

**Building
tomorrow,
together
with science**



“Innovation is no longer the same as the one we used twenty, ten, or even five years ago. R&D at Air Liquide adapted, we are agile, we are testing new methodologies and processes. More than ever, we are engaging customers, users and partners to learn, test and refine concepts to propose concrete business disruption.”

Olivier Letessier
VP Research & Development,
Air Liquide

R&D

AT AIR LIQUIDE

Air Liquide's Research and Development operates on all activities of the Group.

To support Air Liquide's strategy, R&D stimulates collective intelligence to foster **innovation with ecosystems** across current and future markets.

Located on Innovation Campuses, R&D **supports its customers at both local and global levels** in the most efficient way possible in Europe, the Americas and Asia.

Our aim? Provide solutions relying on operational excellence to deliver long-term performance and contribute to addressing society's sustainability challenges.



SAFETY IS OUR PRIORITY

Safety is a top priority for the Group, a key element in a decision-making process. One of Air Liquide's major challenges in each region, in each entity, is to strive to continuously and durably improve health and safety in the workplace.

5 
CAMPUSES

16 000 VISITORS

partnerships with laboratories, start-ups, industrial players and customers

18 
ESSENTIAL SMALL MOLECULES

+ 500 
EMPLOYEES



60%

R&D Portfolio devoted to reduce CO₂ emissions*

**by reducing the carbon content of Air Liquide products or those of its customers*

Embracing

INNOVATION ECOSYSTEMS

Today's changes in society and industry are key challenges. To be able to face them, we are required to work on a collaborative response with our ecosystems. Consequently, by inviting customers, universities, technology institutes, start-up companies, researchers and business developers into our network, **we prepare the future together.**

TO DO SO, WE MUST...



Understand

Our successful developments start with a precise understanding of the customers' operational needs, as well as anticipating strategic issues and identifying market drivers.

Ideate



Our teams rely on collaborative and innovative tools, as well as agile project management approaches to run innovation efficiently and make adequate decisions.

Find the proper fit

We believe that a project should generate the key benefits expected by the customers. To achieve this goal, we develop iterative processes to quickly «test and learn» until we obtain scalable, and profitable methodologies.



Embracing open innovation makes it possible for Air Liquide to **develop world-class innovation entities and build relationships with customers** such as start-up companies, research laboratories, even technology institutes.



Agility... more specifically

In the past five years, R&D launched initiatives on **essential small molecules** and **data & decision sciences**. The objective is to stimulate scientific excellence and enrich Air Liquide's offers. The approach relies on experiences' diversity and knowledge sharing: a small core team supported by a community of experts beyond R&D and outside of Air Liquide's environment.



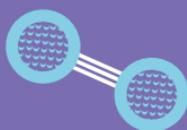
CO_2
Carbon Dioxide

UNPARALLELED SCIENCE AND RESEARCH EXPERTISE

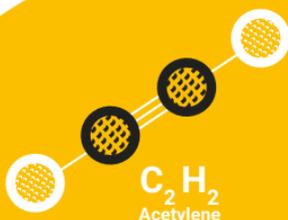
Molecules have been at the core of Air Liquide's activities since its creation - and, naturally, of our Innovation Campuses.

The importance of essential small molecules is growing due to the roles they play in global challenges. It includes environmental issues, energy transition, global resources scarcity, urban development, shifts in consumption patterns and the fact that the world's population is living longer and increasing rapidly.

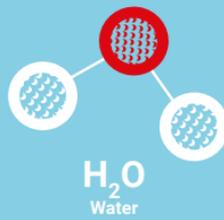
Each Campus incorporates a prestigious community of experts and talents dedicated to designing new ways of using the properties of our essential small molecules and developing innovative applications for our business partners and customers.



N_2
Nitrogen



C_2H_2
Acetylene



Ne
Neon



Air Liquide's Scientific Challenges

Our «**Scientific Challenge**» is an integral part of our drive for **innovation and openness**.

Since 2016, this open competition has inspired the scientific community to develop innovations **related to the sustainable world through the essential small molecules**. Winners are granted a prize and a funding plan to pursue their projects.

By enriching our knowledge on molecules, we contribute **to solving crucial issues** in the areas of production, purification, transport, and storage.

We design the innovations to build the future.

In 2019, the winners worked on:

- > Development of a new process using a reactor membrane to produce purified hydrogen (H₂) in a single step.
- > Development of efficient catalysts for the use of hydrogen (H₂) and carbon dioxide (CO₂) to produce methanol (CH₃OH).
- > The use of water enriched with hydrogen (H₂) in agriculture to reduce the use of fertilizers and pesticides.

▶ www.airliquide.com/magazine/science/2018-air-liquide-scientific-challenge

R&D shares its knowledge about molecules in its Gas Encyclopedia

www.encyclopedia.airliquide.com



Ar
Argon

CAMPUSES THAT RESONATE AROUND THE WORLD



Campuses housing our R&D centers offer a uniquely open and innovative research environment. Each Campus is part of a global network that facilitates collaboration and the sharing of both knowledge and insights. They are the most productive way to learn, share, and grow.

They include researchers, customers, business partners, start-up companies, and academics but also technical teams from other Air Liquide entities such as Healthcare,

Large Industry, Industrial Merchant, Global Markets & Technologies, Engineering & Construction, etc.

Our five Campuses are diverse, beneficially adapted to their local environment to better support our customers.

They are strategically located in leading countries in technological innovation: the United States, France, Germany, China, and Japan.





To discover our
Innovation Campuses,
watch this video

youtu.be/4b4JdqAEQEw



INNOVATION CAMPUS DELAWARE



The Innovation Campus Delaware **provides technical and innovation support in gas separation, serving the industrial and healthcare markets.**

The Campus boasts researchers hailing from 21 different countries and hosts 7 entities besides R&D. The Campus has a diverse blend of scientific and engineering skills, all helping to accelerate our technological developments.

In this way, our Campus benefits from a broad scale of scientific and creative talents across the Americas through numerous industrial and academic partnerships with US universities such as Princeton, the University of Delaware, Carnegie-Mellon, and the Wharton Business School.

The Campus also relies on a team based in Montreal (Canada).

7 laboratories

including the Data & Decision Science Lab



140 people

contributing to innovation for Air Liquide, and located on the Campus

5 experimental platforms

Advanced Fabrication Center - Fine Chemistry for Primary Electronics - Advanced Materials for Membranes - Process Engineering & Combustion - Life Sciences

AREAS OF EXPERTISE

Advanced Fabrication and Manufacturing | Analytical Science
Cobotics and Automation | Combustion | Deposition, Etching, Cleaning, or Activation of surfaces | Digital and Data Science | Energy | Experimental Set-up and Methodology | Gas Technologies for Aerospace and Aviation | Healthcare | Industrial Gas and Chemicals Production Processes | Life Sciences and Applications | Modeling and Numerical Simulation of Chemical and Physical Processes

INNOVATION CAMPUS PARIS



The Innovation Campus Paris is **our flagship**. Its design relies on an open environment to bring together customers, business partners, academics, both small and large scale entities to create, collaboratively, tomorrow's solutions.

Our Campus is located in the south of Paris, at «Plateau de Paris-Saclay,» which drew inspiration from the foremost Silicon Valley. **It is at the heart of the best European innovation ecosystem.**

Taking advantage of the best European academic institutions, state-of-the-art laboratories, and experimental platforms, **the Campus turns today's discoveries into tomorrow's solutions.** It addresses the pain points of our European customers, and thereby designs value-added solutions.

The Campus hosts Accelair that is a deep tech start-ups accelerator.

 accelair.airliquide.com

The Campus also relies on a team based in Krefeld (Germany).

59 laboratories



+450 people

contributing to innovation
for Air Liquide, and located
on the Campus

8 technical platforms

Gas Safety - Process
Engineering - Computational
and Data Science - Material
Qualification - Combustion -
Food processing - Additive
Manufacturing - Gas Analysis

AREAS OF EXPERTISE

Advanced Fabrication and Manufacturing | Analytical Science | Chemical processing Unit Operations | Cobotics and Automation | Combustion | Digital and Data Science | Energy | Experimental Set-up and Methodology | Gas Technologies for Aerospace and Aviation | Healthcare | Industrial Gas and Chemicals Production Processes | Life Sciences and Applications | Low Temperature and Specialty Cryogenics | Materials Usage and Raw Material Production | Modeling and Numerical Simulation of Chemical and Physical Processes | Packaging

INNOVATION CAMPUS FRANKFURT



The Innovation Campus Frankfurt focuses on main activities in process development and engineering solutions on: **Carbon Management** and **Less Carbon Emissions** for Hydrogen & Syngas Production.

Its strength is to develop, plan and operate unique test facilities - safely and reliably. With specific analysis methods the Campus supports experimental work on pilot plants as well as research in the industrial environment.

It creates value by allowing teams to collaborate with major industry customers in the chemicals and petrochemical sectors, as well as developing strategic partnerships with German and European academic and research institutions of international reach.

27 laboratories



60 people

contributing to innovation for Air Liquide, and located on the Campus

2 technical platforms

Process Engineering + Analytical Science dedicated to hydrogen/carbon monoxide/carbon dioxide ($H_2/CO/CO_2$)

AREAS OF EXPERTISE

Analytical Science | Chemical processing Unit Operations | Energy | Experimental Set-up and Methodology | Industrial Gas and Chemicals Production Processes | Modeling and Numerical Simulation of Chemical and Physical Processes



INNOVATION CAMPUS SHANGHAI



The Innovation Campus Shanghai **is a driving force, a transformation tool to help Air Liquide prepare for its future.** It provides a unique blend of R&D teams, digital specialists, experts in customer applications, and teams from various Air Liquide entities. They are all dedicated to exploring new markets, accelerate the development of solutions to improve energy efficiency, reduce carbon footprint, and evolve new energies, including hydrogen and biomethane.

The Campus provides a broad spectrum of customers with innovative, customized energy solutions, application technologies, and services. **In this way, we help drive our customers' performance and reduction of environmental impact.** The focus is on developing advanced processes that would contribute to energy transition, materials, particularly for the manufacture of «next-generation» semiconductors, flexible displays, energy storage and distribution.

10 laboratories



220 people

contributing to innovation for Air Liquide, and located on the Campus

10 industrial test platforms

Combustion - Wave Soldering - Reflow Soldering - Food Processing - Flame Cutting - Gaseous Heat Treatment - Laser Cutting - Life Sciences - Powder Metallurgy Sintering - Welding

AREAS OF EXPERTISE

Advanced Fabrication and Manufacturing | Analytical Science | Combustion | Digital and Data Science | Energy | Industrial Gas and Chemicals Production Processes | Life Sciences and Applications



INNOVATION CAMPUS TOKYO



The Innovation Campus Tokyo, **laboratories and pilot platforms are equipped to facilitate research and development**, all undertaken in collaboration with Air Liquide's customers as well as start-up companies or academic partners. **Fostering customer-centric innovation is the core mission** of our 8,000m² state-of-the-art facility, which creates a collaborative environment promoting open-innovation and knowledge-sharing.

The Campus develops the latest thin film deposition and etching technologies for applications in electronics, batteries and fuel cells, as well as strategies for production and distribution of low carbon hydrogen. **It also works on improving the performance of the processes for its industrial customers**, particularly in the fields of additive manufacturing, life science and heat treatment.

The Campus also relies on a team based at Yonsei University in Seoul (South Korea).

12 laboratories



100 people
contributing to innovation
for Air Liquide, and located
on the Campus

6 industrial test platforms

Combustion - Heat treatment - Food processing - Welding - Surface treatment - Rubber deflashing

AREAS OF EXPERTISE

Thin Film Deposition, Etching,
Cleaning and Surfaces Activation |
Energy | Materials Science |
Analytical Science | Advanced
Fabrication and Manufacturing |
Industrial Gas and Chemicals
Production Processes



Working for our future

Thanks to our team's expertise, we design and deploy new offerings focusing on three major trends: energy transition, healthcare, and digital transformation.

We are committed to reducing the environmental impact of our assets and our customers.



Carbon capture

The combustion step liberates CO₂ molecules in the atmosphere.

To reduce these emissions, our teams developed technologies enabling them to capture and store this CO₂.

We allow, at last, after chemical transformation to use these CO₂ molecules again. We convert them into basic chemicals such as Olefins and Methanol.



Energy-efficient combustion technologies

Some industrial installations need a lot of energy to achieve high temperatures. During the combustion process, they reject fumes containing water vapor.

Our teams are working on optimizing technologies to recover them. Thereby, they enable not only **to save energy but also to reduce air pollution and greenhouse gas emissions.**



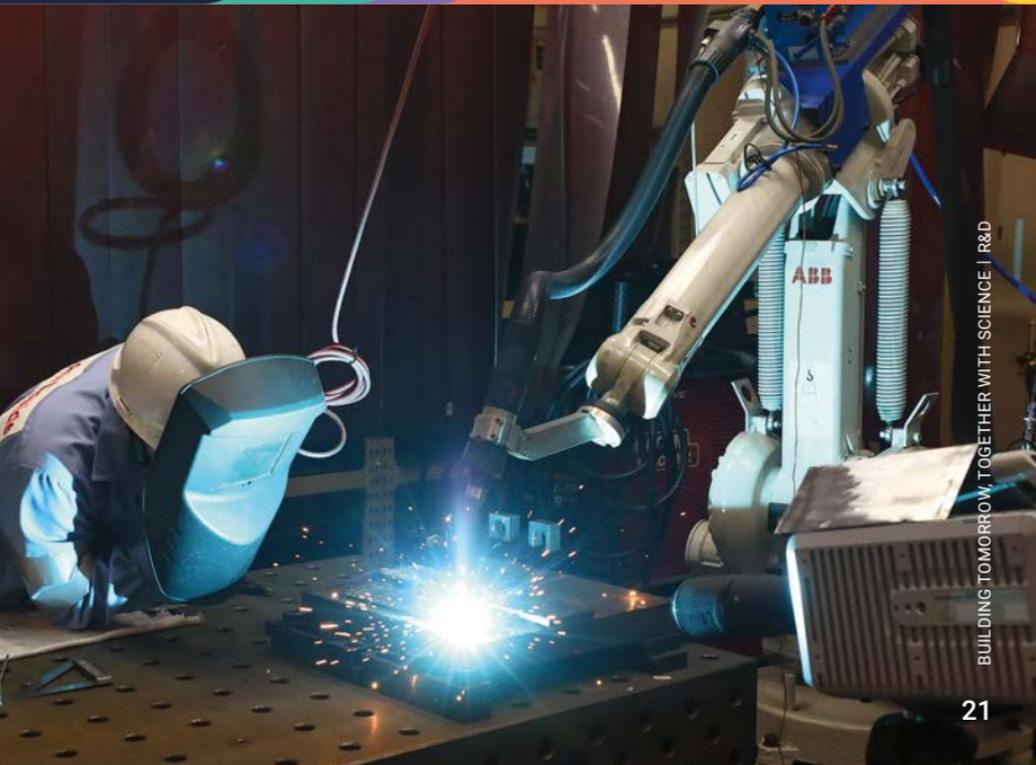
Cobot to handle small welding production

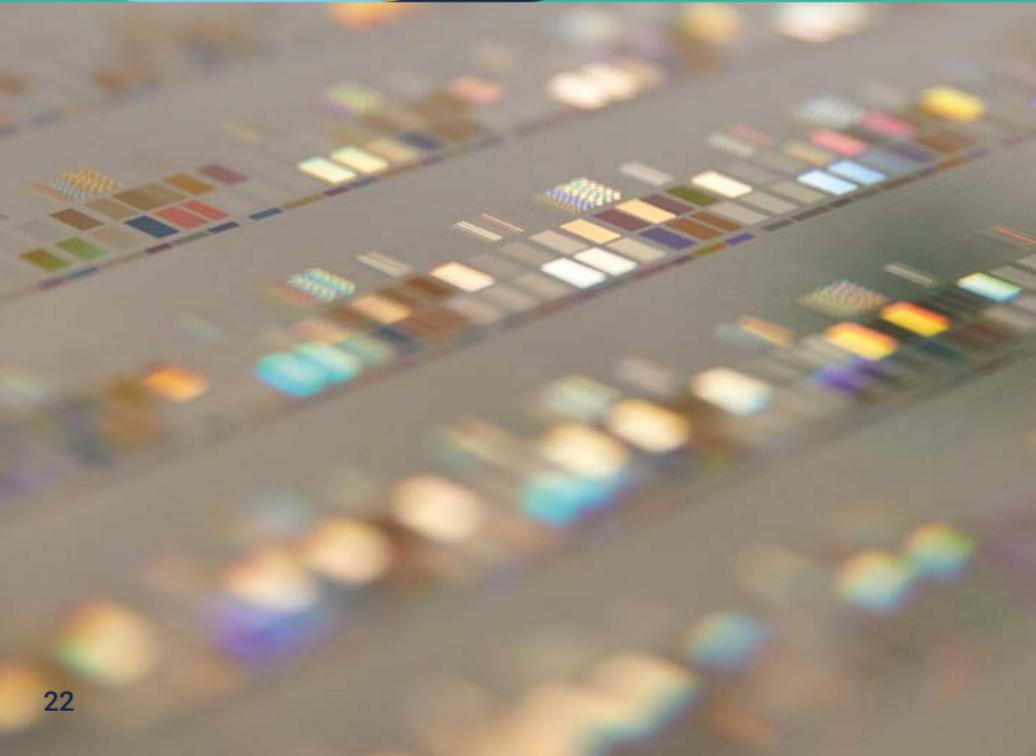
Cobots (collaborative robots) are designed to work safely in a human environment. **We are currently developing an app-controlled cobot for a multi-dimensional arm equipped with a welding torch.** It uses Air Liquide's ready-to-use ARCAL™ shielding gas solution as well as proprietary weld recipes which cover 80% requirements of a welding shop.



Etch molecules with low environmental impact

In the competitive context of data storage capacity, **we developed new families of etching materials.** This solution addresses both the growing complexity of the 3D design of new memory chip structures and the sustainability of the business. Indeed, thanks to their chemical structure lowering their lifespan in the atmosphere, these materials allow reducing the environmental impact of the etching process.





Working for our future



E-health for chronic patients

Improving the quality of life and care of patients at home is a significant global challenge, both socially and technologically.

To contribute to this effort, R&D teams have rolled out a remote medical surveillance solution improving the home monitoring of patients with chronic diseases. This monitoring relies on the analysis of data transmitted by individualized connected medical devices.



Biomethane for a circular economy

In a world where energy needs and sources are changing rapidly, the ability to transform organic resources into renewable and carbon-free energy is poised to become part of the new energy mix.

Fully aware of this fact, the R&D teams have studied biofermentation to **boost the production of biogas from agriculture or household waste. We develop separation technologies that purify biogas to convert it into biomethane,** injected into domestic grids. **When used as a fuel, it helps reduce 90% of vehicles' CO₂ emissions,** compared to diesel. R&D is involved across the entire biomethane value chain.



Produce hydrogen without steam

The willingness to reduce carbon emissions is a daily challenge for everyone. Among the solutions that can be put in place today, the use of hydrogen becomes obvious. However, conventional hydrogen plants are producing hydrogen and steam as a by-product, which is, in fact, wasted energy. Our teams worked on the development of patented technology, allowing us to **fully recycle the heat inside the plant,** thus eliminating steam and allowing for more efficient hydrogen production.



Digitalization of decision

The success of customer experience is at the heart of our performance. It has to be efficient, simple and customized. **Our teams developed a tool** that provides dispatch analytics and models of customer demands using data science. **The tool enables us to provide extra-volumes of gases to our customers at specific times at the best prices.**



Sustainable agriculture

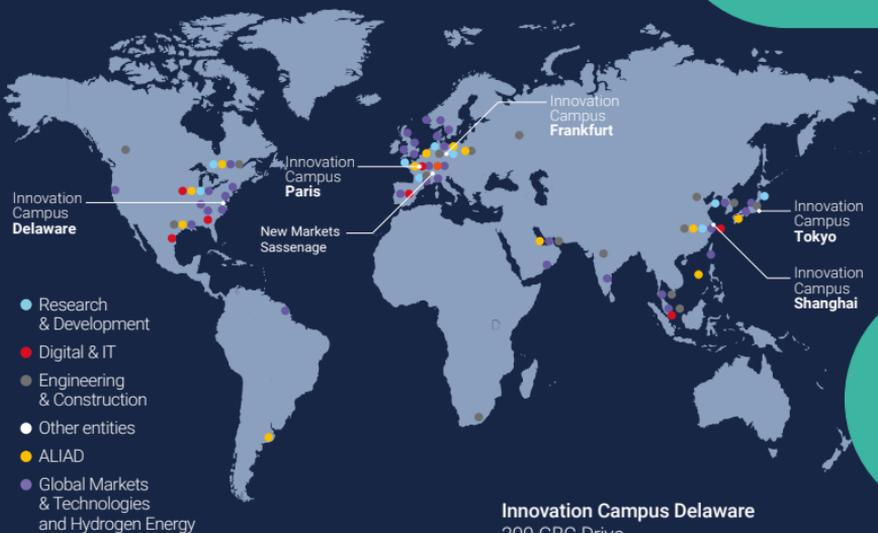
The reduction in the use of pesticides and fertilizers is a global priority for agriculture and food security.

Within Air Liquide R&D, the second edition of the Scientific Challenge highlighted the importance of a project related to the possibility to reduce this use.

More specifically, it is a question of identifying the role of using hydrogen-rich water to decrease nitrite accumulation in vegetables and fruits during their shelf life.



Campuses work with an Innovation Global Network



Innovation Campus Delaware

Innovation Campus Paris

New Markets Sassenage

Innovation Campus Frankfurt

Innovation Campus Tokyo

Innovation Campus Shanghai

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