Air Liquide
ENGINEERING & CONSTRUCTION

Cryogenics & Lurgi technologies

HYDROGEN PRODUCTION

Technology Solutions for clean Industry & Mobility

Air Liquide Group

A world leader in gases, technologies and services for Industry and Health

Air Liquide is present in 75 countries with approximately 66,400 employees and serves more than 3.8 million customers and patients. Oxygen, nitrogen and hydrogen are essential small molecules for life, matter and energy.

They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902. Air Liquide's ambition is to be a leader in its industry, deliver long term performance and contribute to sustainability – with a strong commitment to climate change and energy transition at the heart of its strategy.

Air Liquide Engineering & Construction

A technology partner of choice

Air Liquide Engineering & Construction builds the Group's production units (mainly air gas separation and renewable/low-carbon hydrogen) and provides external customers with efficient, sustainable, customized technology and process solutions.

Our core expertise in industrial gas, energy conversion and gas purification, enables customers to optimize the use of natural resources.

We cover the entire project life cycle: license engineering services and proprietary equipment, high-end engineering and design capabilities, project management and execution services. In addition, our worldwide capability enables us to offer efficient customer services internationally.

As a technology partner, customers benefit from our research and development activities to achieve energy transition goals.

We cover all applications with our low-carbon solutions for producing Hydrogen, Syngas, Methanol and Ammonia.

All these are available for any capacity and can be optimized for any low-carbon energy application, from feed-in to product-out, backed by engineering and operational experience on a global scale.

Powered by our suite of Technologies

Hydrogen generation, purification and recovery

- Autothermal Reforming (ATR)
- Low-carbon Steam Methane Reforming (SMR, SMR-X™)
- Gas Partial Oxidation (GasPOX)
- Electrolyzers
- Integrated Power-to-X
- Pressure Swing Adsorption
- Hydrogen Membranes

CO_2 capture and liquefaction

- Cryogenic carbon capture (Cryocap™ suite)
- Physical solvent based carbon capture (Rectisol™ and Recticap™)
- Amine solvent based carbon capture
- Carbon dioxide liquefaction

Energy carriers

- Hydrogen liquefaction
- Ammonia
- Methanol

3
Manufacturing centers

15
Engineering centers and front end offices

347
New patents filed in 2020

It is time to ACT for a sustainable future

ADVANCE, Air Liquide's strategic plan for 2025, is a milestone in the company's history. It places sustainable development at the heart of the Group's strategy, firmly setting Air Liquide on a clear course to deliver targeted global performance, combining financial and extra-financial dimensions.

The Group develops solutions contributing to climate and the energy transition—particularly with hydrogen—and takes action to progress in areas of healthcare, digital and high technologies. Air Liquide also helps its industrial customers to reduce their carbon emissions, developing new technologies and skills to support their low-carbon transition.

In full support of the 2015 Paris agreement, Air Liquide commitments for sustainability address the urgency of climate change and energy transition, targeting carbon neutrality by 2050 with key intermediary milestones in 2025 and 2035:

- to start reducing its absolute CO_2 emissions by around 2025
- to achieve a 33% reduction in Scope 1 & 2 CO_2 emissions by 2035.

Air Liquide ENGINEERING & CONSTRUCTION | Hydrogen

Supporting the energy transition with hydrogen

The world of energy is changing rapidly, but the challenge of the energy transition is long and complex.

Hydrogen has a vital role to play in decarbonizing industrial processes such as refineries and chemical plants and in developing cleaner transportation. It has use in a wide range of industries and its versatility means it can be used in diverse applications.

- Across industry, hydrogen produced in combination with renewables can support the decarbonization of a wide range of industrial processes.
- In mobility, hydrogen supports the use of fuel cells, enabling the decarbonization of various forms of transport.

Hydrogen is an integral part of our product portfolio and we have developed a portfolio of technologies for clean, cost-effective and efficient hydrogen production.

This experience allows us to apply these technologies in our own operations and also to support our customers in their transition.

A value proposition for our customers

The breadth of our portfolio and experience enables us to provide the most innovative technology solutions, focused only on what best meets the needs of each customer. We have extensive skills and experience in guiding customers through hydrogen technology decision making processes. Our experience and analytical capability, at this point of development in what is an emerging market, is invaluable when guiding companies towards the right solution.

- **Air Liquide Engineering & Construction's licence to operate relies on continuously achieving high levels of safety** (process, road and occupational safety), reliability and environmental performance, and security. It is also a prerequisite for our success and that of our customers.
- **Our comprehensive technology portfolio** extends across the entire hydrogen value chain, covering technologies for production, liquefaction, storage, and decarbonization.
- **The range of technologies we offer** enables us to address diverse needs across sectors, variations in scale, a range of feedstocks, or different product requirements. We can offer flexible solutions that address all these factors.
- **As we own and operate hydrogen production, liquefaction, storage and distribution assets,** we receive constant operating feedback and understand from hands-on experience the challenges related to process safety, reliability, and maintenance. We use this insight to design and build plants and equipment with an operating mindset and have a solid understanding of the challenges of on-site installation and complex projects
- **We guarantee quality, reliability, and efficiency as standard.** We can do this because our operational experience means we understand what our customers need and how to achieve it.


Air Liquide

Our hydrogen production solutions

A range of innovative technology solutions that address the diverse needs and individual requirements of our customers.

Low-carbon hydrogen

Autothermal Reforming (ATR)

ATR is a process for producing syngas, composed of hydrogen, carbon monoxide and carbon dioxide, by partially oxidizing a hydrocarbon feedstock with oxygen and steam and subsequent catalytic reforming. The advantage of this method of syngas production is that the entire reaction is happening within a single reactor. Due to this feature up to 99% of the carbon can be removed directly from the syngas in a concentrated manner leading to lowest carbon capture costs. This makes the ATR process when combined with CO-Shift and carbon capture technology one of the most cost effective solutions to produce low-carbon hydrogen at scale.

Air Liquide is the only company that has all the proprietary technologies and capabilities needed to combine ATR with carbon capture technology into a seamless integrated technology chain. For this, Air Liquide provides a range of carbon capture technologies suitable for ATR which will be applied depending on energy economics.

It is a reliable and robust setup that can transform natural gas or other feedstocks into syngas for hydrogen, ammonia and methanol, the overall setup being chosen to the advantage of each project.

Air Liquide has a proven track record, successfully designing, integrating and operating ATR plants, including 12 large ATR plants with a single-train ATR capacity of up to 450,000 Nm^3/h syngas.

Steam Methane Reforming (SMR)

SMR is a long proven, highly cost-effective and energy efficient way of producing hydrogen.
High levels of purity can be reached by employing in-house Pressure Swing Adsorption purification technology.

For low-carbon Hydrogen production, different combinations of CO_2 capture technologies in the process streams and SMR flue gas can be selected and integrated with a process scheme that is optimized to any given project needs. These highly competitive solutions allow for overall CO_2 capture rates up to 99% and differentiate Air Liquide from other licensors by the optimal integration of its proprietary technologies.

SMR-X™ integrated heat exchange steam reforming with a superior energy efficiency is available to further reduce the residual carbon footprint.

Today, we provide SMR technology for hydrogen production on both a small and large scale with carbon capture and storage.

Our technology allows for flexible utilization of feedstocks, and designs may be optimized for lowest operating expenditure, highest efficiency or lowest total lifecycle cost. Different degrees of modularization and standardization can be applied to meet project requirements.
For all plant designs, excellence in availability and reliability remains a prime focus. In this area, our customers benefit from Air Liquide's vast experience in operation with our own large portfolio of steam reforming plants.

For small hydrogen capacities, Air Liquide Engineering & Construction offers a modularized and standardized approach to SMR which features compact layout and comes in four different plant sizes with pre-defined equipment, piping arrangement and modules.

Gas Partial Oxidation (GasPOX)

GasPOX technology is similar to that described for ATR as a method for producing syngas or pure hydrogen.
The major difference is that a POX does not use a catalyst.

While ATR is limited to converting natural gas, the POX reactor can convert a wide range of gaseous hydrocarbons to make syngas (hydrogen, carbon monoxide, CO_2). In this process, we can adjust the individual syngas components through further processing so that it can be tailored to any clients' needs.

GasPOX is a proven process, well-referenced and with lower capital costs than other methods of syngas production. These features have resulted in growing market interest in this technology in recent years. The POX technology is of particular interest for clients who want to turn crude syngas from a biomass gasification into renewable syngas and hydrogen.

Our hydrogen production solutions

CO_2 Capture and Liquefaction

A distinctive aspect of our CO_2 management is our range of technologies which allows us to serve many customers and industries to decarbonize their processing facilities.
One of our key capabilities is our market-leading development and application of cryogenic processes, which involves the use of extremely low temperatures to separate gases.

With this background, one of our principal range of products developed in this area is known collectively as Cryocap™.

Cryocap™ H_2 combines cryogenic and membrane technologies to produce hydrogen. Cryocap™ FG captures CO_2 from flue gases and is of particular value to sectors such as refining or cement production. Cryocap™ Oxy captures and purifies flue gases to produce higher quality CO_2, with lower levels of impurities. Cryocap™ Steel can be retrofitted to steel production processes or installed new to boost process efficiency, and Cryocap™ XLL offers large scale CO_2 liquefaction, with low operational expenditure and high rates of CO_2 recovery.

Recticap™ is a streamlined version of our proprietary and well referenced syngas cleaning technology Rectisol™, specifically tuned for CO_2 capture. It is optimized for large-scale production of decarbonized hydrogen by ATR, and delivers high purity gaseous CO_2.

We also engineer amine-based technologies to capture CO_2 from syngas or flue gas. This can deliver high purity gaseous CO_2 at low pressure.

With our proprietary technologies for CO_2 capture (Cryocap™, Recticap™ and for integrated impurity removal, Rectisol™), and our referenced experience in the application of amine washes, coupled with our extensive operational experience, we have a range of highly competitive and tried-and-tested solutions for CO_2 capture.

Pressure Swing Adsorption

One of our technologies, known as Pressure Swing Adsorption, can recover and purify hydrogen from a wide range of hydrogen-rich streams.
The technology relies on differences in the adsorption properties of gases and can separate them under pressure.

It is an effective method of producing very pure hydrogen — reaching purity levels of more than 99%. The units that carry out this process are compact and skid-mounted and designed for unmanned, automatic use.

Renewable hydrogen

Hydrogen Membranes

Air Liquide has developed unique expertise for high-performance hydrogen membranes.
Membranes can be used on a stand-alone basis for recovery of hydrogen from a process stream (such as ammonia purge gases), or integrated in a Cryocap™ H_2 to debottleneck hydrogen production from an existing Steam Methane Reformer while capturing CO_2 from process gas.

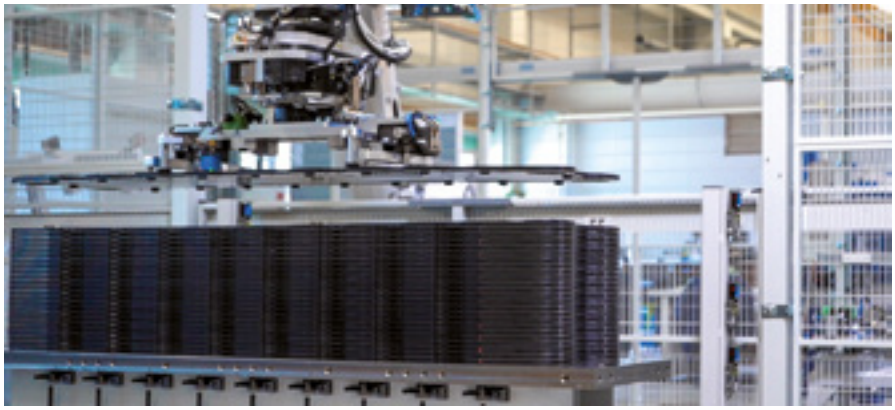
Integrated Power-to-X plants (PtX)

The conversion of electricity into chemical energy is called PtX where the 'X' may represent liquid hydrogen, methanol, ammonia or other energy carriers.
For these three options, Air Liquide Engineering & Construction is able to deliver integrated production plants, optimized for a direct coupling with fluctuating renewable energy sources.

For example, a CO_2-to-methanol plant consists of an electrolyser, a carbon capture unit and a methanol production plant. As we possess all three of these technology elements, we are in a unique position to deliver superior integration concepts by also leveraging our experience in hydrogen storage and adding flexibility to the downstream process.

The same capability applies to integrated liquid hydrogen plants and we are also able to integrate ammonia synthesis to produce low-carbon Ammonia.

Our hydrogen production solutions



Electrolyzers

A core technology in renewable hydrogen production is electrolysis — the process of splitting water into hydrogen and oxygen by applying an electrical current.
We have proven experience of electrolysis on an industrial scale and have made some of the largest industrial investments ever seen in this technology.

Our offer to customers includes either Proton Exchange Membrane (PEM) or Alkaline (AEL) technologies.

Our capability has been reinforced by our joint venture with Siemens Energy, which will produce industrial scale renewable hydrogen electrolyzers for customers worldwide. The partnership is strongly supporting the emergence of a sustainable hydrogen economy in Europe and will help to foster a European ecosystem for electrolysis and hydrogen technology.

The joint venture will produce electrolysis modules for a broad range of customers to serve the rapidly growing market. Based on PEM electrolysis technology, the modules feature a high degree of efficiency and are ideally suited to harvest volatile renewable energy.

Customers benefit from our partnership with Siemens Energy, leveraging pre-developed and extensively optimized products based on our own projects that are already in execution. Our cooperation is driving the co-development of the next generation of PEM electrolyzer technologies, which will allow further efficiency improvement, contributing to the cost competitiveness of low-carbon hydrogen.

Energy Carriers

Hydrogen Liquefaction

The use of liquid hydrogen is of increasing importance in mobility.
We offer hydrogen liquefiers at varying scales, from small to large, with highly efficient technologies that have low maintenance costs and high levels of reliability.
Our equipment is designed and manufactured in-house.

We have 60 years of experience in the design, engineering and operation of ultra-low temperature liquefaction plants. With the growth in hydrogen mobility and the transition to low-carbon societies, we are supplying the high performance equipment for the largest hydrogen liquefaction plant in the world in South Korea, which will have a production capacity of 90 tonnes per day of liquid hydrogen. We are already working on the next generation of H_2 liquefiers with a size above 100 tpd for large liquid hydrogen export projects.

We have several proprietary technologies including expansion turbines, heat exchangers, advanced insulation cold boxes, and a range of standard H_2 liquefiers. Our optimized hydrogen liquefaction plant portfolio enables us to address the growing need, driven by clean mobility demand.

Ammonia as a hydrogen carrier

Ammonia, with its potential for decomposition into nitrogen and hydrogen, can play an important enabling role in establishing hydrogen as an integral part of a low-carbon future.
Air Liquide offers customers access to low-carbon ammonia production concepts. With our expertise for large scale hydrogen production, nitrogen production and carbon capture technologies, we offer solutions beyond the conventional ammonia production routes.

Thus customers can benefit from seamless integrated low-carbon ammonia production concepts at scale. With the addition of the necessary infrastructure for transport and storage, customer needs can be complimented to make ammonia a valuable low-carbon energy carrier.

Once transported, ammonia can be readily re-converted to create a valuable hydrogen supply.

Methanol: a low-carbon fuel and chemical commodity

CO_2 is the lowest energy containing carbon derivative, which is left when combusting hydrocarbons.
Although already a part of nature's value chains, CO_2 produced from fossil fuels cannot be recovered by nature in the quantities being emitted.

One way of making use of CO_2 is to produce methanol, which is used in various chemicals and recently used as a marine shipping fuel. Air Liquide Engineering & Construction offers a technology for the conversion of CO_2 to methanol.
Together with our catalyst partner, Clariant, the technology is commercially available at any scale.
For the production of renewable methanol, hydrogen should come from electrolysis from renewable sources or from steam biomethane reforming with carbon capture.
CO_2 shall be sourced from a renewable origin, as well as, for example, fermenters or CO_2 capture from a biomass combustor.

Our experience and commitment

Air Liquide is investing in hydrogen projects and partnerships that demonstrate the potential for a cleaner energy future.

North Las Vegas, Nevada

the largest liquid hydrogen production and logistics infrastructure

In May 2022, Air Liquide opened its largest liquid hydrogen production and logistics infrastructure facility in North Las Vegas, Nevada. The facility will supply the growing needs for hydrogen mobility, but will also allow to provide hydrogen to a wide array of industries while the mobility market continues to mature.

The facility, and the associated logistics infrastructure, marks a $250 million investment by Air Liquide in the United States hydrogen market and will position Nevada as a leader in hydrogen energy production.

The North Las Vegas facility will produce 30 tonnes of liquid hydrogen per day which will be utilized by various customers, notably by those in the growing clean mobility market on the West Coast, especially California. The facility is powered by fully renewable electricity and can also use renewable natural gas to meet the California Low Carbon Fuel Standard (LCFS) when supplying the California mobility market.

The renewable hydrogen produced can serve over 40,000 fuel cell vehicles in California, significantly improving the hydrogen supply for mobility, a critical enabler for market growth. While the clean mobility market continues to mature, the plant configuration will also allow for the sale of hydrogen to a wide array of sectors with a range of renewable and low-carbon options for customers.

Seine Valley

a cornerstone of the decarbonization ecosystem

The Air Liquide Normand'Hy project is a cornerstone of the decarbonization ecosystem which is being set up by Air Liquide with other major industrial players on the Seine Valley axis in Normandy, France.

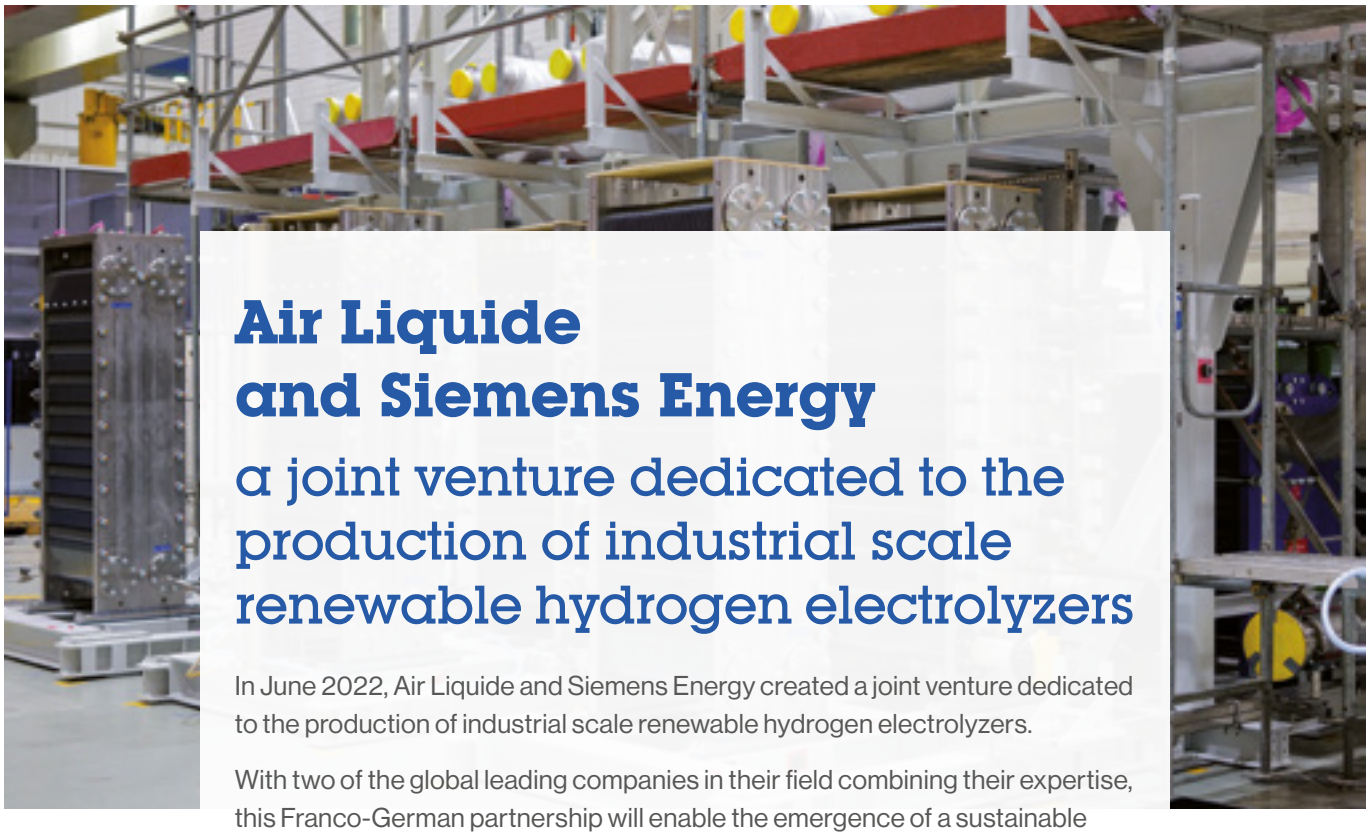
Air Liquide already operates its largest hydrogen production unit in France in Port-Jérôme. In 2015, the Group installed a process that is unique in the world, the Cryocap™ technology, which recovers and isolates the CO_2 emitted during hydrogen production using a cryogenic process.

In 2021, TotalEnergies and Air Liquide joined forces to decarbonize hydrogen production at TotalEnergies' Normandy platform in France. This project will enable in time, for the supply to TotalEnergies by Air Liquide of low-carbon hydrogen and the implementation of a large-scale CO_2 capture and storage solution (CCS). Under a long-term contract agreement, Air Liquide will take over and operate the 255 tonnes-per-day hydrogen production unit at the TotalEnergies platform in Normandy.

In July 2021, Air Liquide, Borealis, Esso S.A.F., TotalEnergies and Yara International ASA also signed a Memorandum of Understanding to explore the development of CO_2 infrastructure including capture and storage, to help further decarbonize the industrial basin located in the Normandy region with the objective to reduce CO_2 emissions by up to 3 million tonnes per year by 2030.

Air Liquide will also connect a 200 MW Proton Exchange Membrane (PEM) electrolyzer to its hydrogen pipeline network in Normandy, which would supply renewable hydrogen for industrial and heavy mobility applications. This project, which is planned to be commissioned in 2025, will avoid the emission of more than 250,000 tonnes of CO_2 per year and contribute to the development of the world's first low-carbon hydrogen network.

Our experience and commitment



Air Liquide and Siemens Energy

a joint venture dedicated to the production of industrial scale renewable hydrogen electrolyzers

In June 2022, Air Liquide and Siemens Energy created a joint venture dedicated to the production of industrial scale renewable hydrogen electrolyzers.

With two of the global leading companies in their field combining their expertise, this Franco-German partnership will enable the emergence of a sustainable hydrogen economy and foster an ecosystem for electrolysis and hydrogen technology. Production will begin in the second half of 2023 and ramp-up to an annual production capacity of three gigawatts by 2025.

The joint venture multi-gigawatt factory that produces electrolysis modules (“stacks”) is located in Berlin and will supply both Groups for their respective broad range of customers worldwide and to serve the rapidly growing market.

Based on Proton Exchange Membrane (PEM) electrolysis technology, these stacks will feature a high degree of efficiency and are ideally suited to harvest volatile renewable energy.

In addition, Air Liquide and Siemens Energy are dedicating R&D capacities to the co-development of the next generation of electrolyzer technologies.

The strategic partnership benefits from a portfolio of hydrogen projects combining both Air Liquide and Siemens Energy’s pipelines, targeting large industrial-scale hydrogen projects in collaboration with customers. This will create a solid basis for the required rapid ramp-up of electrolysis capacities and thus is expected to make competitive renewable hydrogen available sooner.

Becancour

the world's largest PEM electrolyzer

In January 2021, Air Liquide completed the construction of the world's largest Proton Exchange Membrane (PEM) electrolyzer. Supplied with renewable energy, this unit is now producing up to 8.2 tonnes per day of low-carbon hydrogen in Bécancour, Québec.

The 20 MW PEM electrolyzer, is the largest operating unit of its kind in the world and helps meet the growing demand for low-carbon hydrogen in North America. Bécancour's proximity to the main industrial markets in Canada and the United States helps ensure the supply of low-carbon hydrogen for industrial use and mobility. Today, the electrolysis unit increases by 50% the capacity of Air Liquide's Bécancour hydrogen production complex.

Compared to the traditional hydrogen production process, this production unit avoids the emission of around 27,000 tonnes of CO_2 per year, which is equivalent to the emissions of 10,000 cars per year. The Bécancour location ensures access to abundant renewable power from Hydro-Québec and the proximity to the hydrogen mobility market in the northeast of the continent.

With this large-scale investment, the Group confirmed its long-term commitment to the hydrogen energy markets and its ambition to be a major player in the supply of low-carbon hydrogen.

Air Liquide ENGINEERING & CONSTRUCTION | Hydrogen

With more than 60 years of experience, Air Liquide masters the entire hydrogen value chain: production, transport, storage and distribution.

Air Liquide
ENGINEERING & CONSTRUCTION

A global presence

A fundamental goal at Air Liquide Engineering & Construction is to provide our customers with competitive solutions that are safe and reliable. Our aim is to make sure that our customers can secure the best possible performance from their operations and make the most efficient use of natural resources that support the transition to a low-carbon society.

Contact us
hydrogen@airliquide.com

www.engineering-airliquide.com