



Many of Corning Incorporated's activities in France relate to specialty glasses.

Credit: Corning Incorporated

bulletin | cover story

Global groundbreaker: France innovates and collaborates to serve society

From bioceramic breakthroughs to sodium-ion innovations, France's research teams catalyze ceramic and glass advances.

By Alex Talavera and Randy B. Hecht

France plays host to 84 million visitors each year—which means that during any 12-month period, the ratio of travelers to residents is 1.3:1. But, if the French are outnumbered by their own tourists, they are represented in scientific achievement at a volume that is disproportionate to their population size. France is the only country with two organizations named to the top five on the 2015 Reuters Top 25 Global Innovators–Government list. On the list overall, it is tied with Japan for second place with four organizations, behind six from the United States and ahead of Germany, with three.

Leading that list is the French Alternative Energies and Atomic Energy Commission, known as CEA, which in May signed a research and development agreement with Intel for increased collaboration in “several key areas of digital technology.” Joint research in the area of high-performance computing will include pursuit of the development of new materials to further miniaturize electronic components used in mobile phones. (Also in the top five was CNRS, France's National Center for Scientific Research. See the sidebar for information on this mammoth organization.)

The CEA initiative is driven in part by priorities established by the European Union's Horizon 2020 program, which launched in 2014 and will invest almost €80 billion in research and development over the course of seven years. This money, in tandem with private investment, is intended to generate a spate of European “breakthroughs, discoveries, and world-

firsts” that move “great ideas from the lab to the market.”

Another European Union directive driving innovation is the Regulation on Registration, Evaluation, Authorization, and Restriction of Chemicals. Known as REACH, it “shifts responsibility from public authorities to industry with regard to assessing and managing the risks posed by chemicals” and has an impact on “companies across many sectors beyond the chemical industry.”

For example, when the REACH regulation was announced, Alteo had to consider its significance with regard to the company’s environmental footprint—particularly in relation to bauxite residue. In addition to evaluating alumina’s status within the requirements, the company also is reworking its overall strategy. “We need to become more specialized and more focused on higher-quality, higher-

purity, better products, and that will continue,” says Mike Rodgers, director of marketing business development and communication at Alteo Gardanne.

In late July, Alteo received an offer from Imerys for the acquisition of its Alteo ARC and Alufin plants. Negotiations were at an early stage as this article went to press, and there is no guarantee that the sale will go through, but it does align with Alteo’s shift in strategy. Its biggest impact would be with regard to Alteo’s refractory and abrasives customers.

Areas of specialty sales that the company hopes to move into or penetrate further include higher-value refractory, ceramic, and glass markets. “Historically, Gardanne is quite a big plant for non-metallurgical aluminas,” Rodger says. “The capacity for Gardanne is 500,000 tons a year, which is big for a nonmet-

allurgical alumina plant. We have a number of commodity businesses, applications, and so on that we supply. So, by focusing purely on Gardanne, it will help us develop and concentrate all our interests on specialty aluminas—ceramics, refractories, glass.”

Another of this year’s environmental developments is an initiative announced in January by Saint-Gobain Sekurit and Corning Incorporated. The companies established a joint venture to “develop, manufacture, and sell lightweight automotive glazing solutions” in response to global industry demand for glazing solutions that “improve fuel efficiency, environmental impact, and vehicle handling.”

This is the companies’ second collaboration, following on the success of EuroKera, which develops glass-ceramic cooktops, in keeping with Corning’s focus on advanc-

CNRS: Service-centered research

The National Center for Scientific Research works in service to society and science

The French government founded the country’s National Center for Scientific Research in 1939. Its mission is to conduct research “capable of advancing knowledge and bringing social, cultural, and economic benefits for society,” and this focus is key to understanding the way the organization works and how it selects its fields of inquiry. At CNRS, research can drive commercial opportunity, and commercial opportunity can drive research—but underpinning every venture is the mandate to serve society. Regardless of a project’s focus, it must serve societal needs.

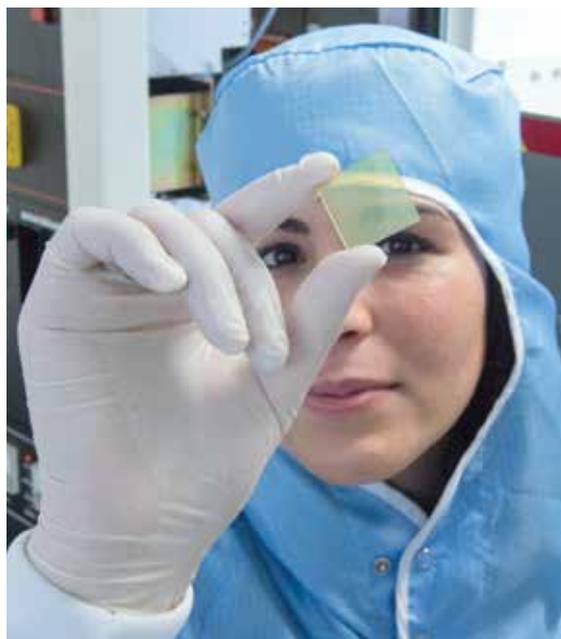
“Our basic mission at CNRS is not to work for companies,” says CNRS researcher Thierry Chartier. “It is to improve the knowledge and know-how—the science—for the benefit of everybody, of the whole society. Of course we work with companies. Otherwise we do not have enough funding for research. So, we always have to find a good balance between the industry-driven work and the basic research, which is our mission.”

The organization has achieved a remarkable record of performance within those parameters. During the first year of the Horizon 2020 program, CNRS submitted 1,229 project proposals, of which 231 were approved. This became an engine for the country achieving the highest selection rate that year, when 18.5% of approved projects originated in France.

Optoelectronics research, bone tissue engineering, and biosensors used in cancer therapies are strong areas of focus, in line with the mandate to serve societal needs.

“We also work on environment, so basic research lines are linked to how we can develop novel ceramics taking advantage of what nature is capable of doing, trying to mimic nature,” says CNRS researcher Fabrice Rossignol. “There is a big consideration with sustainable development as well, whether for energy production, energy savings, or storage.” Other areas of focus at CNRS labs include process intensification—strategies for reducing the energy cost of a process—nanomaterials processing, and the additive manufacturing value chain.

Partnerships are key to pursuing innovation in these fields, and the organization is “strongly convinced that, today, it is not possible to perform good research with visibility at the international level without working with others, and especially outside France,” Chartier says. “You can be skilled in a few things at a high level, but not in everything, so we are encouraged to establish collaborations with international institutions.”



Credit: Hubert Raguier, CNRS Photothèque

A scientist at the CNRS Interuniversity Material Research and Engineering Centre in Toulouse, France, holds an oxide thin film deposited on a glass slide to study its photocatalytic properties.

The two researchers work in a lab that is “highly focused on ceramic processing, and we are recognized for this at the international level. But we come from Limoges, and Limoges is a nice place, but a small city,” Rossignol says. “CNRS always is thinking not only at the national level, but also at the European level or international level.” For that reason, he and his colleagues are “always happy” to launch a joint venture with an international partner—ideally one that understands and embraces the need to work in line with CNRS mandates. ■

Global groundbreaker: France innovates and collaborates to serve society



Scientists at the Corning European Technology Center are designing new glasses and improving glass crystallization.

ing heat-resistant glass-ceramics. Research fellow Monique Comte works extensively on the EuroKera project and focuses generally on research and development of new glass and ceramics. “Another important topic is glass forming,” she says. “It is a good thing to have glass composition, but after, you need a method to form the glass, to shape it.”

Daniel Ricoult, director of the Corning European Technology Center, notes that many of the company’s activities in France relate to sophisticated spe-

cialty glasses, such as those used in ophthalmic lenses or high-refractive glasses. His team’s support extends to designing new materials, improving the glass crystallization cycle, and ensuring that materials have the necessary attributes.

Precision testing and analysis are essential to this work, and his team’s expertise in “understanding and testing what makes components work” is valuable within the plant, to the business overall, and “ultimately to customers, with whom we interact very closely in

Europe,” he says. “We are recognized within Corning global as the center of excellence in this area.”

The need for ceramics that perform in extreme conditions also drives research at the Laboratory of Thermostructural Composites. Director Gerard L. Vignoles, who also is on the faculty at the University of Bordeaux, is working on applications related to atmospheric re-entry, transformation of ceramic foams for use in energy management, and applications related to chemical engineering. Each area of development focuses on creating materials that are able to withstand exposure to extreme temperatures. An additional, emerging field of inquiry is ceramic-matrix composites for components in civil aircraft engines.

This research is spurred by world, not just European, market demand for aircraft that make more efficient use of fuel and reduce emissions of nitrous oxide. “Everything is pushing this material to appear,” Vignoles says. “Lighter materials are capable of operating at higher temperatures, which are more efficient and more environmentally friendly.”

Also on the energy frontier is work being conducted by RS2E, the

Intercontinental commerce

Influential and bigger than realized, France puts cross-border enterprise on the map

Most people think of France as a European country, and they are not wrong—but the French Republic is larger and more geographically dispersed than that. Since the beginning of this century, the former territories French Guiana (South America), Guadeloupe and Martinique (both in the Caribbean), Mayotte (an island in the Mozambique Channel, midway between northern Mozambique and Madagascar), and Reunion (an Indian Ocean island east of Madagascar) have been reclassified as French regions and full members of the Republic.

As of July 2015, the country’s total population was 66,553,766—or 62,814,233 if you count only those living on the continent. Urban dwellers comprise 79.5% of the total. Its labor force was estimated at 29.84 million in 2015—services account for 75.7% of the workforce, followed by industry (21.3%) and agriculture (3%). The unemployment rate for 2015, including the overseas regions, stood at 9.9%, unchanged from 2014 and up from 7.8% in 2008. Youth unemployment has been a particular challenge for the country and peaked at 25.4% in the fourth quarter of 2012. It has improved marginally since then.

France achieved 1.1% growth in its GDP from 2014 to 2015, following increases of 0.2% and 0.7% in the two preceding years. Its 2015 GDP (purchasing power parity) was estimated at \$2.422 trillion, or \$41,200 per capita. However, this growth falls short of expectations, and public debt is an enormous challenge in 2015—it exceeded 68% of GDP, and it may reach 100% this year.

Services, industry, and agriculture generate 79%, 19.3%, and 1.7% of GDP, respectively, and the industrial production growth rate for 2015 was 0.5%. Leading industries include machinery, chemicals, automobiles, metallurgy, aircraft, electronics, textiles, and food processing.

France is closing its trade gap. In 2015, export and import volume were \$509.1 billion and \$539 billion, respectively. Year over year, that marks a decrease from \$584.5 billion in exports and \$631.1 billion in imports during 2014. Leading French commodity exports are machinery and transportation equipment, aircraft, plastics, chemicals, pharmaceutical products, iron and steel, and beverages. Commodity imports are led by machinery and equipment, vehicles, crude oil, aircraft, plastics, and chemicals. Germany is the country’s top trading partner for exports and imports. Leading foreign commerce partners for export and import also include Belgium, Spain, Italy, the U.K., and the U.S. The Netherlands and China also are key import partners.

For further details and export support, see the Export.gov France Country Commercial Guide, Doing Business in France page, and information on business service providers—French representatives, agents, and distributors who the U.S. government has determined are available and qualified to help U.S. firms launch their products and services in France. Additional resources include a compendium of economic data and reports maintained by the U.S. Embassy in Paris and the American Chamber of Commerce in France website. There also are French American Chambers of Commerce in many major U.S. cities, including Atlanta, Boston (New England), Charlotte, Chicago, Cleveland, Dallas, Denver, Detroit, Houston, Los Angeles, Miami, Nashville, New York, San Diego, San Francisco, Seattle, and Washington, D.C. ■

Research Network on Electrochemical Energy Storage. As its name implies, the network's focus is energy storage devices, including rechargeable batteries, supercapacitors, and "other alternative techniques intended for multiple commercial products." Late last year, RS2E announced that it had produced the first sodium-ion battery in the industry-grade 18650 format. "The energy density performance (90 W•h/kg) is above expectations," the organization says, "especially considering the excellent cycle life (at least 2,000 charge/discharge cycles)."

As these ventures suggest, French research laboratories, institutes, and corporations depend on collaboration and knowledge sharing, and they welcome the opportunity to form cross-border partnerships, within the European Union and worldwide. CNRS alone has 35 international joint units in opera-



Credit: Vincent GULLY/CEA

French scientists recently developed the first rechargeable sodium-ion battery in an industry-grade format.

tion, including five created in 2014. And the organization notes that 95% of its research and service units "operate in partnership with academic and research institutions or other types of organizations and businesses, in France and abroad."

Professor Anne Leriche, who teaches at the University of Valenciennes and Hainaut-Cambrésis and works in the university's Laboratory of Ceramic Materials and Associated Procedures, is a past president of the 27-member-nation European Ceramic Society. Her work

Associations, institutes, and government agencies

ANDRA

French National Radioactive Waste Management Agency
1/7 rue Jean Monnet, Parc de la Croix-Blanche
92298 Châtenay-Malabry CEDEX
Phone: 33 1 4611 80 00
Website: <http://www.andra.fr/international>

France took an early lead in establishing public policy with regard to radioactive waste management. In 1991, Parliament created ANDRA and made the agency responsible for identifying and implementing safe solutions. The country adopted deep disposal and established the Cigeo project and the Meuse/Haute-Marne reversible geological disposal facility for radioactive waste.

CEA

French Alternative Energies and Atomic Energy Commission
CEA/Siege (Essonne), 91191 Gif-sur Yvette CEDEX
Phone: 33 1 6450 1000
Website: <http://english.cea.fr>

The CEA operates 10 centers of research and development located throughout France and 51 joint research units that generated 753 priority patent filings in 2015. Its work is concentrated in the areas of defense and security, nuclear energy (fission and fusion), renewable energies, climate and environment, technological research for industry, and fundamental research in physical and life sciences. Since 1972, its work has sparked the launch of 187 startup ventures in the innovative technologies sector.

European Ceramics Centre

12 rue Atlantis, 87068 Limoges CEDEX
Phone: 33 5 8750 2300
Website: <http://www.cec.unilim.fr/indexEn>

The European Ceramics Centre serves as a nexus of higher education and ceramic materials research by leading laboratories. Located in a technology and research park, it is adjacent to the European Ceramics Cluster, where a €247 million budget funds 171 projects. Areas of research focus include gas detection and antipollution filters; bioceramics for implants and bone reconstruction; electronics, optics, and photonics; aeronautical and aerospace applications related to improving resistance to extreme temperature and friction; energy conservation via hydrogen synthesis, fuel cells, turbine components, and nuclear power stations; automotive coatings; refractory materials; and materials for the housing sector. The Centre also houses the Laboratoire de Science des Procédés Céramiques et de Traitements de Surface and L'Unité Mixte de Recherche Science des Procédés Céramiques et de Traitements de Surface.

CNRS

National Center for Scientific Research
3 rue Michel-Ange, 75794 Paris CEDEX 16
Phone: 33 1 4496 4000
Directory of contacts by discipline: <http://www.cnrs.fr/en/home/contacts.htm>
Website: <http://www.cnrs.fr>

Organized under the French Ministry of Education and Research, CNRS comprises the Institutes of Biological Sciences, Chemistry, Ecology and the Environment, Engineering and Systems Sciences, Information Sciences and Technologies, and Physics as well as the National Institute for Earth Sciences and Astronomy, the National Institute for Mathematical Sciences, and the National Institute of Nuclear and Particle Physics. See the sidebar for an overview of the organization's objectives and work related to ceramic technologies.

Institute of Condensed Matter Chemistry of Bordeaux

87 avenue du Dr. Albert Schweitzer, 33600 Pessac
Phone: 33 5 4000 2650
Website: <http://www.icmcb-bordeaux.cnrs.fr/?lang=en>

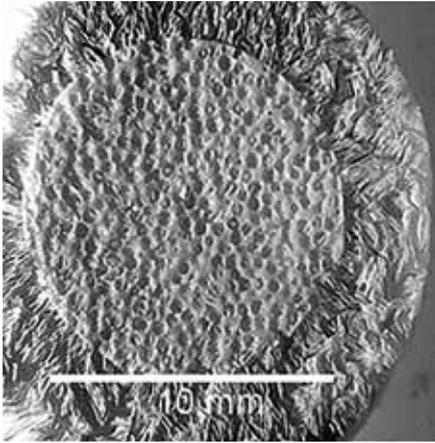
With expertise in solid-state chemistry, materials science, and molecular science, the institute uses its capabilities in synthesis, shaping, and characterization of materials on projects related to energy, functional materials, nanomaterials, and environment and sustainable development. Its research and development of nanomaterials focuses on discovery of new materials and properties. Areas of inquiry include chemistry in supercritical media; organic-inorganic hybrids; nano-objects and functionalized nanoparticles; magnetic, ferroelectric, and luminescent nanoparticles; nanomaterials for electrodes in batteries or fuel cells; and photophysics.

Institute for the Separation Chemistry in Marcoule

Site de Marcoule, Bâtiment 426
BP 17171 F-30207 Bagnols sur Cèze CEDEX
Phone: 33 4 6633 9279
Website: http://www.icsm.fr/index.php?project=icsm_eng

ICSM operates the Laboratory for Nanomaterials for Energy and Recycling, which conducts research related to the use of nanomaterials in the field of energy. Areas of inquiry include separative chemistry (solid-liquid or with phase transformation) and nanostructured materials (fuel and confinement materials) and cover synthesis methods of nanostructured materials and their functionality, characterization, and behavior under stress.

Global groundbreaker: France innovates and collaborates to serve society



Calcium phosphate bone substitute developed in the lab of Anne Leriche. The material is designed to have differing porosities to mimic compact and spongy bone.

focuses on bioceramics for bone substitution. “We study different processing techniques to control the porosity, size, and shape and to try to remake the natural bone,” she says. In recent years, she has been exploring the use of 3-D printing, which allows modification of shapes and angles. Her areas of research extend to ceramic coatings and nanocomposites.

As a university professor, she is particularly committed to ECerS goal of promoting “activities interesting to the young

ceramicists in Europe” and helping them “to progress in their work and to get better positions.” The organization hosts an international conference in Europe every two years and promotes interest in all ceramics development, with an emphasis on technical ceramics, she says. At the most recent conference, topics of particular interest included bioceramics, dental applications, and carbide ceramics.

Another transcontinental initiative is Europe Makes Ceramics, a European network pursuing developments in additive manufacturing of ceramics. The organization was launched by academic members and plans to integrate corporate members soon.

Modeled on America Makes (Youngstown, Ohio), its goal is to increase European competitiveness in this field, but collaboration is not closed to organizations beyond the continent. “American partners—especially the ones involved in America Makes—are very welcome to establish collaborations or some links with EMC to get an even higher coordination at the international level between America and Europe,” says CNRS researcher Thierry Chartier. “We also are trying to establish connections with America Makes.”

There is an established process for universities, institutes, and corporations in the United States that want to collaborate with French colleagues. Those interested should begin by searching the European Research Council’s database to identify researchers at work in fields relevant to their areas of interest. That will allow identification of French laboratories at work on related projects. Contact made at a higher level—such as the national CNRS headquarters in Paris—also can work for larger institutions, but that is not always the most constructive approach.

“The directors of those labs are quite focused on the research line and are very accessible,” CNRS researcher Fabrice Rossignol says. “If you know your needs, the best way is to contact the director, who always will answer or at least forward your request to relevant colleagues.” Bear in mind that French laboratories and institutes favor long-term partnerships over project-specific research ventures. But if there are strong parallels between the research objectives and those of a French research lab, it is possible to begin the relationship there and expand it as opportunities arise. ■

Associations, institutes, and government agencies

Institute of Electronics, Microelectronics, and Nanotechnology

Avenue Henri Poincaré
CS 60069, 59 652 Villeneuve d’Ascq CEDEX
Phone: 33 3 2019 7979
Website: <http://www.iemn.fr/en/the-institute>

Created by CNRS in collaboration with two universities and an engineering school, IEMN engages in scientific activity that covers a spectrum from the physics of materials and nanostructures to microwaves, telecommunications, and acoustics instrumentation. It characterizes itself as “very open to international collaborations” and notes that more than 20 countries are represented by more than 100 scientists who currently work at IEMN. Among its fundamental areas of research are nanostructures, nanocomponents, and molecules, with a focus on “studies of thin layers, heterostructures and periodic structures, and nanostructures (2-D, 1-D, 0-D) of advanced materials for electronics, optics, acoustics, optoelectronics, and nanotechnology.”

Institute of Mineralogy, Materials Physics, and Cosmochemistry

4 place Jussieu 75005 Paris
Phone: 33 1 4427 4427
Website: <http://www.impmc.upmc.fr/en>

The IMPMC uses a multidisciplinary approach to research by teams whose members have backgrounds in physics, earth science, and biology. It uses experimental platforms to

investigate “interactions between the living world (including bacteria) and the mineral world,” including issues “related to the alteration of minerals of the environment, modeling of protein complexes by cryo-electron microscopy, or the synthesis of ultrahard materials under extreme conditions.” One current area of research is “the study of magnetism in nano-objects for which their low dimensionality (0-D for nanoparticles, 1-D for wires, and 2-D for surfaces) creates emerging physical and chemical properties.”

Institute for Nanosciences and Cryogenics

Website: <http://inac.cea.fr/en>

Based in Grenoble, INAC is a leading researcher in topics related to condensed matter, soft matter, and cryogenics. Its work in physics, chemistry, and at the interface with biology falls for the most part within the parameters of nanoscience, and its programs focus on such strategic areas as low-carbon energy, information technology, health technology, global defense and security, development and use of large facilities, and cryogenics for space and for large facilities. The organization describes its “three major commitments” as publishing pioneering results, training top scientists through doctoral and postdoctoral studies, and protecting the intellectual property generated as its breakthroughs are converted into applications, which result in 25 patent awards annually.

Paris Institute of Chemistry Research

Website: <http://www.ircp.cnrs.fr/?lang=en>

The institute’s research encompasses a broad spectrum of chemical and physicochemical science topics, from molecular and polymer chemistry to energy, materials, and processes. Its research groups are organized to include: Theoretical Chemistry and Modeling; Materials for Photonics and Optoelectronics; Resources and Materials for a Sustainable Energy; Interfaces, Electrochemistry, Energy; Physical Chemistry of Historical Materials; Physical Chemistry of Surfaces; Structural Metallurgy; Plasma, Processes, Microsystem; Organometallic Chemistry and Polymerization Catalysis; and Catalysis, Synthesis of Biomolecules and Sustainable Development.

Laboratory for Thermostructural Composites

3 allée de la Boétie 33600 Pessac
Phone: 33 5 5684 4700
Website: <http://www.lcts.u-bordeaux1.fr/KitSC/modeles/en/introduction.htm>

The Laboratory for Thermostructural Composites conducts research into “ceramic composite materials for applications in extreme environments: at high temperatures, under mechanical and thermal constraints, under oxidation, and even under irradiation,” the organization’s website notes. Included in its mission are completion of fundamental research and development of future specialists in ceramic composites.

Associations, institutes, and government agencies

MINATEC

3 parvis Louis Néel, 38054 F-Grenoble CEDEX 9
Website: <http://www.minatec.org/en>

The MINATEC campus is a center of research that uses cross-disciplinary collaboration to accelerate microtechnology and nanotechnology. Its areas of focus include memory, MEMS, biochips and biosystems, photonics, RF components and systems, and spintronics. Within that context, it maintains dedicated research platforms for upstream technology, nanocharacterization, CIME nanotech, MEMS 200, Nanotec 300, nanosafety, chemistry, integrated circuit design, and biology and healthcare technologies. The organization files more than 350 patents and publishes more than 1,600 scholarly works annually and maintains strong industry ties throughout the world—it receives visits from 80 foreign delegations each year and engages in joint projects with leading centers in the United States, Japan, Korea, and Taiwan.

French Ceramic Society

6-8 rue de la réunion, Les ULIS, 91955 Courtaboeuf cedex
Phone: 33 1 5656 7000
Website: <http://www.ceramique.fr>

CORPORATIONS

Alteo

Route de Biver - B.P.62, 13541 Gardanne CEDEX
Phone: 33 4 4265 2222
Website: <https://www.alteo-alumina.com>

Alteo is the leading producer of high-value specialty aluminas designed for ceramic applications, refractories, abrasives, specialty glass, and the chemicals industry. Its product line includes alumina trihydrate, calcined aluminas, fused aluminas (white and brown), tabular alumina, zirconia alumina, and sintered bauxite. The company is headquartered in Gardanne, France, which also is home to its largest production site and R&D facility, with additional production sites in La Bâthie and Beyrède, France, and Teutschenthal, Germany.

Areva

1 place Jean Millier, 92400 Courbevoie
Phone: 33 1 3496 0000
Website: <http://www.areva.com>

Headquartered in France, which is the source of 39% of its revenue, Areva works in the fields of nuclear power and renewable energy. Its roadmap for 2016–2020 calls for the company to refocus on its nuclear fuel cycle business, including production and recycling of nuclear materials and waste management, and to develop its business in the areas of mining, uranium chemistry (conversion and enrichment), used fuel recycling, logistics, dismantling, and fuel cycle engineering. “The alignment of interests within the nuclear sector in France decided by the government also involves the takeover of AREVA NP by EDF,” the company’s website states. The sale to EDF will divest the company of its activities in the areas of NSSS design, supply, construction, maintenance and modernization activities, and fuel design and fabrication.

CILAS

8 avenue Buffon, 45100 Orléans
Phone: 33 2 3864 1555
Website: <https://www.cilas.com>

With demonstrated expertise in lasers and optronics, CILAS serves a variety of vertical markets, including defense and security, laser programs, scientific applications, industry, and space instrumentation. Additional areas of focus include laser target designation, laser range finding, adaptive optics, optical coatings, industrial instrumentation, and active imaging. Direct exports account for more than half its turnover, and the company is pursuing increased international market penetration.

Corning European Technology Center: S&T European Laboratory

7 Bis avenue de Valvins, CS 70156 Samois-sur-Seine,
77215 Avon CEDEX
Phone: 33 1 6469 7400
Website: <https://www.corning.com>

Located less than an hour southeast of Paris, this facility focuses on providing research, development, and engineering work that supports Corning’s global objectives in terms of innovation and growth. The company’s initiatives in France include two joint ventures with Saint-Gobain: EuroKera, which is pursuing advances in the development of glass-ceramic cooktops; and a second partnership devoted to creating lightweight automotive glazing solutions. Additional areas of inquiry span such diverse topics as augmented reality, glass forming, and new materials for life sciences. Corning’s operations in France frequently involve R&D keyed to markets beyond the country and region and extend, in particular, to work with partners in the U.S. and China.

Imerys

154 rue de l’Univsite, 75007 Paris
Website: <http://www.imerys-ceramics.com>

Imerys Ceramics develops and markets high-performance solutions based on minerals, including kaolin, ball clays, feldspars, steatite, cordierite, and high-purity quartz. The markets it serves encompass tableware, sanitaryware, floor tile, fiberglass, and technical ceramics, including solar applications and electronics. In addition, the company offers cordierite, mullite, and silicon carbide-based kiln furniture.

Kerneos

Immeuble Pacific, 11, cours Valmy, Paris
Phone: 33 1 4637 9000
Website: <http://www.kerneos.com>

With its focus on aluminate technologies, Kerneos develops and markets a wide range of products to customers in 120 countries. Included in its product line are calcium aluminate-based hydraulic binder; synthetic calcium aluminum silicate aggregate obtained from a fusion process; binder developed for use in high-temperature applications; and high-alumina cements used in solutions designed for the construction industry. The team at its Research and Technology Centre near Lyon is focused on developing solutions in collaboration with customers and plants. The company also provides clients with technical solutions and support related to these products.

LafargeHolcim

61 rue des Belles Feuilles
Phone: 33 1 4434 1111
Website: <http://www.lafargeholcim.com>

LafargeHolcim markets cement, concrete, aggregates, and asphalt products, solutions and services to the building, infrastructure, distribution and retail, oil and gas, and affordable housing industries. Customized and sectoral solutions are among its areas of expertise. Following the 2015 merger of France’s Lafarge and Switzerland’s Holcim, the new company employs more than 100,000 people, has an established presence in 90 countries, and is targeting emerging markets for continued growth. At the same time, it is working toward development of sustainable products that can improve buildings’ energy efficiency and promote increased materials recycling. Its interests in sustainability extend to solutions that reduce CO₂ emissions per ton of cement—to that end, it is exploring new production techniques, alternative energy sources, waste management programs, and opportunities to preserve water resources. The company’s Lafarge Centre de Recherche, located in Lyon, is the world’s leading research center for building materials. Research is organized by major market segments, including building structure and shell, building finished work, infrastructure, energy, ultra-high-performance fiber-reinforced concrete (UHPC) solutions, and packaging.

Mineral Research Processing

7 rue Garnier 69330 Meyzieu
Phone: 33 4 2618 9399
Website: <http://www.tricalciumsilicate.com/en>

A leader in the French market for tricalcium silicate used in the ceramics sector, Mineral Research Processing pursues R&D of synthetic minerals with controlled chemistry and mineralogy in the field of silicates, aluminates, phosphates, and titanates. Target markets for its products include structural ceramics, glass-ceramics, bioceramics, and medical and dental ceramics.

Nanoe

34 route de Longjumeau, Lot 25, 91380 Chilly-Mazarin
Phone: 33 9 8198 3364
Website: <http://www.nanoe.com>

Nanoe was launched in 2008 to advance the elaboration of high-purity nanopowders. Its ready-to-sinter alumina and zirconia products are designed for sintering high-performance ceramics. Solutions include ready-to-press granulates and slurries developed to meet customer needs. "So far, the adoption of nanoscale ceramics has been plagued by limited production capacity, high prices, and low reliability of nanopowders," the website notes. "Nanoe's mission is to bring the full potential of nanotechnology to advanced ceramics manufacturers." The company also touts its ability as a startup to respond quickly to specific needs, including green machining, special slurries, and granulates for thermal spray.

ONERA

29 avenue de la Division Leclerc, 92320 Châtillon
Phone: 33 1 46 73 40 40
Website: <http://www.onera.fr/en>

ONERA is France's aeronautics, space, and defense research lab. Its mission encompasses directing and conducting aeronautical research and supporting commercialization of that research in France and Europe. It provides industries and government agencies with high-level technical analyses and related services. In addition, and in keeping with its responsibility for training researchers and engineers, ONERA is engaged in technology transfer to small- and medium-sized enterprises. Its services are tailored to the needs of this sector and include design studies, technology development, technical analysis, software licensing, and testing.

Pall Exekia

Lotissement industriel Bazer 0, 65460 Bazer
Phone: 33 5 6233 4183
Website: <http://www.pall.com>

Saint-Gobain

Les Miroirs - 18 avenue d'Alsace, 92400 Courbevoie
Phone: 33 1 4762 3000
Website: <https://www.saint-gobain.com/en>

With 170,000 employees working in about 70 countries, Saint-Gobain is a global leader in habitat solutions, which generate more than 70% of its sales. Although its business is concentrated in residential construction and renovation, it also is active in industrial sectors. The company researches and develops high-performance materials for demanding applications in the automotive, aeronautical, health, defense, security, and food and beverage industries. The company's website notes that one in four of its current products did not exist five years ago, and Thomson Reuters has named it one of the Top 100 Global Innovators. Saint-Gobain and CNRS jointly operate the Ceramic Synthesis and Functionalization Laboratory, which conducts "fundamental research on functional ceramic materials, in particular, ceramic materials having charge transfer properties." It also studies how combining functional properties can lead to development of innovative materials.

Safran-Herakles

Website: <http://www.safran-group.com>
Safran Ceramics Website: <http://www.safran-group.com/company/safran-ceramics>

A global high-technology group that serves the aerospace, defense, and security industries, Safran-Herakles is the product of a merger that created a company with 2015 sales in excess of €17.4 billion. For the year, its R&D expenditures exceeded €2 billion. Safran Ceramics is the company's center of excellence in high-temperature ceramic composites developed for space, aviation, and other industries. These products contribute to overall improvements in aircraft engine performance as measured by reduced fuel consumption and emissions.

SETARAM Instrumentation

7 rue de l'Oratoire, 69300 Caluire
Phone: 33 4 7210 2525
Website: <http://www.setaram.com>

Setaram is an industry leader in the manufacture and sale of high-performance thermal analyzers, calorimeters, gas sorption analyzers, and high-pressure mass spectroscopy instruments for pharmaceutical, life science, advanced materials, energy, process safety, and other applications. Its products and solutions encompass 3-D calvet calorimetry, microcalorimetry, high-pressure calorimetry, high-pressure and drop calorimetry, reaction calorimetry, and nondestructive assay for nuclear waste characterization.

Thales Research & Technologies

Rue Départementale, 91120 Palaiseau
Phone: 33 1 6941 5500
Website: <https://www.thalesgroup.com/en>

Thales is a worldwide leader in air traffic management: 40% of the world's aerospace is managed by Thales air traffic control centers. It is Europe's leader in avionics and ranks third worldwide. "With the development and evolution of new global technologies and threats, most of Thales's business activities are technology intensive, making innovation a strategic priority and the driving force behind the long-term development of the Thales Group," the company notes on its website.

Verallia

Directory of locations in France: <https://fr.verallia.com/our-company/our-locations-in-France>
Website: <https://fr.verallia.com/en>

The world's third largest manufacturer of food and beverage glass containers, Verallia serves more than 10,000 customers in 45 countries. The company has integrated sustainable development into its strategy for continued growth. To that end, it pledges to maximize use of recycled glass in its furnaces, pursues increased energy efficiency in its manufacturing processes, reduces CO₂ emissions, and optimizes use of water resources. In addition, it is conducting R&D of green electricity, biogas, and syngas produced from biomass as a means of implementing alternative energy solutions at its plants.

UNIVERSITIES

CIMAP—University of CAEN

25 rue Leblanc, Bâtiment Le Ponant D, 75015 Paris
Website: <http://iramis.cea.fr/en>

ENSCI

French National School for Advanced Studies in Design

48 rue Saint Sabin, 75011 Paris
Phone: 33 1 4923 1212
Website: <http://www.ensci.com/en>

ESPCI

Paris Tech

10 rue Vauquelin, 75005 Paris
Phone: 33 1 4079 4400
Website: <https://www.espci.fr/en>

Laboratory of Reactivity and Chemistry of Solids (LRCS)—University of Picardie Jules Verne & Ceramics Technologies and Industries

33 rue Saint Leu, 80039 Amiens CEDEX
Phone: 33 3 2282 7572
Website: https://www.u-picardie.fr/labo/lrscs/Index_en.htm

University of Bordeaux

Phone: 33 5 5757 1010
Website: <http://www.u-bordeaux.com>

University of Bordeaux IMS Laboratory

Bâtiment A31, 351 cours de la Libération, 33400 Talence
Phone: 33 5 4000 6540
Website: <https://www.ims-bordeaux.fr/en/ims-laboratory>

University of Bordeaux—CELIA

351 cours de la Libération, F-33405 Talence CEDEX
Phone: 33 5 4000 3769
Website: <http://www.celia.u-bordeaux1.fr>

University of Bourgogne

Esplanade Erasme, 21078 Dijon
Phone: 33 3 80 39 50 00
Website: <http://en.u-bourgogne.fr>

University of Franche-Comte—FEMTO-ST Institute

15B avenue des Montboucons 25030 Besançon CEDEX
Phone: 33 3 6308 2400
Website: <http://www.femto-st.fr/en>

University of Limoges/ENSCI

12 rue Atlantis, 87280 Limoges
Phone: 33 5 8750 2301
Website: <http://www.ensci.fr/en>

University of Littoral Opal Coast

50 rue Ferdinand Buisson, 62100 Calais
Phone: 33 3 2146 3600
Website: <http://www.univ-littoral.fr>

University of Lyon

92 rue Pasteur, 69007 Lyon
Phone: 33 4 3737 2670
Website: <http://lyon-university.org>

University Pierre and Marie Curie

4 place Jussieu, 75005 Paris
Phone: 33 1 4427 4427
Website: <http://www.upmc.fr/en/index.html>

University of Poitiers

15 rue de l'Hôtel Dieu, 86000 Poitiers
Phone: 33 5 4945 3000
Website: <http://www.univ-poitiers.fr/home-750171.kjsp>

University of Strasbourg

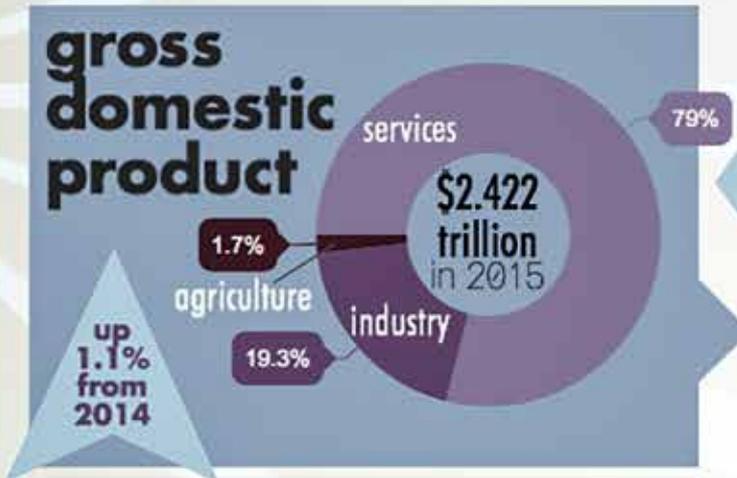
4 rue Blaise Pascal, 67081 Strasbourg
Phone: 33 3 6885 0000
Website: <https://www.unistra.fr/en>

UPMC—College of France

Rue Saint-Jacques and rue des Ecoles, Paris
Phone: 33 1 4427 6539
Website: <http://www.labos.upmc.fr/lcmcp>

FRANCE

gross domestic product



trade



EXPORTS



Data source: Observatory of Economic Complexity, Central Intelligence Agency World Factbook