

**LET'S
BE PROUD**
OF DRIVING
HYDROGEN-POWERED
VEHICLES!

REDUCING YOUR CARBON FOOTPRINT

TODAY

FOR TOMORROW

TOWARD A HYDROGEN-BASED SOCIETY



Pierre-Étienne Franc,
Vice President
Hydrogen Energy
WBU, Air Liquide

Facing energy transition challenges, Air Liquide brings solutions with a 50 years experience in gas expertise.

Air Liquide especially covers the whole hydrogen supply chain.

The fast-moving energy field presents many challenges. Hydrogen has the potential to answer clean mobility challenges: reducing pollution and fossil fuels dependency.

We see hydrogen playing tomorrow a key role in the energy transition.

That's why Air Liquide is actively involved in hydrogen development and is contributing to the widespread use of it for a clean transportation.

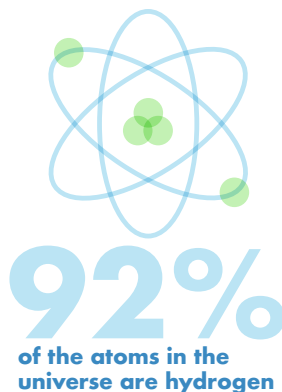
Prototypes and experimentation phases are well behind us. Hydrogen mobility demonstrates every day its effectiveness worldwide.

In France, **the successful development of the hydrogen-powered taxis fleet called "hype", launched during 2015 United Nations Climate Change Conference (COP21), is one of the most significant symbols.** Let's now move up a gear and roll out this model on a wider scale.

WHAT IS HYDROGEN?

Hydrogen is a gas that has existed since the origin of the universe and is set to change a lot in the future.

If one had poetic tendencies, one might say that hydrogen was born in the stars. And yet it is the truth. The atoms of this gas helped to create the elements that make up our planet. Hydrogen always bonds with other molecules. The most common bond, with oxygen, forms water, which covers approximately 70% of our planet. In other words, hydrogen is everywhere.



Hydrogen is the main component of the Sun and other stars.

It can also be found in natural gas and crude oil. It is used in many sectors, chemistry, industry, metallurgy, pharmacy, and the food industry, as well as in the rocket thrusters that take us into space. It is also the lightest of all chemical elements.

“ We are convinced that by 2023-2025 this technology will have naturally made huge strides worldwide. It is inconceivable that this technology does not become the major part of mobility in the future. ”

Didier Leroy,
Executive Vice President
of Toyota Motor Corporation

Autonews Green, 13/07/18 "Toyota Mirai, Hydrogen really is an energy source for the future."



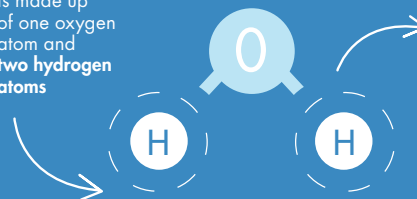
HYDROGEN IS NUMBER ONE IN Mendeleeev's periodic table of elements WHICH CELEBRATED ITS 150TH BIRTHDAY IN 2019!



We have known since 1806 that hydrogen can be used to power a motor. A discovery owed to the Swiss researcher, Isaac de Rivaz. At the time, hydrogen was extracted from coal. From this first prototype, to the hype taxis, the hydrogen-powered motorcar capitalized on many advantages.

BACK TO SCHOOL CHEMISTRY

Water (H₂O) is made up of one oxygen atom and two hydrogen atoms



We now know how to extract hydrogen and convert it into an energy carrier



AIR LIQUIDE: A KEY ROLE

With many innovative projects, Air Liquide is a leader in hydrogen energy development.

Although energy transition is already well under way in many parts of the world, there remain decisive challenges to come. In order to take them up, hydrogen is a key solution for providing clean energy, reducing greenhouse gas emissions, urban pollution, and fossil fuel dependency. Operating along the whole hydrogen energy value chain (in production, storage, and distribution), Air Liquide is actively involved in its development and is contributing to the widespread adoption of hydrogen use in transport by supporting the creation of hydrogen charging stations worldwide.

“ Clean mobility solutions for individuals, charging stations for buses and trucks, and dedicated programs for corporate fleets. These innovative projects make us a leading company in hydrogen energy development. ”

Pierre-Étienne Franc,
Vice President
Hydrogen Energy WBU,
Air Liquide

TODAY
OUR
PRODUCTION
COULD
POWER
10 MILLION
VEHICLES

The Hydrogen Council was founded in 2017, on the initiative of Air Liquide, in partnership with other international companies. This first global initiative brings together 53 leading players of car, energy, and industry sectors. They speak as one voice to convince the authorities and investors of the industry's potential.

OBJECTIVE:
To face
the challenges
of energy transition



Since its creation in 1902, Air Liquide has been a world leader in gases, technologies, and services for industry and health. In 2018, the Group sold 1.4 billion m³ (494.4 billion ft³) of hydrogen.

HOW IS HYDROGEN PRODUCED?

Hydrogen can be found in several natural sources. There are three ways of extracting it.

1

BY NATURAL GAS REFORMING

This involves separating methane into its constituent atoms. Methane reacts to steam and heat, producing hydrogen on one hand, and carbon dioxide on the other. CO₂ is then captured and reused in a various applications (carbonated beverages, for example), thanks to Cryocap™ H₂ technology.

Cryocap™ H₂, a world premiere of CO₂ cold capture system

Air Liquide has developed a unique system named Cryocap™ H₂. The only process of this type in the world, it was put into service in 2015 at Air Liquide's largest French plant, in Port-Jérôme-sur-Seine, Normandy. Cryocap™ technology collects and isolates the CO₂ released when hydrogen is produced. It is stored in liquid form for use by industrial processes that require a permanent supply of CO₂ (such as beverage carbonation, deep-freezing and agricultural applications).

The Cryocap™ H₂ plant in Port-Jérôme-sur-Seine has an annual capture capacity of 100,000 tons of CO₂. Air Liquide has committed to making at least 50% of the hydrogen required dedicated to energy applications by these low-carbon processes by 2020.



«Water is the coal of future»

Jules Verne.
Visionary!

2

BY GASIFICATION

Charcoal or organic waste are partially combusted in a reactor.

At very high temperature, emitted gases are essentially hydrogen and carbon monoxide.

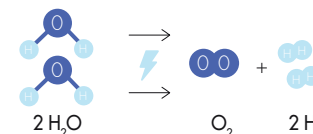
“Hydrogen is the lightest and most ubiquitous element found in the universe. When harnessed as a form of energy, it becomes “the forever fuel”. It never runs out, and, because it contains not a single carbon atom, it emits no CO₂.”

Jeremy Rifkin,
The Hydrogen Economy

3

BY WATER ELECTROLYSIS

This method consists in recovering hydrogen naturally present in water by placing two electrodes in it. The passage of an electrical current through it breaks down water molecules into hydrogen on one side, and dioxygen on the other.



Electrolysis itself does not produce any carbon dioxide (CO₂), which is harmful for the environment. However, one must consider how the electricity is produced. If the electricity is produced from carbon-free sources (with renewable energies like solar or wind power, for example), this means that no greenhouse gases are produced while producing hydrogen.

Air Liquide already uses the water electrolysis method to produce hydrogen, and intends to ramp up its use in the future.

HYDROGEN AND ENERGY TRANSITION: COMMON GOALS

Producing hydrogen with non-polluting technologies: a dream that is within reach.

With Blue Hydrogen®, Air Liquide is moving toward a decarbonization of its hydrogen production dedicated to energy applications.



In practical terms, Air Liquide has made a commitment to produce at least 50% of the hydrogen necessary for these applications through carbon-free processes by 2020 by combining:

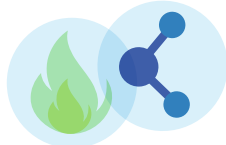
- biogas reforming;
- the use of renewable energies during water electrolysis;
- the use of technologies for the capture and upgrading of carbon emitted during hydrogen production from natural gas.

Even when it is produced from natural gas, hydrogen is a virtuous energy: for equal distance travelled, hydrogen cars enable to reduce GHG emissions by 20% compared with internal combustion vehicles and don't produce any fine particles.

«Green» hydrogen, another production alternative

«Green» hydrogen, produced from sources like solar and wind power help to decarbonize various economic and human activities that still depend on fossil fuels: transport, residential heating, industrial energy consumption, etc.

**By 2030
50 million
homes around
the world
could be
connected to
a distribution
network combining
gas and hydrogen**



Hydrogen and renewable energies

1 PRODUCTION

Wind turbines (and solar panels) can sometimes produce more electricity than needed when demand is low, or during very windy (or very sunny) periods.

What should be done with this unused electricity?



2 STORAGE

Using this electricity to produce hydrogen through water electrolysis!



3 UTILIZATION

This hydrogen powers fuel cells fitted into vehicles, which in turn generate electricity to power the motor.



The circle is completed, and the wind (or solar) energy has not been produced in vain.

HYDROGEN-POWERED CARS SPECIFICITIES

Cars that are not so different from what we're used to.

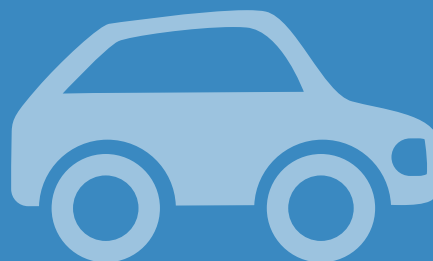
With a charging time of less than five minutes and a range of more than 500km, hydrogen fuel cell vehicles are an efficient solution for long trips, which represent 75% of CO₂ emissions.

Motors powered by fuel cells do not generate any pollution at their point of use (no CO₂ or particle emissions) and are extremely quiet.

Hydrogen fuel cell vehicles have all advantages of battery-powered electric vehicles, without their disadvantages: a longer range and a shorter charging time!



**MORE THAN
120 CHARGING
STATIONS
HYDROGEN**
HAVE ALREADY BEEN
DESIGNED AND BUILT BY
**AIR LIQUIDE
WORLDWIDE**



- **Rapid hydrogen charging:**
between 3 and 5 minutes
(compared to an electric car
which can take several hours).



3 to 5 min

- **Long range:**
over 500km (electric cars
currently have a maximum range
of approximately 400km).



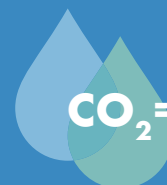
500km

- **A competitively priced energy:**
1 kg of hydrogen = 100km



1kg = 100km

- **No pollution:**
no CO₂, particles, or noise.
The car's only waste output is water.

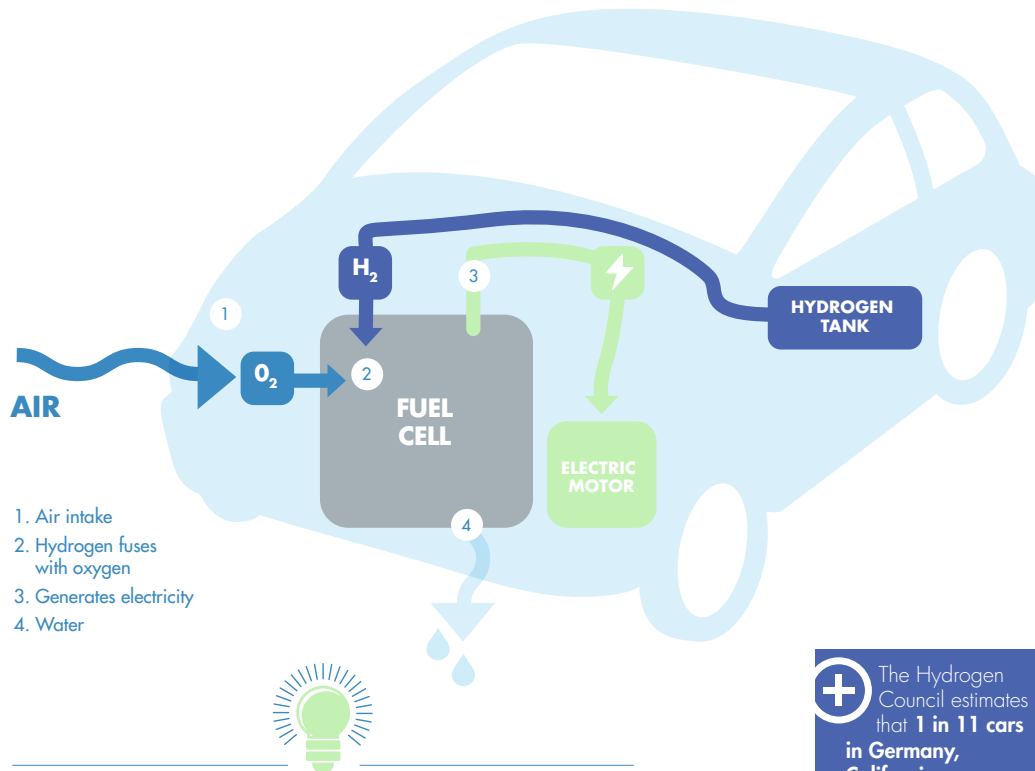


CO₂ = 0

HOW DOES THIS CAR WORK?

Fitted with a hydrogen-powered fuel cell, this car generates its own electricity.

Hydrogen-powered cars run thanks to a fuel cell producing electricity directly on board. The hydrogen stored in a tank fuses with ambient oxygen inside the fuel cell, thereby generating electricity, with water as the only by-product.



The operating principle of the fuel cell is not recent. As early as 1839, an English scientist named William Robert Grove demonstrated that one can simultaneously produce electricity, heat, and water by combining dihydrogen and dioxygen.



1KG OF HYDROGEN
**RELEASES THREE
TIMES MORE ENERGY**
THAN 1KG OF PETROL
WITHOUT PRODUCING
ANY CARBON DIOXIDE

Comparison of relative engine efficiency

Engine efficiency is the ratio between the amount of energy used to power it and the quantity of mechanical energy it produces.

• Petrol engine:	35%
• Diesel engine:	37%
• Hydrogen-powered electric engine:	60%
• Battery-powered electric engine:	80%

+ The Hydrogen Council estimates that **1 in 11 cars** in Germany, California, South Korea, and Japan will be hydrogen-powered by 2030.



Some received wisdom about hydrogen

1

Hydrogen, a gas that raises questions...

As with all gases, its use must be carefully controlled. Its volatility represents an advantage though: it disperses far more quickly in air than natural gas or petrol vapor, reducing the explosion risk.

Hydrogen-based systems are designed and built according to the most stringent standards, to minimize potential risks.

Nowadays, the hydrogen tank (made of carbon fiber) is by far the vehicle's strongest component. It is also fitted with a valve that closes automatically in the event of a collision. And the entire hydrogen system is isolated from the cabin by an airtight wall. Car manufacturers even subject the tanks to gunshot tests!

2

Hydrogen is a clean gas. But in order to use it in a vehicle you need a fuel cell. Is that also clean?

Current fuel cells contain more platinum than a catalytic converter, but unlike catalytic converters, they can also be recycled. According to recent research, in the future it will be possible to replace the platinum with cheaper graphene (graphite crystals), or even bacterial enzymes.

3

Hydrogen-powered electric vehicles don't have the same type of electric motors as other 100% electric vehicles, they are less efficient...

False. The engine is the same. The difference is how this electricity is produced and stored. A standard electric vehicle is fitted with a battery charged at a charging station. Hydrogen-powered electric vehicles produce their own electricity thanks to an on-board fuel cell.

HYDROGEN FOR CARS AND OTHER VEHICLES

From buses to bikes, from seas to stars, hydrogen is propelling mobility well into the future.

Public transport authorities are already testing fuel cell technology. Since 2001, **some thirty hydrogen-powered buses** have been launched in nine European cities as well as in Perth, Beijing, and Reykjavik. Half of the hydrogen needed is produced with renewable energies. And **12 million passengers** have already used them. The first French hydrogen-powered electric bus line will soon be launched in the Paris region.

The experiment has also been tried on **trains** and **boats**. Hydrogen also powers **forklift trucks** for materials handling in Europe, Asia, and South America.

H₂



Focus on...



Energy Observer

The world's first energy-autonomous hydrogen-powered vessel, which produces no greenhouse gases or particles. In partnership with Air Liquide, this former competition sailing yacht has been converted into a ship of the future, with electrical propulsion that operates thanks to a combination of renewable energies and a decarbonized hydrogen production system that uses seawater. Air Liquide is backing this scientific and technological project, which is testimony to the role of hydrogen and the energy transition. The Group's financial support for this project also illuminates its desire to contribute to a more sustainable world.



HY4

With an 80 KW motor, the HY4 carries four people, with a range of between 750 and 1,500km, and a cruising speed of 145 km/h.



Alpha

Powered by a hydrogen fuel cell, this electric bike invented by the Frenchman Pierre Forté, and manufactured by Pragma Industries, has a range of 100km and can be recharged in less than a minute!



Navibus

Commissioning of the Jules Verne 2 riverboat, which connects two university campuses located on either side of the Erdre river, in Nantes. It can carry 12 passengers and six bicycles. Air Liquide supplies the hydrogen for the Navibus.



Ariane 5

The main stage of the Ariane 5 launch vehicle is powered by a cryogenic engine. It operates for approximately 10 minutes, using 220 tonnes of liquid propellants (hydrogen and oxygen). As the world's leading expert in space cryogenics, over the last 50 years, Air Liquide has supported the successive evolutions of Ariane launch vehicles 1 to 5, and now Ariane 6.



Coradia Iint, Alstom

This train can travel 1,000km on a full charge and has a top speed of 140km/h. Alstom will build 14 of these fuel cell trains for the local transport authority of Lower Saxony, to replace their diesel motor-coach trains. They will travel between Cuxhaven, Bremerhaven, Bremervörde, and Buxtehude starting in December 2021.

Keep your head in the stars

“ Nowadays, people are talking about creating fuel for space ships from in situ resources, i.e. by mining asteroids to get hydrogen, in the form of water, by separating hydrogen from oxygen to make space fuel. It's eco-friendly too as you no longer need to pollute unspoiled environments. ”

Thomas Pesquet,
Astronaut for the European
Space Agency

“ Since my earliest childhood, I can remember hearing about legendary sailors - navigators who crossed the Atlantic alone - and that's what inspired me. Energy Observer is [...] a ship that uses multiple renewable energy sources; and stores its energy in a battery, in the form of hydrogen. This hydrogen is produced through seawater electrolysis. It's a system that really symbolizes what can be done at global level, at a small, medium, and very large-scale. ”

Victorien Erussard,
Energy Observer's Captain

