

# PUSHING BACK THE FRONTIERS

*Innovative solutions for aerospace and space*

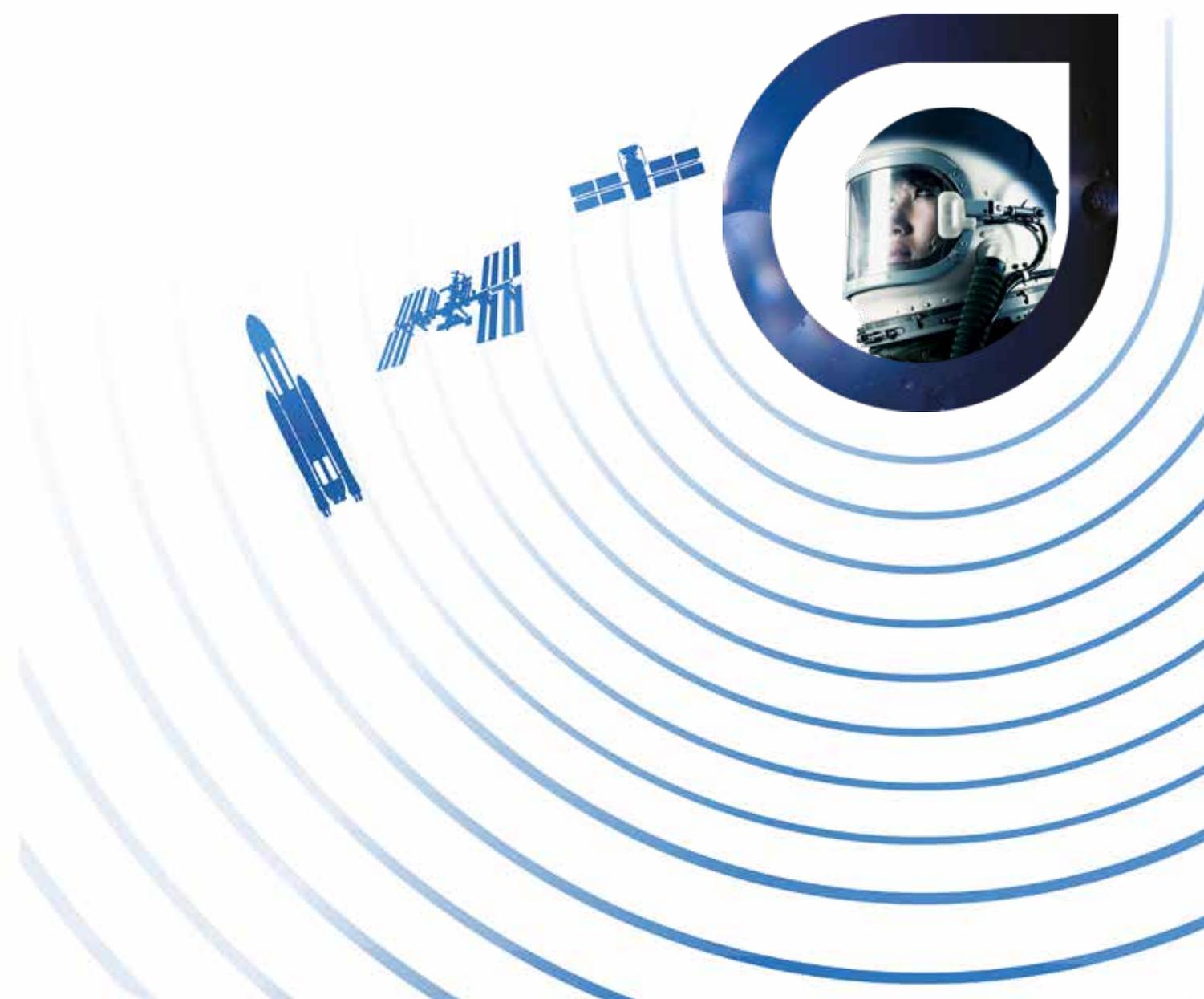
Press kit



International Paris  
Air Show 2019







# Air Liquide, a major player in aerospace and space

A world leader in gases, technologies and services for Industry and Health, Air Liquide is a major partner in civil and military aviation and has participated in the space adventure for more than 50 years.

Air Liquide designs systems that generate gas for use both onboard aircraft and on the ground. Air Liquide has also established its reputation in the field of space thanks to its expertise with rocket launchers (ground resources and Ariane launchers), in the design of cryogenic equipment for satellites as well as space exploration (MTG, Herschel, Planck, Melfi, Curiosity, ExoMars, etc.).

The Group continues to innovate and is constantly pushing back the frontiers of technology, helping to shape the contours of the world of tomorrow by developing industrial solutions that address the major economic and environmental challenges of today.

On the occasion of this new edition of SIAE, Air Liquide will present its latest innovations in space and aerospace, such as the use of hydrogen as a viable energy alternative for aircraft, solutions for the additive manufacturing of exchangers/reactors and for using supercritical carbon dioxide when cleaning metal parts. You will also discover new technologies developed for the future Ariane 6 launcher or for electric propulsion for satellites and its projects in connection with space exploration (moon village analogue, Mars, etc.).

# Air Liquide, a key partner for life support in aerospace



A world leader in the field of air gas separation technologies, Air Liquide has developed cutting-edge expertise in aerospace and, today, is a favored partner in civil and military aviation. Air Liquide offers equipment and systems related to the supply of gas on aircraft or helicopters and on the ground.

- On board gas generation for aircraft: the OBOGS for the supply of oxygen on board aircraft, the OBIGGS for the protection of aircraft fuel tanks,
- Portable oxygen equipment for cabin crew or for passengers,
- Gas generation for ground devices, cryogenics for optronics and aerospace customer support,
- Hydrogen energy for aerospace: reducing pollution in airports and in the air.

# Onboard gas generation for aircraft

## OBOGS brings oxygen on board aircraft

The autonomous generation system OBOGS (On Board Oxygen Generating System) produces unlimited oxygen enriched air for use on board aircraft. Designed to replace the liquid oxygen reserves on board and thus to reduce the weight of breathing gear, it meets all the physiological needs of pilots (breathable gas and anti-G protection). Selected for use in numerous military aviation programs, the Air Liquide OBOGS will soon equip more than half of all new generation aircraft and also aspires to equip civil aircraft in the near future.

The OBOGS prototype flew for the first time aboard a Mirage 2000 in 1989, before being selected by Dassault the very next year to equip the Rafale (maiden flight in 1993). More than 500 fighter jets are equipped with OBOGS equipment and systems (Rafale, F35, L159, M346).

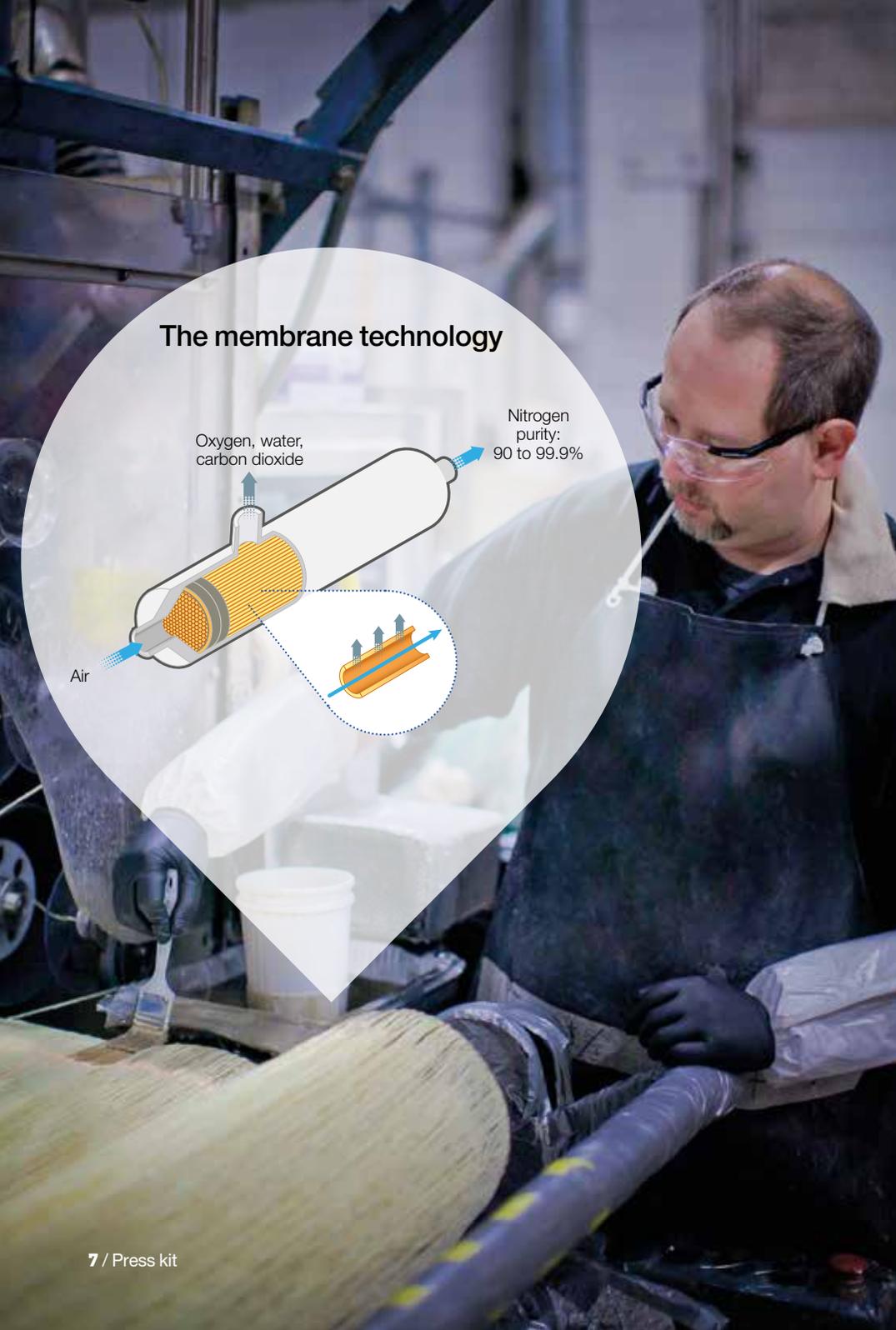
## OBIGGS protects aircraft fuel tanks

The OBIGGS (On Board Inert Gas Generating System) line improves the safety of airplanes and helicopters thanks to an interting system that protects aircraft fuel tanks against any risk of fire or explosion. Based on Air Liquide's hollow fiber separation process MEDAL™, the OBIGGS produces the flow of Nitrogen Enriched Air (NEA) required in flight to protect the aircraft.

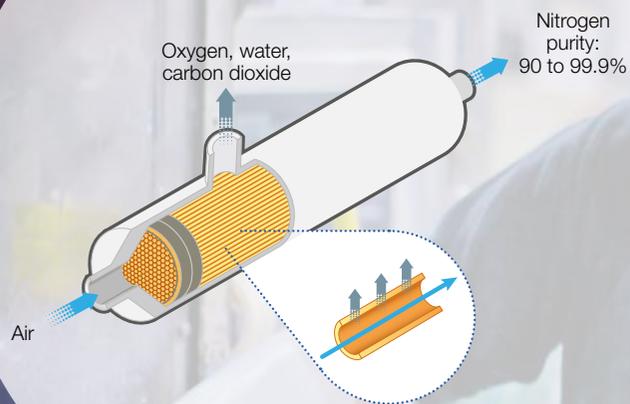
The Air Liquide OBIGGS was delivered in 1991 to Eurocopter in order to equip the German Tiger aircraft. To date, Air Liquide has supplied the OBIGGS to more than 380 military helicopters (ALH, Tiger, KUH Surion/KHP). This equipment was recently sold for use in civil aviation and today is installed on the Boeing B-737.



OBOGS equipment.



## The membrane technology



## The Air Liquide membrane technology for gas separation

The membranes of Air Liquide Advanced Separations lie at the heart of the OBIGGS system. Made of hollow polymer fibers, the OBIGGS reduce the oxygen content in fumes in aircraft fuel tanks. OBIGGS systems prevent these fumes or vapors from igniting and thus reduce the risk of fire or explosion.

Air Liquide Advanced Separations, a subsidiary of the Group which is the merger of two US entities, MEDAL and PoroGen, designs and manufactures an extended range of hollow fiber membranes required for gas separation and purification.

## How does it work?

The polymer used to make the membrane is what determines the degree of separation. By manipulating the degree of pressure, the gases selectively pass through the membrane based on differences in size, shape and solubility, using the driving force of the partial pressure. As an example, oxygen molecules pass through membranes 2 to 9 times faster than larger, less soluble nitrogen molecules.

The advantages of Air Liquide's membrane technology:

- Light and compact system
- Productive and energy efficient membrane
- Adaptable solution and integration

# Portable oxygen equipment

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## Protection breathing equipment for cabin crew (PBE hoods)

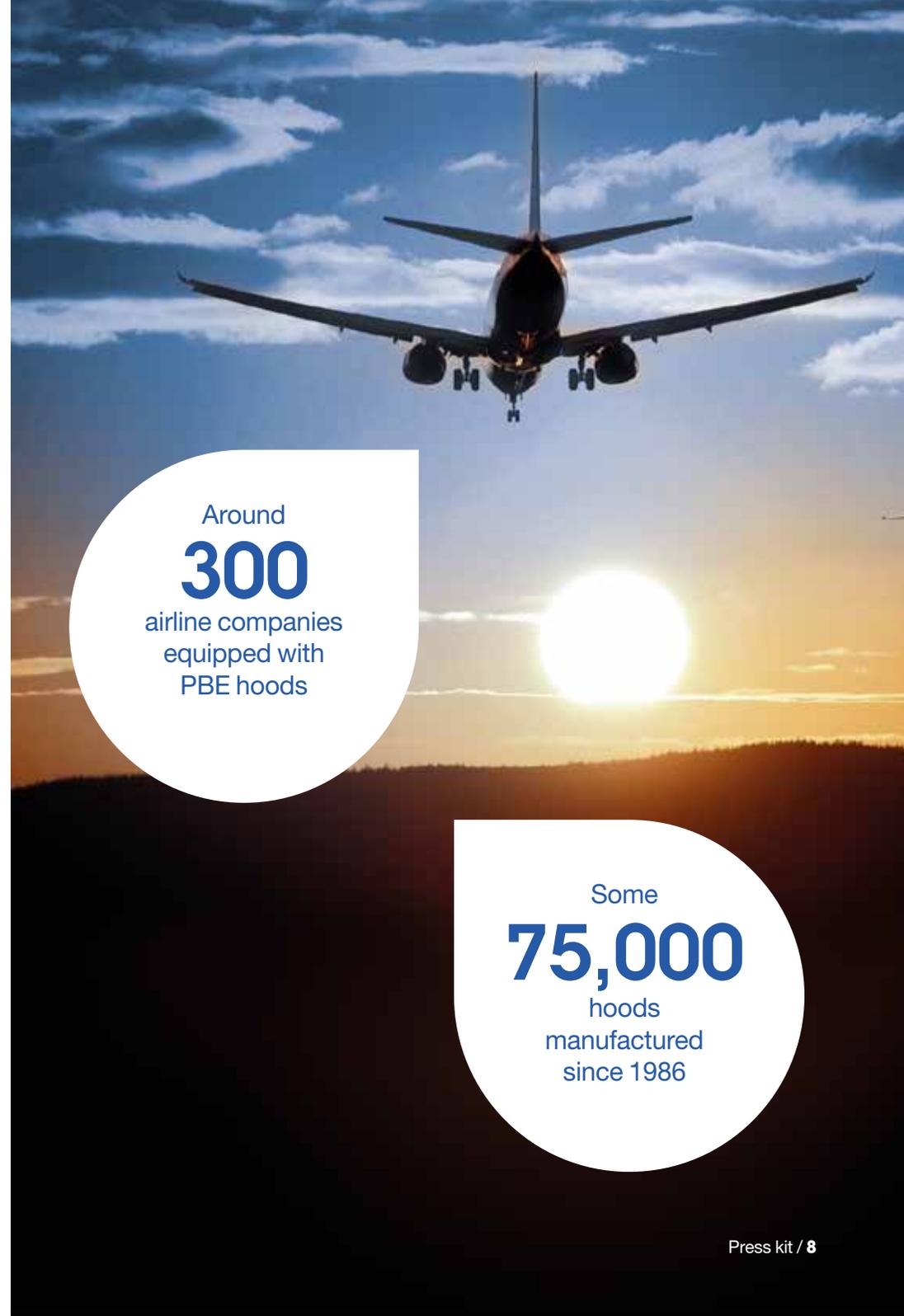
Air Liquide designs and manufactures protective smoke hoods, specially designed for cabin crew. This PBE uses compressed aeronautical quality oxygen and delivers this oxygen to commercial flight crew members, as soon as it is put on, for 15 minutes of operating time.

This is an autonomous oxygen delivery in closed-loop systems for contaminated areas or forced sea landings thanks to the smoke hood who offers flight personnel the protection required for organization of evacuation operations in the event of fire.

## Portable Pulse Oxygen Cylinders - DE Series

Air Liquide has acquired the portable oxygen systems of Avia Technique, which specializes in mechanical gas distribution. Its signature technology is aircraft emergency, first aid and therapeutic oxygen delivery on board commercial aircraft.

A pulse dose therapeutic oxygen conserving system designed for passengers who have a pre-existing medical condition and pre-book oxygen for their flight(s). It can also be used for emergency purposes (First Aid). Its innovation is based on "pulse" oxygen distribution, which allows the individual user to trigger the delivery of oxygen while controlling the amount of oxygen that is delivered. The benefit is immediate: these onboard oxygen cylinders offer 5 times the autonomy of other systems.



Around  
**300**  
airline companies  
equipped with  
PBE hoods

Some  
**75,000**  
hoods  
manufactured  
since 1986

# Gas generation for ground devices

In order to meet the logistic requirements of both armies and airlines, Air liquide has developed ground devices: gaseous Nitrogen Mobile generators are used for equipment service operations such as damper and tire inflation, and high pressure capacity filling. Gaseous or liquid Oxygen Mobile Generators are used to fill the pilot and crew oxygen bottles and converters. Air Liquide meets both army and airlines restraints by relieving them of heavy logistics.

- Elimination of logistics restraints related to liquid nitrogen and oxygen storage and cylinder transportation systems.
- Oxygen and nitrogen production in harsh environments such as aircraft carriers.
- Supply of high purity oxygen in large quantities for field hospitals.

## Cryogenics for optronics

Air Liquide offers a wide range of miniature cryocoolers, able to cool down below 100K infrared detectors designed for various optronic applications. Cooling down infrared detectors or electronic components, on the ground or on board, in harsh conditions.

## Aerospace customer support

The aerospace customer support provides preventive and curative maintenance for on-board gas generating systems, ground production and storage in order to maintain the equipment in operational conditions.



Filling of an on-board oxygen converter  
via an autonomous generation system.



# Hydrogen energy for aerospace

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## Reducing pollution on airports and in the air

Hydrogen could be used for the next generation of aircraft looking for alternative sources to power non-propulsive aircraft systems. Air Liquide develops high-tech hydrogen storage and distribution systems for aircraft manufacturers investigating the use of non-fossil fuels to generate electrical power on board for several applications.

Air Liquide also conducts studies on hydrogen supply chain options including the airport hydrogen infrastructures for the applications mentioned above.

## About hydrogen

Hydrogen is a clean energy source that can be sustainable. It is also an effective means of storing energy. As an energy solution, hydrogen shows high potential and offers many advantages, from its low environmental impact to its durable nature.

It can be produced from many sources that are available in large quantities on Earth: water and electricity, biomass, biogas, natural gas, etc.

# Facts and figures

## Air Liquide and aerospace

WORLD LEADER  
IN ONBOARD GAS  
GENERATION  
FOR MORE THAN  
**30** YEARS



AROUND **300**  
AIRLINE  
COMPANIES  
EQUIPPED  
WITH PBE HOODS



AROUND  
**75,000**  
HOODS MANUFACTURED SINCE 1986



**1,000**  
MOTORIZED  
VALVES  
PRODUCED  
ANNUALLY



MORE THAN  
**500**



FIGHTER JETS EQUIPPED  
WITH OBOGS SYSTEMS  
AND EQUIPMENT

MORE THAN  
**380**



HELICOPTERS  
EQUIPPED WITH  
OBBIGS

MORE THAN  
**5,000**  
COMMERCIAL JETS



WITH TANKS INERTED USING  
AIR LIQUIDE EQUIPMENT  
(MEDAL MEMBRANES)

Breathing protection for  
cabin crews designed  
by Air Liquide are  
selected by Air France

25 years of flying  
for Air Liquide's  
oxygen generating  
system OBOGS

1987



OBOGS adopted on  
the Rafale program,  
to be fitted on over  
200 planes

1990

First in-flight  
OBBIGS  
system in Italy



2001

US Air Force gets  
fitted out with oxygen  
analysers designed by  
Air Liquide (F-35 JSF)

2003

2014

2018



Protective breathing  
equipment  
production peak  
year: 7,000 units

# Air Liquide, a leader in space cryogenics



Air Liquide has built a solid reputation in the space industry as a partner of the scientific community and a player in the fabrication of tanks and cryo-technical equipment, with respect to the production of industrial gases and the provision of related services. Thanks to its mastery of cryogenics, Air Liquide is associated with the largest international space projects: the Ariane program, observation satellites (Herschel, Planck, etc.), and the International Space Station (Melfi).

Today, Air Liquide is pursuing its ambitions in the space industry via:

- **Launchers and the Ariane 6 project**, capitalizing on its savoir-faire and experience acquired from the start of Ariane 1 through to Ariane 5, in connection of a global offer that covers ground, onboard, gases, and services
- **Satellites**, thanks to its innovative pulse tube technology (cold production using pulsed gas tubes) and complete offer for electric propulsion,
- **Space exploration** involving the challenges of renewable energy production, in particular for future facilities on the Moon (Moon village analogue) and equipment for MOMA (Mars Organic Molecule Analyzer), the principal instrument of ExoMars, which will be launched in 2020.

# Air Liquide, at the heart of the european launcher Ariane 5

Since the Ariane program kicked off in Brussels in 1973, Air Liquide has contributed to all successive evolutions of the launcher, from Ariane 1 to Ariane 5, a flawless collaboration with European partners during the 247 Ariane flights recorded to date.

Armed with its expertise in Ariane's cryogenic tanks, Air Liquide brings unique added value to the sector, with more than 50 years of experience in space cryogenics, dozens of specialized staff, and a dedicated test center.

At Les Mureaux in the greater Paris area, Euro Cryospace (a strategic partnership between Air Liquide and Airbus Defense and Space) is involved from the design of cryogenic tanks to their integration into systems and proposes innovative solutions designed to optimize launcher performance.

Euro Cryospace has 150 employees. It designs, develops and manufactures the tanks on the main stage of the launcher, which contain 175 tons of liquid hydrogen and oxygen, as well as the liquid hydrogen tank of the upper cryogenic stage.

Air Liquide Advanced Technologies, located near Grenoble, employs 150 people who design and produce the main stage liquid helium subsystem as well as the Ariane 5 ECA cryogenic top-level oxygen tank, which is capable of propelling two satellites, weighing nearly 10 tons in total, into geostationary orbit.

Air Liquide will continue to manufacture Ariane 5 tanks until 2022, at which time Ariane 6 will take over.



1 Pressure control components



2 Pressurised helium tank



3 ESC-A\*: Liquid hydrogen tank



4 ESC-A\*: Liquid oxygen tank



5 Level gauges, propellant management devices (anti-vortex...), insulation



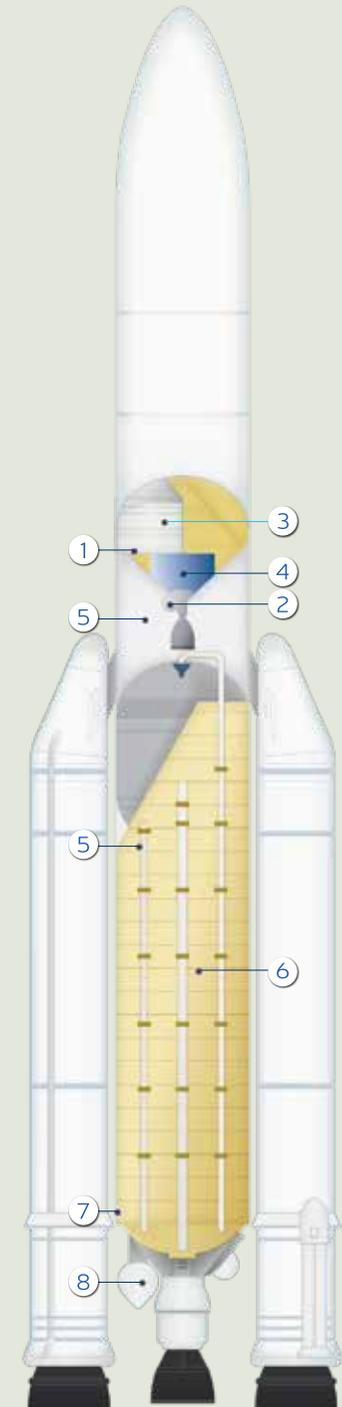
6 EPC\*\*: Liquid hydrogen and oxygen tanks



7 Cryogenic feed lines



8 Pressurising liquid helium tanks



\*ESC-A: Cryogenic upper stage "A"

\*\*EPC: Main cryogenic stage



High pressure regulation plate



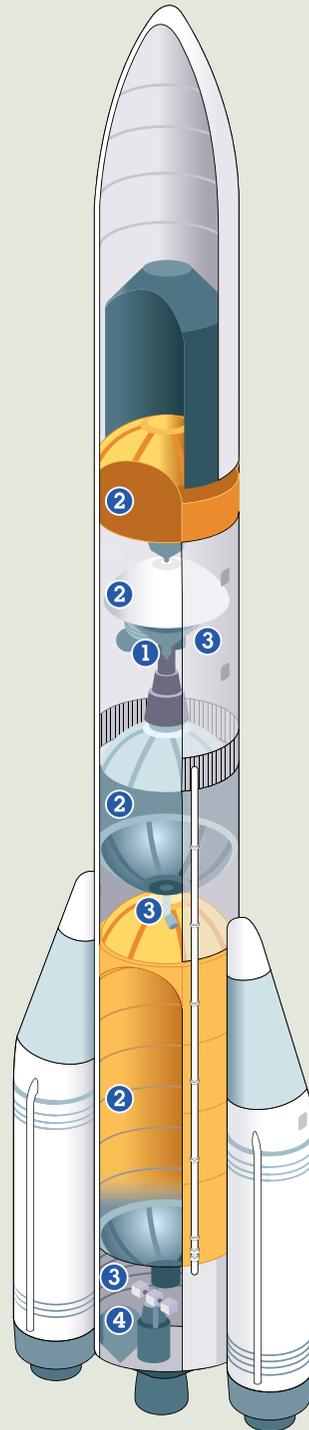
Propellant management devices: level gauges (liquid hydrogen and oxygen), anti-vortex, etc.



Cryogenic feeding and pressurization lines



Pressurizing liquid helium tanks



# Air Liquide, on board the future Ariane 6 European launcher

Today, Air Liquide is a partner of the new Ariane 6 launcher. The Group is the design authority for the cryogenic segment of this new three-stage rocket, two of which are hydrogen.

The Group will be in charge of cryogenic studies, and will notably **design and manufacture the cryogenic lines of the tanks of the main and upper stages** of the launcher, which contain 175 tons of liquid hydrogen and oxygen. On the Kourou launch pad in Guiana, Air Liquide was also chosen for the **design of equipment for the distribution of cryogenic fluids** - oxygen, nitrogen, hydrogen and helium - required for the propulsion of the new ELA4 launcher system dedicated to Ariane 6.

Air Liquide seeks to maintain and strengthen the foundation built around launchers with its unique ground expertise, implemented at Kourou, and unique expertise in cryogenics, on the Ariane 6 project, capitalizing on our expertise and experience acquired from Ariane 1 to Ariane 5, as part of a **ground / onboard / gases / services offer**.

To achieve this aim, Air Liquide has developed innovative cryogenic technologies to meet the new challenges of the sector, in particular the need for “versatility” in connection with the future Ariane 6 launcher, which must be able to adapt to different missions. This calls for a major change, since the cryogenic engine that propels the upper stage will have to re-ignite in flight.

# Air Liquide in the Guyana Space Center in Kourou

On the space launch sites of Kourou in Guyana, in Cape Canaveral in the USA, Tanegashima in Japan, as well as Xichang and Wenchang in China, Air Liquide has been preparing, testing, and optimizing the installation and connections of cryogenic lines for launch pads since the 1980s.

The creation of **Air Liquide Spatial Guyane** - an integral part of the Guyana Space Center - in 1991 allows Air Liquide to produce and supply all the gases and related services needed to launch the Ariane rocket directly on the launch pad in Kourou. On the Kourou launch pad in Guiana, Air Liquide was also chosen for the **design of equipment for the distribution of cryogenic fluids** - oxygen, nitrogen, hydrogen and helium - required for the propulsion of the new ELA4 launcher system dedicated to Ariane 6.

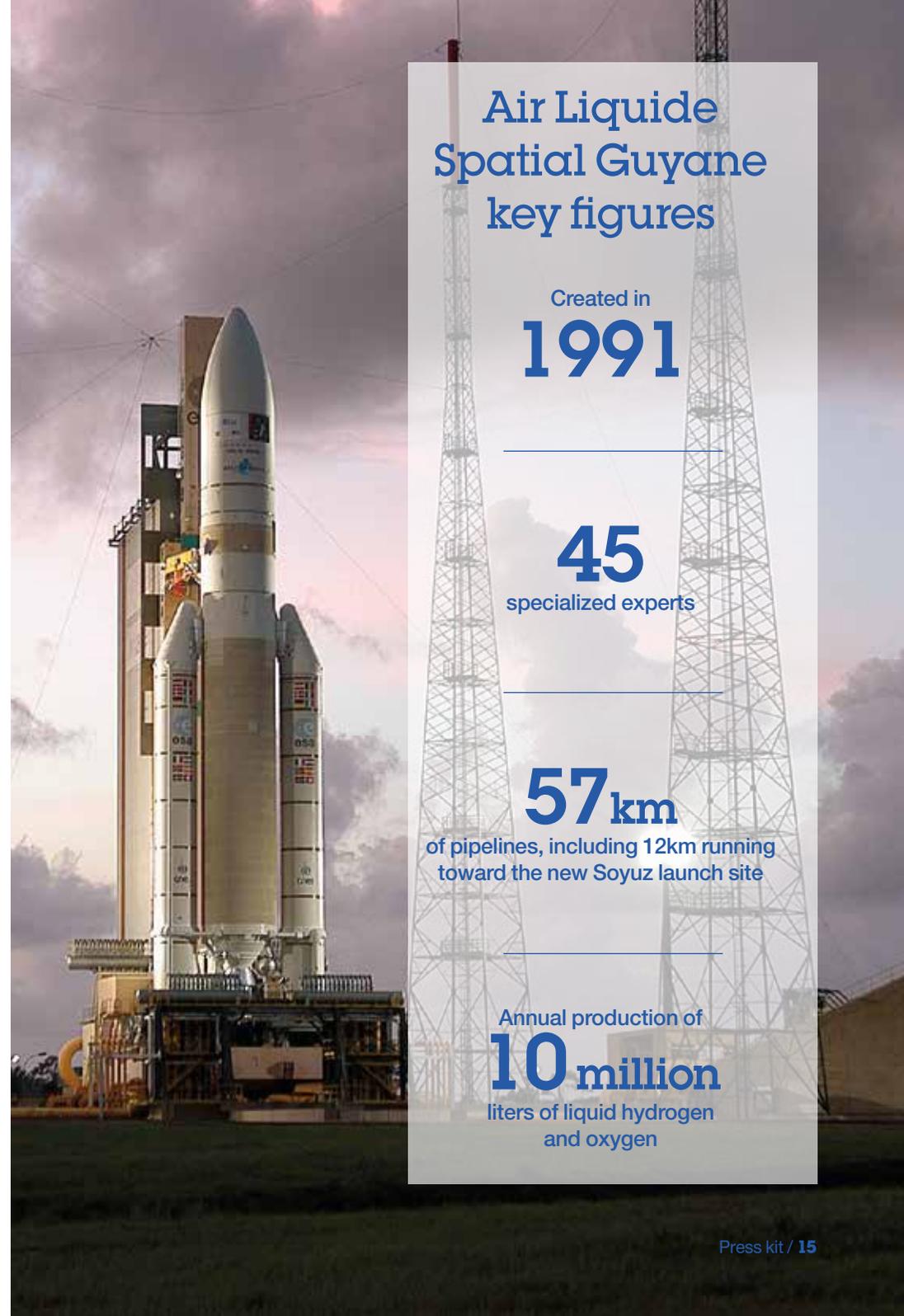
## Supplying propulsion fluids

- Liquid hydrogen and oxygen for the propulsion of launchers
- Helium stored in its liquid state, after it has been reheated, is used to pressurize the main oxygen tank,
- Gaseous helium and nitrogen used for pressurization, cooling and draining.

## Assistance, onsite services and support up to launch

The services provided by Air Liquide go well beyond the supply of gases: the helium liquifier (HELIAL) and the hydrogen liquifier (HYLIAL) are also used in the production of liquid helium and hydrogen that can be stored and redistributed. In addition, Air Liquide offers full maintenance services, cryotechnical or other, for equipment sets, particularly vacuum super-insulated transfer lines.

Air Liquide experts are on hand in Kourou during each launch campaign and take care of inspecting the cryogenic tanks and equipment all the way up to the time of the launch. Arianespace, like the CNES, has entrusted Air Liquide Spatial Guyane with responsibility for supervising the full maintenance programs for a whole range of equipment and for all of the flexible pipes that connect the launcher to the launch umbilical tower.



## Air Liquide Spatial Guyane key figures

Created in  
**1991**

**45**  
specialized experts

**57 km**  
of pipelines, including 12km running  
toward the new Soyuz launch site

Annual production of  
**10 million**  
liters of liquid hydrogen  
and oxygen

# Cold for space

## Cryogenic equipment for satellites

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Beyond the launchers, Air Liquide solutions are present in space through the cryogenic equipment that is essential for the operation of satellites for the observation of the earth as well as astrophysics missions. The technologies developed by Air Liquide make it possible to meet a wide range of needs:

- Cooling of one of the scientific observation instruments on the **Planck satellite** with the installation of a dilution cooler,
- Storage of superfluid helium at cryogenic temperatures for the **Herschel satellite**,
- Cooling of the **infrared sensors** on satellites designed to observe the universe,
- Conservation of biological samples taken in space with the **Melfi** cooling system installed at the International Space Station.



### Pulse tube technologies

The fruits of ten years of R&D, **cryocoolers** make it possible to keep the infrared instruments – put in orbit mainly for the observation of the Earth – at very low temperature for the duration of the mission. The production of cold on the pulse tube is from 10 to 200 kelvin. They operate on the basis of the Stirling engine principle, with the noticeable improvement of an absence of moving parts on the cold part.

Embedded on board, this particularly innovative technology ensures high resolution and stability of the instruments, essential to the quality of the observations and infrared images transmitted by the satellite.

# The Planck and Herschel satellites

Launched in 2009, the Planck and Herschel satellites have probed the depths of the universe, with a temperature of only 3 Kelvin (-270° Celsius). To measure a precise signal, their sensors need to be cooled to a lower temperature. To detect the weakest signals emitted, it was therefore essential to operate the cryogenic systems on board Planck and Herschel at a very low and stable temperature of 0.1 Kelvin (near -273° Celsius), which is a tenth of a degree above absolute zero.

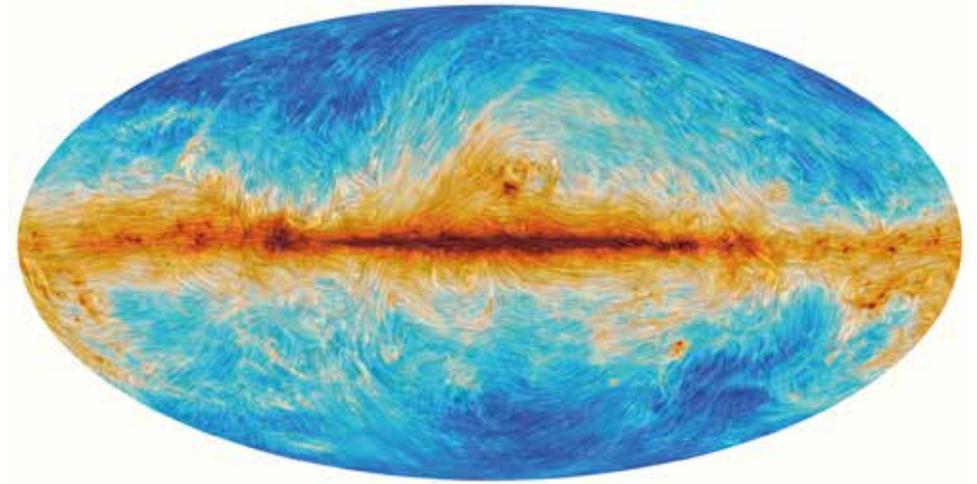
The technology developed for this dilution cooler ensures continuous operation without emitting vibrations or magnetic fields that could disrupt the observations. It ran non-stop for a period of two-and-a-half years, which is more than twice the duration that was initially expected. **This is the first time that this technology was qualified for use in space.**

For this exceptional project, Air Liquide teams worked in close collaboration with experts from the Institut Néel (CNRS, Centre National de la Recherche Scientifique, France) and the Institut d'Astrophysique Spatiale (IAS) on behalf of the Centre National d'Études Spatiales (CNES, France).

Several discoveries have been captured in images, like the one representing **the structure of the magnetic field of our galaxy**. But Planck has also led more recently to other major breakthroughs, in particular the constitution of **a unique catalogue of more than a thousand galaxy clusters**.

For the Herschel satellite, Air Liquide designed and built – in collaboration with Airbus Defense and Space and for the European Space Agency – a **liquid helium tank** that holds 2,400 liters, designed to cool the telescope and its three observation instruments.

This satellite has become the **largest and most powerful space telescope ever deployed in outer space**. Air Liquide also supplied the helium transport lines and thermal shields that insulate tanks and instruments from the external environment. Herschel observed the hidden cold Universe for more than three years with success.



Map of the magnetic field of our galaxy © ESA - collaboration Planck



The Herschel satellite during the tests at European Space Research and Technology Centre (ESTEC) in the Netherlands.

# Melfi, the space fridge

Melfi was loaded onto the Discovery space shuttle, en route to its final destination on board the International Space Station, from which it was operational as of July 2006. Under this NASA mission, with the support of the ESA, Melfi is a **cryogenic freezer** that can preserve biological and other scientific specimens or experimental results – at temperatures as low as  $-95^{\circ}\text{C}$  – until they are safely delivered to the planet earth.

Air Liquide designed and developed the cold producing turbo engine that constitutes the active part of Melfi and that has a rotation speed of up to **80,000 revolutions per minute!** The Group's specialists rose to a genuine challenge when they managed to pack equipment normally found in industrial facilities into a very small space, while also maintaining the high standards of reliability and safety required for manned flights. Initially set to last 2 years, the turbo engine operated continuously with a rotation speed up to 80,000 revolutions per minute, to at least the end of 2024.

Melfi was the very first experiment in space for the Turbo-Brayton machine. Air Liquide was able to leverage its experience to propose the **Turbo-Brayton technology**, which includes one or more turbomachines needed to refrigerate or liquefy gases between 25K and 200K (which is between  $-73$  and  $-253^{\circ}\text{C}$ ). Developed on the basis of the Brayton Cycle, the Turbo-Brayton helps to improve the reliability of the yields of the cooling and liquefaction processes and reduces the costs of installation and operation related to the electricity consumption of the systems and to maintenance operations.

French astronaut Thomas Pesquet celebrates 10 years of Melfi aboard the International Space Station, November 2016.





# The space adventure continues

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## In satellites

Satellite developments can be grouped into three categories:

- **Design and fabrication of cryocoolers** for satellites launched to observe the earth, military (“national program”) or commercial satellites, with the aim of industrializing and standardizing the product in order to lower the cost, the time needed for production, and thus contribute to the development of the earth observation satellite field on the international scale.

The satellite that integrates the first pulse tubes and associated electronics, is the optical reconnaissance device for the space and defense imaging program of France and its partners, which joined space in 2018. Air Liquide also equips the **MTG satellite** (MeteoSat Third Generation) with 12 pulsed gas tubes that should be operational for about 10 years. In addition, Airbus Defense and Space and CNES have chosen to entrust the cooling of their new generation of Atmospheric Sound Interferometer-Next Generation (IASI-NG) sounder to Air Liquide.

- **For a wide range of satellites (nano, small and large): design and production of components for electric propulsion and supply of the related rare gases**, such as xenon and argon. In this capacity, Air Liquide may propose a global electric propulsion offer: rare gases / onboard distribution system / services.
- **Design and fabrication of components for the thermal control of satellites.**

# The space adventure continues

## In space exploration

The objective of the European Space Agency (ESA) is to establish a **Lunar Village (LUNA)**, a concept that calls for international participation to carry out a broad variety of missions on the moon. Air Liquide has announced that it will participate in this project by offering its expertise in different areas, such as **renewable energy, life support and transportation on the moon, on Mars or even further away.**

After having touched down in August of 2012, the **robot Curiosity** continues to explore Mars today and is delivering its results gradually based on its observations and analysis of the planet's atmosphere as well as its soil.

In April 2015, the analyses of data sent by the robot lent strength to the hypothesis that there might be liquid water on the planet Mars. This robot is equipped with 10 instruments, including **Sample Analysis at Mars (SAM)**, a project in which Air Liquide has been involved since 2005. The Group got involved in this project during the design of the gas chromatograph by soldering and welding the capillaries, but also various assembly-related tasks on SAM at NASA's Goddard Space Flight Center (GSFC) in Washington DC.

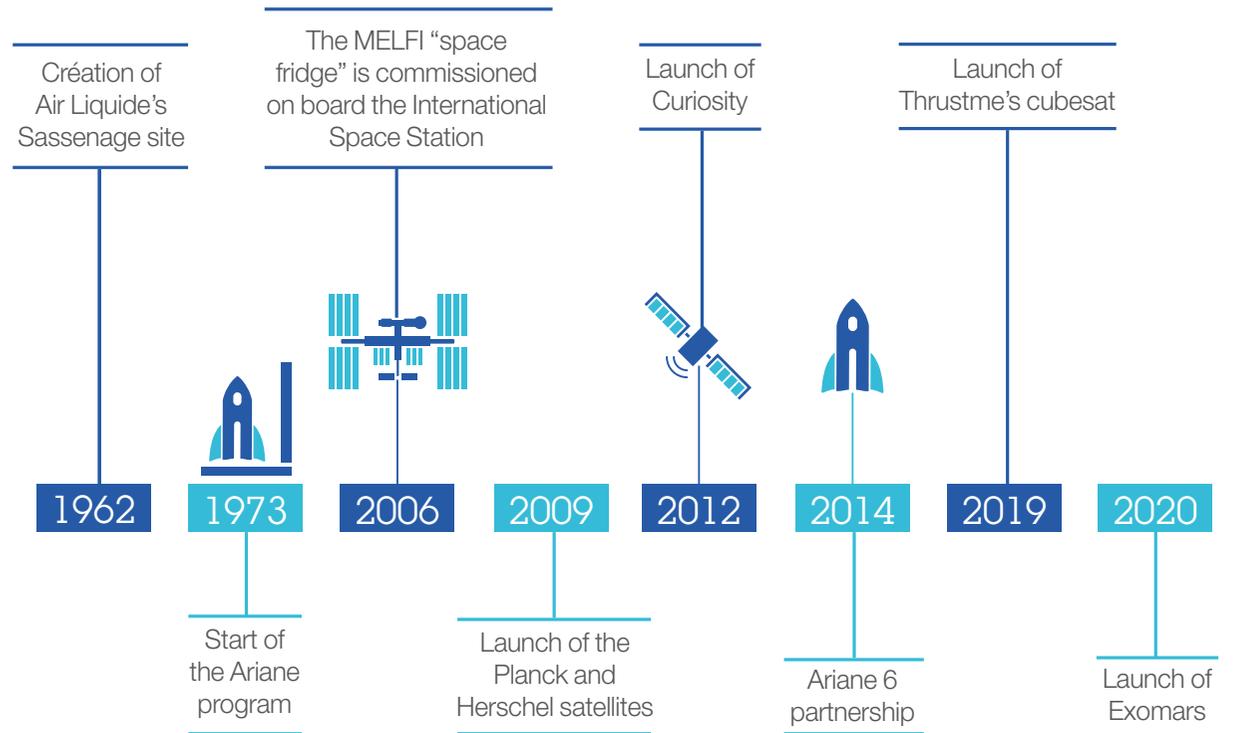
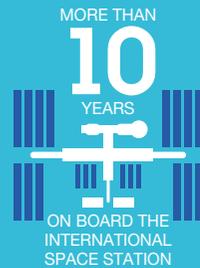
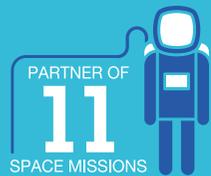
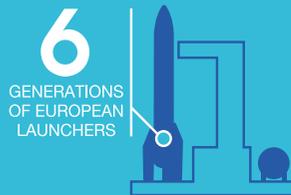
The ESA, with the participation of the Russian space agency Roscosmos, plans to send the **rover ExoMars** on yet another exploration of the red planet in 2020. This rover will look for signs of past life and will analyze the composition of the Mars sub-stratum. Teams at Air Liquide are using the work that was done on Curiosity for MOMA (Mars Organic Molecule Analyzer), the principal instrument on ExoMars. In addition, **MOMA GC** contains a helium sphere and a micro-relaxer (a technology developed by the Max Planck Institute), sized, qualified, and fabricated by Air Liquide, to supply the helium serving as the vector gas for chromatography.



The robot Curiosity landed on Mars in August 2012.

# Facts and figures

## Air Liquide and space



# The Air Liquide group

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



Present in  
**80**  
countries



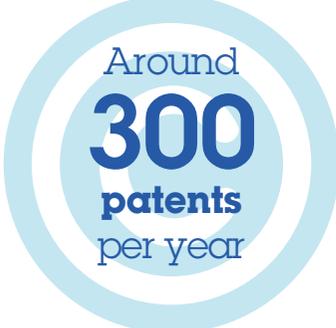
Approximately  
**66,000**  
employees



More than  
**3.6**  
million  
customers  
& patients



**9**  
Research & Development  
sites  
**15**  
main  
Engineering centers



Around  
**300**  
patents  
per year



2018 Revenue  
**€21** billion



FOR FURTHER INFORMATION,

please contact:

**Air Liquide Global Markets Technologies Communications**

Agnès Renard +33 (0)4 76 43 59 28

agnes.renard@airliquide.com

Camille Giry +33 (0)4 38 03 12 08

camille.giry@airliquide.com



@AirLiquideGroup



Air Liquide



[www.advancedtech.airliquide.com](http://www.advancedtech.airliquide.com)

**Air Liquide advanced Technologies**

2, rue de Clémencière

BP 15 – 38360 Sassenage, France

A world leader in gases, technologies and services for Industry and Health, Air Liquide is present in 80 countries with approximately 66,000 employees and serves more than 3.6 million customers and patients.

