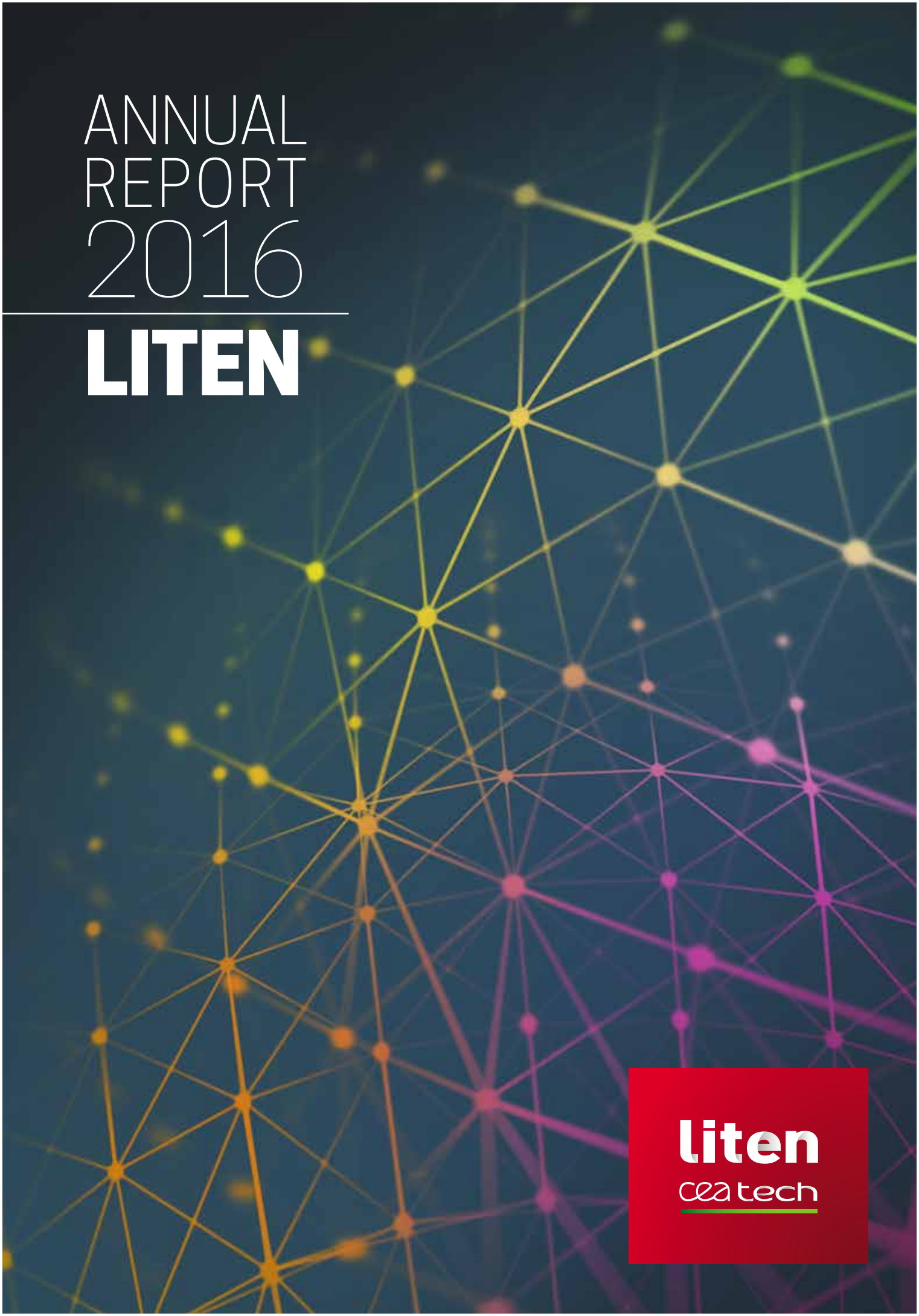
ANNUAL
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LITEN
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# DIRECTOR'S FORWARD

## Liten, leading the way in France's renewable energy landscape

Renewable energy research at Liten is structured to support the French government's energy transition policies, with activities focusing on the following areas:

- Renewable energy production, with a specific emphasis on solar and bio-based energy. Research at Liten covers the entire value chain, from component fabrication and integration into basic systems through to integration into energy systems characterized by far greater complexity—microgrids, neighborhood grids, and, in the future, municipal and regional grids—and often including storage capabilities.
- Energy efficiency, with a focus on energy-efficient buildings and industrial processes.
- Reducing greenhouse gas emissions and, in particular, carbon dioxide, through advances in electric mobility and $CO_2$ recovery using a variety of conversion technologies.
- Finally, our materials efficiency research is playing an increasingly crucial role. Our work includes synthesizing new generations of materials and developing new processes like 2D and 3D printing.

This year's Annual Report highlights the results of our research in these pivotal areas. At end-2016, Liten had achieved some major technological advances in electrical, thermal, and hydrogen energy. Read on to learn how Liten's comprehensive systemic approach to these different energy carriers is leading to energy efficiency gains, mainly through co-generation technologies.

The energy sector saw several major events in 2016. The first was the French government's decree enacting the initial measures of the nation's Energy Transition for Green Growth Act, a piece of legislation with clearly-stated renewable-energy targets that will bring about an energy revolution characterized by distributed production and storage resources. We also pursued work in an area we began focusing on several years ago: the development of software platforms to enable the dimensioning and agile management of complex energy systems.

We demonstrated our capacity for innovation in 2016 by filing a substantial number of patents as in previous years, helping to secure the CEA's position as one of the world's most innovative organizations for the sixth year running. Hydrogen also took center stage in France in 2016 with the government's call for local hydrogen-energy projects. These projects will produce a large number of demonstrator systems and prototypes that will help clarify the role hydrogen will play in the energy transition.

Last but not least, 2016 was a banner year for Liten's international development, with new international partnerships with Morocco's Masen on concentrator thermal solar energy, with Tunisia on smart grid implementation, and with India through the new International Solar Alliance.

**Florence Lambert,**
*Director, Liten*

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# LITEN: THE DRIVING FORCE BEHIND THE SUSTAINABLE ENERGIES OF THE FUTURE

Liten is Europe's largest renewable-energy technology research institute. Based mainly in Grenoble and Chambéry, France, we boast high-quality facilities staffed by world-caliber scientists and engineers prepared to lead the energy transition.

Liten, the Laboratory for Innovation in New Energy Technologies and Nanomaterials – a branch of France's leading research organization, the CEA – is spearheading the EU's efforts to limit dependency on fossil fuels and reduce greenhouse gas emissions. Liten is the only research institute to cover the entire value chain, from the synthesis of materials to the development of complex demonstrator systems. Liten offers its industrial partners personalized technology development services and digital dimensioning tools for energy systems.

## 400 R&D agreements each year

We are the partner of choice for manufacturers of all sizes, regardless of where they are on the technology value chain. Every year we put in place 400 research contracts and carry out R&D on behalf of industrial partners from a wide range of market segments: energy, transport, construction, civil engineering, environmental, and IT industries, amongst others.

## 1,400 patents: a robust intellectual property portfolio

Intellectual property forms a major part of our activities. We have a portfolio of more than 1,400 international patents and are one of the CEA's most active generators of intellectual property, filing around 230 patents per year.

## A three-pronged approach to strategic research

Our R&D addresses technological and economic challenges in three main areas:

- Renewable energy, especially solar and biomass.
- Energy efficiency and energy storage, including environmentally-friendly mobility, energy-efficient buildings and building energy management, and power generation systems (from production and storage through to conversion and management of thermal energy, electricity, and gas).
- Materials for energy and new environmental challenges.

## Liten a partner of energy initiative Institut Carnot Energies du Futur

Liten and ten academic research labs worked together to renew their Institut Carnot accreditation in 2016. The institute is now poised to build on a decade of efforts to create direct partnerships between research labs and industrial companies. And, to continue to drive innovation, around 20 technological innovative research programs were set up, ranging from renewable energy production to grid management. These programs will pave the way for future partnerships.

INSTITUT CARNOT Energies du futur

## INES 2: the INES Energy Transition Institute

Liten, along with its partners at the French Solar Energy Institute (INES), is eligible for government funding as an Energy Transition Institute (a French government initiative). INES 2 was set up to support and accelerate the development of France's solar-energy industry, from PV and solar thermal energy production through to building-integrated systems and grid integration. The funds allocated to this program are helping expand the existing technical facilities and supporting research and training at the international state of the art.

ines INSTITUT NATIONAL DE L'ENERGIE SOLAIRE
ITE – Institut pour la Transition Énergétique

www-liten.cea.fr

# WORKING WITH LITEN

At Liten, we are poised to meet the needs of businesses of all sizes, from start-ups and SMEs to major multinationals. Our main facilities in Grenoble and Chambéry, France, are supplemented by regional offices in Bordeaux, Metz, Toulouse, Nantes, Cadarache and Lille, and by experimental technology platforms in Cadarache and Corsica.

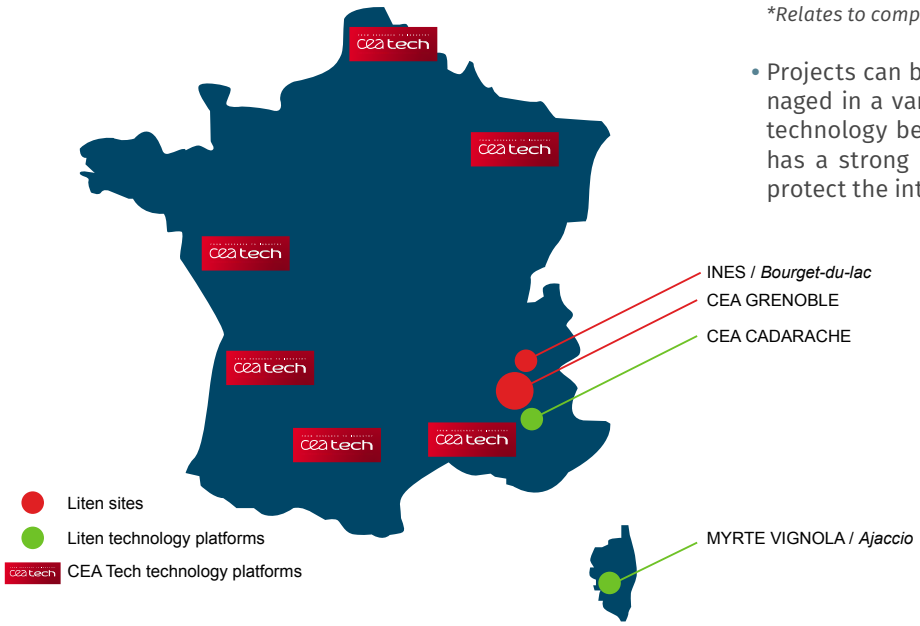
We offer a flexible range of R&D services that can be tailored to our industrial partners' specific innovation strategies. Our turnkey services are designed to boost our partners' competitiveness, with targeted solutions for all stages of technology development, from material characterization and economically-viable components through to complete systems to address the current and future needs of a specific market. Moreover, all our services are provided in an ISO 9001-certified environment with the right systems and resources to ensure confidentiality, cost efficiency, and on-time completion of development projects.

## Choose from four types of partnership

- **Industrial research agreement:** Covers a given time period and a 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) to secure additional financing and extend a project's reach. Our engineers have proven experience with this type of collaborative project and can provide expert assistance at all stages.
- **Affiliate programs:** Multipartner R&D programs with simplified administrative procedures; especially suited to SMEs with little or no in-house R&D capabilities.
- **Joint R&D lab:** We set up a joint research team with our partner under a reciprocal agreement for a period of up to several years. Shared goals, technology milestones, and joint management mechanisms are outlined in the agreement.
- **Technology transfer:** Partners can license our technology under certain conditions, and benefit from our technical support to transfer mature, patented technology to industry.

## A tailor-made offering

- We tailor the technical resources, number of scientists and engineers, budget, and calendar for each joint development project to meet each partner's unique needs.
- In some cases*, 60% of the R&D costs billed to our partners may be eligible for the French government's Research Tax Credit program.
  **Relates to companies paying tax in France.*
- Projects can be financed and intellectual property managed in a variety of different ways depending on the technology being developed and its maturity. The CEA has a strong intellectual property policy designed to protect the interests of its partners worldwide.



# MATTER AND MATERIALS

**New processes, improved performance**

At Liten, we carry out targeted R&D programmes to improve the performance of materials for energy and flexible electronics. Our researchers are coming up with innovative solutions that leverage nanostructuring to exacerbate given material properties, or combine several different materials when no single one can meet an application's specifications. We are also developing alternatives to some current materials—rare-earth elements, indium, gallium, lead, and solvents—that could become difficult to procure or use due to geopolitical, economic, or regulatory transformations.
And our materials work doesn't stop there. 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 and processes (by addressing process energy efficiency and eliminating substances like solvents); and integrate greater proportions of recycled material. Since 2016, we develop plastronics solutions applicable in a wide range of industries.

## MATERIALS ENGINEERING

### New strip-casting equipment ready to produce NdFeB alloys

Liten acquired and installed strip-casting equipment to produce the neodymium-iron-boron (NdFeB) type alloy ribbons crucial to the manufacture of permanent magnets. The laboratory-grade equipment, unique in France and virtually anywhere else in Europe, can handle 10 kg to 50 kg fusion baths. The metal is melted down by induction coupling before being cast on a variable-speed roller. Solidification speeds can reach $10^5$ K/min. The equipment will provide researchers with the resources they need to address challenges to obtaining high-performance NdFeB magnets like optimizing magnet composition from the alloy-formulation stage, recycling spent magnets, and controlling microstructures to generate fine powders.

### NdFeB ribbons with homogeneous structure

Initial tests on the strip-casting equipment acquired by Liten in 2016 delivered some promising results. The NdFeB ribbons obtained presented a homogeneous microstructure with quite no alpha iron precipitates that are detrimental to the material's magnetic properties and with a magnetic dendrite thickness of less than five microns. Controlling the ribbons' microstructure has a substantial impact on the properties of the permanent magnets produced using the material and will ultimately lead to reductions in the amount of dysprosium required. Dysprosium is a rare-earth element that is added to prevent capacity loss at high temperature and can be eliminated by reducing grain size and improving the composition of the alloys used to make the ribbons. Liten's facility will be used to complete lab-scale tests to advance toward these objectives.

## Powder injection molded Ni-Zn magnetic ferrite cores

Liten demonstrated that powder injection molding (PIM) was suitable for the production of passive magnetic components for high-frequency circuits. The technique, which entails injecting a blend of powder and polymers, presents the advantage of allowing complex part geometries that can help evacuate heat and reduce component size at equivalent power capacities. The researchers made Ni-Zn magnetic ferrite cores and demonstrated that the material's properties were not altered at any of the steps in the process. The components made using PIM (with a commercially-available Ni-Zn ferrite powder) had the same structural and magnetic characteristics as components made using conventional (compaction and sintering) processes.

## Prodways and Liten develop new 3D metal printing technology

Liten and Prodways developed a new 3D printing process to make metal parts from a photosensitive organic liquid blended with a metal powder. The technique is derived from a method for manufacturing plastic parts and consists of depositing thin layers of the blend with a high load of metal; the paste is then polymerized by exposure to UV rays. Finally, the part undergoes cleaning, and then debinding and sintering (a heat treatment) to eliminate the organic fraction and produce a dense metal part. The new technique is up to five times faster than direct metal 3D printing and can be used with all types of metal. Overall production times and costs are lower than with traditional manufacturing technologies; plus the process is more energy efficient and produces parts with unique levels of precision.

## Poudr'Innov brings metal injection molding to manufacturers

Liten's Poudr'Innov powder metallurgy platform has demonstrated the technical and economic benefits of metal injection molding (MIM) for machining-free production of complex metal parts. The process was used successfully to make a model part presenting the largest possible number of geometrical challenges (hemispheres, meplats, angles, forks, micrometric branches). Once the researchers finalized the specifications, they improved the powder formulation and process parameters (debinding, sintering), which must be tailored to each type of part. They then produced 600 parts per hour with excellent dimensional reproducibility and a reject rate of less than 1%—all for a unit cost of less than €0.50. Manufacturers can take advantage of a full range of services offered by Poudr'Innov, right up to test production runs.

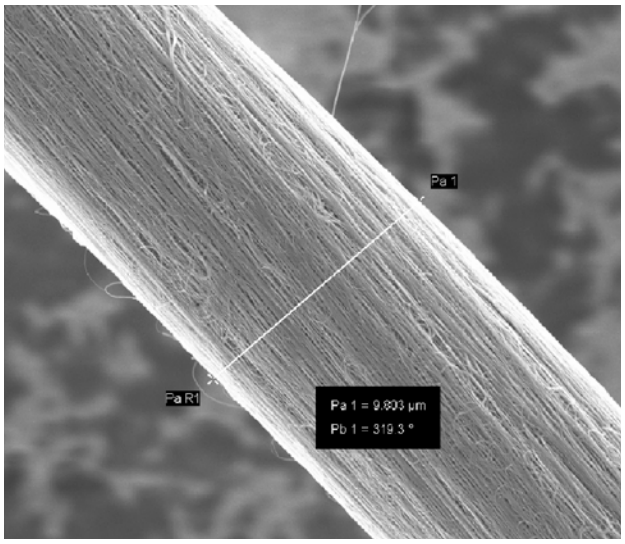
## Polymer air-liquid heat exchangers made using additive manufacturing technique

Several heat-exchanger prototypes were made from a polymer using stereolithography-type 3D printing. Several photosensitive resins and designs were tested before a very modular structure was chosen for the flexibility it offered in terms of configuring the heat-exchange area. The research also set out to show the benefits of 3D printing for designing low-cost, high-performance heat exchangers. The technique is well-controlled in lab conditions and allows complex part geometries (tubes, waves, channels, etc.) that can offset the performance losses stemming from the use of lower-cost materials than the metals typically used.

# NANOMATERIALS

## Carbon nanotube conductors for energy conversion and storage

Conductive threads of 20 µm in diameter and several dozen meters in length were produced from carbon nanotubes (CNT) using a technique borrowed from the textile industry. A substrate coated with a thin layer of iron is placed in a CVD reactor to grow carbon nanotubes. The density of the resulting "carpet" of nanotubes can reach $10^{12}$ CNT/cm$^2$. The conductor is obtained by pulling on one CNT, which pulls the others along with it, and placing it in a thread-spinning machine. The growth process must be improved further to boost the performance of the wire. The CNT-based threads are conductive and could be a lightweight, mechanically-robust replacement for copper wire. The wires also perform well at high frequency, putting them in the running for energy storage and conversion applications.

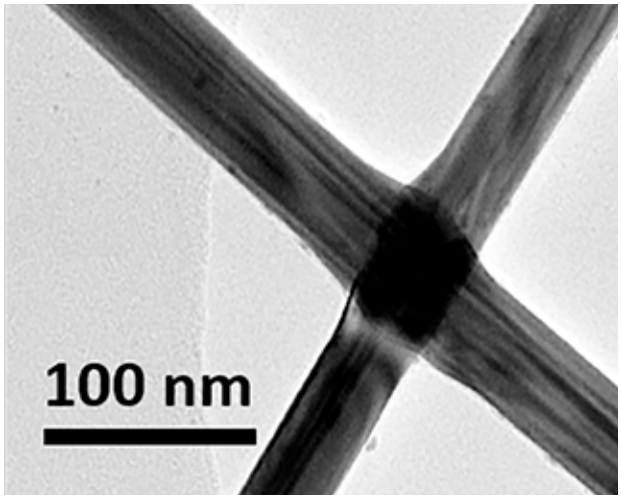



## NanoWet nanoparticle production laboratory opens

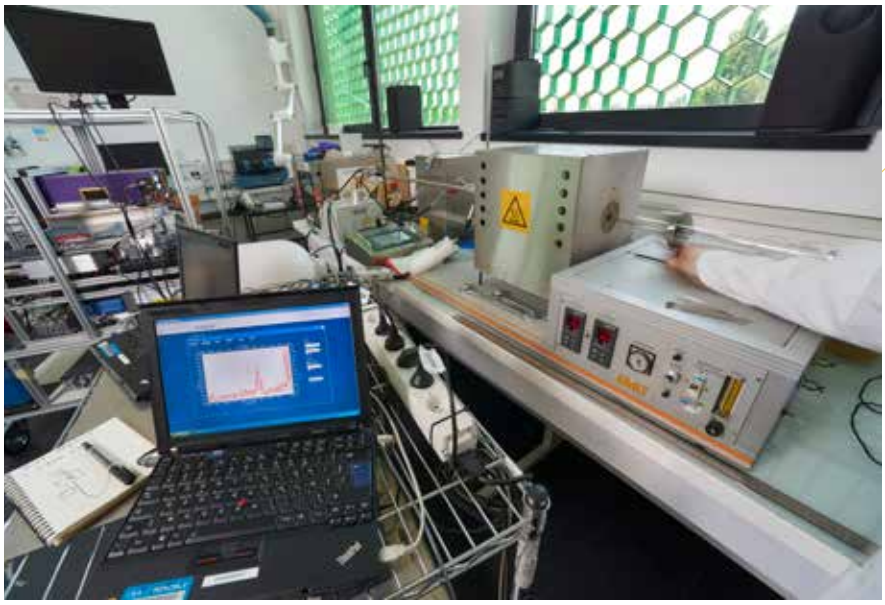
A test nanoparticle synthesis laboratory has been created at Liten. The lab can house a selection of equipment (20 liter glass reactor, microwave reactor, supercritical $CO_2$ reactor, etc.) for producing nanoparticles in aqueous colloidal solutions or solutions containing solvents. The laboratory also boasts treatment and purification equipment (centrifuge, extractor, tangential filtration system). Manufacturers can use the facilities to produce nanoparticles in quantities sufficient for initial representative tests. So far, two types of nanoparticles have been synthesized successfully: silver nanowires and yttrium vanadate nanoparticles. In both cases, the particles' morphologies, grain sizes, and optical and electrical properties were equivalent to what can be obtained at lab-scale.

## IR thermography to view electrical conduction pathways in percolating silver nanowire networks

Percolation pathways in silver nanowire networks were observed for the first time ever using the Lock-in Thermography (LiT) technique available at Leti. Holes in the structure of the silver nanowire networks make it possible to produce transparent, flexible electrodes. Tests were completed to demonstrate the discontinuous activation of conduction pathways in the electrodes when a current was applied under certain conditions. The capacity to observe the active conduction pathways provides new insights into the associated physical phenomena and a deeper understanding of the material's performance for the applications targeted. This new knowledge is helpful in determining strategies to improve electrode performance and homogeneity.



## Study on $TiO_2$ nanoparticle release during nanocomposite incineration



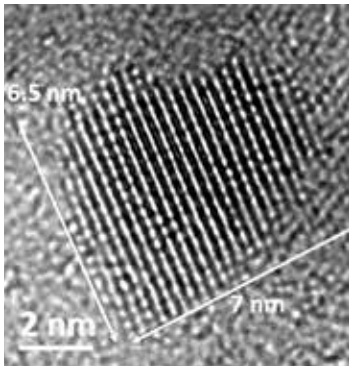
In research conducted under the EU-funded GUIDENANO project, the release of nanoparticles during the incineration of nanocomposites made up of polypropylene and $TiO_2$ nanoparticles, known for their flame-retardant properties, was studied. The tests were carried out in a laboratory furnace that very closely replicated incineration at 850°C. A variety of formulations were analyzed to identify which one released the smallest quantities of nanoparticles into the environment. The combustion fumes were collected at the incinerator stack and tested using different techniques. The research revealed that the fumes are made up of volatile organic compounds (VOCs), mostly nanometric in size and free from $TiO_2$, nanoparticles, all of which were accounted for in the incineration ash. “Safe by Design” practices to reduce VOC emissions are currently being tested.

## Structured surfaces with variable surface energy and controlled porosity compatible with large dimensions

Liten developed a process compatible with industrial scale-up for structuring polymer or composite surfaces to modify the surface properties such as those related to flow or tribology, for example. The friction between two mechanical parts submerged in water can thus be modified by trapping air at their interface. Hydrophobic particles are first deposited on the surface to be treated, and then partially encapsulated using a hot stamping process. A final cleaning step eliminates excess material, revealing hydrophobic cavities. The “super-hydrophobic” properties that result reduce the friction between a solid part and liquid, a quality that is of interest to industries with flow-related challenges. The process could also be of use in other fields like microfluidics, filtration, and optics.

## Transparent ultraconductive films with unique properties

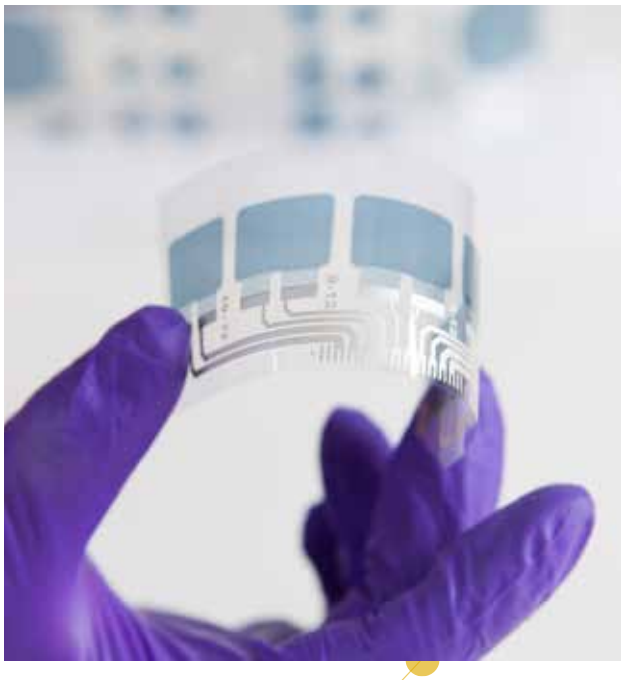
Liten produced virtually-transparent PEDOT films with never-before-seen electrical conductivity (5,400 S/cm) and remarkable thermoelectric performance. The dopant typically used was modified and the synthesis process was improved by adding an organic co-solvent, resulting in a patent. These enhancements increased the polymer doping rate and improved its crystallinity. The synthesis method produced highly-conductive films. The characterization work completed with INAC revealed the material’s structure and enabled the researchers to come up with a conduction model that explained the doping effect, which will help with future improvements. The films are the perfect candidates for applications in organic optoelectronics, electronics, and thermoelectricity.



# ORGANIC ELECTRONICS

## Joint research on printed electronics by Arkema and Liten earns kudos at TechConnect World 2016

Liten's joint research with Arkema and Arkema subsidiary Piezotech earned an Innovation Award at the TechConnect World 2016 international innovation conference and expo. The R&D partnership was set up in 2012 to develop and improve electroactive inks and use them in systems—memory components, piezoelectric and pyroelectric sensors, acoustic transducers—printed on flexible substrates. An ink formulation leveraging relaxor terpolymers was one of the innovations developed under the partnership. The ink's particularly beneficial electrostrictive properties offer potential for a broad range of applications, including human-machine interfaces, IoT, energy recovery, and haptic systems with touch-sensation capabilities.



## Touch-enabled dashboard demonstrator to be unveil at Geneva International Motor Show

Liten will unveil a partial demonstrator of a touch-enabled car dashboard made using printed electronics at the 2017 Geneva International Motor Show. The demonstrator, developed under the EU-funded Happiness project, consists of a mobile key and a touch-enabled interactive façade with eight capacitive sensors that present as push- or slide-buttons. The active components are printed on a polycarbonate film, and then thermoformed, cut out, and plastic-injection overmolded to obtain a single part. The materials selected are both conductive and compatible with the thermoforming process used. Ultimately, haptic switches made from a piezoelectric material that vibrates (200 Hz–300 Hz) when in contact with a human finger will be integrated into the demonstrator.

# HYDROGEN ENERGY

**Toward environmentally-friendly mobility and energy storage**

At Liten, our hydrogen-energy R&D mainly focuses on extending the range of clean electric vehicles to encourage their widespread adoption for intercity driving. Specifically, we are looking at ways to bring down fuel-cell costs and developing combined battery-fuel cell systems with advanced capabilities like self-regulation.
We are also looking at hydrogen as a way of storing energy as an alternative to batteries for making excess renewable energy available when needed. We are developing effective power-to-gas solutions that combine high-temperature, high-yield electrolyzers with ways to use the hydrogen produced, either by adding $CO_2$ to transform it into synthesis methane, or by making it directly available to industrial consumers.

## Successful Proton Exchange Membrane Fuel Cells (PEMFC)-type electrodes production run

Liten produced more than 270 electrodes for PEMFC on its pilot fuel-cell manufacturing line, achieving yields of 99% at the printing stage (not including irreducible waste). This excellent performance is proof that Liten's ink and electrode production processes are efficient at a semi-industrial scale, offering good reproducibility and, therefore, effectively controlled production costs. The electrodes were then combined with bipolar plates to make 20 kW stacks, the main component of the low-temperature fuel-cell system that will power the Energy Observer hydrogen-powered vessel. The next steps will be to determine reliable acceptability criteria that reflect electrode quality and to develop automated characterization and segregation tools.

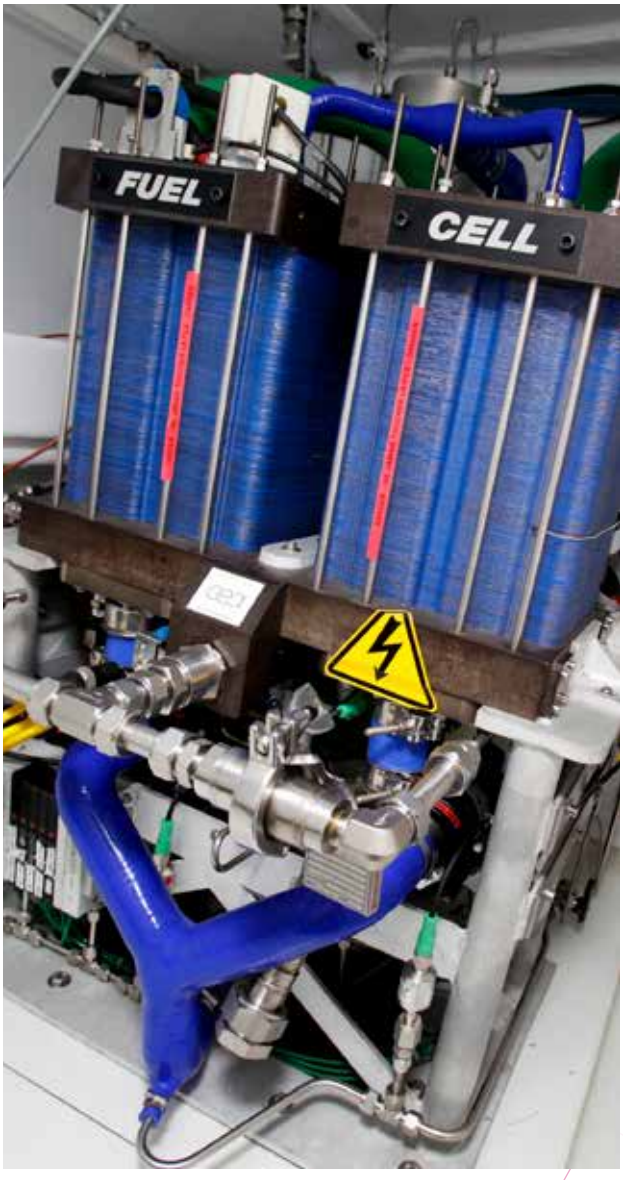
## Membrane-electrode assembly technology matures

A 20 kW stack made up of 240 cells was manufactured 100% at the CEA through research conducted with an industrial partner under the EU Hycarus project. The electrodes were designed and printed at Liten and the membrane-electrode assemblies (MEA) put together on the Materials Department's automated assembly line (DMAT). The MEAs were then stacked with CEA-designed bipolar plates in Grenoble on a recently-acquired stacking robot. The stack's performance was confirmed on a test bench, both for the low-pressure and low-humidity conditions required by the industrial partner (a company in the aeronautics industry), as well as for other conditions representative of automotive applications. The research confirmed that Liten's know-how can effectively contribute to the development of a PEMFC industry in France.

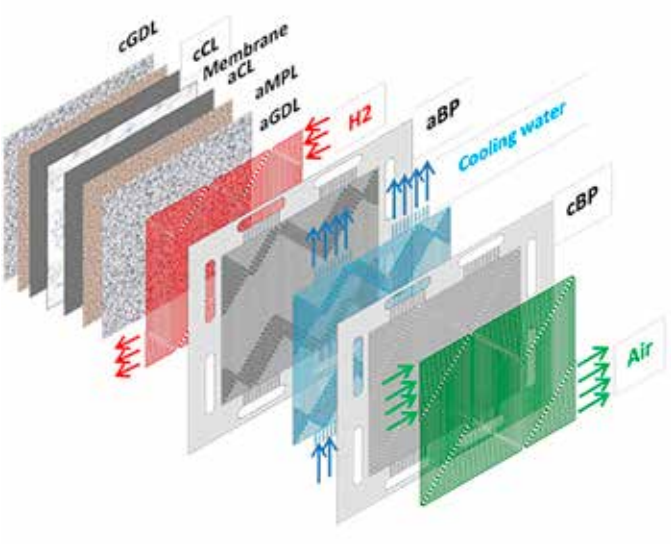
## Predicting liquid water distribution in PEMFCs

Water formation in membrane-electrode assemblies (MEA) is at the root of certain degradation mechanisms that affect the performance of proton exchange membrane fuel cells (PEMFC). Liten investigated water formation in research conducted with CNRS Toulouse and the Paul Scherrer Institute in Switzerland. Pore network modeling was used to generate theoretical results, which were then compared to observations of water distribution in a fuel cell during operation. The theoretical results were consistent with the water concentration profiles in the MEAs and with current density measurements taken using miniaturized sensors developed at Liten. The tools will be useful for improving water-management-related balance in PEMFCs improving overall performance and lifespans.

** PSI : Paul Scherrer Institut, Switzerland*




## Liquid water simulation and observation in high-power PEMFCs




A novel multiphysics model combining thermics, electrochemistry, and fluidics was developed at Liten to identify the phenomena that cause spatial heterogeneities in large-area PEMFCs. Local measurements of different parameters like temperature and current combined with neutron-beam images of the liquid water in the fuel cells during operation were then used to check the consistency between the simulations and observations, confirming the model's validity. The model will be useful in predicting liquid water distribution in different operating conditions. The initial simulations show a close relationship between water distribution, mainly affected by cooling-circuit design, and local degradation of certain fuel-cell components.

## Preventing reversible PEMFC performance degradation

Liten researched the reversible degradation mechanisms that affect PEMFC performance during operation. The drop in voltage observed just after start-up, restored after a long shut-down, could be due to the formation of platinum oxide PtOx at the electrode surface. Tests done on stacks at different voltages showed that the phenomenon abates at the lowest voltages—in other words, at voltages under the potential for PtOx reduction, confirming suspicions about the substance. The workaround the researchers came up with and tested involved regularly depriving the cathode of oxygen in a transitory manner (two seconds), causing a reduction of platinum oxides. This promising technique was presented at the Electrochemical Society Meeting.

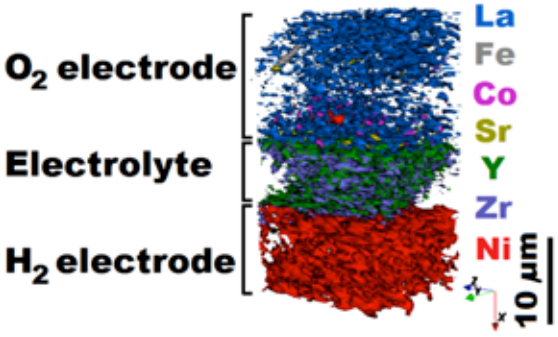
## A hybrid energy source for mobile applications

An energy source combining a fuel cell and a small battery was developed at Liten in partnership with Safran. The energy source developed has some interesting properties: power from 10 W to 30 W, an operating temperature range of –20°C to 44°C, and 72 hours battery life—all at around half the weight of a battery with similar properties. The hydrogen is stored as hydrides in the cartridge and interacts with water (borohydride hydrolysis) blended with antifreeze to produce hydrogen in real time, eliminating the need to store pressurized gas. The research also included the development of the energy management system and the mechanical integration of the energy source. The technology is safe, reliable, and robust, making it an excellent candidate for portable fuel-cell applications.

## Liten driving the development of France's hydrogen-energy industry


The *Territoires Hydrogène* call for projects kicked off in May 2016 at the initiative of Liten Director Florence Lambert as part of France's national industrial renewal policy. A total of around 30 projects were certified, with the CEA contributing to eight as a provider of either technology or know-how. The purpose of the call for projects is to develop models for the hydrogen economy at the local level. The innovative technologies developed at Liten are driving eight of the proposed projects, which cover seven regions, three types of local economies (urban and periurban, rural, and island), and a broad range of activities, including modelling and simulation on the Odyssey platform to pre-dimension and optimize local energy solutions. For some of the projects, the CEA will gather feedback on the technologies implemented, especially in the field of mobility. Finally, the CEA will develop and implement innovative technologies like high-temperature electrolysis. Sylfen will be subcontracting a high-temperature electrochemical converter subsystem to the CEA for several projects.

## Original combination of technologies used to characterize solid-oxide cells




In research conducted within Instituts Carnot Atrium project, Liten and Leti demonstrated the effectiveness of combining ToF-SIMS (Time-of-Flight Secondary Ion Mass Spectroscopy) and FIB (Focused Ion Beam) to produce 3D reconstructions of solid-oxide cell component chemistry and microstructure with a resolution of 100 nanometers. This type of detailed characterization is used to gain insights into the relationships between a component's chemical and microstructural properties and electrolyzer performance and better understand the active degradation mechanisms when operating at high temperatures. The technique, which was tested on a new cell, revealed issues related to the diffusion of nickel in the electrolyte and produced images of the 3D distribution of pollutants like aluminum, chromium, and silicon.

# RENEWABLE ENERGY

**From solar to bio-based energy**

Our renewable-energy research covers photovoltaic, solar thermal, and bio-based energy and spans the entire value chain, from materials to grid-connected systems. Prototyping at our technology platforms is one of the ways we ensure our work meets manufacturers' real-world needs.

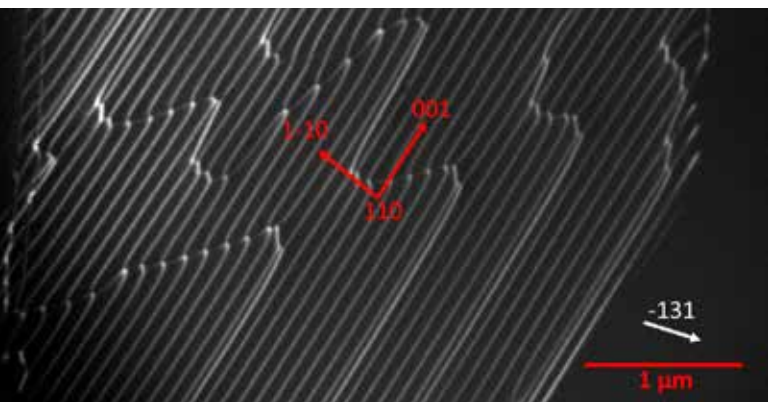
Our PV program focuses on premium modules offering very high yields and communications, self-troubleshooting, and other advanced features and on integrated modules designed for specific applications, such as the "solar road". Our solar thermodynamic work supports France-based companies in their efforts to develop solutions for foreign markets. Our bio-based energy research looks at ways to convert liquid and solid waste such as wastewater treatment sludge and solid recovered fuel into energy.

## SOLAR ENERGY



### Understanding how sub-grain boundaries form in monolike silicon ingots

Transmission electron microscopy was used to investigate defects in monolike silicon ingots obtained by directionnal solidification. The purpose was to gain insights into the mechanisms that influence the formation of sub-grain boundaries, undesirable defects that decrease the material's quality. The investigations revealed that the defects are actually made up of several types of tiny breaks, or dislocations, in the crystal lattice. The first type of dislocation propagates by epitaxy at the solid-liquid interface, which explains why the defect propagates at the ingot scale. Furthermore, mobile dislocations very likely play a role in the densification of sub-grain boundaries. As migration is hindered, they build up at the dislocation wall and are integrated into the defect, which is in turn magnified during the ingot's growth. These new knowledges could help researchers adjust certain solidification parameters to reduce the formation of such defects.



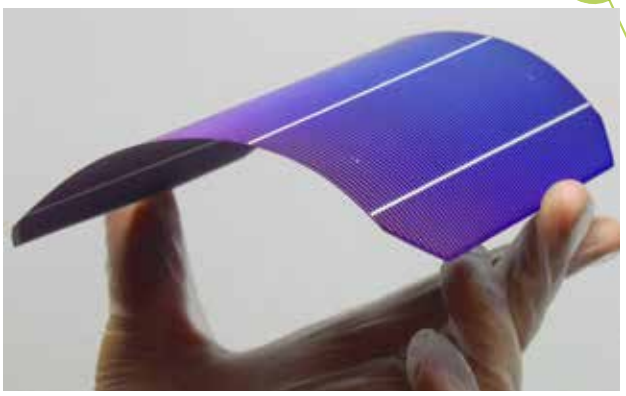

### Ingots crystallized from silicon recycled from PV production waste

Liten crystallized two silicon ingots from charges made from recycled PV-cell production waste. The first, a G1 (10 kg) ingot, was made using standard crystallization; the other, a G2 (55 kg) ingot, was made by growth on seeds (monolike). The ingots contain 24% and 100% recycled silicon, respectively. The silicon used to make the first ingot was purified using a vacuum fusion process developed at Liten; the silicon used in the second ingot was purified using an industrial chemical process. The resistivity of the ingots confirmed that recycled silicon is compatible with standard crystallization processes, even given the particular demands of monolike technology. Wafers have been prepared and cells are currently being manufactured from the ingots to assess the material's performance.

## LID falls below 2% in monolike silicon cells

The effects of light-induced degradation (LID), responsible for monolike silicon solar cell performance losses, were reduced to less than the 2% manufacturers generally require. LID mainly affects the top of the ingot, where metal impurities are segregated and was reduced by enhanced thermal treatments during the cell manufacturing. More specifically, the diffusion of phosphorus step was enhanced to augment a well-known mechanism called external gettering, in which metal impurities are drawn to the surface. This brought LID down to just 1.5% at the top of the ingot (the maximum observed). The result, which was obtained without adding any steps to the cell manufacturing process, will pave the way to industrial scale-up of monolike silicon.


## Heterojunction cells on 70-micron substrates



The feasibility of producing heterojunction (HET) photovoltaic cells on very thin substrates was successfully demonstrated. Wafers were produced and then thinned using KOH (potassium hydroxide) etching so that the production of thin cells could be investigated on Liten's LabFab pilot line.The thinnest cells were produced from 70-micron substrates (as compared to the traditional 160-micron to 180-micron substrates generally used) and delivered yields of nearly 19%. Similar yields were obtained on a four-cell mini-module, confirming the results. Because materials account for 30% of cell costs, thinner substrates are one way to help bring cell costs down and make the technology compatible with industrial scale-up.

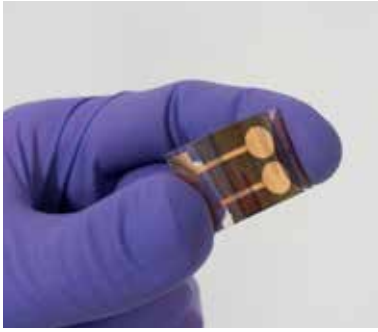


## Pulsion Solar ion implantation machine in full operation at Restaure platform

A Pulsion Solar plasma immersion ion implantation machine manufactured by IBS was installed at the French Solar Energy Institute (INES) Restaure platform. The machine, originally designed for the microelectronics industry, was successfully modified for use with photovoltaic manufacturing technologies. It will be used for the phosphorus (and later, boron) doping of solar cells. Substantial work went into ensuring uniform doping concentrations and improving the phosphorus implantation parameters. The semi-industrial prototype installed at the Restaure platform can process 21 cells at a time homogeneously and in a single chamber. More than 500 AI-BSF-type solar cells were produced with an average yield of 19.1% and very low dispersion. The next steps will be to conduct boron doping tests and, ultimately, obtain fully-doped (n and p) cells by plasma immersion.

## Perovskite solar cells with yields of 18%

Liten produced photovoltaic cells and modules using hybrid perovskite-type materials with yields of 18% and 12.4% for surface areas of 13 sq. mm and 8 sq. cm, respectively. The perovskite formulation and deposition process were substantially enhanced and n-type interface surface treatments were investigated to eliminate the need for high-temperature annealing. Annealing temperatures under 150 °C are compatible with heterojunction silicon technology, which, when used with perovskite to make tandem PV cells, could boost yields to more than 30%. Perovskite-type materials offer a number of benefits that include reasonable costs, ease of implementation, and very attractive optoelectronic properties, making them a promising candidate for tomorrow's PV solutions.



# SOLAR ENERGY

## Robust, lightweight photovoltaic modules for portable applications

Liten worked with industrial partner 2CA to design and produce lightweight yet rigid photovoltaic modules. The aluminum frame and tempered glass that protect traditional PV modules were replaced with pre-impregnated composite materials and 3D honeycomb reinforcements. The modules are three to four times lighter and at least three times thinner than traditional modules. The prototypes produced passed the most stringent aging tests required by standards IEC 61215 and 61730. The military market could bring the first opportunities for the innovative modules. However, they could also be used to power weather balloons. Finally, the modules' weight and shape can be adjusted to meet the needs of the target application.

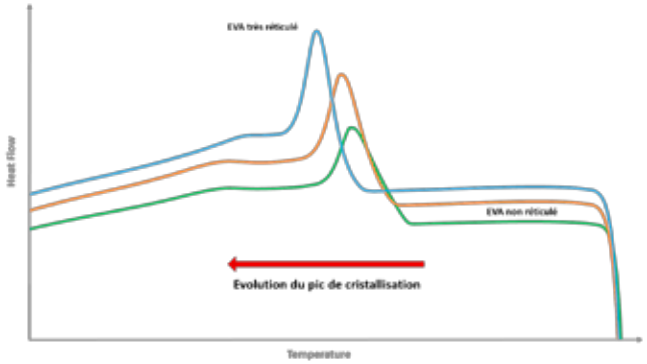


## Drone wings outfitted with ultra-lightweight photovoltaic modules

A custom ultra-lightweight photovoltaic module was designed to outfit a Sunbirds drone for use in addition to the drone's battery. The size of the module was determined based on commercially-available cells. The encapsulation materials were selected specifically to meet the weight, power, and reliability requirements of use on a drone. Module manufacturing processes and a method for integrating the module onto the available wing surface were also developed. The modules met the target requirements, passing IEC 61215 standard reliability tests with flying colors. The drone's range was extended from two hours to more than six hours. The manufacturing process was transferred to a France-based manufacturer. Sunbirds plans to start selling the drone in 2017.

## Materials evaluation method developed by Liten and Arkema included in new international standard

A method developed by Liten and Arkema for determining the reticulation rate of the materials used to encapsulate photovoltaic modules was integrated into a new international standard for photovoltaic modules, IEC 62788-1-6: 2017. The peak in crystallization of the encapsulant material is observed using Differential Scanning Calorimetry (DSC); the method takes just a few minutes and does not require toxic substances, contrary to the traditional solvent-extraction method. The method, called Melt Freeze, was shown to be effective on different types of EVA (ethylene-vinyl acetate) encapsulant materials and is currently being tested on other materials. Another method using Raman spectrometry is also being investigated in the lab in partnership with optics and photonics materials and systems lab LMOPS.



## Solar road now a reality

The ribbon on the world's first-ever solar road was cut on December 22, 2016 in Normandy. Liten made improvements to the paver manufacturing process and produced more than 1,000 units. Reject rates were brought down steadily throughout the production run to reach 3.9%. The solar cells delivered performed as expected, with maximum production of 118.9 Wp for each 4 cell x 7.5 cell paver, and the modules passed the most stringent PV IEC 61215 tests. Liten researchers will continue to work on module cost and reliability. One potential area for improvement is the complete system's electrical architecture. The goal is to reduce installation times and improve operation of the solar road's lifespan. Finally, the pavers will be given new features like lighting and heating for integrated signage and defrosting.

## First agrivoltaics demonstrator built at French Solar Energy Institute INES

A 10 kWp agrivoltaics demonstrator was built in partnership with the SunAgri2B project consortium. The project aims to create synergies between PV energy production and farming by planting crops under solar panels. To effectively produce energy while achieving acceptable crop yields, Liten dimensioned PV modules built on a double-glass architecture with enhanced transparency. The early prototypes built easily passed the weather durability and reliability tests required by the IEC 61215 standard. A total of forty-five 250 Wp modules were produced; the modules were then mounted on trackers (single-axis, east-west) three meters above the ground. The demonstrator system, which was set up at the INES INCAS platform, will be used to monitor energy production under different intermittent shade management scenarii.

## Semi-industrial demonstrator system with 60 bifacial PV modules could help bring PV energy costs down

A frameless double-glass module architecture optimized for monolike silicon cells was developed as a result of research conducted under the BIPPP project to develop a bifacial PV technology capable of collecting photons on both sides of the panel. A first semi-industrial demonstrator system with 60 modules was built. To build the demonstrator, 60 bifacial modules were produced on Liten's semi-automated assembly line at French Solar Energy Institute INES—a first. The modules power five 3 kWp PV systems each. Performance measurements, which are still ongoing, will be used to develop a numerical model to predict the production of bifacial power plants and assess the benefits of bifacial cell technology over one-sided cells. The project was financed in part by the French government's economic stimulus package, Investissements d'avenir.

# PV AND CSP POWER PLANTS

## Photovoltaic module arrays could soon get self-diagnosing capabilities

Liten developed electronics that can isolate an array of 20 photovoltaic modules from the rest of a plant and trace the current-voltage curve in just 100 milliseconds. The curve is then analyzed by software specially-developed to identify the electrical signatures characteristic of different types of faults. The system can also pinpoint the exact location of the fault in the production chain. In the future, faults will be detected and identified in record time, without stopping production or shutting down the inverter. A twelve-module (750 V, 12 A) prototype was successfully tested at French Solar Energy Institute INES. Life-sized testing will take place at six solar power plants in France in the coming months.

## Photovoltaics to help regulate grid frequency

With regulatory changes just over the horizon, Liten investigated how PV power plants can help regulate grid frequency, developing methods to calculate operating reserve capacity based on one-day production forecasts for a plant or pool of plants and plant management solutions. Technical and financial simulations completed using the SPIDER environment showed that committing to a downward reserve was profitable for PV plants. The use of electrochemical storage is being looked at as a way to provide upward reserve capacity. The new tools will be implemented at around 20 plants for a total of 120 MWp for 2017–2019. The demonstration will be a world first.

## Predicting concentrator solar plant production

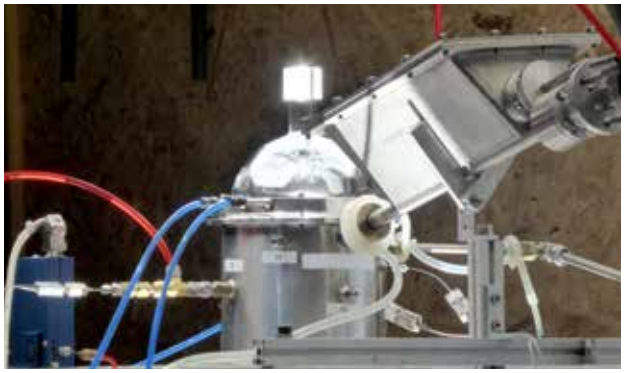
Liten developed a tool that can predict concentrating solar plant production based on direct sunlight forecasts. The tool leverages meteorological data to calculate direct sunlight. Next, a concentrator solar plant production model uses the direct sunlight calculation to predict production. The model becomes more accurate with use, learning from mistakes like gaps between predictions and actual measurements. During testing it predicted the thermal production of the prototype Fresnel plant at the CEA's Cadarache site with a margin of error of just 10%. The tool should help plant operators predict grid behavior and improve plant operation and energy storage strategies.

# BIOMASS

## GENEPI converts bioresources into energy

Liten's GENEPI platform opened in September 2016. GENEPI is a world-class facility that possesses all of the equipments and systems needed for the thermochemical transformation of biomass into syngas from preparation of bioresources by drying, grinding, and/or torrefaction through to gasification in a continuous-flow reactor. The platform, which includes a gasifier outfitted with an oxy-combustion unit, offers a set of characteristics unique in Europe in terms of flow rate, temperature (1,500°C), and pressure (30 bars). Tests completed on wood-based biomass were conclusive. The next steps will be to improve powder injection and dosing and test waste like solid recovered fuels (SRF).

## REACSOL transforms biomass into solar fuel



The REACSOL solar reactor developed by Liten was used for high-temperature gasification of biomass in tests conducted in partnership with CNRS-PROMES. The tests, carried out on wood-based biomass continuously fed into the reactor, provided an opportunity to compare different protocols and assess the influence of parameters like temperature (tests were carried out at 1,200°C to 1,400°C); the direct or indirect absorption of the concentrated solar energy; and the addition of water vapor or $CO_2$ to the process. The results showed that all of the energy contained in the biomass was converted and that some of the solar energy was stored in the form of a high-quality syngas. The tests confirmed the potential of solar reactors for endothermic reactions. Models of the reactions and transfers will be used to determine how the technology can best be extrapolated and scaled up.

## First fluidized-bed gasification tests on solid waste completed

Several gasification tests were completed on Solid Recovered Fuels (SRF) using Liten's high-temperature fluidized-bed gasifier, which was originally designed to convert biomass to gas. The research was conducted as part of a project to find an alternative way to turn non-hazardous, non-recyclable waste into energy. Currently, this type of waste, due to its high heating value, is incinerated at concrete plants. After gasification at 850°C using an autothermal process with air added for oxidation, around 60% of the energy contained in the waste was recovered as a syngas containing 70% of the incoming carbon. The syngas can be used for combined heat and power (CHP) generation. The process must still be improved further, especially to boost conversion efficiency and reduce tar concentrations in the syngas.

# ENERGY EFFICIENCY

**Recovering, storing, and redistributing energy**

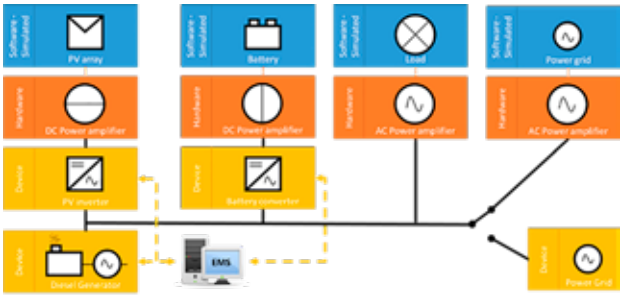
Developing effective ways to manage the intermittency of renewable energy will mark a crucial step toward grid integration. Finding solutions for managing the intermittent availability of power generated from renewable sources is critical if they are to be connected. That's why Liten is working on systems to store energy -from several hours to several months- then release it when needed.
Our researches focus on three markets: the construction industry, where we are developing models to predict building energy performance according to building components-like walls, glazing, and HVAC-and occupant usage; the manufacturing industries, where we are coming up with solutions to reinject waste heat from various processes or recycle it in other forms; and electricity grids, with simulations and optimizations to help right-size storage systems and determine optimal management strategies.



## First-ever smart solar mobility road opens in Corsica

Ajaccio, Corsica recently got its own 100% solar carport. The new station, along with the one that opened a few months ago in Bastia, mark the opening of the first-ever "smart solar mobility road." The service stations, operated by Driveco, produce their own energy using a 29 kWp solar power plant combined with a small stationary battery and can charge any type of electric vehicle at any time. The smart energy management system, designed in partnership with Liten, provides power to the charging terminals when an electric vehicle plugs in, or sends the electricity to the battery to be stored, or sends surplus energy back to the grid. It allows the service stations to operate on a network, which means that one station's surplus energy can be used to offset the consumption of another. The goal is to reach self-consumption rates of nearly 100%. Ultimately, 70 of such service stations will be rolled out in Corsica.

## Test bench for hybrid PV-diesel systems




The introduction of renewable energy into the energy mix in isolated areas can help reduce energy production costs and, as a result, curb the environmental impacts of conventional (diesel, gas, etc.) electricity generation. In efforts to work toward this goal, preliminary technical and economic studies leveraging simulation and laboratory testing were completed. The technical feasibility of the target hybrid solution was demonstrated. The hybrid PV-storage-diesel test bench developed by Liten responded to the need by delivering the capacity to investigate several system configurations with different control strategies (EMS) to boost PV energy penetration rates. The modular test bench can also be used to test hybrid systems combining real and emulated equipments up to the hundreds of kilowatts.

## First-ever experimental wood and concrete home built at Cadarache site

In the framework of a collaborative research project involving several partners (Trecobat, Atlantic, Velux, K-Line, Delta Dore, and Vicat), Liten helped design and build the first-ever experimental home to combine a concrete core offering excellent thermal inertia and lightweight wood façade panels. The house, built at the CEA Tech site in Cadarache, in the south of France, has been up and running for a year now, and the initial results are in. A novel cooling system with a sliding window that opens automatically onto an interior patio at night allows cool air to circulate throughout the house, cooling the concrete core. The air then escapes through a skylight, which is operated automatically depending on the indoor/outdoor temperature gradient. The system, used in conjunction with sun protection, keeps the home's temperature under 25°C all summer long. In addition, the crawl space under the house is used to remove "stale" and hot air from the house, recovering the heat with a heat pump in winter.

## Interactive software improves integration of new buildings' architecture into existing neighborhoods

Software for improving the integration of new buildings into existing neighborhoods was developed in research conducted under the French National Research Agency (ANR) MERUBBI project. The purpose of the project was to enhance the design of construction projects that aim to increase the density of existing city blocks. Liten developed an algorithm to calculate building's geometrical characteristics (windows, sun protection, etc.) to achieve optimal energy consumption by taking full advantage of solar energy while protecting the building from the sun's heat. The interactive software evolved with updated specifications the designer enters all along the project. An extension will be developed to support the overall integration of new buildings into existing neighborhoods. The extension will be able to simulate a neighborhood's potential for improvement, integrating the new building into a block of existing buildings with which it will interact in terms of energy.

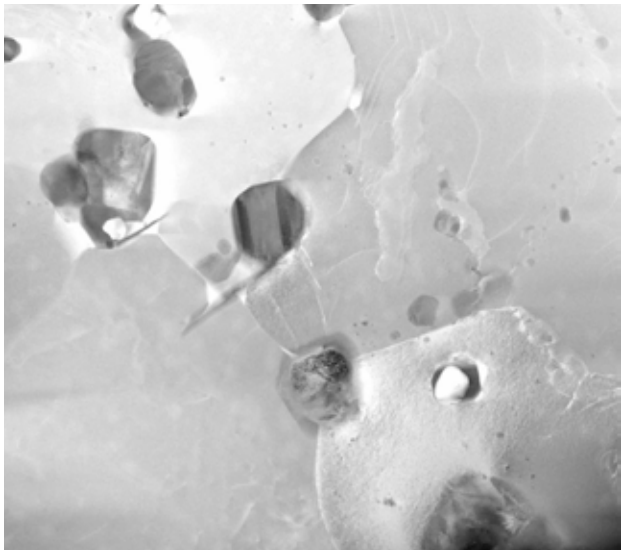


## INES gets new building envelope component testing unit

A new building envelope component testing unit was installed at the INCAS platform at INES. It is used to assess the performance of innovative technologies on a 1:1 scale over a year of exposure to the weather. The unit, called FACT (FAÇade Tool), was financed by the French government's economic stimulus package "Investissements d'Avenir". FACT is a modular testing unit made up of cells whose geometry and interior environment can be modified. Façade components of different thicknesses, widths, and heights and weighing up to four tons can be mounted on the structure. FACT is available for use for industrial R&D projects and publicly-funded research. Several such projects are currently making use of FACT, including the EU H2020 project Homeskin (hygrothermal measurements on a silicon aerogel superinsulated façade) and the Conipher (concrete insulation photovoltaic envelop) and Actidalle (cooling and heating slab).

## Improving hafnium distribution in half-Heusler alloys

The relationship between a half-Heusler-type material's microstructure and its thermoelectric properties has been established using TEM and SEM images that revealed the presence of hafnium oxide ($HfO_2$) nanoprecipitates at the material's grain boundaries and $TiO_2$ inside the grains. Understanding the role of hafnium in improving half-Heusler alloys' thermoelectric performance will help make better use of hafnium and lower hafnium contents in the alloys. Hafnium indeed accounts for 75% of the final cost of these alloys. A hafnium-free alloy was created and hafnium oxide precipitates were added directly to it. The method reduced the cost of the alloy by up to 60% while improving its thermoelectric properties.

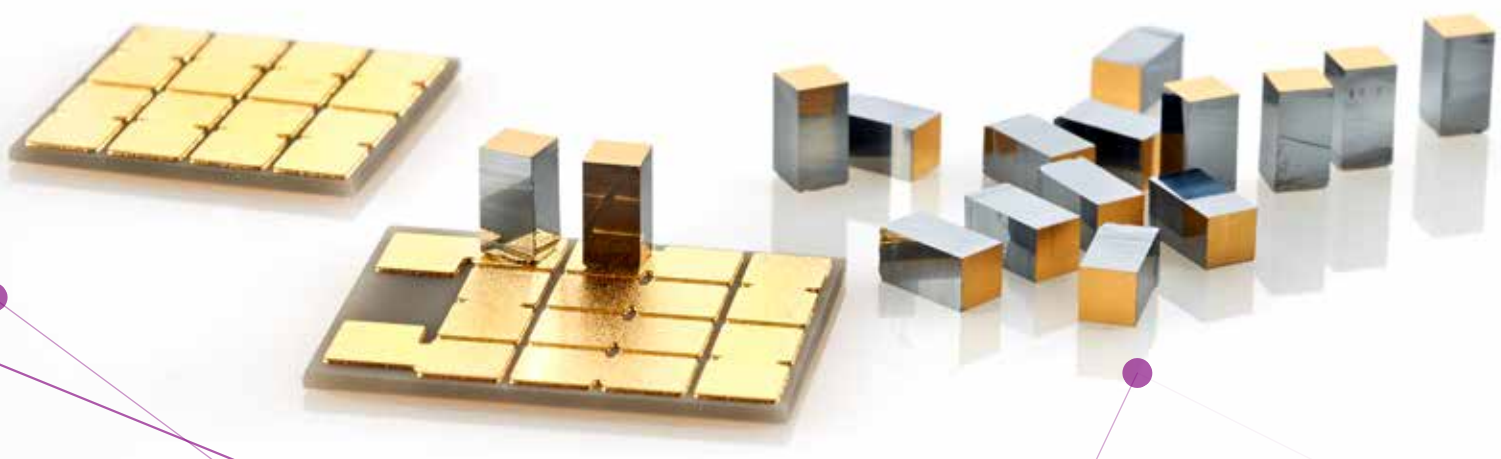


## AlmaBTE the first open-source multi-scale heat exchange simulation software

Liten released AlmaBTE, the first open-source software capable of simulating thermal exchanges in multi-scale systems with no need for previous configuration nor parametrization (www.almabte.eu). The software uses the Boltzmann-Peierls equation to simulate the behavior of nanometric structures in which various quantum effects generate heat not predictable using Fourier's Law dedicated for the macroscopic transport properties of heat. AlmaBTE is an extension of ShengBTE, software that manages heat transport in homogeneous materials. It can be used to design materials and structures to improve heat management in systems. Applications are mainly in GaN power electronics and all new technologies where heat transport is a crucial issue.

## Innovative, durable thermoelectric silicides enhanced and synthesized on a pre-industrial scale

Silicides are thermoelectric materials that offer excellent performance for their cost. In research conducted under the French National Research Agency project PHIMS, Liten modelled the materials' thermoelectric properties and made recommendations to reduce their thermal conductivity (such as by incorporating germanium). At the same time, Liten successfully scaled up the laboratory synthesis processes to reproducibly make up to two kilograms of the material with properties equivalent to those obtained at lab scale. The joint research on assembling the silicides resulted in the commercialization of thermoelectric modules by startup HotBlock OnBoard. The research is continuing, with a focus on improving the modules' durability for use at higher temperatures.



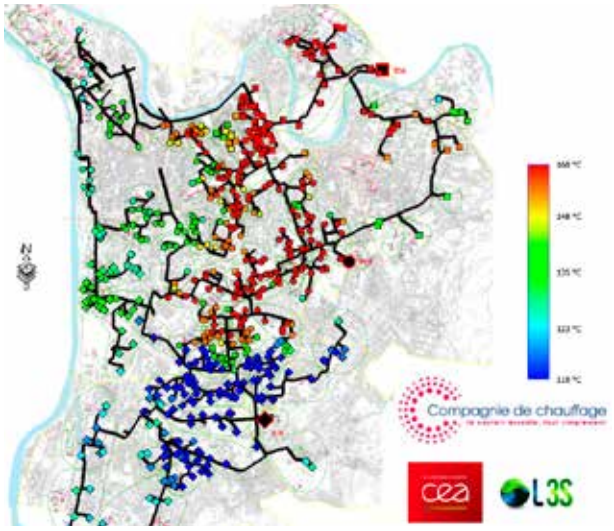
## Numerical model of batch fluidized bed reactor thermochemical storage system developed and approved

An innovative concept for storing heat for high-power concentrator solar power plants and high-temperature industrial heat was developed under the StoRRe project leveraging a lime hydration and dehydration principle. Liten completed around 60 charge-discharge cycles on a lab-scale batch fluidized bed reactor (discontinuous), confirming the numerical model of the system before experiments on a continuous reactor were conducted. These experiments were then conducted on Cochyse, a continuous test system unique in Europe, and marked another step forward toward representing the industrial-scale process so that it can be studied over several days. The researchers are currently working on scale-up.

## Smart thermal storage demonstrator system

The SETI project for smart thermal energy storage led by IDEX aims to develop a thermal storage system capable of using all renewable energy sources (solar, wind, heat recovered from wastewater, etc.) to feed urban heat networks. In the first phase of the project, which won the Bpifrance Concours Mondial d'Innovation, Liten helped design and build two prototypes of a compact thermal storage system with a capacity of 2 MWh and peak output of 1 MWth. Bio-based phase-change materials with high energy density (100 kWh/m$^3$) were identified and tested. Finally, the original patented tank design can store heat and electricity and make them available simultaneously as heat.

## Improving heat network management




A smart heat network management system developed under PhD research at Liten, also funded by ADEME and CCIAG, won second prize in the DHC (District Heating and Cooling) competition. The approach developed is based on improving both power production and distribution in relationship to the temperature. It reduces heat losses and lowers the required starting temperatures and makes it possible to use the network itself to store heat to avoid using backup generators during peak demand. Finally, the system lowers production costs by around 8% compared to the present management system. Scale-up in partnership with a heat network operator is underway. The research is also continuing, with a focus on integrating energy consumption adjustment capabilities and moving toward comprehensive management of production, distribution, and consumption.

# ENERGY STORAGE

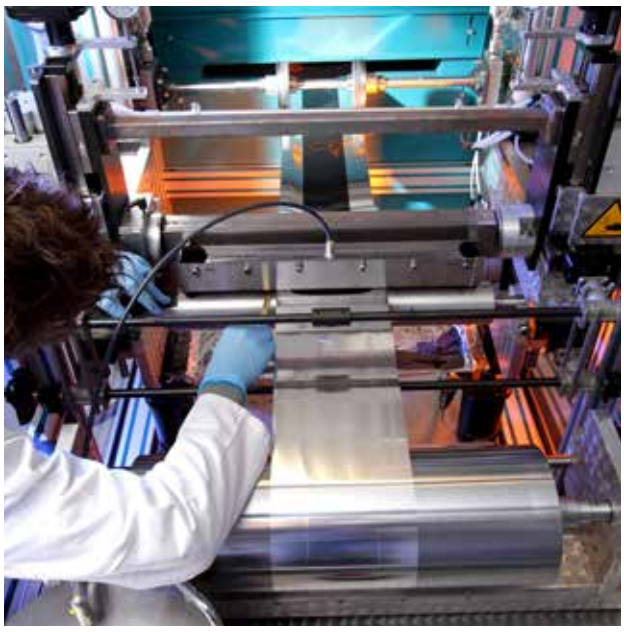
**For stationary and embedded applications**

Liten's electrochemical energy-storage research focuses on solutions for stationary and embedded applications, from the substantial power required for electric vehicles down to mobile objects like wearable technology and medical devices.
Our work looks at technologies such as lithium-ion, which are already available on the market, as well as breakthrough technologies like lithium-sulfur and sodium-ion.
With projects targeting materials design, batteries, and battery management and monitoring systems, our work covers the entire energy-storage value chain. We are developing battery instrumentation and supervision systems to track thermal behavior and identify critical thresholds—crucial to improving reliability and lengthening the lifespans of tomorrow's storage systems.

## Advances in hybrid potassium chloride supercapacitors

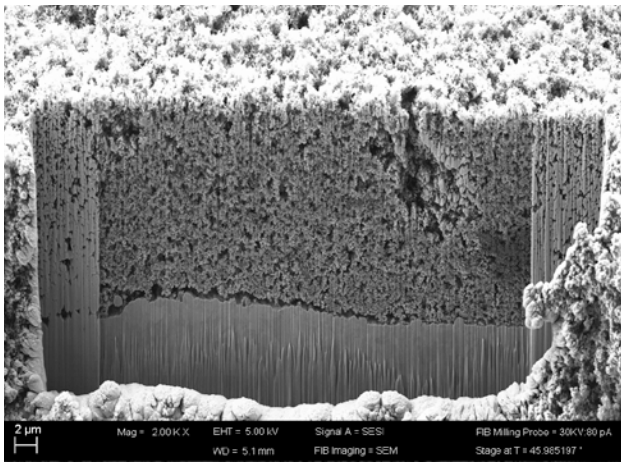
Since 2013 Liten has been working on a new hybrid potassium chloride (KCl) supercapacitor technology that does not require strategic (lithium, transition metals) or toxic materials. The energy density achieved in standard 18650 cell size (10.5 Wh/L) is around twice as high as commercially-available supercapacitors with similar power density (3.4 kW/L). High-power cycling tests showed excellent capacity stability up to 100,000 cycles. When tested at low temperatures (–20°C) the supercapacitors delivered sufficient performance for combustion-engine-powered vehicle starter and hybridization applications. The KCl supercapacitors, which should soon achieve energy densities of 20 Wh/L, could be in the running to replace lead automotive batteries.

## First-ever standard-format sodium-ion battery electrode



Liten produced its first 18650-format negative electrode for sodium-ion batteries. First, the researchers made improvements to small amounts of the hard-carbon-based ink formulation. They then tested the material on a reduced-scale coating bench. Next, a bifacial electrode measuring 40 meters by 180 millimeters was produced on a semi-industrial coating bench—a first. The experiment was a success: the grammage obtained was constant and within the allowed tolerances (+/- 8%; +/- 0.2 mg/cm$^2$). Furthermore, the performance measured was equivalent to that achieved at a smaller scale. The electrodes will be used to produce cells, which will be assembled into packs. Further testing will be completed either into a remote-controlled robot or on stationary energy storage equipment.

## True causes of silicon electrode aging revealed



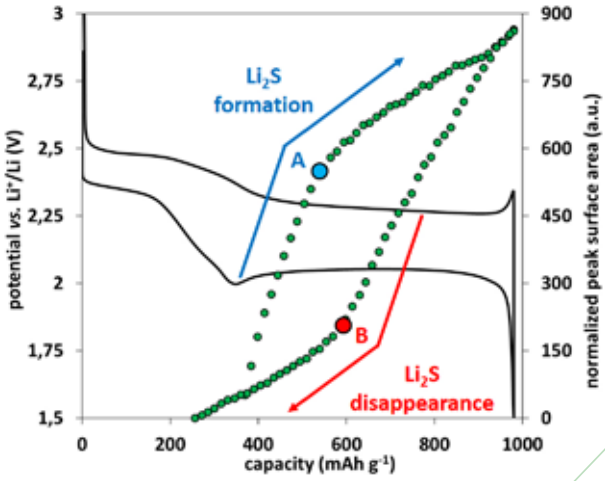

Liten studied the degradation mechanisms affecting nanosilicon electrodes, which could replace the graphite electrodes in lithium batteries. Degradation mechanisms were observed for the first time ever in real-world conditions with limited lithium loading, revealing phenomena that had previously been underestimated. The main degradation mechanism appears to be caused by parasite reactions that trap lithium, resulting in a lack of lithium. These results contradict earlier work that suggested that excessive Solid Electrolyte Interphase (SEI) generation was one of the main sources of electrode degradation. Several imaging and spectroscopy techniques were combined in such a way as to make the observation of electrodes after the cycling of complete cells possible.

## First-ever cylindrical lithium-sulfur battery made at Liten

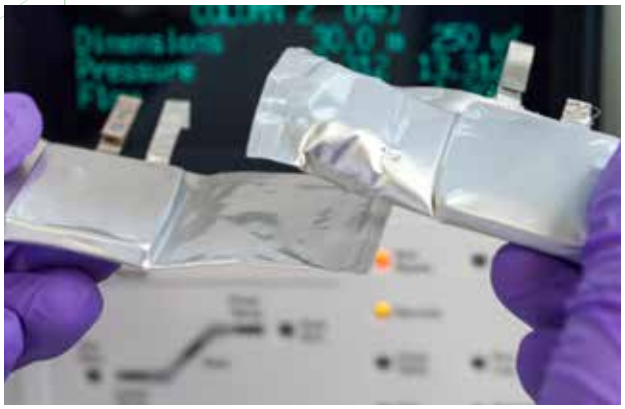

The first-ever cylindrical lithium-sulfur battery was made at Liten. The technology is validated at button-cell scale in lab conditions and is very difficult to scale up due to sulfur solubility issues and the use of lithium in metal form. The problem was partly resolved by modifying the battery design to make the sulfur more available for the oxide-reduction reactions and improving electrode implementation processes. The cylindrical battery delivered performance comparable to button cells with nearly 900 mAh/g of sulfur per cell, or 56% of theoretical sulfur capacity, recovered. The performance obtained was validated over several cycles and, according to the researchers' estimates, could be improved further by changing the cylindrical cell's format.

## Lithium-sulfur battery charge-discharge mechanisms determined

Liten worked with LEPMI to study Lithium-sulfur batteries in operation using X-ray diffraction on "pouch cells" to measure the solid substances formed on the positive electrode at the end of charging and discharging. Two discharge stages were identified, revealing the formation of a byproduct, that should be $Li_2S_2$, responsible for capacity loss during cycling. Furthermore, the morphology of the $Li_2S$ deposited on the surface of the electrode also appears to be meaningful. The observations conducted suggest that nanoparticles of the material are more electrochemically reactive than microparticles. This could pave the way to battery performance enhancements and, therefore, reduced battery sizes.

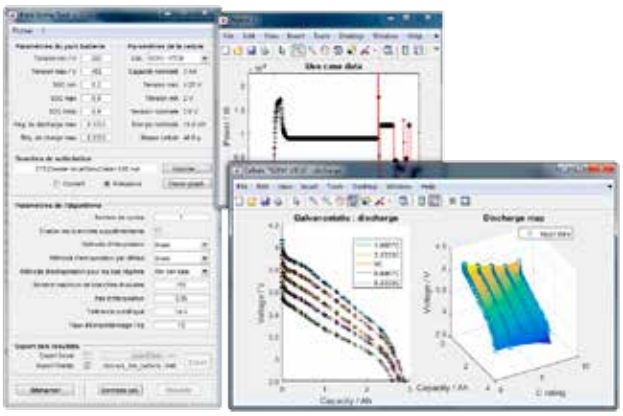


## A shared database of energy storage systems



Liten is currently developing a database to gradually centralize all available information on electricity storage systems, covering different technologies and scales from cell up to complete pack. Liten and DAM started by learning and configuring GRANTA MI, a software package, and then populated the database with information on lithium-ion batteries. This first module of the database contains electrical performance, post-mortem, and abuse testing data on around 50 cells' references. The next step will be to create modules with PEMFC and, possibly, thermal storage system data. Ultimately, the database will serve as a central repository for energy storage system data, facilitating comparisons between available storage technologies.

## All-in-one battery-pack dimensioning tool

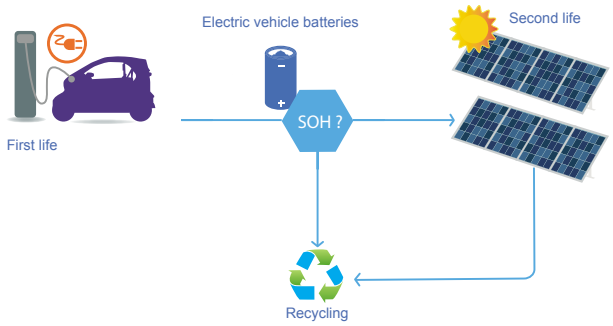


Liten developed a battery-pack dimensioning tool based on customer's specifications for power and electro-thermal behavior of the chosen cells. The tool can calculate the optimal series or parallel configuration in terms of energy. The calculations are based on Liten's large cell cycling database and leverage proven thermal, electrical, and aging models in a single algorithm. The algorithm was developed to keep total battery-pack energy to a minimum taking into account the customer's various requirements. Finally, a user-friendly interface was developed to make the system easy to use by anyone, even non-experts. The all-in-one tool could be made available to manufacturers for their preliminary dimensioning studies.

## Electric batteries for construction machinery

Métalliance turned to Liten to dimension, select, and test the components for a complete powertrain, including the battery, for a rubber-tired electric train. The purpose of the project is to develop a replacement for the highly-polluting diesel vehicles used in tunnel construction. The target solution entails integrating electric motors into the train wheels. The motors would be powered by two battery systems for a total of 90 kWh per vehicle. Each axle has two 60 kW motors and would be powered by one battery system made up of 26 commercially-available modules connected in series. The battery pack developed can withstand exposure to dust, vibration, and heat. Most importantly, it meets the particularly stringent safety requirements of tunnel construction. The train was presented at World Tunnel Congress 2016 in San Francisco.

## Lithium-ion batteries get second life




Liten worked with SNAM to develop and test a method for assessing the state-of-health (SOH) of lithium-ion electric vehicle batteries at the end of their useful life. The goal is to be able to rapidly sort batteries by those that can be remanufactured and integrated into stationary applications, giving them a second life, and those that must be recycled. The patented method was tested on spent battery packs, where it was used to assess the SOH of each module and each module's cells with 96% accuracy. Software leveraging the method was developed. An "overaging" model for the batteries' second life was also developed based on testing representative of reuse in stationary applications. The model can estimate the life expectancy of remanufactured batteries.

## Hot degradation mechanism affecting lithium-ion batteries identified

In research conducted under the EU Mat4bat project, commercially-available lithium-ion batteries underwent accelerated aging tests. The batteries were stored at temperatures of 45 °C or higher and rapidly lost capacity. A post-mortem visual inspection of the components revealed suspicious deposits and stains on the separator. Physicochemical testing pinpointed the degradation of one of the electrolyte additives; the same additive was found to be responsible for gases that generate more resistive areas. When current is applied, part of the lithium is deposited in metal form on these areas rather than reversibly entering the graphite electrode. These new insights into lithium-ion battery degradation have already been incorporated into Liten's battery-aging models.

## PowerUp for optimal battery management

PowerUp, a Liten spinoff, was created to develop and commercialize a solution to supervise fleets of batteries used to power portable items. The system will enable fleet managers to perform predictive maintenance and efficiently manage battery charging. A demonstrator system built for five Lumila lithium-ion battery powered lamps was presented at the Avene PME trade fair in late 2016, resulting in the creation of PowerUp in April 2017. PowerUp's solution leverages a battery management system that can use Bluetooth, LoRa, or any other wireless communication protocol to transmit data from the batteries (which are also geolocated) on the network. In addition, an optimized charge-management algorithm lets fleet managers remotely manage battery charge status, extending the batteries' useful lifespan.

# AN INTERNATIONAL PRESENCE

## High-level conferences' organization

Energy storage technologies by power to fuels and chemicals event

100 attendees

SiliconPV 2017

300 attendees

Material Challenges for Fuel Cell & $H_2$ technologies

60 attendees

nanoSAFE

350 attendees


## Partnerships launching

masen
Moroccan Agency for Solar Energy

Concentrated solar power : aging in real-world conditions

**MOROCCO**

Société Tunisienne de l'Electricité et du Gaz

Smart grid roll-out

**TUNISIA**

Green Village Ventures

teri

Outreach 100 GW of solar production by 2022

**INDIA**

# 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 and Leroux & Lotz.

## 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, Cofely and Roquette are currently engaged in R&D projects with the platform.

## Photovoltaic solar platform

This platform was set up to support France's 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, Thermocompact, B.E.A., Sunpartner, CNR, ECM, Armor...) to large corporations (EDF-PWT, Arkema...).

## Smart-grid systems platform

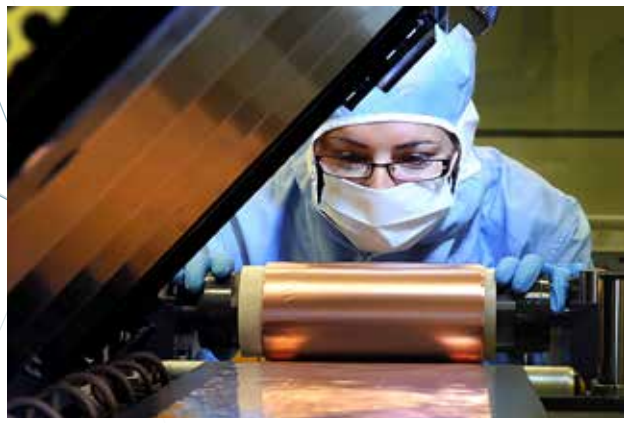
This platform looks at how to scale, operate and optimize energy systems connected to intermittent power sources and electricity storage systems. The platform has all of the necessary equipment to study a variety of grid configurations, manage system components, and determine effective operation strategies. Around 50 industrial partners, including corporations like RTE, SOREA, Urbasolar, 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, and heat storage. The platform has a staff of 40 people and five instrumented test buildings including a new building envelope component testing unit.

## 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.



## 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 Saint-Gobain, Vicat and startup Sylfen.

## 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 and Zodiac, conduct R&D at the platform.

## 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.

## 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).

## 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, finechemicals, and other markets. The platform is staffed by around 50 people.

## 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.

## Large-surface printing platform

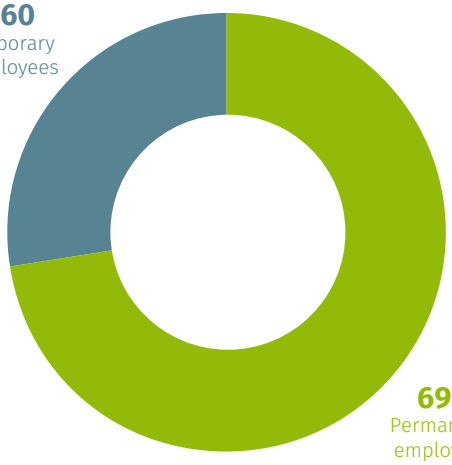
The Pictic large-surface printing platform enhances plastic, paper, and textile substrates by enabling them with electronics like sensors, optics, logic circuits, and display systems. The applications for these flexible circuits include human-machine interfaces, smart lighting, interactive displays,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

## Nanosafety platform

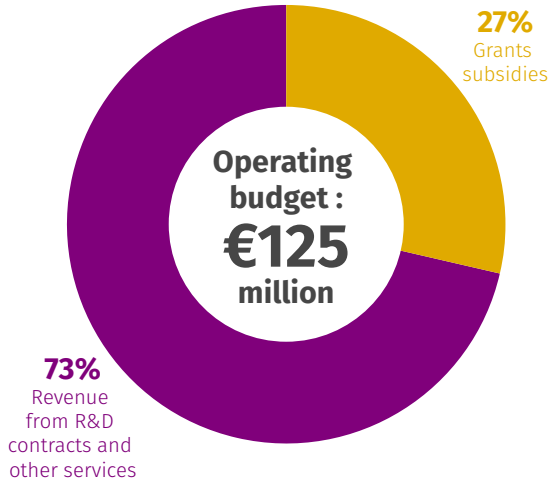
The nanosafety platform investigates protection, health, and security issues related to the handling and the use of nanomaterials. The platform conducts R&D and can take on operational assignments such as on-site measurement campaigns, audits, emergency response personnel, and training. No other facility in France—or probably Europe—offers such a broad range of services.

# KEY FIGURES

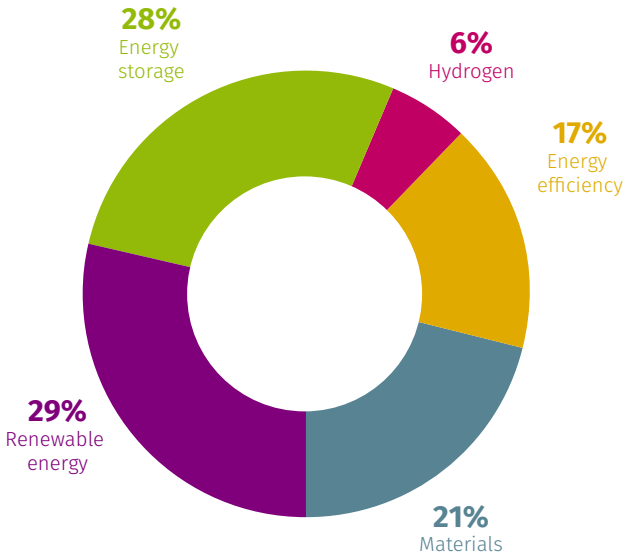
## Total staff



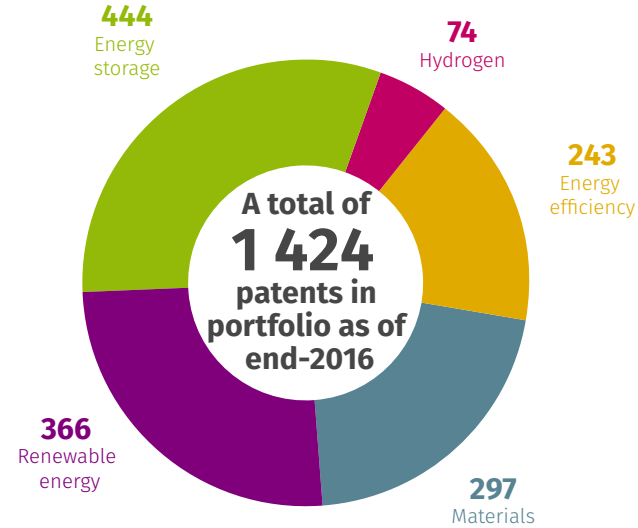

## Budget




## R&D staff by program




## Breakdown of intellectual property

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