

An aerial photograph of a long, straight road that tapers and ends at a body of water. The road is light gray with a dashed white line down the center. A small blue car is visible on the road in the upper third of the image. The surrounding landscape is a mix of brown and green fields. The text "DESTINATION: HYDROGEN" is overlaid in the center of the image.

DESTINATION: HYDROGEN

03 | INTRODUCTION

04
05 | THE SOURCE
OF LIFE

06 - 07 | OUR FRIEND
HYDROGEN



11
12 | BUILDING
DISTRIBUTION
NETWORKS

08 - 10 | DESTINATION :
HYDROGEN

13 | HYDROGEN TAKES
TO SOCIAL MEDIA

14 - 17 | OVERVIEW OF THE HYDROGEN
MOBILITY MARKET

19
20 | UNLIMITED
CLEAN ENERGY

18 | THREE QUESTIONS
FOR JULES VERNE



21 - 22 | TIME TO
SCALE UP



23 | HYDROGEN
ON LINE

24 - 25 | THE HYDROGEN
ECOSYSTEM

26 | INTERVIEW WITH
THOMAS PESQUET



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orn in the stars, hydrogen is one of the major components of our planet. The advantage of this abundant, colorless, odorless and non-corrosive element is that it contains three times more energy per kilogram than petrol. Because its atoms are so simple – made up of just one proton and one electron – it is the lightest chemical element.

Hydrogen does not occur naturally on its own. It is always bonded with other molecules, most commonly to form water, and water covers 70% of the Earth's surface. Hydrogen has been a common feature of industrial innovation through the ages, since the Swiss inventor Isaac de Rivaz harnessed its power in the first hydrogen engine in 1806. Space exploration would, of course, have been impossible without it. We find hydrogen in many industries – metallurgy, chemistry, petrochemistry, and pharmacy – but until recently it was not used for transport. Mechanical engineering has traditionally steered away from the hydrogen engine. It resurfaced periodically, each time presenting itself as a reinvention of a great idea, but the verdict was always the same: too expensive! Why would you run an engine on hydrogen, which has to be extracted from natural gas, when you can use CNG or LNG directly, or just stick with cheap petroleum-based fuels? You can produce hydrogen through water electrolysis, however, the process uses a great deal of electricity and can therefore be even more expensive.

Everything changed with the advent of renewable energy. Renewable sources are capable of producing unlimited amounts of electricity, but not always when we want it. And that's where hydrogen comes in. The major issue with electricity is that it must be used when it is produced. If it is not used immediately, the electricity generated by a wind turbine or solar cell is simply lost (this is known as "unavoidable energy"). Because this electricity would otherwise be lost, cost-effectiveness becomes irrelevant and water electrolysis makes sense. And because it is easy to store, hydrogen provides us with a way of storing electricity in gas or liquid form, simply by compressing or cooling it. The hydrogen can be converted back into electricity as and when it is required by powering a turbine or fuel cell. These are mature, familiar technologies that give us another way of meeting the challenge of climate change while cutting our oil import bill.

So, when will we be ready to replace fossil fuels with hydrogen? We're actually ready now! The prototype and experimentation stages are well behind us. Hydrogen proves every day that it is a great solution for transportation and storing electricity. It is now time to scale these solutions up, to industrialize them, to create the markets that will establish a hydrogen-based green economy, and spread the word to the general public. People will then begin to understand that hydrogen solutions are more than just responses to a technological and environmental problem. They are the signs and symbols of a society that is moving towards more resilient lifestyles. We're not just changing the fuel we use; we're changing our way of life. The air is looking purer and suddenly, the future of humanity is so much clearer.

Abundant, clean, renewable

THE SOURCE OF LIFE

THE FUEL CELL IS DISCREETLY INSTALLING
ITSELF IN OUR LIVES : POWERED BY HYDROGEN,
IT PRODUCES ELECTRICITY... BY MAKING WATER.

Hydrogen's calorific value was discovered in the nineteenth century: burning a kilo of hydrogen produces almost three times as much energy as burning a kilo of petrol. It was then that we began to use hydrogen for heating and lighting, before it lost its place to oil and natural gas. On the other hand, hydrogen's very low density means that it takes up more space than the equivalent mass of petrol; 4.6 liters of dihydrogen compressed at 700 bars are needed to produce the same amount of energy as one liter of petrol. Hydrogen is abundant almost everywhere, and in particular in water molecules (which consist of two atoms of hydrogen and one atom of oxygen) and carbon chains, but it is rarely alone. It therefore must be extracted as a gas, in its diatomic form dihydrogen (two atoms bonded together). We have a long history of extracting hydrogen from coal, and later natural gas. Today, we understand the negative impact of these processes on the environment: they produce the greenhouse gases that cause climate change. As an alternative, we can produce hydrogen through electrolysis or through CCUS (Carbon Capture Utilization and Storage) technology. This hydrogen gas can then be used to power a fuel cell, which was invented by a British scientist, Sir William Robert



In 1839, Sir William Robert Grove (1811-1896).

Grove. In 1839, he demonstrated that recombining dihydrogen and dioxygen produced electricity, heat and water simultaneously. The synthesis of water is the principle behind the fuel cell.

A fuel cell is made up of a positive terminal – the cathode – and a negative terminal – the anode. Electrons and ions (the elements of an atom) are made to flow between them. The cathode and the anode are separated by a solid or liquid electrolyte. In a fuel cell, the dihydrogen arrives at the anode and the dioxygen at the cathode. The oxygen attracts the hydrogen atoms, but to reach

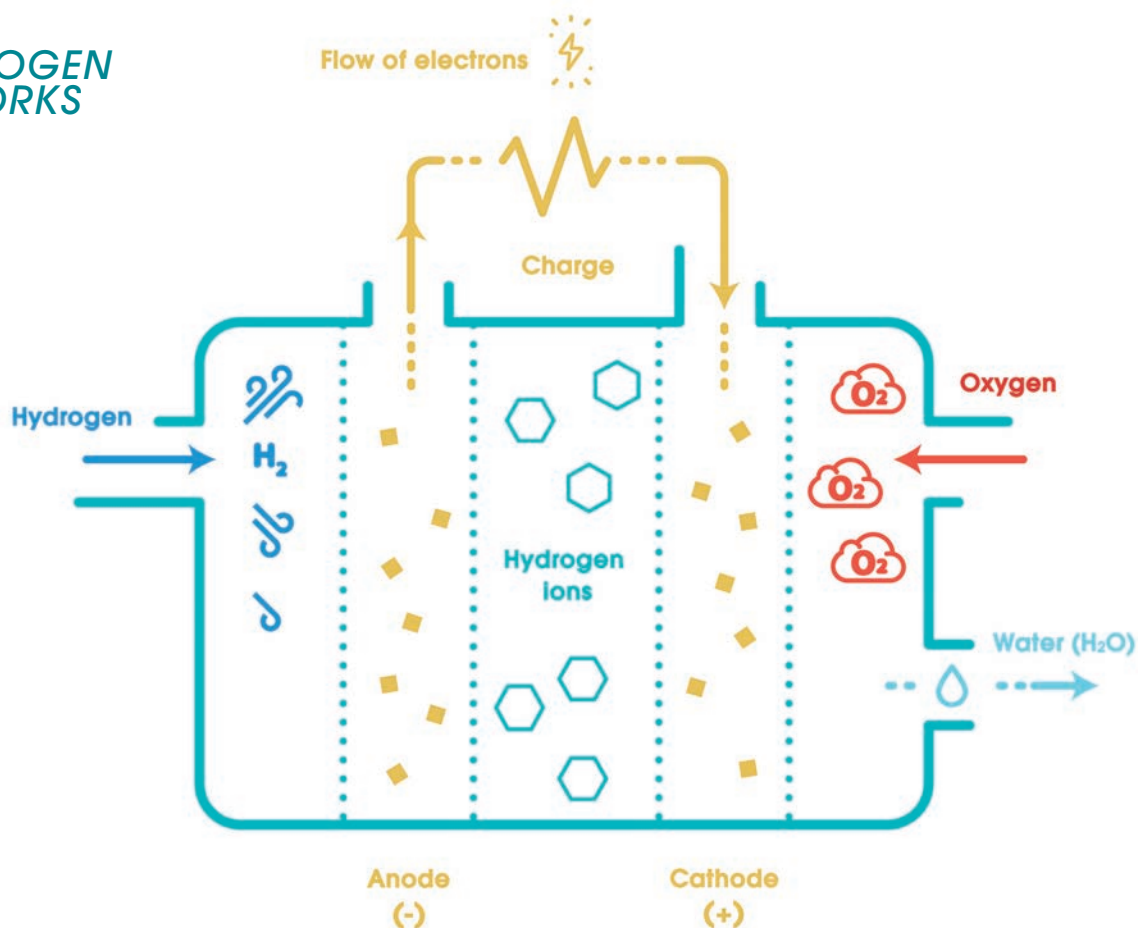
it they have to divide into electrons and ions, because the electrolyte blocks the electrons and forces them into a circuit where they generate an electric current. At the same time, the hydrogen ions flow through the electrolyte to reach the oxygen, and combine with it to form water. The entire chemical reaction also produces heat, which can be recovered. The fuel cell's total energy efficiency is around 60% (compared to 35% for a standard combustion engine in a petrol car).

LOW-CARBON HYDROGEN

Hydrogen is a secondary energy carrier. It must be isolated from the molecules it is combined with to extract its own energy. The source of hydrogen used will affect the carbon footprint of the processes it powers. Natural gas (mainly methane) is still used on a large scale today to produce dihydrogen for industry, and in particular for the desulfurization of hydrocarbons: in 2017, the volumes of hydrogen supplied by Air Liquide to refineries across the world saved 1.5 million tons of sulfur oxides from being released into the atmosphere. This represents around ten times the total emissions of a country like France. Hydrogen is also used in metallurgy, chemistry, pharmacy, electronics, and food processing.

HOW A HYDROGEN FUEL CELL WORKS

A hydrogen atom includes positive ions and negative electrons. Oxygen (O_2) is pumped in through the cathode, attracting the hydrogen atoms (H_2) which are introduced at the anode. To get to the oxygen, the hydrogen atoms have to cross an electrolyte or membrane which blocks their electrons. These electrons are forced into another circuit which produces electricity. The ions (H^+) on the other hand, flow through the electrolyte to reach the oxygen atoms which they bond with to form water (H_2O). This process produces heat, which can also be used as a source of energy. Current research is focused on perfecting the membranes.



In France, industry consumes 900,000 tons of dihydrogen per year. Worldwide, the figure is 50 million tons. Producing hydrogen from methane leaves a residual gas composed of carbon dioxide (CO_2) and hydrogen. To solve the issue of CO_2 emissions from this method of producing hydrogen, Air Liquide has developed a unique

system named CryocapTM. The only process of its type in the world, it was put into service in 2015 at Air Liquide's largest French plant at Port-Jérôme-sur-Seine, in Normandy.

Cryocap technology collects and isolates the CO_2 emitted when hydrogen is produced. It is stored in liquid form for use by industrial processes that

require a permanent supply of CO_2 (such as beverage carbonation, deep-freezing and agricultural applications). The H_2 Cryocap plant at Port-Jérôme-sur-Seine has an annual capture capacity of 100,000 tons of CO_2 . Air Liquide has committed to making at least 50% of the hydrogen required by these processes low-carbon by 2020.

COMPARISON OF THE CALORIFIC VALUE OF VARIOUS TYPES OF FUEL

Calorific value is a measure of the thermal energy released when a substance is burned. It is expressed in megajoules per kilo of fuel (MJ/kg) or in kilowatt hours per kilo of fuel (kWh/kg).

The table below compares the gross calorific value of fuels commonly used for heating, transport or electricity production.

	MJ/kg	kWh/kg
Coal	20	8
Petrol	47	9
Diesel	44	10
Natural gas	50	10
Hydrogen	142	39

EFFICIENCY OF DIFFERENT ENGINES

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

Powered by
DIESEL
37%

Powered by
A FUEL CELL
60%

Powered by
PETROL
35%

Powered by
A BATTERY
80%



OUR FRIEND HYDROGEN

ALL AROUND US

•

HYDROGEN HAS AMAZING POTENTIAL FOR HELPING SOCIETY TACKLE THE ENERGY TRANSITION CHALLENGE BY INCLUDING RENEWABLE SOURCES IN THE ENERGY MIX AND DECARBONIZING THE END USES OF FOSSIL FUELS.

Climate change is forcing us to adapt the way we source and use energy. The world is moving towards an energy mix composed mainly of renewable sources.

HYDROGEN, AN ESSENTIAL COMPONENT OF RE

Renewable energy sources (RE) like solar and wind power present a stability issue for electricity distribution networks because they are intermittent. The technical solution for this lies in converting the excess electricity produced during windy or sunny weather into hydrogen through water electrolysis. This stores the energy in gas form so that it can be used as and when it is needed, meaning that RE can be easily integrated

into existing networks. Combining RE with hydrogen production can also make islands and isolated regions energy self-sufficient. If, in the future, renewable energy confirms its ability to be competitive, it will be possible to store and transport it from one continent to another in the form of liquid hydrogen or combined with other molecules.

DECARBONIZING THE ECONOMY

The green hydrogen produced from RE also offers a way of decarbonizing many of the economic and human activities that still depend on fossil fuels:

- Decarbonizing transport by using fuel cells for private vehicles (cars and

motorbikes), trucks, freighters, ferries, airplanes, buses and taxis, as well as powering trains and trams on non-electrified rail networks.

- Decarbonizing heating for buildings by using cogeneration to produce combined heat and power (fuel cells and hydrogen turbines).

- Decarbonizing the energy required for industry by using the green hydrogen produced with RE for chemistry and to produce stationary electricity.

- Serve as a decarbonized raw material in numerous chemical and industrial processes, including the production of ammonia, methanol, and amines.

- Act as a “buffer” energy source to increase the resilience of the electrical network. Today, at global level, part of the energy is stored in fossil form (equal to 15% of demand), tomorrow it should be stored in hydrogen form.

**GREEN HYDROGEN
IS ESSENTIAL TO
DECARBONIZING
NUMEROUS ACTIVITIES**

LET'S DEBUNK SOME MYTHS!

IT'S EXPLOSIVE!



People will tell you hydrogen is a dangerous explosive: look at the Hindenburg airship fire, the H bomb, and the Apollo 13 explosion! False!

THE HINDENBURG DISASTER, 1937

It was the cotton and aluminum envelope of the airship that caught fire when an electrical discharge caused by the excessive electrostatic charge of the highly flammable coating on the envelope was transmitted to the metal frame. All those who remained aboard the shuttle were safe.

THE HYDROGEN BOMB, 1952

The hydrogen used for industrial and mobility applications is the “standard” hydrogen atom that is found in water molecules (H_2O) or natural gas (CH_4) used for heating. These are the two main sources of hydrogen (produced respectively from water electrolysis or natural gas reforming). It is significantly different from the other forms of hydrogen mentioned when referring to nuclear arms.

The thermonuclear bomb—incorrectly called “hydrogen bomb” as a result of a linguistic shortcut—is based on the principle of fusion of the deuterium and tritium atoms, both hydrogen isotopes, which are atoms that share certain characteristics* with hydrogen. Deuterium and tritium are rare on

Earth and must be produced, concentrated and packaged in a highly specific way for their use in a thermonuclear bomb. For military uses, extremely specific conditions, triggered by a human being, are needed to initiate the fusion of deuterium and tritium, resulting in a chain reaction.

Hydrogen for industrial and mobility uses does not share the isotopic or reactive characteristics of hydrogen related to thermonuclear reactions.

**Same number of protons but different number of neutrons.*

APOLLO 13, 1970

Two oxygen tanks exploded during the American Apollo 13 lunar landing attempt, endangering the lives of the three astronauts on board. The explosion was not linked to either the hydrogen fuel or the fuel cells. It was caused by a short-circuit in the fan cables in one of the oxygen tanks.

Because dihydrogen molecules are small, the risk of leaks from tanks is higher than with a traditional fuel (it is easier for the molecule to get through the walls of the tank). However, because hydrogen is highly volatile, it disperses more quickly in the air than natural gas or petrol vapor, reducing the risk of an explosion.

IT'S INEFFICIENT!



This argument is based comparing the efficiency of hydrogen-powered electric motors – which use the electrolysis of renewable energy (35% efficiency from well to wheel) – with that of electric batteries (50-60% efficiency). This is true if the entire chain is based on renewable energy, but false in the current energy mix where the electricity used in batteries is produced in gas power plants, the hydrogen is extracted from natural gas and the CO_2 is captured and stored (a process called CCUS, see page 4). In this case, the efficiency levels are equivalent (around 40% for both systems). Moreover, this analysis does not take into account the additional advantages of H_2 , particularly in terms of the storage of renewable energies, and their use in industry and by consumers.

IT USES RARE METALS!



Current fuel cells contain no 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.

DESTINATION: HYDROGEN

PIONEERING COMPANIES IN THE MOVE TO HYDROGEN

TRANSPORTATION IS RESPONSIBLE FOR 23% OF GREENHOUSE GAS EMISSIONS WORLDWIDE, MAKING IT ONE OF THE MAJOR FOCUSES FOR THE ENERGY TRANSITION. HYDROGEN IS INCREASINGLY EMERGING AS A LOGICAL SOLUTION.

Cars, planes, boats and trains – if we want to keep the increase in global mean temperatures within the 2°C target, we need to stop using hydrocarbon-based propulsion as soon as we can. This major energy shift has begun across all areas of transport and energy production. Hydrogen is a simple, clean and efficient solution, but only mass production can reduce its cost.


IN FACTORIES

Hydrogen-powered forklifts are

working wonders in industrial material handling within logistics platforms across the world. In addition to their long range, they recharge quickly and do not pollute the air around them. Some 20,000 forklifts are already in service in companies around the USA, including 50 in Coca-Cola's California center, which Air Liquide supplies hydrogen for. In Canada, Air Liquide supplies the hydrogen that powers a fleet of over 750 forklifts serving the Walmart retail group's four logistics centers. There will

be an estimated 10,000 forklifts on the European market by 2020. Prélodis, the logistics service provider for Grand Frais stores, is spearheading the transformation with its Prelocentre site in Saint-Cyr-en-Val, France, which uses only hydrogen-powered forklifts. Air Liquide has built a charging station on the site for more than 60 forklifts.

Remaining on the subject of fuel supply, Air Liquide has built a hydrogen station for FM Logistic's Neuville-aux-



The hydrogen used in launch vehicles is in liquid form. NASA scientists believe that a solution to solidify the fuel could pave the way for a new generation of even faster launch vehicles.



The charging station at Prelocentre, Saint-Cyr-en-Val, which supplies more than 60 forklifts with hydrogen.

London is one of nine European cities that have used hydrogen-powered buses.



Bois warehouse. There are currently 46 forklifts running from it. The 2015 project was part of the HAWL (Hydrogen And Warehouse Logistics) project, supported by the European private-public partnership FCH JU (Fuel Cells and Hydrogen Joint Undertaking). This platform “for hydrogen and fuel cells” will co-finance almost €1.3m worth of projects between the end of 2014 and 2019.

PUBLIC TRANSPORT

Public transport is already testing fuel cell technology. This market is both a source of economic development and a chance to educate people about sustainable mobility. In Europe, since 2001 the CUTE (Clean Urban Transport for Europe) project has supported the commissioning of some thirty hydrogen-powered buses in nine European cities (Amsterdam, Barcelona, Hamburg, London, Luxembourg, Madrid, Porto, Stockholm and Stuttgart) with three associated projects (Perth, Beijing, and Reykjavik). The buses have already provided pollution-free transport for 12 million passengers, with no incidents reported. Over half of the hydrogen consumed has been produced from renewable energy sources. The experiment has already been duplicated elsewhere. In Rosenholm, near Oslo in Norway, Air Liquide has installed a hydrogen station to recharge five buses. Other stations have been built in Rotterdam (Netherlands) and near Versailles (France), where cars and HGVs have been able to recharge with hydrogen

since 2018. The latter station will supply France’s first hydrogen bus service, which will serve the Vélizy-Villacoublay to Versailles line from 2019.

In Reykjavik, Iceland, hydrogen buses have been in service since 2003; in Korea and California they have been on the roads since 2006. In Japan, the East Japan Railway has been running a fuel-cell-powered train on a non-electrified suburban line since June 2007. In Germany, the Lower Saxony region began tackling the challenge of replacing diesel trains by ordering 14 fuel-cell-powered trains from Alstom, to be commissioned in 2021. And of course, we must not forget to mention the first hydrogen-powered ferries, which are already transporting passengers within the port of Hamburg in Germany, and across the River Erdre in Nantes, France.

PRIVATE VEHICLES

Since the 1990s, most major car manufacturers have developed prototype

hydrogen-powered cars. Initial research focused on using hydrogen as a fuel for conventional combustion engines (by BMW, Ferrari, Fiat, Ford, GMC, Lancia, Tata and others). This idea was discarded due to efficiency issues. Subsequent efforts focused on hydrogen fuel cells. This research is now reaching maturity, with numerous prototypes (by Audi, Cadillac, General Motors, Honda, Hyundai, Kia, Mazda, Mercedes, Nissan, Opel, Toyota, Volkswagen, etc.) in use by vehicle fleets operated by companies and local authorities. These engines have already proved themselves in terms of reliability, and they offer a major advantage over battery-powered models because their range (400 to 600km) and short charging times (3 to 5 minutes) are close to those achieved with internal combustion engines. Today, the first mass-produced hydrogen-powered cars are rolling off the production lines (Honda Clarity, Hyundai Nexo, Toyota Mirai, and Daimler’s GLC F-Cell). In Europe, BMW intends to release its model in 2020.

HYDROGEN-POWERED CARS: RANGE AND CHARGING TIMES COMPARABLE TO INTERNAL COMBUSTION ENGINE VEHICLES



Toyota is in the process of creating a renewable energy power station at Long Beach port in California, USA. Scheduled to open in 2020, the power station will generate 2.35 megawatts of electricity and 1.2 tons of hydrogen per day. It will therefore supply the fuel for vehicles passing through the port. Toyota has also built a hydrogen recharging stations on the site.



BUILDING DISTRIBUTION NETWORKS

SHOULD WE WAIT FOR THE NUMBER OF HYDROGEN CARS TO REACH CRITICAL MASS BEFORE WE BUILD A NETWORK OF RECHARGING STATIONS, OR TAKE A RISK AND CREATE THE NETWORK FIRST? BY DEVELOPING THE NETWORK IN LINE WITH SALES OF THE FIRST MASS-PRODUCED HYDROGEN-POWERED CARS, AIR LIQUIDE HAS FOUND A THIRD WAY.

IN THE USA, hydrogen is already out on the road, promoted by Arnold Schwarzenegger's car in California, where Air Liquide is operating a hydrogen charging station in Anaheim. The ZEV (Zero Emission Vehicle) program was set up by the California Air Resources Board, and adopted by eight other American states. It requires car manufacturers to sell a minimum quota of zero emission vehicles, thereby encour-

aging the take-up of hydrogen cars.

Since January 2018, California has also been considering banning the sale of new diesel and petrol vehicles – private cars and trucks – from January 1, 2040. More generally, Air Liquide is supporting the commercial launch of the Toyota Mirai (photos below, right) in Boston and New York by creating a network of 12 hydrogen charging stations in North-

Eastern USA, in collaboration with Toyota Motor Sales USA, Inc.

IN JAPAN, the government views hydrogen as a major energy and its stated ambition is to become a hydrogen-based society. 100 charging stations already exist, and the roadmap provides for 320 stations by 2025. Air Liquide is a member of the “Japan H2 Mobility” (JHyM) consortium of

DESTINATION: HYDROGEN

nearly 20 companies focused on attracting new investors and operators to support the development of a network of hydrogen stations in Japan. JHyM will begin by installing 80 more hydrogen stations over the next four years (in addition to the 100 existing ones), to fuel some 40,000 hydrogen-powered electric cars. Air Liquide's contribution between now and 2021 will be to build and operate some twenty stations, in addition to the six already in service in Nagoya, Toyota, Saga, Fukuoka, Kobé and Kawasaki. The Nagoya and Toyota stations, in Aichi prefecture, were developed by a joint venture between Air Liquide and Toyota Tsusho.

IN THE UNITED ARAB EMIRATES,

Air Liquide opened the country's first hydrogen charging station in Dubai in October 2017, in partnership with Al-Futtaim Motors, the UAE's exclusive Toyota dealer. The station uses cutting-edge technology to cope with the region's weather conditions. This initiative is a perfect example of the measures taken under the UAE's Vision 2021 National Agenda to reduce CO₂ emissions and promote cleaner, sustainable transport within the Emirates.

IN GERMANY, Air Liquide has opened 12 hydrogen stations as part of various

partnerships, including the H2 Mobility Deutschland joint venture, created by Air Liquide, Daimler, Linde, OMV, Shell and Total. These companies joined forces to take the existing network of hydrogen stations – currently 43 – to 400 facilities, with the support of the German government. Through this initiative, Air Liquide Group is playing its part in building Europe's largest hydrogen distribution network.

IN NORTHERN EUROPE, Air Liquide opened its first station in Rotterdam, Netherlands in September 2014. Five other hydrogen stations have also been installed in Denmark, operated by Air Liquide's subsidiary Copenhagen Hydrogen Network (CHN). These five stations – three in Copenhagen, one in Aalborg and one in Vejle – come in addition to the two already operating in Denmark (one in Copenhagen and one in Holstebro).

IN FRANCE, in January 2015, Air Liquide opened a hydrogen charging station in Saint-Lô, on behalf of the Manche Departmental Council. It is the fifth hydrogen charging station opened by Air Liquide in France for cars and buses. Air Liquide has also opened a station on the GEG site in Grenoble, to fuel the company's vehicle fleets. It is part of the Hyway project, co-funded by the Auvergne-Rhône-

Alpes regional council, ADEME, and the European Union (as part of the ERDF – European Regional Development Fund – program) and supported by DREAL, the French Regional Directorate for the Environment, Planning and Housing. The project involves the H2 industry's main players, all of whom are based in Auvergne-Rhône-Alpes: Air Liquide, CEA, CNR, GEG, GNVERT, McPhy Energy, PUS (Cofely Services), and Symbio, coordinated by Tenerrdis. It aims to use captive fleets to trial and verify the technical and economic justification for a "hydrogen kit" to extend the range of hybrid electric vehicles.

In addition, to mark the COP21 in December 2015, Air Liquide opened central Paris's first hydrogen charging station at Pont de l'Alma in partnership with STEP (Société du Taxi Electrique Parisien, a start-up which Air Liquide is a minority shareholder of). Air Liquide also supported STEP in launching Hype, the world's first fleet of hydrogen fuel cell taxis. Today, there is a fleet of 100 hydrogen-powered vehicles (Hyundai ix35 and Toyota Mirai). They can also recharge at the new stations built by Air Liquide at Paris-Orly airport and Loges-en-Josas, near Versailles. STEP plans to be running 600 taxis by the end of 2020.



Air Liquide has opened the first hydrogen charging station in Paris, enabling STEP to operate a fleet of hydrogen-powered electric vehicles called "Hype" in the French capital.

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HYDROGEN TAKES TO SOCIAL MEDIA

CH₂ANGE IS AN AIR LIQUIDE GROUP INITIATIVE ON FACEBOOK, TWITTER, MEDIUM AND YOUTUBE, OFFERING A UNIQUE FORUM FOR DISCUSSION ON THE ROLE OF HYDROGEN IN THE ENERGY TRANSITION. IT IS A PLACE FOR SCIENTISTS, SPECIALISTS AND ANYONE WHO IS INTERESTED TO SHARE VIDEOS, IN-DEPTH ARTICLES AND INTERVIEWS WITH EXPERTS.

*([HTTPS://FR-FR.FACEBOOK.COM/CH2ANGE/](https://fr-fr.facebook.com/CH2ANGE/))

As climate change forces us to rethink the way we live, travel and produce energy, it is vital to provide a forum for evidence-based, constructive debate to raise awareness of the urgency of the situation and find solutions. Hydrogen is one of the keys to shaping the mobility of the future. It must be central to our discussions.



« The first step is to change habits and opinions, and that's undoubtedly what's already happening. »

MARY DOLORES NICHOLS

Chair of the California Air Resources Board (CARB)



PROF. KATSUHIKO HIROSE

Engineer and researcher specializing in hydrogen and fuel cells for Toyota Motor Corporation

« The road ahead will see the coexistence of two evolving technologies that meet the needs of different segments. [...] Consumers will choose the vehicle and technology that best meet their needs and expectations in terms of price and performance. As a manufacturer, we must offer the consumer choice, and we see battery-powered and fuel cell vehicles as the future options. »

« If we don't start to take large-scale hydrogen conversion seriously, I can't see how we can meet climate change commitments. Governments need to be realistic: the availability of hydrogen for heating, transport and electricity will have a critical role to play. »



DAN SADLER

H21 Programme Director
Leeds City Gate

OVERVIEW OF THE HYDROGEN MOBILITY MARKET

FROM THE SEA TO THE STARS,
HYDROGEN VEHICLES ARE BECOMING
PART OF OUR EVERYDAY LIVES.



ENERGY OBSERVER

The world's first energy-autonomous hydrogen-powered vessel, which produces no greenhouse gases or particulates. 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 testament to the role of hydrogen in the energy transition. The Group's financial support for this project also illustrates its desire to contribute to a more sustainable world.





NAVIBUS (APRIL 2018)

Commissioning of the Jules Verne 2 riverboat, which connects the 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 tons of liquid propellants (hydrogen and oxygen).

Air Liquide has supported the successive evolutions of Ariane launch vehicles 1 to 5, and was involved from the beginning of the Ariane European program due to its cutting-edge gas expertise and position as a global leader in space cryogenics.





1. BYD'S ARTICULATED EBUS (2015)

With hundreds of hydrogen buses around the world, the Chinese manufacturer BYD is the market leader. This articulated bus above is 18 m long.



3. 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 100 km and can be recharged in less than a minute!

5. NIKOLA MOTORS (2016)

The American manufacturer has announced the release of two fuel cell trucks — Nicola One and Two – in 2021. 1,000 HP, 0 to 100 km/h in 30 seconds, with a range of 1,300 to 1,900 km. The company claimed to have received more than 8,000 orders by early 2018.



5

2.HY4 (2016)

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

4. CORADIA ILINT, ALSTOM (2017)

This train can travel 1,000 km on a full charge and has a top speed of 140 km/h. Alstom will build fourteen 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.



6

6. TOYOTA MIRAI (2014)

113 kW/154 HP. Reached the landmark of 3,000 cars sold in California in January 2018. Range: 650 km.



7

7. HYUNDAI NEXO (2018)

This SUV will replace the ix35 Fuel Cell (in countries where it is imported); 163 HP ; 179 km/h - range: 800 km - 0 to 100 km/h in 9.5 sec.

8. HONDA FCX CLARITY FUEL CELL 2^E GÉNÉRATION (2017)

130 kW/ 177 HP - 165 km/h - range: 500 km.



8



9

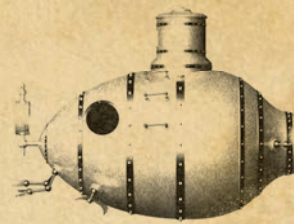


9. GREEN GT H2 (2012)

The first electric-hydrogen competition prototype. Fitted with a 400 kW/540 HP drivetrain. This car, driven by former F1 driver Olivier Panis, opened the 2016 24H Le Mans race.



THREE QUESTIONS FOR JULES VERNE



« WATER IS A GIFT FROM THE EARTH AND BELONGS TO ALL HUMANITY.
IT IS UP TO US TO BORROW IT WISELY SO WE CAN PASS IT ON. »

JULES VERNE WAS AN INTERNATIONALLY RENOWNED SCIENTIFIC VISIONARY
FOR WHOM "WATER IS THE COAL OF THE FUTURE". HERE, HE LAYS OUT HIS VISION FOR
THE FUTURE DEVELOPMENT OF THE HYDROGEN INDUSTRY.

**WE KNOW YOU ENJOY INVENTING NEW
PROPULSION METHODS. WHAT DO YOU
SEE AS THE FUEL OF THE FUTURE?**

JULES VERNE : As I've been saying for many years, I believe that one day water will be used as a fuel. The hydrogen and oxygen of which it is made will be used separately or together to supply us with an inexhaustible source of heat and light far more intense than coal could ever be.

**YOU'VE BEEN USING FUEL CELL ENGINE
YOURSELF FOR ALMOST FIFTY YEARS. WHAT
ARE THE ADVANTAGES OF THAT?**

J.V. : I've actually built a small power station for my family at our house in Nantes. I've put solar panels on the roof and a wind turbine in the garden facing the Loire river. I use the electricity they produce to electrolyze water (either tap water or rain water). That produces hydrogen and oxygen, which I store under pressure in canisters. I recombine the two gases myself to heat the house, produce hot water and power the cooker and refrigerator. I use the hydrogen on its own to recharge the fuel cell in my car. I even collect the water produced by the car in a second tank. So, I'm actually only borrowing the water - using it temporarily. I'm also trialing the use of algae to produce hydrogen without electrolysis.

**DO YOU THINK YOUR
INVENTIONS WILL BE WIDELY
USED ONE DAY? HOW COULD
THAT COME ABOUT?**

J.V. : A few days ago, the Secretary General of the UN told me that, in an endeavor to protect the planet, he had placed on the agenda of the general meeting a motion to end the use of fossil fuels within five years, and list my processes as sustainable development tools. I may receive a support for my research on algae and bacteria! In truth, I can tell you that by making water once again central to our society and economy, we will restore it to its rightful place within the ecosystem. Water is a gift from the earth and belongs to all humanity. It is up to us to borrow it wisely, so we can pass it on!



IMAGINARY INTERVIEW
BASED ON "THE
MYSTERIOUS ISLAND"



Cryocap™ H₂ unit on the Air Liquide site in Port-Jérôme, France. It uses cold (cryogenics) to capture the CO₂ emitted during hydrogen production. This is a world first.

UNLIMITED CLEAN ENERGY

FACED WITH THE CHALLENGE OF CLIMATE CHANGE, THE GROWING USE OF HYDROGEN MAKES SENSE IF THE GAS PRODUCED IS CARBON NEUTRAL. THERE ARE THREE INDUSTRIES FOR WHICH THIS IS THE CASE: BIOGAS REFORMING; THE H₂ CRYOCAP METHOD, WHICH DECARBONATES ITS PRODUCTION THROUGH NATURAL GAS; AND WATER ELECTROLYSIS, WHICH HAS THE ADVANTAGE OF STORING THE SURPLUS OF ENERGY PRODUCED FROM RENEWABLE SOURCES.

The development of hydrogen mobility requires growing quantities of hydrogen. This hydrogen must be extracted from the molecules that contain it (water and organic compounds like natural gas and biomass), without releasing carbon into the atmosphere. 90% of total global hydrogen production is from organic compounds but it is possible to control the CO₂ emissions related to this process. Thanks to Air Liquide's Cryocap H₂ technology, it is possible to capture and reuse the carbon dioxide released during hydrogen production from natural gas (so-called Carbon Capture, Utilization, and Storage technology (CCUS), see article on page 4).

A SOLUTION AT OUR FINGERTIPS

There is another burgeoning hydrogen production industry though:

the decomposition of water. Water electrolysis is a simple, clean, and sustainable solution. Water covers over 70% of the earth's surface. Extracting hydrogen from water through electrolysis requires electrical energy, which has long affected its profitability but the development of renewable solar and wind energy changes things. Firstly, because the price of sustainable energy is becoming competitive, and secondly, as they produce electricity at times when demand is low, large quantities are wasted. Water electrolysis is a convenient way to store energy in the form of hydrogen. Hydrogen therefore gives us renewable energy on tap. In the case of transport, using renewable energy to electrolyze water and then using it to produce electricity via a fuel cell later creates a virtuous energy circle.

TECHNOLOGICAL INTELLIGENCE

The dawn of a new energy era is characterized by effervescence in development research. As well as its own research laboratories, Air Liquide also supports innovative companies working in the hydrogen industry. Air Liquide's venture capital subsidiary, ALIAD, has, for example, taken minority stakes in three companies: McPhy Energy, Plug Power, and Ergosup.

Find out more:

<https://www.airliquide.com/fr/groupe/aliad-venture-capital>

CLIMATE-COMPATIBLE HYDROGEN

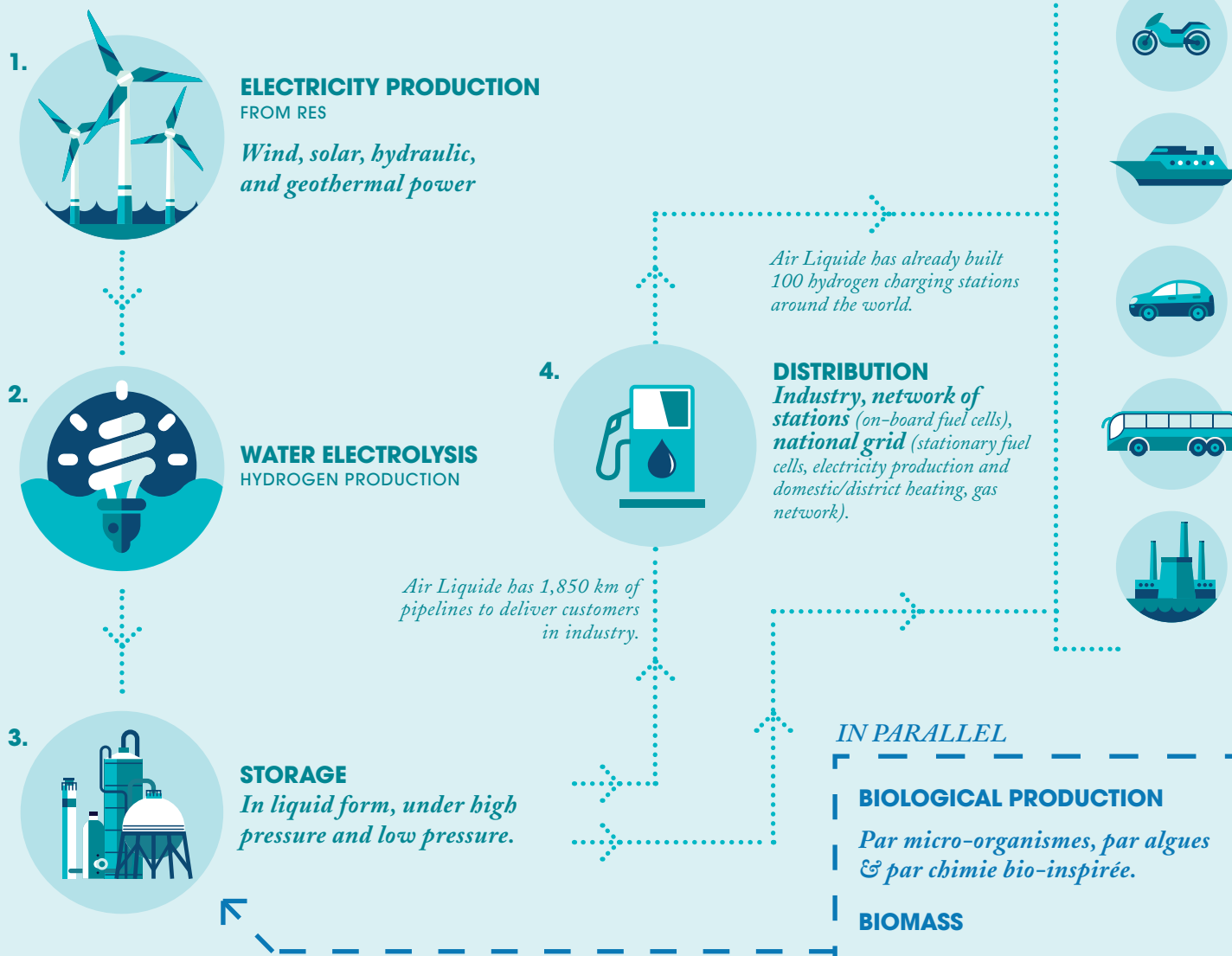
Blue Hydrogen® is an Air Liquide initiative that aims to gradually lower the carbon content of Air Liquide's hydrogen production dedicated to energy applications. Concretely, Air Liquide is committed to achieving at least 50% of low carbon hydrogen necessary for these applications by 2020, by combining:

- the use of low carbon energies, water electrolysis, and reforming of biogas,
- carbon capture and valorization technologies for the CO₂ emitted during the production of hydrogen from natural gas.

Even when produced using natural gas, hydrogen is a virtuous energy: over an equal distance traveled, the use of hydrogen fuel cell electric vehicles decreases greenhouse gas emissions by 20% compared with combustion vehicles and does not emit any particulate matter.



FROM PRODUCTION TO USE





TIME TO SCALE UP

•

HYDROGEN PUTS US ON THE CUSP OF A NEW ECONOMY WHICH IS WAITING TO BE BUILT. THE PLANS AND THE MATERIALS ARE READY. BUT MANY COUNTRIES ARE STILL MISSING THE STRATEGIC AND POLITICAL VISION TO TAKE THEM FORWARD.

To produce hydrogen from renewable energy sources, generate heat, commit to clean transport and decarbonize various activities, we need to develop every link in numerous production chains, build new synergies and train people to work in the hydrogen industry of the future. They will be employed producing hydrogen and manufacturing electrolyzers, electrolytes, fuel cells, autonomous service station networks, turbines, boilers of all sizes, and propulsion mechanisms for cars, ships, trains, buses, drones, mopeds and bicycles. The efforts required are extensive, but also feasible and full of promise. Extensive because they cover a wide range of sectors; feasible because all the solutions are on the table; and full of promise because of the future they will carve out for our children and our children's children. It's something we can all get excited about. So, what's

holding us back? It is the alignment of all stakeholders, whether they be industrial or political, that has so far prevented hydrogen solutions from taking off. We have spent a long time dragging our feet on the experimentation stage, while a country like South Korea is moving forward quickly, aiming to put 10,000 hydrogen-powered cars on the road by 2020. Japan already boasts 100 hydrogen charging stations and is using fuel cells to heat some

200,000 homes. California wants to ban all fossil-fuel engines by 2040. The national hydrogen plan announced on June 1 by France's Minister for the Ecological and Inclusive Transition, Nicolas Hulot, could mark the end of the carbon-powered old world's hesitation.

CHANGING DIRECTION

The shift should not be too difficult. The Ariane rocket and its peers have used hydrogen engines to put hundreds

*THE DIFFICULTY IS ALSO
THE ALIGNMENT OF INDUSTRY
AND POLITICS*

of satellites into orbit since the 1980s, and NASA has entrusted the lives of its cosmonauts to fuel cells. People have been driving hydrogen-powered cars for more than 20 years. The major technical pitfalls were overcome decades ago. Price remains a barrier, and the only way it can fall is through mass production in each market segment where hydrogen is used. A strong signal from the markets or from politicians is needed to bring these technologies into widespread use. The impetus could come from an announcement of a ban on fossil-fuel engines, financial support for hydrogen distribution networks, measures to subsidize the cost of the first mass-produced vehicles (tax incentives, rebates for buyers, and bonuses for scrapping old cars, etc.), or any decision that identifies hydrogen as society's fuel of the future.

By 2030, the Hydrogen Council expects one in twelve cars in Germany, California, South Korea, and Japan to be hydrogen-powered. On a global scale, 250 to 300 TWh of unused solar or wind-turbine energy could be converted into hydrogen, and industry could replace 10 to 15 million tons of chemical raw materials with hydrogen. Lastly, over 50 million homes could also



THE MAJOR TECHNICAL PITFALLS WERE OVERCOME DECADES AGO

BREAKING OUT OF THE VICIOUS CIRCLE OF IMMOBILITY

Today, the factors limiting the growth of hydrogen cars are the lifespan of the fuel cell (around 150,000km), the price of the vehicle, and the hydrogen distribution network. Research laboratories are already working on strategies for improving fuel cells. The price of hydrogen cars is still high (from €66,000), although rental contracts offer a cheaper solution. Purchase prices will automatically reduce as the cars go into mass production, but who is going to want to buy a hydrogen car if there is nowhere to refuel it? Political and financial support is vital to the development of the hydrogen distribution network. Air Liquide is proactive within the hydrogen industry. It is innovating by building hydrogen service stations to keep pace with sales of hydrogen-powered cars. So far, Air Liquide has designed and installed some 100 hydrogen service stations across the world. Of them, around forty are directly owned and operated by Air Liquide Group. We must develop distribution networks so we can move away from fossil fuels. Given the climate emergency, these networks are a public good.

be connected to a combined gas and hydrogen network by 2030.

Annual investments of \$20 bn to \$25 bn will be needed to achieve these ambitions. To put these figures in perspective, global energy spending equates to \$1,700 bn per year. The sector's businesses are capable of meeting the challenge, but this level of investment can only be achieved in close collaboration with the authorities, and with the support of appropriate public policy measures.

Across the hydrogen industry, all the teams and their captains are ready to set a course for the future.

HYDROGEN ON LINE

WITH THE SUPPORT OF EUROPE
AND UNDER THE COORDINATION OF
AIR LIQUIDE, DENMARK IS LAUNCHING
100% RENEWABLE ENERGY MIXES, WHERE
HYDROGEN PROVIDES NETWORK STABILITY.



This is a European first that is worth focusing on. HyBalance – short for Hydrogen Balance – is an industrial system that illustrates hydrogen's important role in the energy transition. HyBalance covers the entire value chain, from the production of hydrogen from renewable energies to the end user, via energy storage and retrieval to facilitate grid balancing. Europe's decision to create this futuristic demonstrator in Denmark was just reward for this country's commitment to the energy transition. In 2012, the government decided to eliminate all fossil fuel use for heating and electricity by 2035. And by 2050, all fossil fuels will be replaced by a mix of renewable energies.

GREEN HYDROGEN

The plant, inaugurated in 2018, is located in the Hobro region, in the north of the Jutland Peninsula. Wind turbines in the region provide the power needed to produce hydrogen through water electrolysis. This is what we call

power to gas. This green hydrogen is stored under pressure and used in grid balancing, and to supply manufacturers and five existing hydrogen charging stations operated by Air Liquide through its subsidiary, Copenhagen Hydrogen Network (CHN). These stations are already used to recharge 60 hydrogen fuel cell vehicles and will soon also be used by three buses in Aalborg.

HyBalance uses key new hydrogen production technologies, for example a 1.2 MW PEM (proton exchange membrane) electrolyzer supplied by Hydrogenics, and a high-pressure hydrogen supply chain for the charging

stations. HyBalance received a €8 million grant from the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) – a European public-private partnership on hydrogen and energy storage, and also receives support from the Danish program EUDP (Energy Technology Development and Demonstration Program).

The objective of a 100%-renewable energy mix highlights the ubiquity of hydrogen in clean energy storage, its role in grid balancing, and its potential for liberating transportation from its addiction to fossil fuels.

HYBALANCE FEATURES KEY NEW PRODUCTION TECHNOLOGIES

Hydrogen Council

THE HYDROGEN ECOSYSTEM

HAVING GROWN FROM THIRTEEN TO MORE THAN FIFTY MEMBERS IN ONE YEAR, THE HYDROGEN COUNCIL ILLUSTRATES THE DESIRE OF THE SECTOR'S MAIN PLAYERS TO PLAY THEIR ROLE IN REALIZING THE COMMITMENTS OF THE COP 21. DIRECTLY OPERATIONAL, IT IS PUTTING HYDROGEN AT THE FOREFRONT OF THE ENERGY TRANSITION FOR MOBILITY, ENERGY, INDUSTRY, BUILDING HEATING AND POWER.

The hydrogen economy relies on a range of competencies from a variety of players, none of whom master all aspects; contrary to electricity where a single player can produce, build, and distribute – as was the case with EDF and as Elon Musk currently does from solar panels to the electric car. Faced with the indisputable and indispensable complementarity of businesses and companies, the directors of leading companies in the industry's various segments agreed to set up the Hydrogen Council.

ACCELERATING THE ENERGY TRANSITION

The Hydrogen Council (<http://hydrogencouncil.com/>) is the hydrogen economy's task force, launched at the Global Economic Forum in Davos (Switzerland), in 2017, with 13 CEOs from the sector's biggest companies

(Air Liquide, Alstom, Anglo American, BMW Group, Daimler, ENGIE, Honda, Hyundai Motor, Kawasaki, Royal Dutch Shell, The Linde Group, Total, and Toyota) and managed by two presidents from two different regions and different sectors. In one year, its membership has tripled and it has developed a shared vision with governments and civil society at major international events (Global Economic Forum, Cop23, etc.). This coalition of multinationals represents more than €1,600 billion in revenue and more than 2.5 million jobs around the world (2017). Being made up of CEOs allows the Hydrogen Council to define strategies and make the relevant operational decisions. They work on the harmonization of industry standards across regions and sectors, provide their expertise in terms of the feasibility of decarbonization solutions, and ask policymakers to provide a long-term

strategic framework to guide the energy transition, and coordinate and encourage investment. As the co-president of the Hydrogen Council and CEO of Air Liquide, Benoît Potier, says «*we need governments to support hydrogen through actions that only they can undertake – for example through major infrastructure investments.*»

GLOBAL GOVERNANCE

To date, the Hydrogen Council has published two studies – «*How hydrogen empowers the energy transition*» and «*Hydrogen, scaling up*» – which present the first global vision of hydrogen's potential in the energy transition, as well as the actions it believes are necessary from policymakers to implement and enable the emergence of a veritable ecosystem for the tiny, essential molecule that is hydrogen. This dynamic is vital to support the disruptive technological innovation that hydrogen introduces to the energy transition, to create economies of scale, and reduce costs.

In its recent reports, the International Energy Agency (IEA) highlights that current projected levels of greenhouse gas emissions would cause global warming of 6°C by 2100. To remain within the 2°C limit announced at the COP21, the IEA recommends that 25% of the global car fleet be fitted with fuel cells by 2050. This ambition and urgency justify the removal of economic barriers to the development of hydrogen at the global level and to make it an everyday reality.

CAPTIVE FLEETS

The development of hydrogen mobility in France has started with captive fleets (cars, buses, bicycles). The Mobilité Hydrogène France consortium brings together all the public and private stakeholders, from energy companies to users. The Manche Departmental Council has set itself the aim of acquiring a fleet of 40 hydrogen-powered vehicles, five buses, and one fishing boat, as well as three charging stations. The Auvergne-Rhône-Alpes region's Zero Emission Valley program supports the creation of a network of 20 hydrogen charging stations devoted to captive fleets, around 15 of which will produce their own hydrogen through electrolysis. In total, it will allow 1,000 hydrogen fuel cell vehicles to circulate in the region.

INTERNATIONAL PARTNERSHIPS

IN OVER FIFTY YEARS, AIR LIQUIDE HAS DEVELOPED UNIQUE EXPERTISE ACROSS THE ENTIRE HYDROGEN CHAIN; FROM PRODUCTION, TO STORAGE, AND DISTRIBUTION. THE GROUP IS ACTIVELY PURSUING A TWIN-PRONGED STRATEGY: THE DEVELOPMENT OF RESEARCH AND INNOVATION IN HYDROGEN IN ORDER TO IMPROVE EXISTING TECHNOLOGIES AND TO DEVELOP MORE EFFICIENT ONES, AS WELL AS INVOLVEMENT IN MAJOR INTERNATIONAL DEMONSTRATION PROJECTS. INCLUDING:



Japan Hydrogen Mobility is a joint venture created in 2018 by Air Liquide Japan and 17 Japanese companies from various industries and finance to accelerate the deployment of hydrogen stations and fuel cell vehicles in Japan, with the support of the Japanese government. The objective is to set up a network of 320 stations by 2025, and 900 by 2030.



Air Liquide is part of Hydrogen Europe – an association that represents more than 100 companies in the hydrogen sector. Hydrogen Europe is working with the European Commission and the community of researchers to ensure these clean technologies reach the energy and transportation industries more quickly.



The Fuel Cell and Hydrogen Energy Association is focused on advocating, educating and providing a voice to promote the environmental and economical benefits of fuel cell and hydrogen energy technologies.



The Fuel Cells & Hydrogen Joint Undertaking (FCH JU), a public-private partnership co-managed by the European Commission and European manufacturers operating in the sector. FCH JU co-finances major research and demonstration projects around Europe to improve and promote fuel cell and hydrogen technologies.



Air Liquide is a founding partner of the joint venture «H₂ Mobility Deutschland», created in 2015 with Daimler, Linde, OMV, Shell, and Total, in order to continue to develop the infrastructure of hydrogen stations started by the Clean Energy Partnership. H₂ Mobility has set itself the objective of 400 stations, with the support of the German government.



Air Liquide is a member of the *Association Française pour l'Hydrogène et les Piles à Combustible* (French Association for hydrogen and fuel cells).



Air Liquide supports the *Alliance Mondiale pour les Solutions Efficientes* (global alliance for efficient solutions) created in 2016 on the initiative of the Solar Impulse Foundation and its president Bertrand Piccard. Air Liquide has provided the Alliance with a group of experts to evaluate concrete energy solutions that combine economic and ecological benefits with energy efficiency.



The California Fuel Cell Partnership is an industry/government collaboration aimed at expanding the market for fuel cell electric vehicles powered by hydrogen to help create a cleaner, more energy-diverse future with no-compromises zero emission vehicles.



THE BIG INTERVIEW

THOMAS PESQUET

IN SPACE THANKS TO HYDROGEN ENGINES

HYDROGEN IS THE MOST COMMON ELEMENT IN THE SUN, MOST STARS, AND INTERGALACTIC MATTER. COSMONAUT THOMAS PESQUET, WHO SPENT 196 DAYS ON THE INTERNATIONAL SPACE STATION, GIVES HIS TAKE ON HYDROGEN.

When I say hydrogen, what you think of?

Thomas Pesquet : I think of propulsion, because most space vessels have hydrogen engines. That's what takes us into space.

Do you think that the lessons learned in space can help us on earth?

Yes, that's already the case for many things. We developed solar power for space and now we are seeing its applications on Earth; likewise, for hydrogen and space propulsion, which has given us fuel cell vehicles. These fuel cells were used in the space shuttle to produce electricity. Space is a very hostile environment. You need to adapt, which requires effort and ingenuity, but then, whether it be scientific research

for the space station or the technology that enables us to reach space, the results trickle down to the rest of society.

Have hydrogen solutions proved their reliability for getting to space?

Yes, of course! There have never been any accidents related to that. There are a lot of advantages. Hydrogen is a part of our everyday life in space exploration, but we need to go further and find solutions. Nowadays people are talking about creating fuel for space ships from in situ resources, i.e. by mining asteroids to get hydrogen – that is to say water – by separating hydrogen and oxygen, to make space fuel. This means that, as long as you can mine in space, you have all the fuel you need. It's eco-friendly too as you no longer need to pollute unspoiled environments.

We tend to forget the hydrogen is a major component of the cosmos.

Yes, you can find it in huge quantities around you in space, even very far away from Earth. In fact, we have unlimited access to hydrogen. We find it buried, in the form of liquid water and ice. We know that ice is buried at the poles on Mars, and, therefore, that there are abundant energy, fuel, and oxygen resources to support life.

Does an understanding of hydrogen's potential change the way you see the world?

It's like wearing infrared glasses: you see things differently, it's a filter that you couldn't have previously imagined. When you look toward space, you need to wear the right goggles to try and find what would keep us alive.

AIR LIQUIDE

KEY FIGURES

AIR LIQUIDE AND HYDROGEN ENERGY



100 hydrogen stations
designed and installed
in the world.



A hydrogen station can
recharge vehicles in
less than 5 minutes.



A hydrogen car can ride
more than 600 km with
one charging.



Zero CO₂ emission.
Zero particle.
Zero noise pollution.



Hydrogen produced by Air Liquide
in 2018 for the refinery and
petrochemical markets:
14 billion m³.
The current production could allow
to recharge around 10 million
hydrogen Fuel Cell Electric Vehicles.



Revenue from hydrogen
for refineries and
petrochemical markets
in 2018:
€2 billion.

THE AIR LIQUIDE GROUP



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 and patients.



300 millions euros of
innovation expenses.



Around **300 patents**
per year.



2018 Revenue:
€21 billion.
2018 Net profit:
€2.1 billion.

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