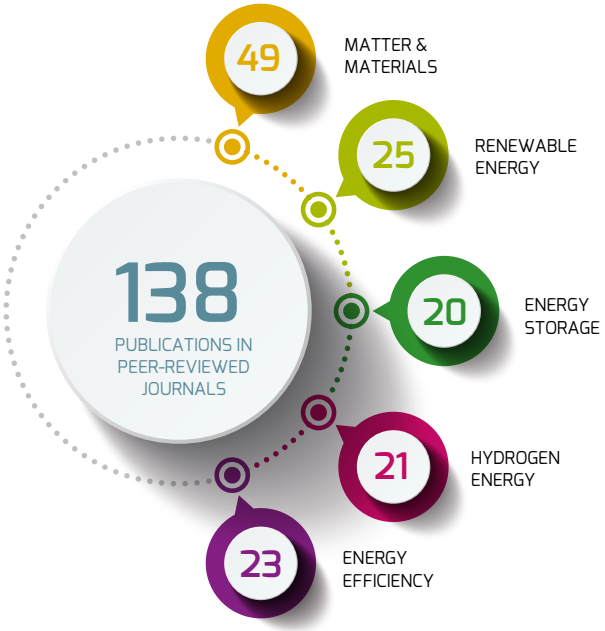
BUDGET

OPERATING BUDGET

€ 125 MILLIONS



BREAKDOWN PUBLICATIONS



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PATENTS IN PORTFOLIO AS OF END-2017