



AIR LIQUIDE

Air Liquide and Hydrogen, Clean energy carrier



Official technological suppliers
of the Nissan Pan European Tour

July 2008

Air Liquide, official technological supplier of the Nissan Pan European Tour

- From June to September 2008 Air Liquide is the official **technological supplier of the European tour that is being organised by Nissan**. As such, Air Liquide will install service stations and the necessary Hydrogen for the shows organised by Nissan, around the fuel cell operated X-Trail vehicle.
- The Hydrogen energy carrier is, in fact, a **promising alternative solution**. Battery operated, Hydrogen is mixed with Air to produce electricity; it discharges only water. Hydrogen can be extracted from a great number of raw materials (natural gas, carbon, water + electricity or even biomass. Although today 95% of Hydrogen is produced from natural gas, the multiple sources of production guarantee a secure supply. Hydrogen represents a wonderful potential to provide renewable clean and quiet energy to sustain the vehicle of tomorrow.
- In practical terms, this European tour covers several aspects:
 - Air Liquide devised and developed the installation of **service stations** and supplied Hydrogen to vehicles at the various show places.
 - The supply of Hydrogen to these stations.



Air Liquide, official technological supplier of the Nissan Pan European Tour

- Relying on Air Liquide technologies, **Hydrogen service stations are equipped with a high pressure (700 bar and 350 bar), rapid distribution mechanism** that is totally safe and straightforward for drivers and vehicles alike. **It only takes 3 minutes to fill up a tank** large enough to drive several hundreds of kilometres.
- For Air Liquide too this event is an **opportunity to heighten public awareness** to use **Hydrogen** as a new, **clean and quiet source of energy** that will sustain the car of tomorrow and improve the knowledge of **innovative technologies** that it develops to enhance the natural resources.



Air Liquide and Hydrogen: Key figures

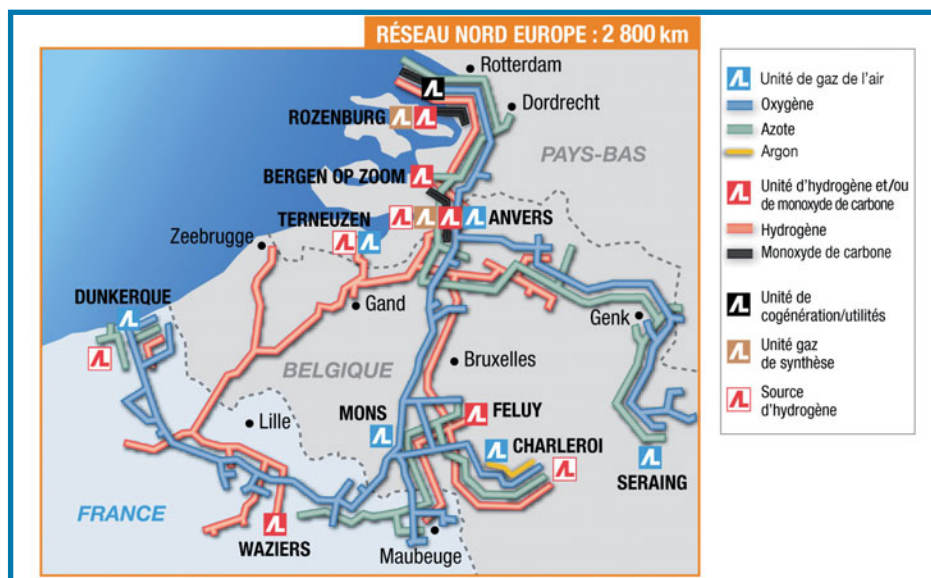
- More than 40 years experience in the Hydrogen trade: Control over the whole of the Hydrogen chain, over research and production, distribution and other applications.
- Production: More than 200 production/manufacturing units among which 40 with the greatest production capacity in the world (gaseous or liquid Hydrogen).

50 units of great capacity production



- Distribution: 1800 km of Hydrogen pipelines (the greatest Hydrogen pipeline network of the world) and 12 Hydrogen networks in the world.

Example: Hydrogen pipelines in Northern Europe



Control of the entire Hydrogen chain

■ General use:

- **Industry:** Air Liquide controls **all current general Hydrogen uses of industry** (glass manufacturing, semi-conductors, steel transformers...).
- **Clean energy carrier/supplier:**
 - Air Liquide devised and developed tanks for stocking and for Liquid Hydrogen transport at very low temperatures (-253°C). With its sister company Cryospace, Air Liquide is, notably/among others, the constructors of Hydrogen and Oxygen tanks for the European satellite launcher ARIANE.
 - Air Liquide develops the use of Hydrogen resources with its sister company Axane who devise and produce fuel cell batteries.

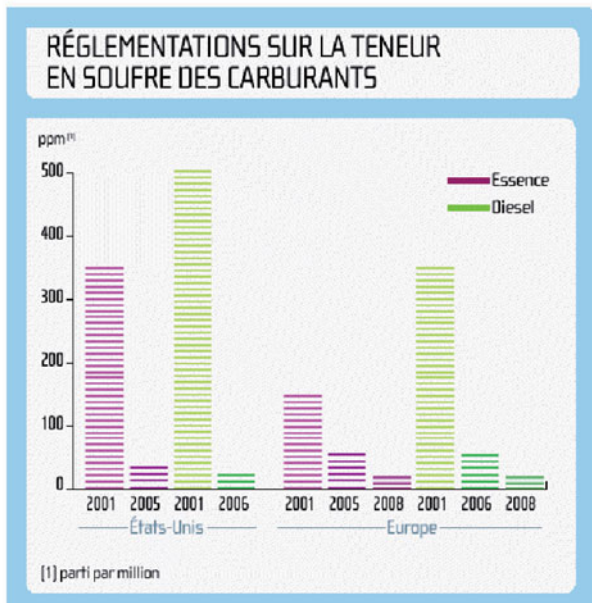


- **Group Hydrogen business figures: Around 1 thousand million Euros in 2008. Production 2007: 6.5 thousand million m³ Hydrogen.**

Hydrogen today:

■ Removal of Sulphur from Hydrocarbon, main current usage of Hydrogen

- The most important current usage of Hydrogen (nearly 2/3 of the quantity sold by the Group) is the de-sulphurisation of Hydrocarbon in order to produce fuels without sulphur.
- This de-sulphurisation of Hydrocarbons is necessary to reduce the Sulphur Dioxide emissions into the atmosphere. In fact, these Sulphur Dioxides can cause serious respiratory problems in humans. They are not only responsible for the pollution smog of certain built up areas (conglomerations) but also for acid rains that causes deforestation and the acidification of water. Sulphur is also a poison of catalysts because it very quickly deteriorates the performance of catalytic converters on vehicles.
- Hydrogen is supplied by Air Liquide to refineries all over the world to avoid discharging 780,000 tons of Sulphur Dioxide per year into the atmosphere. France discharges 450,000 tons every year.



Hydrogen today

■ Wall to wall supply of energy (Supply of energy without interruption)

- Air Liquide develops stationary fuel cells and the necessary equipment to put them into operation. The Group and its sister company Axane have signed, within the framework of the French project Ballises, a joint contract with Bouygues Telecom, to make the most of the fuel cells, supplying one to each telephone GSM network station on isolated sites in France.
- Other projects of a similar nature are being realised in Greece and in Spain. The fuel cells allow the supply of electricity where there is no electricity substation without spoiling the landscape, without noise and without CO₂.



- Air Liquide devises and produces portable electricity generators that work using fuel cells. These generators allow the supply of clean electricity, quietly and without any vibration, i.e. for a council's works vehicles. It can also be used in film sets where quietness is of essence.

Hydrogen tomorrow

Hydrogen – indispensable for the promotion of energy resources

- The steep rise of petrol prices combined with society's concerns to respect the environment, contribute to renewed investments into alternative forms of energy, i.e. the use of bituminous sands in Alberta or Canada in order to reclaim petroleum, the conversion of gas and carbon into petroleum. All these procedures need immense amounts of industrial gases and represent a very important market that could expand rapidly in the next 5 to 10 years.

Hydrogen – clean energy vehicle

- Thanks to its in-depth knowledge of all aspects of Hydrogen, Air Liquide works equally well on the future Hydrogen usage as fuel for cars as for fleets of town/city buses.
- Air Liquide is particularly active on the following points:
 - The **storage of Hydrogen in vehicles**. Air Liquide develops all kinds of storage facilities, particularly for the storing of **high pressure (350 to 700 bar) Hydrogen gases** and for **liquid Hydrogen at very low temperatures (-253°C)**. Air Liquide also conducts research programmes relating to the stockpiling of Hydrogen under chemical development (Hydride).
 - **Distribution of Hydrogen**. To allow the supply of vehicles using Hydrogen as fuel, Air Liquide develops Hydrogen distribution service stations. These stations allow to fully refuel in less than 3 minutes with the same safety and ease as with a conventional petrol station.



Hydrogen tomorrow

Hydrogen – clean energy vehicle

■ Air Liquide is pursuing an important demand in R&D and participates on major international exhibition projects.

➤ During the last 4 years Air Liquide has already designed and put into service an increasing number of Hydrogen filling stations.

Examples: In Madrid – (a bus fleet); in Kawasaki, Luxemburg, and Shanghai with a mobile station for the Bibendum of Michelin Challenge; in Singapore, South Korea the group is also developing display stations for the European automobile manufacturers.

In 2007 Air Liquide has devised and installed **5 Hydrogen stations for General Motors in the United States**. In Canada it provided three stations for the **BC Transit Company** for a fleet of 20 buses. By the end of 2008 13 stations will be operational in North America.

The Group also has a permanent display station available at Sassenage (near Grenoble in France).



Hydrogen tomorrow

Hydrogen – clean mobility energy

■ For the long term future the group will be involved with the job of **replacing conventional fuels with Hydrogen in specific vehicles.**

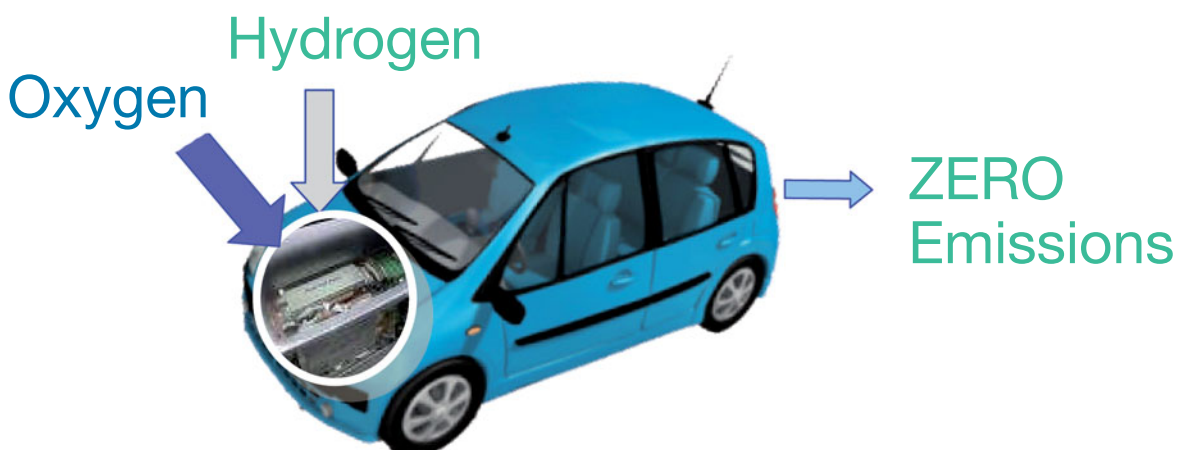
- Further to the usage of Hydrogen for fuelling a classic, internal combustion engine directly (thermal), the fuel cell battery shows promising. Compared with Hydrogen used in a thermal engine, a raised output and a smaller tank can be achieved.

The whole thing is made up of a fuel cell battery, using Hydrogen and an electric motor that offers a number of advantages:

- Hydrogen stored in the vehicle fuels the battery that produces water and electricity. In turn the electricity fuels one or more electric motors that move the wheels of a car. This diagram is realistically at pollution scale zero. As of today, looking at the global report, from the 'well to the wheel' the Hydrogen line generates around 25% less CO₂ emissions per km covered than the classic fuel line.
- The system offers an excellent energy output, twice more than one from an internal combustion engine.

	Effectiveness
Fuel Cell	38%
Petrol Engine	16%

Axane, sister company of the Air Liquide Group was founded in May 2001 and has designed, developed, produced and marketed combustion batteries fuelled by Hydrogen.



Hydrogen tomorrow

Raising the technological and social barriers

- To reach these technologies of the future it is sometimes necessary to raise technological and social barriers:
 - For storing Hydrogen in a car: A minimum range of 500 km per tank has to be offered to users. This can be achieved in 2 ways:
 - One way is to compress the Hydrogen: At a pressure of 700 bar there is only 3 times more Hydrogen needed than petrol.
 - Another way is to load the Hydrogen at -253°C ; in this case there is only twice as much Hydrogen needed than petrol to achieve the same number of kilometres.

To achieve **500 km** it needs:

- 40 litres petrol
- 60,000 litres liquid H_2
- 200 litres compressed H_2 at 350 bar
- 125 litres compressed H_2 at 700 bar
- 75 litres liquid H_2 at -253°C



- The same goes for the fuel cell battery: Axane, sister company of Air Liquide, works on the performance, the cost and the lifespan of a fuel cell battery.
 - The new technologies and the industrial progress made have reduced the manufacturing costs of the fuel cell battery by 10 in 4 years!
 - The Group is committed to progress the lifespan of a PAC by making viability tests, for instance, under climate controlled conditions.
- The fuel cell battery is a break-away innovation: The people are going to learn to do it 'differently'. That's why Air Liquide participates in projects and events that encourage people to use alternative energies like Hydrogen. Through training Hychain makes the social aspects of Hydrogen energy more understandable, how it ties up with security and the acceptance of the public of an innovation.

Air Liquide participates in several research programmes with car manufacturers or in European and international projects (Hychain-Minitrans, STORHY, Nesshy), or French companies like H2E – Horizon Hydrogen Energy (supported by the French Government).

Air Liquide, main co-ordinator of the Hychain-Minitrans project

Hychain, a world premiere: The deployment of a great number of hybrid fuel cell battery vehicles in 4 regions of Europe.

- Transport in Europe depends 95% on fossil fuels and is responsible for 20% of the total of emissions of CO₂. **Europe has decided to use 20% alternative energy by the year 2020** among others **Hydrogen, the clean energy carrier/vehicle/agent**.
- The European Commission has launched the Hychain project that consists of 24 partners who are co-ordinated by Air Liquide. Objective: To test, under real-life conditions, 158 urban vehicles fuelled by electricity via a fuel cell battery using Hydrogen in 4 regions of Europe: 30 scooters, 40 tricycles, 34 medical armchairs (mobility vehicles), 44 light commercial vehicles and 10 minibuses. **Budget: 36,7 million Euros**. Of which 17.2 million is financed by the European Commission.
- Concerning the services of the partner city fleets and the mobility vehicles that have been put into circulation in partnership with certain hospitals in the region **Rhone-Alpes in France** (village/town community of Grenoble Alpes Metropole), **Emilia Romagna in Italy** (town of Modena), **Castilla y Leon in Spain** (town of Soria and Leon) and **Nordrhein Westfalen in Germany** (village/town community of the region Emscher Lippe).



- This project is to proceed over **5 years** in two phases.
 - ✓ 2007 and 2008 will be devoted to the manufacturing of the vehicles and to the development of the Hydrogen distribution infrastructure.
 - ✓ From 2009 to 2010 vehicle testing will take place in the 4 regions under real life conditions.
- To fill these vehicles with Hydrogen in the simplest and safest way, the Hychain project will develop an innovative logistic procedure: At automatic distributors it will be possible to refill the vehicle's fuel cell battery with Hydrogen by replacing an empty Hydrogen gas cartridge with a full one, under very high pressure (up to 700 bar) in perfect safety, thanks to the **'Clip-on' technology developed and patented by Air Liquide**. The independence of these new, clean 'hybrid' vehicles is thus tripled.
- Hychain hopes **for the people to accept** this totally innovative technology mainly through training, by setting guidelines that will apply to these technologies so respectful of the environment and by developing a new industrial network. To fill a vehicle with Hydrogen is, in fact, a breakthrough development.

Hydrogen: Key dates

- **1967:** Air Liquide constructs its 1st production unit of **liquid Hydrogen** for the Space Industry.
- **1973:** Brought into service the 1st Hydrogen production unit by **changing/improving natural gas** (SMR) at Isbergues (France) and the 1st Hydrogen pipeline (30 km).
- **1979:** First launch of **Ariane 1** with a liquid Hydrogen tank.
- **1985:** Extension of the Isbergues pipeline to Belgium (Zeebrugge), thus creating international multi-sourced network for different customers. Length of system about 140 km.
- **1987:** Air Liquide constructs Europe's most important **Hydrogen Liquefaction** in Waziers (France) and assures the Hydrogen supply for Ariane. A Hydrogen liquefaction unit was installed at Becancour (Canada) and one in Japan in 1988.
- **1988:** First launch of Ariane 4. Setting up of **Cryospace**.
- **1991:** 1st Hydrogen unit installation of great capacity (10,000 Nm³/hr) and extension of the Hydrogen network to a 3rd country: Netherlands.
- **1997:** Connection of the Northern European pipeline at Rotterdam and the South Belgium network. New length of system: 800 km. 1st Hydrogen unit production at **Rotterdam** and in the **United States** for Dow chemical in Freeport, Texas.
- **1997-2000:** Development of the two Hydrogen networks in Texas (Corpus Christi and Freeport, Texas City, USA).
- **1999:** Installation of the first Hydrogen production unit in **Asia** (Thailand).
- **2000-2003:** Installation of the first Hydrogen unit in **Singapore** and 2 units at Yosu (**South Korea**).
- **2003-2004:** Installation of the first SMR with a production capacity of 100,000 Nm³/hr at Anvers (Belgium) and a second unit at El Segundo (USA).
- **2005:** Installation of the first SMR of great capacity at Caojing, near Shanghai (China). Air Liquide's Hydrogen sales reached **650 million Euros** for a volume of 5 thousand million per m³.
- **2006:** Construction of a 2nd production unit of 100,000 Nm³/hr at Anvers.
- **2007:** Development of Hydrogen stations, new investments in the Hydrogen production system (140 million Euros on the coast of Gulf of Mexico in the USA), partners Hychain and Horizon Hydrogen Energy.
- **2008:** Air Liquide's Hydrogen sales should reach **1 thousand million Euros**.

Hydrogen identity file

What is Hydrogen?

■ The simplest atom

Hydrogen is the world's simplest form of atom. Its nucleus does not contain a single particle of proton. Around this nucleus revolves a single electron.

1 atom consists of a nucleus that contains protons (charged +) and sometimes neutrons (without charge). Around this nucleus revolve electrons (charged -). One atom possesses as many protons as electrons.

■ The oldest element

The scientific community says that it is the first element that has been formed on Earth. Hydrogen would thus have given birth to all the other elements that make up matter.

■ The lightest gas

The Hydrogen molecule is made up of 2 Hydrogen atoms. It is sometimes called the 'Di-hydrogen (H₂)'. It is the world's lightest gas. 1 litre weighs less than 90 milligrams. It's only a question of time when this gas will become the clean energy carrier/vehicle/agent of tomorrow.



Di-hydrogen molecule

As comparison:

1 litre of Hydrogen weighs 90 milligrams; that is the weight of 3 postage stamps.

The gas in the air that we breathe is 16 times less than 1 litre of Oxygen.

It is 65 times less than 1 litre of xenon, the heaviest of the rare gases used in the headlights of cars.

Hydrogen, where do we find it?

■ Unobtainable/Inaccessible Hydrogen!

Hydrogen is a light gas, very light..., so light in fact that it cannot be kept in our atmosphere. It rises and never stops. Even lighter than Helium with which we inflate balloons. It is impossible to find Hydrogen on Earth, and so...

■ Though present everywhere

The Hydrogen atom is the most abundant in the world... We can find it everywhere but never on its own. It is always associated with other atoms. First of all in water. The water molecule is made up of 1 Oxygen atom and 2 Hydrogen atoms. Water we have plenty, it covers 70% of our Earth and makes up 60% of our body!

Then in Hydrocarbon. As its name suggests it is made up of Carbon and Hydrogen.

Hydrogen identity file

Hydrogen, where do we find it? - continued

For example:

Methane that is found in gas deposits is made up of 1 Carbon atom and 4 Hydrogen atoms.

Butane that produces the flame on a cooker is made up of 4 Carbon atoms and 10 Hydrogen atoms.

Super or Diesel Fuel that is used in cars is a mixture that contains several liquid Hydrogen.

To manufacture Hydrogen the scientists want to extract its molecules that are made up of Hydrocarbon or water.

For example:

*Passing an electric current through water will produce Hydrogen and Oxygen, that's **electrolysis**.*

*Re-combining, **at high temperature methane and water vapour**, will produce a rich mixture of Hydrogen.*

Nearly 95% of today's industrial Hydrogen production is based on this system.

Hydrogen holds a lot of energy. 1 kilogram of Hydrogen holds 3 times more than 1 kilogram of petrol.

■ Energy of stars

Stars, like our sun, are essentially made up from Hydrogen. By a fusion reaction between 2 Hydrogen atoms the sun produces a great quantity of energy and transforms into Helium. This is the energy that heats Earth.

■ Rocket Fuel

Hydrogen is already being used for rockets taking off. The launcher ARIANE carries 150 tons of H₂ and liquid Oxygen. Their combination produces a very great quantity of energy that propels the rocket and all its cargo.

■ ... And a new source of electricity

A fuel cell battery allows Hydrogen to be changed into electricity, a little like batteries for personal stereos or batteries for mobile phones.

Conventional alkaline batteries wear out and have to be changed regularly. A fuel cell battery does not wear out. It produces electricity as long as there is Hydrogen. To re-charge a mobile phone battery takes several hours. To re-charge a fuel cell battery with Hydrogen is instantaneous: It only takes seconds to exchange an empty battery for a full one.

Finally, a fuel cell battery is clean: It only discharges water into the atmosphere.

How do we transport Hydrogen?

■ Too light – a real problem

Hydrogen is a very light gas, too light. For transporting 1 kilogram of Hydrogen it would need a reservoir of more than 11,000 litres. Much too big a reservoir for such a small quantity. Hydrogen is a gas and in a gas the molecules are getting away from each other and occupy a great volume. In order to reduce this volume a solution has to be found to bring them closer together.

Hydrogen identity file

How do we transport Hydrogen? - continued

Do you know?

1 kilogram of Hydrogen contains 3 times as much energy than 1 kilogram of petrol but 1 litre Hydrogen contains 3000 times as much energy than 1 litre of petrol.

■ **One solution: Bring the Hydrogen molecules closer together**

For this scientists use 2 methods.

Force many gas molecules to enter a small, very strong reservoir. Scientists call this '**increasing pressure**' or 'compress' the gas. Today, reservoirs/cylinders/containers at a pressure of 700 bar are being manufactured. That's a pressure of 700 times greater than the air pressure on the Earth's surface, called atmospheric pressure.

When it is compressed to a pressure of 700 bar, 1 kilogram gaseous Hydrogen can be transported in a 23 litre reservoir/cylinder/container.

Other techniques used by scientists: **Cool the Hydrogen** until it becomes liquefied. It has to reach -253°C . When it has cooled down to -253°C , 1 kilogram of Hydrogen can be transported in 14 litre cylinder.

A distance of 500 km uses 5,5 kg Hydrogen, thanks to the increased efficiency/output of a fuel cell battery. In terms of Hydrogen volumes:

- ✓ About 125 litres gaseous Hydrogen at 700 bar pressure;
- ✓ About 75 litres liquid Hydrogen at -253°C .

In short, the solutions exist!

Air Liquide Group in brief

- **World leader** of industrial and medical gases and associated services
- Existing in **75 countries**
- **40,000 employees**
- **8 Research and Development centres**, plus 200 patents registered every year; a global portfolio of 10,000 patents
- The innovation and technology at the heart of development: **One million customers**, in the most divers industrial and the Health sectors
- **380,000 individual shareholders who hold 37% of the capital. 32% non-French investment institutes**, 30% French investment institutes, relationship of trust and transparency with its shareholders since more than 100 years
- A commitment in a **lasting development**: responsibility towards the shareholder, safety and preservation of the environment, social and human commitment, innovation and technological progress.
- Turnover 2007: **11,801 thousand million Euros**
- Net profit: **1,123 million Euros**
- **Dividends 2007: 2,25\$ per share** (+12,5% compared with 2006)



Air Liquide & Co, for the survey and utilising of George Claude's procedures to the capital of 1,299,259,791.50 Euros

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