The ultimate guide to fuel cells and hydrogen technology
About Hydrogen Europe:

Hydrogen Europe brings together more than 90 companies – SMEs as well as sector leaders such as Daimler, Air Liquide or Siemens. Hydrogen Europe is the principal European industry association working to accelerate the market deployment of fuel cells and hydrogen – a key technology recognised by the European Strategic Energy Technology Plan (SET-Plan). It also partners with the European Commission and the research community within the Fuel Cells and Hydrogen Joint Undertaking - worth 1.3 billion euro under Horizon 2020.
in essence

**Hydrogen** is an energy carrier similar to electricity. Being the simplest, lightest and most plentiful element in the universe, hydrogen serves as a versatile energy vector able to store renewable intermittent sources and provide fuel for transport or heating. This unique flexibility gives hydrogen the potential to become a central integrating element in our energy system.

**Fuel cells** are devices that generate electricity from a chemical reaction between hydrogen and oxygen, with pure water and potentially useful heat as the only by-products. Clean and efficient, fuel cells are used in a wide range of portable, stationary and transport applications, from mobile phone chargers to heating units for both domestic and industrial use, to serve as power back-up for data centres and to fuel vehicles. Hydrogen-powered fuel cells are not only emission free, but they also have more than double the energy efficiency compared to traditional combustion.

**About the technology**

**Most common questions**

**Hydrogen is the most abundant chemical substance in the universe but does not naturally exist independently. How is it produced?**

Hydrogen can be produced or extracted using virtually any primary source of energy, be it fossil or renewable. In the case of the latter, it represents an enormous potential for integration of renewables such as wind, solar power, bio-ethanol or biomass.

**Is hydrogen production pollution-free?**

Hydrogen is increasingly being produced by the electrolysis of water, in which water is split into hydrogen and oxygen using an electrolyser. When the electrolyser uses electricity obtained from renewable energy, the hydrogen is produced in a carbon-free way. On the other hand, today, the most cost-effective way to produce hydrogen is from natural gas by a process called “reforming” - either locally, at the point of use, at a refinery or chemical plant. Other sources can be used such as biogas. On a well to wheel basis, the hydrogen produced from natural gas used in fuel cells remains more efficient than internal combustion.

**How exactly can hydrogen be used to store energy?**

Hydrogen can play a significant role in facilitating the integration of large shares of fluctuating renewables in our energy system. Surplus electricity can be converted to hydrogen, which can then be supplied to a range of markets such as fuel cell electric vehicles or the chemical industry. Alternatively, it can be directly injected into the existing natural gas network to serve as an energy storage medium. When the H2 is later...
used for power, as fuel or heat, this process is known as ‘power-to-gas’. By exploiting the huge storage capacity of the gas grid, hydrogen effectively decouples energy supply from demand in time and in location and links the electricity transmission and natural gas grids, thereby enhancing energy security.

**Is hydrogen safe?**

Hydrogen is non-toxic and is as safe as other fuels being widely used today such as gasoline and natural gas. Hydrogen storage and fuel cell power-train technology have been extensively and rigorously tested to ensure safety. For example, hydrogen storage tanks on-board fuel cell vehicles are made of advanced lightweight materials and are extremely resilient and robust. They are less hazardous than gasoline tanks.

**What are the most advanced applications of fuel cells today?**

One of the most visible, tangible and technically ready applications is vehicles powered by fuel cells and hydrogen, also called fuel cell electric vehicles (FCEVs).

**Are there transport applications other than passenger cars?**

Yes. The technology can be applied to a wide range of vehicles; forklift trucks, airport baggage trucks, buses, trains and trams, small boats and even ferries.

**Beyond vehicles, what other applications can use the technology?**

Fuel cells can power everyday products: electronics such as cameras, laptops, printers, torches; but also large industry-scale machines such as generators; Auxiliary Power Units (APU) and material handling equipment (forklifts). The main advantages of using fuel cells in such portable applications are that they operate off-grid, have longer-run times compared to batteries and rapid recharging.

**Can fuel cells and hydrogen technologies be used for heating our homes?**

Yes, we can heat our residential and commercial buildings with fuel cells fuelled by natural gas or biogas. Stationary fuel cells are units which provide electricity and heat in the combined heat and power (CHP) mode but are not designed to be moved. For industrial uses and grid support large scale stationary fuel cells provide primary power through multi-megawatt units with focus on either highest electrical efficiency or industrial heat in CHP application.

**What are the main differences between fuel cell vehicles powered by hydrogen and conventional vehicles?**

They offer the same performance in terms of range, speed, refuelling times or driving experience with the additional advantage of making less noise and vibrations. Performance varies between models, but a typical range reaches 400-600 km per refuel. The key difference with conventional vehicles is that fuel cell electric vehicles can provide zero emission well-to-wheel pathways to cut emissions and make our transportation system more sustainable.

**How are fuel cell electric vehicles different from battery electric vehicles?**

Batteries in electric cars are powered from the grid. In hydrogen powered fuel cell vehicles, electricity is generated on board. Further, an average fuel cell car can refuel in 3-5 minutes. As illustrated by McKinsey,¹ both technologies present a great alternative for small cars, but fuel cell cars are the best choice for family-sized vehicles and longer trips due to their greater range.

**Are fuel cells very expensive?**

Fuel cells are becoming cheaper by the year. For example, research on reducing platinum content and other material costs are advancing and costs continue to fall, on average by 25% per year over the last decade. These improvements are set to continue as the technology comes of age and scales up.

Fuel cells and hydrogen

benefits for Europe

Top 2015 technology by World Economic Forum

Recognised by the World Economic Forum in Davos as one of the top 2015 emerging technologies, fuel cells and hydrogen are amongst the most promising low carbon solutions. They have been rightfully identified by the European Commission as key to Europe’s effort to decarbonise its energy sector and increase energy efficiency.

In essence, they can serve as a bridge to the recognised needs to:

• Store domestic renewables at a virtually unlimited scale, boost their share in the mix and increase Europe’s energy independence.

• Decarbonise transport through the deployment of zero-emission fuel cell electric vehicles powered by hydrogen.

• Reduce primary energy consumption as well as emissions of greenhouse gases, pollutants and particulates for heating and decentralized power production.
A triple win for Europe

Fuel cells and hydrogen constitute a triple “win” for Europe because they simultaneously enhance energy security, improve environmental sustainability, and boost economic competitiveness. Be it for the production of heat and electricity for buildings, as an electrical power source for vehicles or energy storage enabler, fuel cells and hydrogen can help address the most pressing European challenges and priorities.

Sustainability
Solutions
A radical reduction in harmful emissions can be achieved through the deployment of zero emission vehicles and the use of fuel cells for decentralized power production and heating of buildings.

Proof point
CO2 could be cut by between 64 per cent and 97 per cent in 2050

Energy security
Solutions
As hydrogen can be produced from a range of primary energy sources, its availability is almost limitless, thus allowing Europe to enjoy energy security and independence.

Proof point
Cut fuel consumption would deliver between €58 and €83 billion a year in fuel savings for the EU economy by 2030

Competitiveness
Solutions
Hydrogen is an extremely flexible energy carrier that can be used in all fields of the industry, with markets worth billions of euros across numerous applications.

Proof point
Europe could improve its growth prospects and create 500,000 to 1.1 million net additional jobs in 2030 through auto sector innovation

Data based on the report “Fuelling Europe’s Future” by Cambridge Econometrics (CE), in collaboration with Ricardo-AEA (2013). It considers the economic impact of a series of forward looking scenarios that encompass alternative visions of Europe’s future vehicle fleet.*

Fuel cells and hydrogen
the sector today

Growing European industry

The fuel cell and hydrogen sector is developing quickly thanks to global leaders such as Siemens, Air Liquide, Daimler and also a dynamic landscape of innovative SMEs.

With more than 85 member companies established in 18 European countries (doubled over the last couple of years), Hydrogen Europe (www.hydrogeneurope.eu) is the leading industry association working to accelerate the market deployment of fuel cells and hydrogen technologies at the European level.

Dynamism and innovation

According to industry data, the sector has experienced considerable growth since 2008, the year when the first European public-private partnership for fuel cells and hydrogen was launched.

- **10%** average increase of annual turnover
- **8%** average increase of R&D expenditures
- **16%** annual increase in patents granted in the EU to European companies
- **6%** growth in jobs per year while average EU job market has contracted

(compared to an average of 1.5% for all European industries)
Closer than you think

From a technology point of view, fuel cells and hydrogen have achieved remarkable progress and are closer, mature and more ready than one may think:

**hydrogen**

is already produced in large quantities for industrial applications.

**5,000+**

forklift fleets powered by fuel cells and hydrogen are being used in warehouses of corporates such as La Poste in France or Wal-Mart and Coca-Cola in the US today.

**+100,000**

stationary systems are being used around the world by companies like Bouygues Telecom, Toshiba or Apple.

**500+**

electric vehicles powered by hydrogen are already operating in Europe, mainly in Germany, Scandinavia, the UK, the Netherlands and France. The operation of fuel cell buses for public transport has already started in London, Hamburg, Cologne, Milan, Oslo and other cities.

**50+**

hydrogen stations will be built in Germany by the end of 2015. By 2023, Germany will have around 400 hydrogen refuelling stations, becoming the first country with basic hydrogen refuelling station network.

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Globally competitive

To be globally competitive, Europe needs to build on innovation to transform its economy and maintain and create new jobs. According to Ricardo-AEA and the economic modelling by Cambridge Econometrics, innovation in the auto sector could create between 500,000 and 1.1 million new jobs in Europe by 2030. Beyond Europe, other regions of the world such as Japan and California are investing in the technology and moving fast.

**300**

fuel cell electric vehicles and 22 hydrogen stations have already been implemented on California’s roads.

**+100,000**

residential fuel cells installed in Japan, with a set goal of installing them in 5.3 million homes by 2030, about 10 percent of all households

**Japan**

The Government of Japan has recently launched a “hydrogen society strategy” aiming at establishing a “hydrogen society” by 2040.¹

**telecoms**

Global tech/IT and telecom companies in countries like the US or India have entered into partnerships, with a number of fuel cell manufacturers aiming to increase deployment of fuel cells for telecommunications backup and grid stabilization.

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Fuel cells and hydrogen
the importance of
public-private partnerships

Why a public-private

Only a strong public-private partnership can help overcome the lack of economic incentives preventing individual players from moving into markets in which a new technology requires initial high level of investments while offering only very little (to initially negative) returns.

The first European public-private partnership created in 2007, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), supports the research, development and demonstration toward commercial introduction through annual and competitive calls for proposals.

Hydrogen Europe is the sole industry partner of the European Commission and the research community (N.ERGHy) within the partnership. The joint approach (50% funding from industry and research and 50% from the European Commission) and close interaction of public and private players is essential for alignment and joint progress to market deployment.

Breakthroughs to date
(2008-2013) (Investment of close to £1billion)

- Car range improved 100% (from 250 km to 500km)
- PEM electrolyser performance increased by 30%
- Cumulative distance travelled in car demonstrations (km) >5,000,000km
- Bus fuel cell vehicle cost improved by 40%
- Standard refueling protocol for 700 bars in 3 mins (for 4-5 kg)
- Cumulative distance travelled in bus demonstrations (km) >2,000,000km
- Stationary FC cost reduced by 60%
- Bus fuel cell system lifetime improved by 35%
- Standardized refueling nozzles in all countries
- Electrical efficiency of stationary fuel cells improved up to 60%
- 99.4% reliability of stationary fuel cells achieved
- 5 year lifespan of fuel cell stacks achieved

1 in the FCH JU through the States Representatives Group (advisory body) benefited from funding
2 192 Industries (35%), 154 SMEs (28%), 149 Research Organizations (27%), 20 High Education Institutions (4%), 30 Others (6%)

5 year lifespan of fuel cell stacks achieved
Objectives until 2020

Renewed in 2014 with a 45% increased budget commitment totalling €1.3 billion until 2020, the second phase of this public-private partnership will work toward bringing to the point of market readiness a portfolio of cost-efficient solutions for energy and transport. Specifically, it will:

**Improve performance**
- specifically efficiency and durability of the different fuel cells; energy efficiency of the production of hydrogen from water electrolysis and renewable sources whilst reducing operational and capital costs.

**Demonstrate on a large scale**
- the readiness of the technology to enter the market in the fields of transport (cars, buses and refuelling infrastructure) and energy (hydrogen production and distribution, energy storage and stationary power generation).

**Reduce costs**
- of fuel cells across applications whilst increasing their lifetime.

**Reduce the use of ‘critical raw materials’**.

Priorities and deliverables of the Fuel Cell and Hydrogen Joint

**Transport**

**Main priorities:**
- Road transport will be the main priority because it offers the greatest potential for addressing EU climate change and energy security objectives and is critical for European competitiveness.
- In addition to passenger vehicles, the focus will initially be on captive fleets (buses, trucks, vans etc.) along with the specific refuelling infrastructure for these applications.
- Applications for maritime, rail and aviation and other off-road applications require additional research efforts for Auxiliary Power Units (APUs) and possibly propulsion.

**Main deliverables:**
- Reduce cost and improve efficiencies and performance.
- Fuel cell electric vehicles (FCEVs) and Hydrogen Refuelling Stations (HRS) developed using the new generation technologies and demonstrated, for both passenger and commercial vehicles.
- Participation in standards development and definitions necessary for market deployment.

**Energy**

**Main priorities:**
- Hydrogen production for energy storage and grid balancing from renewable electricity will be a main priority – including large ‘green’ hydrogen production, storage and re-electrification systems. The initial focus will be on the role hydrogen can play in the integration of renewable energy sources in the grid.
- Hydrogen production with a low carbon footprint from other resources will be a topic of focus – whereby different hydrogen pathways will be developed and if appropriate demonstrated.
- Fuel cell systems for Combined Heating and Cooling (CHP) and Power only – covering the technical developments necessary to reduce costs, increase lifetime and improve performance is imperative to the Energy Pillar.
- Hydrogen storage, handling and distribution – to allow storage of hydrogen at central production plant and distribution to the customer base should be seen as a top priority for Energy.

**Main deliverables:**
- Electrolysers at variable scales developed and demonstrated for use in renewable energy integration systems, and injection of hydrogen into the grid.
- On-site hydrogen production systems using renewable fuels for decentralised hydrogen production; biological reactors with larger volumetric density & scale.
- Fuel cell systems for CHP and power only applications that incorporate new technologies.
- Hydrogen storage (large scale) and distribution systems developed and demonstrated.
Imagine

Europe needs economic growth, energy security and climate change action. Innovative solutions such as fuel cells and hydrogen are rapidly approaching the technological readiness and maturity levels needed to deliver on these challenges as proven by the early start of several global deployments.

Our vision is to contribute to the creation of a more secure and sustainable economy while positioning Europe at the forefront of global technological developments in the fuel cells and hydrogen sector.

Our vision

Europe today supports large demonstration projects and concrete commitments through power-to-gas programmes with enhanced electrolysis, as well as ‘H2Mobility’ projects1 in Germany, France, United Kingdom, Denmark and other Member States.

By 2020-2025 the sector is aiming to join mainstream technologies.

On transport and refuelling infrastructure:

First generation series of vehicles from several major car manufacturers are already or will be entering the market this decade. The sector aims at having 100,000 fuel cell electric vehicles and more than 250 hydrogen filling stations available in Europe.

On hydrogen production and distribution, including energy storage:

We aim to develop a portfolio of cost-competitive, energy efficient and sustainable hydrogen production, storage and distribution processes, with at least 50% of hydrogen used for energy applications produced from renewable sources or near zero-CO2 emission sources.

On stationary power generation and Combined Heat and Power:

We aim at providing heat and power to more than 50,000 households using stationary fuel cell systems.
# The example of transport

By 2015, existing national and European demonstration projects will have deployed approximately 70 Hydrogen Refuelling Stations (HRS) across Europe.

By 2018 the planned pan-European project will increase the refuelling network across these nations and start to create strategic links along TEN-T corridors.

From 2020, the H2Mobility initiatives would allow nationwide driving in the first-mover countries and start to expand into neighbouring countries along TEN-T Corridors, taking learning from the early deployment centres.

<table>
<thead>
<tr>
<th>Country</th>
<th>Status by 2020</th>
<th>Status by 2023</th>
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</thead>
<tbody>
<tr>
<td>France</td>
<td>The French network will have expanded to ~20 HRS</td>
<td>The French network will keep on expanding with 30-40 HRS by 2020 and 100 HRS by 2023</td>
</tr>
<tr>
<td>Germany</td>
<td>The German network will have expanded to 100 HRS</td>
<td>The German network will keep on expanding with 400 HRS in 2023</td>
</tr>
<tr>
<td>Netherlands</td>
<td>The Dutch network will have expanded to 5-10 HRS</td>
<td>The Dutch network will keep on expanding with 20 HRS by 2020 and 40-50 HRS by 2023</td>
</tr>
<tr>
<td>Scandinavia</td>
<td>The Scandinavian network will have expanded to 25 - 30 HRS</td>
<td>The Scandinavian network will keep on expanding with 35-40 HRS by 2020 and 50 HRS by 2023</td>
</tr>
<tr>
<td>UK</td>
<td>The UK will have deployed at least 30 HRS</td>
<td>The UK network will keep on expanding with 60-70 HRS by 2020 and 100 HRS by 2023</td>
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</tbody>
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1 Public-private partnership between key stakeholders (including OEMs, oil companies, and utilities) to build up the hydrogen fuelling infrastructure.
Fuel cells and hydrogen regulatory & financing issues at stake

The challenges

To achieve European ambitions to reduce global emission of greenhouse gas by 80% before 2050, emissions of the transport and the energy sectors will need to decrease drastically. Additionally, Europe is seeking energy independence and more trade balance while looking for new industrial and technological growth.

Fuel cells and hydrogen technologies can help to address those challenges. However, as often occurs with innovative and disruptive technologies competing with incumbent ones, large scale deployment runs into financing and regulatory bottlenecks. The underlying problems for the sector are:

- **Lack of critical mass**
- **Market failure for first movers**
- **Deficient leveraging of available funding**
- **Fragmentation of legislation across the EU**
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- **Market failure for first movers**
- **Fragmentation of legislation across the EU**

No single enterprise can tackle these barriers alone despite the eventual commercial and environmental gains. The development of fuel cells and hydrogen needs to be supported throughout key European policies as key enabling technologies. The establishment of a regulatory and financial framework favourable for creating a strong and robust market for fuel cells and hydrogen will ultimately determine if the technology makes it through the “valley of death” and helps to support the ambitious EU goals in terms of sustainability, energy security and green growth.

Regulatory incentives

To become an everyday reality, the sector needs appropriate recognition of its potential for the technology in existing and future legislation. We work with policymakers to:

**Hydrogen production, handling & distribution**
- Ensure favourable tax regime for decarbonized hydrogen to incentivize market development.
- Recognise sustainable hydrogen coming from renewable energy or produced with Carbon Capture and Storage (CCS).

**Stationary fuels cells**
- Remove the uncertainty surrounding the classification of gas-based stationary fuel cells under the Energy Labelling Directive.
- Adapt the Network Code on Requirements for Grid Connection Applicable to All Generators to account for the particularities of small scale emerging technologies like fuel cell micro-CHP.

**Grid flexibility**
- Acknowledgement of hydrogen production from the grid or storage as a value-adding component for the energy infrastructure.
- Develop regulation to introduce hydrogen into the natural gas network.

**Transport incl. Power to fuel**
- Increase support for renewable, decarbonized hydrogen as clean alternative fuel for transport (Renewable Energy Directive - RED).
- Complete the list of hydrogen production pathways in the reporting methodology of the Fuel Quality Directive - FQD).
- Develop minimum obligatory targets at Member State level for Hydrogen Refuelling Stations Deployment (Clean Power for Transport Package - CPTP).
Innovative financing instruments

As shown in a recent study conducted by the consultancy Roland Berger, there are critical gaps in the existing available funding sources and methodologies. Those gaps result in insufficient coverage of risk and hinder early adopters’ risk-investment.

To overcome these obstacles and support early adopters’ efforts, innovative financing tools are needed. eg:

<table>
<thead>
<tr>
<th>DEDICATED INSURANCE PRODUCTS MADE AVAILABLE TO THE BANKS TO OVERCOME MARKET DELAY</th>
<th>DIRECT EQUITY INVESTMENT SCHEMES BY THE EUROPEAN INVESTMENT BANK (EIB)</th>
<th>REIMBURSABLE GRANT SYSTEMS</th>
<th>‘GREEN BOND’ OR ‘TECHNOLOGY BOND’ FOR ALTERNATIVE INFRASTRUCTURE INVESTMENTS</th>
</tr>
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The total financing of the sector is manageable in light of the scope of the Investment Plan: €25 billion by 2030 with public and private resources combined. The investment will be taken up primarily by the private sector and it already encompasses the initial deployment efforts necessary by car manufacturers to reach pricing competitive to incumbent technologies.

- 7,000 hydrogen refueling stations (the required critical mass) capable of servicing up to 7,000,000 fuel cell electric vehicles (including buses, trucks etc.).
- 800 units of MW’s size generation capacity through electrolysis technology which allows the storage of up to 7.5 TWh of energy in the form of H2, enough to feed 50% of the vehicles at the time (~3 million vehicles) or to increase the integration of renewable power.

Linked to the policy framework and reform of the European Emission Trading Scheme, another approach could include allocation of advanced carbon credits for early adopters and infrastructure investors (public or private) recognising their effort in creating the base for future deployment of low-carbon technologies – with virtually no cost up front and with a strong potential to attract the financial community to support the energy transition.

The example of transport

Coordinated support from policy makers at EU and national levels is required

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<th>2015-2020</th>
<th>2020-2030</th>
<th>2030+</th>
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**High risk**

Higher co-financing needed:

- EU programmes (Fuel Cells and Hydrogen Joint Undertaking, Connecting Europe Facility - CEF)
- Early incentives from Member States to share risks in Hydrogen Refuelling Stations (HRS) deployment and cover part of cost premium of FCEVs
- Coordination of these agencies with industry is key

**Medium risk**

- Incentives from Member States maintained to sustain market entry but decreasing
- Industry takes in charge an increasing share of costs of continued deployment of infrastructure

**Low risk**

- Fuel cell electric vehicles (FCEVs) reach cost competitiveness in market place on their own
- Further infrastructure deployment to expand coverage continues
What influencers say about fuel cells and hydrogen technologies?

“Securing new economic opportunities for the UK, diversifying our national energy supply and driving down carbon emissions go to the heart of my job in government. […] hydrogen Fuel Cell Electric Vehicles (FCEVs) can have a real impact on all three.”

Michael Fallon, UK Business & Energy Minister, 25 April 2013

“I believe that there is a wonderful opportunity here for the fuel cells and hydrogen sector, which is identified as a booming market segment in various studies. The European market for these technologies is expected to quadruple by 2018, reaching annual revenue of over $600 million. Looking forward to 2030, our joint investments into fuel cells and hydrogen could yield up to a million new jobs linked to transport applications in Europe alone”.

Bernard Meyerson, Chief Innovation Officer and Vice-President from IBM Corporation

“Mass-market fuel cell vehicles are an attractive prospect, because they will offer the range and fuelling convenience of today’s diesel and petrol-powered vehicles while providing the benefits of sustainability in personal transportation. Achieving these benefits will, however, require the reliable and economical production of hydrogen from entirely low-carbon sources, and its distribution to a growing fleet of vehicles (expected to number in the many millions within a decade).”

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“Hydrogen could well become the major component of clean sustainable energy systems in the longer term. It is relevant to all of the energy sectors - transportation, buildings, utilities, and industry. Hydrogen can provide storage options for intermittent renewable technologies such as solar and wind, and, when combined with emerging decarbonisation technologies, can reduce greenhouse gas emissions from continued fossil fuel utilisation.”

International Energy Agency, 2014

“Yes, my friends, I believe that water will be one day used as fuel, that the hydrogen and the oxygen, which make it, used separately or simultaneously, will provide a source of inexhaustible heat and light and with an intensity the coal could never reach”

Jules Verne, L’Île Mystérieuse - 1874

“To maintain Europe’s leading position on clean technology for transport, a stable political framework and joint action is needed to address emissions targets, create new jobs and harness the advanced technology that exists. To deploy hydrogen fuel cell powered vehicles requires a combination of reducing costs and increasing efficiency. Consumer acceptance is key for take-up. Decisive European action from industry and Member States is critical to make our transport system more sustainable and environmentally responsible.”

Siim Kallas, ex Vice President of the European Commission in charge of Transport

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Robert-Jan Smits, Director-General of DG RTD, Stakeholder Forum 2014, 12 November 2014

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1 http://www.iea.org/techno/iaresults.asp?id_ia=23