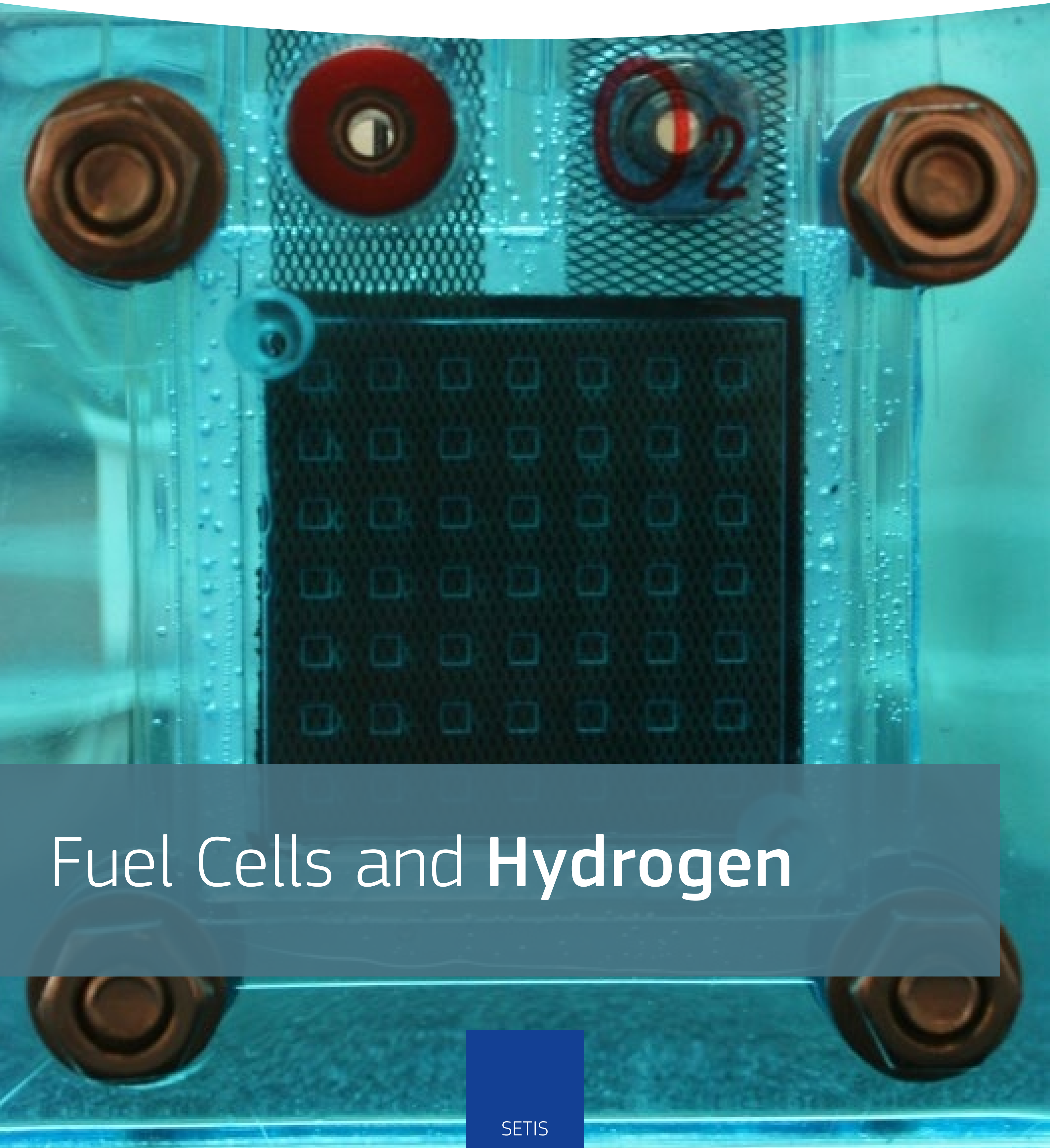
European
Commission

SETIS
Information For Decision-making

SETIS magazine
No. 10 – August 2015



Fuel Cells and **Hydrogen**

SETIS

Cover photo: ©iStock/Chiara levi

Contents

4 Editorial by Fuel Cells and Hydrogen JU Executive Director Bert de Colvenaer

5 SET-Plan update

8 Chair of the FCH Industry Grouping NEW-IG and of the FCH JU Pierre-Etienne Franc talks to SETIS

13 Fuel Cells and Hydrogen Joint Undertaking N.ERGHY Research Grouping Chair Paul Lucchese talks to SETIS

16 Fuel Cells and Hydrogen – part of the paradigm shift - Johan Blondelle, DG Research and Innovation

18 Mimicking nature: Producing hydrogen from sunlight - SETIS feature article

21 Preparing the way for fuel cell micro-CHP roll-out - SETIS feature article

23 Head of the Hydrogen Safety Working Group at the Karlsruhe Institute of Technology (KIT) Dr Thomas Jordan talks to SETIS

26 10 years of JRC activities on Fuel Cells and Hydrogen - Marc Steen, Joint Research Centre

30 Hydrogen as a storage medium - facilitating increased integration of RES - SETIS feature article

32 Frank Meijer, head of the Fuel Cell Electric Vehicle division at Hyundai Motor Europe, talks to SETIS

34 On-board hydrogen storage - Rafael Ortiz Cebolla, Nerea de Miguel Echevarria, Francesco Dolci, and Eveline Weidner, Joint Research Centre

37 Increasing hydrogen liquefaction in Europe - SETIS feature article

Editorial

By Bert de Colvenaer
Executive Director,
Fuel Cells and Hydrogen
Joint Undertaking

Rather than spending more than one billion euros per day on importing fossil fuels from around the world to Europe, just to burn them, many European citizens, industries and politicians dream of a Europe that is self-sufficient in energy.

Fuel cells as an efficient, silent and clean energy convertor

A fuel cell is basically an energy convertor that converts a fuel, usually hydrogen, directly into electricity or heat. It can be integrated into all applications where electricity is currently used: in the transport sector to power cars, busses or fork-lift trucks, or in stationary applications such as home boilers or medium and large-sized power utilities. As this is a one-step conversion process, it is intrinsically very efficient, there are no internal moving parts in a fuel cell, so there is no noise or vibration and, if there is no carbon going in, there is no carbon or CO_2 coming out.

Deploying hydrogen infrastructure

Recent activities in Germany, the UK, Scandinavia and France show that car original equipment manufacturers (OEMs), the petroleum industry and hydrogen gas suppliers are gearing up to conclusively resolve the chicken and egg problem through the simultaneous deployment of both fuel cell cars and hydrogen stations in a coordinated, smart, cost-efficient and committed way. This is a key step towards achieving real market deployment. Once a sufficient volume of fuel cell cars finds its way on to the road, public perception will improve drastically, costs will rapidly decline and more fuel cell applications will find their way to customers.

Green, blue, or grey hydrogen?

Hydrogen is abundant, but its production requires energy. That said, it is not difficult to make hydrogen: blue hydrogen is made by electrolysis from water (H_2O), grey - by reforming from natural gas (CH_4), and gree n - from biomass gasification. However, it is more of a challenge to make it cheaply, efficiently and to store it safely.

What does it take to get there?

The SET-Plan has seen renewables (solar and wind) become integrated into smart systems but, despite this, electricity has become more expensive because of difficulties in managing the intermittency inherent in renewables. This is where hydrogen can offer a solution, as it can act as a storage medium for large quantities of energy and at the same time link renewables to the transport sector. It requires political leadership and industrial commitment to get us there. If, over the next decades, a fraction of the money spent on buying fossil fuel is used to build a renewable energy harvesting and hydrogen storage system in Europe, this will bring us gradually closer to a Europe that is reliant on clean, sustainable and home-produced energy.

A dream? Not so long ago, flying to the moon was a dream...

AUGUST 2015

SET-Plan update

©iStock/pitris

The European Strategic Energy Technology Plan (SET-Plan) aims to transform the way we produce and use energy in the EU with the goal of achieving EU leadership in the development of technological solutions capable of delivering 2020 and 2050 energy and climate targets.
The EU supports Fuel Cells and Hydrogen technology through its Framework Programme for Research and Innovation and other mechanisms, and by creating the legislative and policy framework needed to bring these technologies to market. The following is a chronological overview of some of the actions taken to promote FCH technology in the EU, in addition to a more general look at recent actions in support of the SET-Plan.

Fuel Cells and Hydrogen

- Five national hydrogen organisations established the European Hydrogen Association (EHA) in 2000 and started a close collaboration to promote the use of hydrogen as an energy vector in Europe. In 2004 major European industries active in the development of hydrogen and fuel cell technologies joined the EHA and reinforced this effort to create a commercial market for stationary and transport applications and to underpin Europe's role as market leader in the hydrogen and fuel cell sector. The EHA currently represents 21 national hydrogen and fuel cell organisations and the main European companies active in hydrogen infrastructure development.
- In October 2002, the European Commission launched a High Level Group on Hydrogen and Fuel Cells, comprising top level representatives from major EU automotive and energy companies, public utilities, research institutes, transport companies and policy makers. The aim of the group was to assess the potential benefits of using hydrogen and fuel cells in EU transport, energy production and many other areas, and to help pave the way for more focused EU action in this field. Building on recommendations set out in the Vision Report of the High Level Group, the European Commission facilitated the establishment, in January 2004, of the European Hydrogen and Fuel Cell Technology Platform. This Platform aimed at accelerating the development and deployment of key hydrogen and fuel cell technologies in Europe
- The European Commission is a founding member of the International Partnership for Hydrogen Economy. The IPHE was established in 2003 as an inter-governmental institution to accelerate the transition to a hydrogen economy. It provides a mechanism for partners to organise, coordinate and implement effective, efficient and focused international research, development, demonstration and commercial utilisation activities related to hydrogen and fuel cell technologies.
- The HyWays project, an integrated project co-funded by research institutes, industry and the European Commission (EC) under the 6th Framework Programme, was carried out from April 2004 to June 2007. The project evaluated selected stakeholder scenarios for future sustainable hydrogen energy systems with a view to producing recommendations for a European Hydrogen Energy Roadmap reflecting country specific realities in the participating Member States.
- In July 2005, the European Hydrogen and Fuel Cell Technology Platform published a Strategic Research Agenda to help stimulate investment in research, to provide guidance for policy options and to act as a guide in defining a comprehensive research programme to mobilise stakeholders and to ensure that European competences are at the forefront of science and technology worldwide. This was followed in August 2005 by a Development Strategy that addressed the technical, socio-economic and political challenges of deploying world-class, competitive, hydrogen technology and fuel cell applications in Europe; and by an Implementation Plan in March 2007.
- The Hydrogen Incident and Accident Database (HIAD), developed by the Joint Research Centre (JRC) and the company DNV with the assistance of the project partners in HySafe , a European Network of Excellence funded under the European Commission's Sixth Framework programme (FP6), was launched in July 2006. HIAD is a European knowledge base that aims to assist industry and authorities in better understanding the relevance of hydrogen-related incidents and accidents as well as the safety actions taken.
- Based on the shared vision set out in the three core documents of the European Hydrogen and Fuel Cell Technology Platform, the Fuel Cells and Hydrogen Joint Undertaking was established by a Council Regulation on 30 May 2008 as an industry-led public-private partnership between the European Commission, European industry and research organisations to accelerate the development and deployment of fuel cell and hydrogen

technologies. On 6th May 2014, the Council of the European Union formally agreed to continue the Fuel Cells and Hydrogen Joint Technology Initiative under the EU Horizon 2020 Framework. The second phase - FCH 2 JU - will have a ring-fenced total budget of 1.33 billion euros, provided on a matched basis between the public-private partnership.

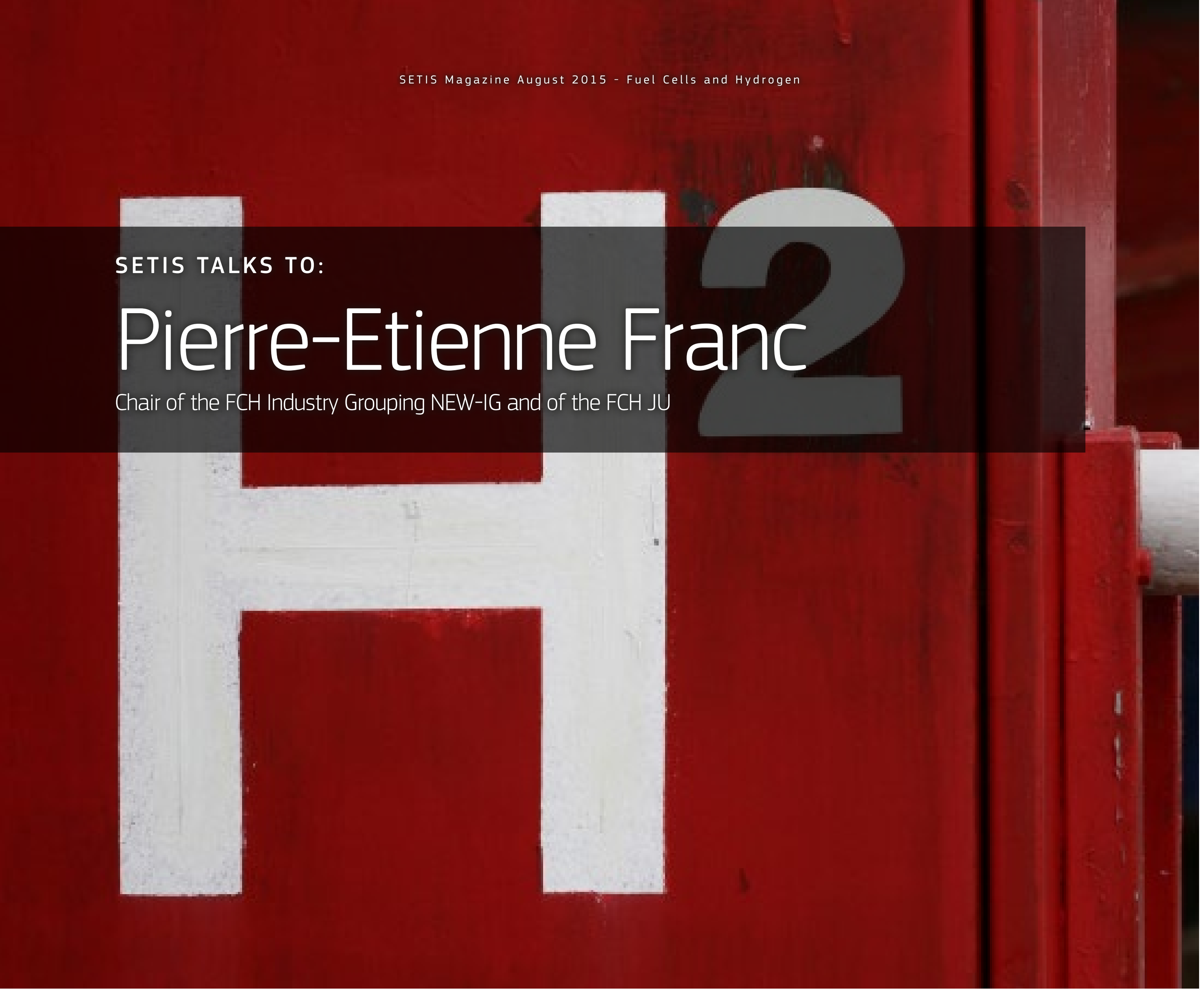
- As a founding member of the FCH JU the NEW-IG is the sole industry partner in this unique public-private partnership NEW-IG works to accelerate the market deployment of fuel cells and hydrogen technologies by, among others, helping formulate the priorities of the FCH JU annual and multi-annual implementation plans.
- The N.ERGHY association was formed in 2008 by the European research community to effectively represent its interests within the Fuel Cell and Hydrogen Joint Technology Initiative (FCH JTI). The objective of N.ERGHY is to promote, support and accelerate the research and deployment process of fuel cell and hydrogen technology in Europe from the point of view of the research community.
- In its 2009 Directive on the promotion of the use of energy from renewable sources (RES Directive, 2009/28/EC), the European Commission committed to presenting a report, by December 2014, addressing the commercial availability of electric, hybrid and hydrogen powered vehicles, as well as the methodology chosen to calculate the share of energy from renewable sources consumed in the transport sector.
- In February 2009, the European Parliament and the Council issued Regulation No. 79/2009 on type-approval of hydrogen-powered motor vehicles. This Regulation facilitated the type-approval procedure provided for by Directive 2007/46/EC of the European Parliament and of the Council from September 2007, which established a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for these vehicles. This was followed in 2010 by the implementing Commission Regulation No. 406/2010.
- The International Association for Hydrogen Safety was founded by members of the EC-supported Network of Excellence (NoE) HySafe in February 2009 as a non-profit organisation. The association facilitates networking for the further development and dissemination of knowledge and for the coordination of research activities in the field of hydrogen safety.
- In May 2011 the European Commission conducted a first interim evaluation of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) with the assistance of a group of independent experts. This evaluation covered the assessment of the quality and efficiency of the FCH JU and its progress towards reaching its objectives. The report concluded that the JU approach is generally regarded as a good means to enhance public-private activities in technology development and demonstration. The FCH-JU is considered as a de facto European Industrial Initiative under the SET-Plan.
- The European Energy Research Alliance (EERA) Joint Program on Fuel Cells and Hydrogen Technologies was officially launched at the SET-Plan Conference in November 2011 in Warsaw. The Joint Programme aims to accelerate and harmonise long-term research on fuel cells and electrolysers in Europe.
- In October 2012, the International Association for Hydrogen Safety (HySafe), in cooperation with the Institute for Energy and Transport of the Joint Research Centre of the European Commission (JRC IET Petten) held a two-day workshop dedicated to Hydrogen Safety Research Priorities. The workshop aimed to bring together stakeholders to address the existing knowledge gaps in the area of hydrogen safety.
- In 2014 the Joint Research Centre, the European Commission's in-house science service, published a report on the State of the Art and Research Priorities in Hydrogen Safety. This report aimed to identify the remaining knowledge gaps with a view to facilitating decision-making on the next steps to ensure the full and safe utilisation of hydrogen. As such, it serves as a reference document for researchers/scientists and technical (including industry) experts working in the area, such as the European Fuel Cell and Hydrogen Joint Undertaking and other funding bodies/organizations worldwide, such as the Fuel Cell Technology Office of US-DoE, that must make decisions on research programmes and on the selection of projects to be financially supported.
- In October 2014, the European Parliament and Council issued Directive 2014/94/EU on the deployment of alternative fuels infrastructure. This Directive stresses the importance of building up sufficient hydrogen refuelling infrastructure in order to make larger-scale hydrogen-powered motor vehicle deployment possible.
- In November 2014, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) organised its Programme Review Days and Stakeholder Forum. This event, held annually since 2011, brought policy-makers together with high-ranking representatives from across the fuel cells and hydrogen industrial sector as well as potential customers for the technology.
- The FP7-funded H2FC European research infrastructure project and the European Energy Research Alliance (EERA) Fuel Cells and Hydrogen Joint Programme organised a European Progress Review on research and development in hydrogen and fuel cells science and engineering in Brussels in April 2015. This meeting aimed to complement the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) Programme Review Days and to present two important documents: the Implementation Plan (IP) of the EERA FC&H$_2$ Joint Programme, which prioritises the basic research necessary in hydrogen and fuel cell science and engineering, and the result of a progress review survey carried out by H2FC.

General SET-Plan related news and activities from JRC/SETIS

- In May 2015, the Joint Research Centre (JRC), the European Commission's in-house science service, published its PV Status Report 2014, which provides comprehensive and relevant information on this dynamic sector for the interested public, as well as decision-makers in policy and industry. The Capacities Map report, provides an assessment of public and corporate R&D investment in low-carbon energy technologies in the EU. Also in May, the JRC published a report on Retaining critical competences in nuclear energy sector: national initiatives and best practices, instruments and tools.
- The EERA Executive Committee met in Amsterdam on June 24-25. This meeting is an annual event that brings the Executive Committee members, the Secretariat and Joint Programme Coordinators together to discuss the development of EERA. This year, the agenda covered a range of topics from collaborations with other SET-Plan organisations to the launch of new joint programmes and the EERA strategy.
- The EERA JP on Energy Efficiency in Industrial Processes (EEIP) held its kick-off meeting in Amsterdam on June 23. More than 24 participants from the initial group of leading research organisations and universities from Europe working on the subject joined the meeting to discuss the current strategic set-up and plans for the future. The JP has three sub-programmes: Energy Intensive Industries coordinated by CIRCE/Spain; Manufacturing Industries coordinated by Fraunhofer IFF/Germany; Agro-Food Industrial Processes coordinated by ENEA/Italy.
- In June 2015, the Joint Research Centre, published its 2014 Wind Status Report, which discusses the technology, economics and market aspects of wind energy in Europe and beyond.
- In July 2015 the Joint Research Centre published a report on Perspectives on future large-scale manufacturing of PV in Europe. This report takes a close look at developments in PV manufacturing in Europe and provides information and perspectives on factors which can influence its future development.
- The latest SET-Plan Steering Group meeting was held on July 7 in Brussels. The discussions focused on considerations for the new SET-Plan Communication under preparation in the context of the 5th pillar of the Energy Union, such as: objectives for the European R&I priorities, an enhanced SET-Plan governance and SETIS reporting and monitoring scheme. Two more Steering Group meetings are scheduled for September - one on September 9 in Brussels, and one on September 23 in Luxembourg, following the SET-Plan Conference.
- The 8th SET-Plan Conference will take place on 21-22 September 2015 at the European Convention Centre Luxembourg, during Luxembourg's Presidency of the European Union Council. The SET-Plan 2015 conference will launch the European debate on the new SET-Plan, and the next steps to implement its actions, at the highest level. The conference focus will be the Communication addressing the European energy system transformation and the role of the SET-Plan due to be adopted in the beginning of September. The new Integrated SET-Plan Communication will define the new Energy R&I Strategy for the EU for the coming years. It will provide the overall framework for promoting strengthened cooperation in Energy R&I between the EU, Member States and stakeholders (research and industry), in order to step up the efforts to bring new, efficient and cost-competitive low-carbon technologies faster to the market and to deliver the energy transition in a cost-competitive way.

Integrated Roadmap and Action Plan

In the context of the process towards the Integrated Roadmap and Action Plan, organisations (universities, research institutes, companies, public institutions and associations) involved in research and innovation activities in the energy field are invited to register in the European energy R&I landscape database, which aims at facilitating partnerships and collaboration across Europe. Registration is open to stakeholders from the EU and H2020 associated countries. Organisations are able to indicate their area of activity according to the energy system challenges and themes, as identified in the SET-Plan process towards an Integrated Roadmap and Action Plan. The document includes fuel cell and hydrogen technologies in connection with a number of challenges and themes as especially valuable in view of their cross-sectoral application (energy, transport, industry). The database is publicly available on the SETIS website.



SETIS TALKS TO:

Pierre-Etienne Franc

Chair of the FCH Industry Grouping NEW-IG and of the FCH JU

©iStock/jean schweitzer

A year ago, the European Council formally agreed to continue the Fuel Cells and Hydrogen Joint Technology Initiative, with a budget of EUR 1.33 billion for 2014-2020. How will this money be spent?

P-E.F.: “ The approval of the continuation of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), with a 40% increased budget, was a major step for the sector. It was a testimony to the excellent performance of the first Joint Technology Initiative (JTI), with the sector witnessing significant growth.

Several good examples, especially in the current economic context, include: Fuel Cell and Hydrogen (FCH) industries saw 6% growth in jobs per year, with the companies increasing their annual turnover by 10%. Companies also experienced an almost 60% increase in R&D expenditure since the foundation of the FCH JU[1].

Under Horizon 2020, the second generation of the Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) aims to speed up the commercial deployment of fuel cells and hydrogen in Europe through the investment of €1.33bn (half public, half private funds) in a range of programmes from research to demonstration and pre-market introduction tests.

The projects under FCH 2 JU will look to deliver a new generation of materials and prototypes as well as demonstrate, on a large scale, the readiness of the technology to enter the market in the fields of transport (cars, busses and refuelling infrastructure) and energy (hydrogen production and distribution, energy storage and stationary power generation).

The funding will be channelled through seven yearly calls, based on the Multi-Annual Working Plan developed by the Industry jointly with the European Commission and our research counterpart N.ERGHY. At NEW-IG level, the process towards this crucial document was led by a Coordination Group composed of all members and organised in five topical committees.

Concretely, we are looking to prepare the FCH technologies for the market by further increasing their efficiency and durability, expanding their lifespan and optimising their cost. Another important goal is to increase the number and size of our demonstration projects as they are a crucial step towards deeper market penetration. The goal is to expedite commercial deployment of those applications with the strongest potential for addressing energy security and climate change.

With an indicative budget of €123 million, the 2015 FCH JU Call for proposals will support a total of 20 topics covering a broad range of applications. The deadline for submission of project proposals is 27 August 2015 and all practical information can be found on the Horizon 2020 Participant Portal. ”

How large a role could fuel cell and hydrogen technologies potentially play in energy transition in the European Union?

P-E.F.: “ Fuel cells and hydrogen constitute a triple “win” for Europe because they simultaneously enhance energy security, improve environmental sustainability, and boost economic competitiveness.

The beauty of hydrogen is that it is an extremely flexible energy carrier. It can be produced from any source of primary energy including intermittent renewables such as wind, solar and bioresources. As a by-product, it is already available in Europe in large quantities from specific chemical processes.

Hydrogen combined with fuel cells creates an efficient conversion technology. The combination forges a high-potential technology for the production of heat and electricity for buildings. It also serves as an electrical power source for vehicles.

As identified in the Strategic Energy Technology Plan (SET-Plan), hydrogen is a bridge towards achieving the recognised needs of the European Union (EU), now also outlined in the Energy Union Package.[2] It can:

- Store domestic renewables at a virtually unlimited scale; thus boosting their share in the mix and increasing Europe’s energy independence;
- Decarbonise transport through the deployment of zero-emission Fuel Cell Electric Vehicles (FCEVs) powered by hydrogen;
- Reduce primary energy consumption as well as emissions of greenhouse gases, pollutants and particulates for heating and decentralized power production.

More specifically, a 2013 study conducted by experts from the European Climate Foundation and Cambridge Econometrics showed that deployment of clean fuels in transport could significantly shift spending from imported fossil fuels towards the European manufacturing industry. In scenarios in which Europe moves rapidly to a fleet of advanced hybrid, battery electric and FCEV’s, the fuel bill for the car and van fleet will be reduced by up to €83 billion by the year 2030 (€180 billion in 2050). At the same time, EU-wide employment in clean energy and low emission propulsion systems and components would increase by up to 1.1 million employees in 2030 and 2.3 million in 2050. While it would reduce the CO_2 emissions from vehicles by 97% by 2050, it would also improve air quality with a reduction of up to 95% in fine particle emissions by 2050 – air pollution responsible for significant public health costs.

Another example is energy storage. As we move away from conventional fossil fuel power generation and from centralised grids, energy storage will grow in importance. Hydrogen is a unique energy storage medium that can be used to to store energy to fuel the FCEVs; maintain balance in the power grids by storing and releasing excess energy; as well as for both residential and corporate use to produce combined heat and power.

The technology has been highly recognised by key European and international organisations: in June 2015, the International Energy Agency released its hydrogen and fuel cell technology roadmap which shows the importance of the role these technologies could play in energy transition. Additionally, the Word Economic Forum in Davos has named Fuel cells and Hydrogen as one of the top 2015 emerging and most promising low-carbon solutions. Now it’s up to us to make that promise a reality. ”

What are the main challenges that need to be overcome if we are to see a widespread market roll-out of fuel cell and hydrogen technology?

P-E.F.: “ We are now at the most important and one of the hardest stages of the development of any disruptive technology. Our applications are technologically mature and market ready, but have not yet reached the scale of market penetration at which the technology becomes cost-effective. To overcome the so-called “valley of death”, the virtual chasm that separates applied research from technology demonstration; any technology requires the right public/private framework of long-term stability combined with risk-sharing tools.

In terms of finance: According to the “Roadmap for financing hydrogen refuelling networks – Creating prerequisites for H_2-based mobility” study made by Roland Berger, there are several critical gaps in the existing available funding sources in Europe. This leads to insufficient coverage of the ramp-up risk and hinders early adopters' risk-investment. We therefore need new and innovative financing schemes to overcome these obstacles.

The Juncker Plan is a step in the right direction, but we continue to support the development of other schemes as well. Our proposed approach would include the allocation of "ETICCs" or "Energy Transition Infrastructures with Carbon reduction Certificates" to early movers i.e. infrastructure developers, to serve as a guarantee to attract financial investors in infrastructure deployment. These ETICCs would be created by public authorities from the outset of an infrastructure deployment project up to the total emissions potentially avoided until the end of its lifespan on the basis of infrastructure functioning at full capacity, with an upfront guaranteed price. These certificates would be monetized by the promoters at a pre-determined fixed price only if the infrastructure is not sufficiently loaded at the end of the project period, to cover part of the losses and/or to secure lenders. This mechanism therefore accelerates the roll-out of low-carbon infrastructure in favour of the energy transition, hence the name ETICC, to distinguish the certificates from credits or conventional carbon quotas traded on the EU-ETS. This system would have virtually no cost up front for public authorities and have a strong potential to attract the financial community to support energy transition.

The second challenge is the regulatory framework. The Energy Union will bring a number of new regulatory initiatives as well as reviews of the existing ones that are particularly relevant for the sector. We need continued development of supportive regulation for market-introduction of FCH technologies (e.g. Clean Power to Transport, Fuel Quality Directive, Renewable Energy Directive), as well as streamlining of fragmented regulatory frameworks at both national and EU level.

Finally, close cooperation across all stakeholder groups remains the key for a successful transition. As recently pointed by the report "Technology Roadmap: Hydrogen Fuel Cells" (2015) of the International Energy Agency: "Overcoming risks related to investment in infrastructure hinges upon close collaboration among many stakeholders, such as the oil and gas industry, utilities and power grid providers, car manufacturers, and local, regional and national authorities." ”

Ultimately, the success of stationary FCH applications will depend on how effectively they compete with current power generation systems. How well do FCH technologies currently compete, and what can be done to improve their performance?

P-E.F.: “ The greatest advantage of stationary FCH's compared to the current systems is the absence of harmful emissions which makes them suitable for almost every location of clean decentralised power production: directly in the city, in urban areas and even in environmental protection zones. They are more efficient (up to 60% electrical efficiency, 25% lower fuel consumption) which leads to much lower OPEX and higher Net Present Value (NPV)[3], which is also based on lower service cost and the absence of moving parts which leads to low noise and no vibrations – FCHs are therefore welcome in every building.

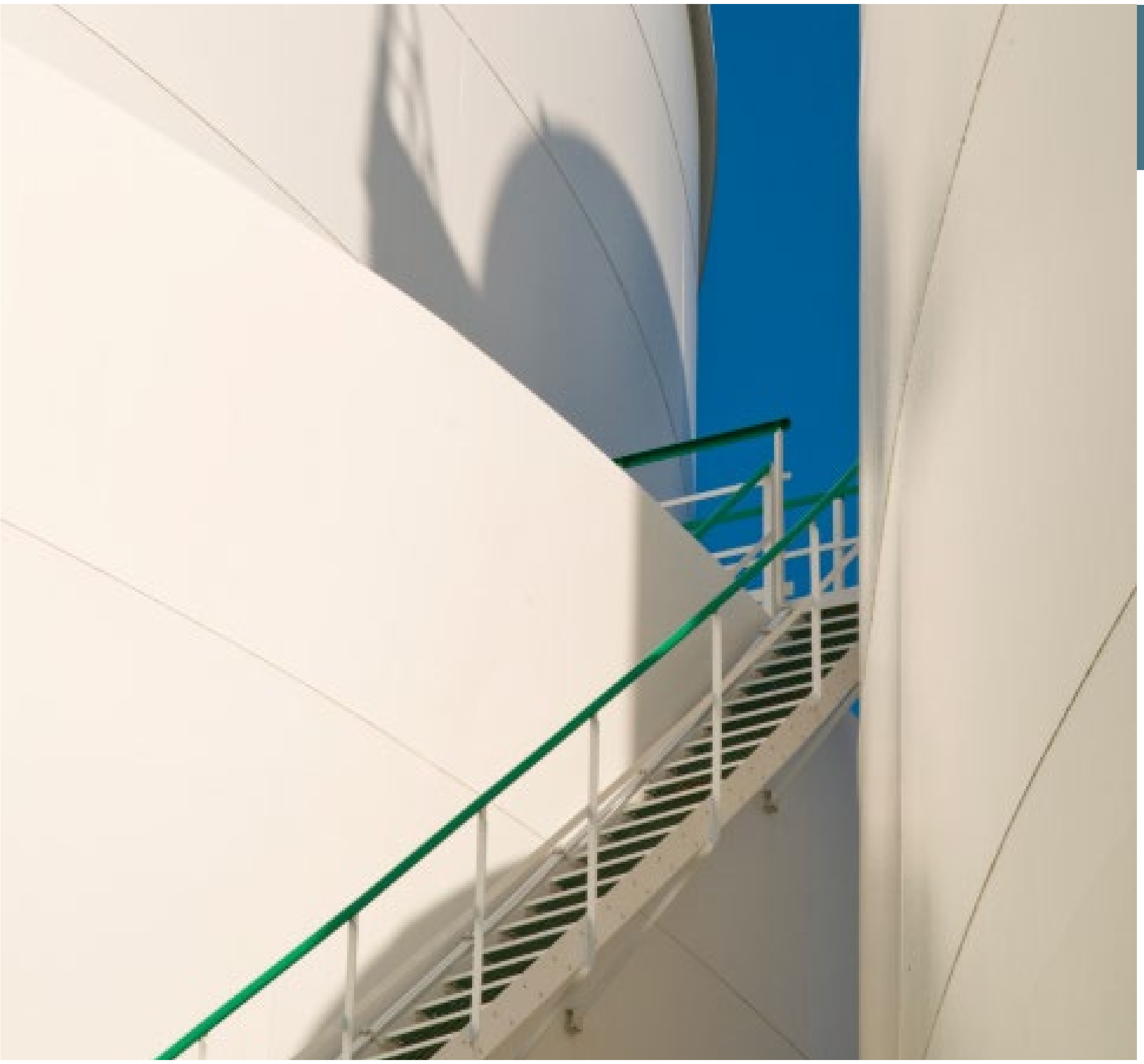
However, there is also a disadvantage; otherwise everyone would buy a fuel cell: currently, Fuel Cells are more expensive than traditional technologies. Nonetheless, they are still quite affordable relative to their environmental impact. The industry performs R&D activities for cost reduction of the equipment combined with supply chain consolidation and market deployment to scale up the production volume for further cost reduction. This engagement should be complemented by a clear commitment of the policy makers for FCHs and also regulations to monetarise the environmental impact. ”

Public acceptance of FCH technology will be critical for its success, and this acceptance will largely depend on the safety of the technology. What is being done to increase safety levels and to inform and reassure the public in this regard?

P-E.F.: “ We are, of course, fully aware of the importance of correctly explaining, in a transparent way, the safety of our technology to the public. All energy carriers and sources comprise risk. Risk management is therefore inherent to their handling. Hydrogen is already well known and mastered at the industrial level. Eventually, it should be handled by any citizen as safely as they currently manage the other energy sources in their daily life.

As a reminder, hydrogen is already largely spread within our society, as industries use very large quantities of hydrogen every day which are transported by thousands of trucks on the road. Hydrogen storage and fuel cell power train technology have been extensively and rigorously tested to ensure safety. Hydrogen storage tanks on-board fuel cell vehicles are made of advanced lightweight materials and are extremely resilient: the tests carried out have shown that the carbon fiber fuel tank is by far the strongest part of the vehicle. Extensive crash tests are also carried out with Fuel Cell Electric Vehicles like for any fuel.

As the technology matures and is deployed we will have to continue informing the public in a transparent way. This should be widely presented and explained to citizens (through demonstration projects for example) as well as through various educational materials which can realistically and truthfully convey the safety of the technology. This is something individual companies can do but is also being addressed through the FCH JU. For example, the H2TRUST project is assessing industry efforts to assure FCH technology is safe and that there is an adequate regulation, hazard awareness, incident readiness and ability to respond to public concerns. ”


©iStock/Andy Nowac

How does FCH market roll-out in Europe compare with the rest of the world? Are there any lessons that Europe can learn from other markets?

P-E.F.: “ There are currently three regions with major investments in FCH technologies: the EU, USA and Japan. Overall, Japan is the worldwide leader in the FCH sector. It has invested heavily into FCH technologies, promoting the so-called "hydrogen society". To illustrate the scope of their activities - they have already installed more than 138,000 residential hydrogen fuel cell units with the aim of reaching 5.3 million households by 2030. Japan recently announced an additional financial boost to residential energy storage with a stimulus package worth EUR 500 million. Japanese car manufacturers such as Toyota and Honda are investing heavily and are putting the first generation series of FCEVs on the streets.

The USA is another growing market, especially in California and the northeast US. There both the Federal government and state legislatures are investing in the technology, both through funding research and through subsidies for first movers (infrastructures and vehicles). This second approach is especially important in California which is building its own "hydrogen highway". There are currently 12 refuelling stations and 300 FCEVs already on California's roads, with more stations built every day.

In the EU, we are fortunate to have a unique public-private partnership (PPP), the FCH JU, which is the largest of its kind in the world and has helped the development of the technology immensely. In addition, there is a private consortium of six industrial players at the national level in Germany, which plans to build 400 refuelling stations by 2023. Besides Germany, strong national programmes and FCH activities can be also found in France, the United Kingdom, the Netherlands, Scandinavian countries and – on a smaller scale – in other EU Member States.

What can we learn from other markets? California, together with Norway in Europe, has shown the way with regards to subsidies and grants for early adopters. California, with its Zero Emission Vehicle Program, has given a boost to the zero emission vehicles domestic market. Japan's dedication to FCH technology can surely serve as an example for Europe going forward as well. We can also look towards the US regarding disparities in development and take-up of FCH technologies between different Member States. What is clear is that different regions take different paths and speeds towards the introduction of any new technology. What is good for us is that FCH covers a wide range of issues and as such will surely find a use in every EU Member State.

What is now needed, at a time when car manufacturers such as Toyota and Hyundai are already bringing FCEVs to the market and when the EU is working hard on integrating its energy market, is to create additional financing schemes to ensure that the whole of the EU will benefit from all the positive work done by the industry and the FCH JU. By following this path we will be able to both scale up in the EU itself but also create a sustainable export platform which will bring additional value to the economy. ”

Development of hydrogen production, distribution and storage technologies is one of the objectives of the FCH JU energy pillar. What advances have been made in this area and which technologies show the most promise?

P-E.F.: “ One of the main technologies advanced via the FCH JU is electrolyser technology where hydrogen is produced from (renewable) electricity. Past R&D programmes have led to a 50% reduction in the electrolyser stack cost since the beginning of the FCH JU with demonstrations at 100s kW scale. The 2016 Call being prepared by the FCH JU will call for demonstration of an electrolyser providing grid services at MW scale as preparation for commercial roll-out. A new study by Ludwig-Bölkow-Systemtechnik (LBST) and Hinicio that will be published in the coming months has identified the most promising green hydrogen production routes that may help us to meet our targets. These include biomass gasification, raw biogas reforming, thermochemical water splitting, photo-electrochemical cell technology and dark fermentation.

As regards distribution, the FCH JU has funded projects involving high capacity compressed hydrogen trucks, thus reducing the cost of distribution and the number of trucks on the road, as well as hydrogen liquefaction processes with reduced energy requirement by 50% for a 20x increase in plant capacity so that hydrogen can be transported in large quantities even between continents. The potential for large scale underground storage of hydrogen in Europe in order to store excess renewable energy has been assessed and found to be viable, increasing the cost of hydrogen by only 0.5 €/kgH_2. The status and potential of other storage technologies, for example solid state storage, still need to be assessed before deciding to support these. Furthermore, less obvious supporting technologies like efficient clean-up and compression of hydrogen have been developed to prototype scale and are expected to contribute to increasing efficiency and reducing costs of a hydrogen-based energy system in the future. ”

---

1. FCH JU Trends in investments, jobs and turnover in the Fuel Cells and Hydrogen sector, February 2013
2. Brussels, 25.2.2015 COM(2015) 80 final
3. OPEX - ongoing cost for running a product, business, or system NPV - defined as the sum of the present values (PVs) of incoming and outgoing cash flows over a period of time.

Pierre-Etienne Franc

Air Liquide Group, Vice-President, Advanced Business and Technologies
Pierre-Etienne Franc joined the Air Liquide Group in 1995 as a strategic analyst and since June 2010, he has supervised a portfolio of high technology businesses and initiatives, in the fields of energy and environment (including H_2 energy activities), space and aeronautics, cryogenics and industrial IT and a venture capital arm for the group, created in 2013. In 2011, he was elected Chairman of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), the European public-private partnership financing Hydrogen and Fuel Cell sector. Pierre-Etienne Franc is a graduate from HEC Paris.

SETIS TALKS TO:

Paul Lucchese

Fuel Cells and Hydrogen Joint Undertaking N.ERGHY Research Grouping Chair

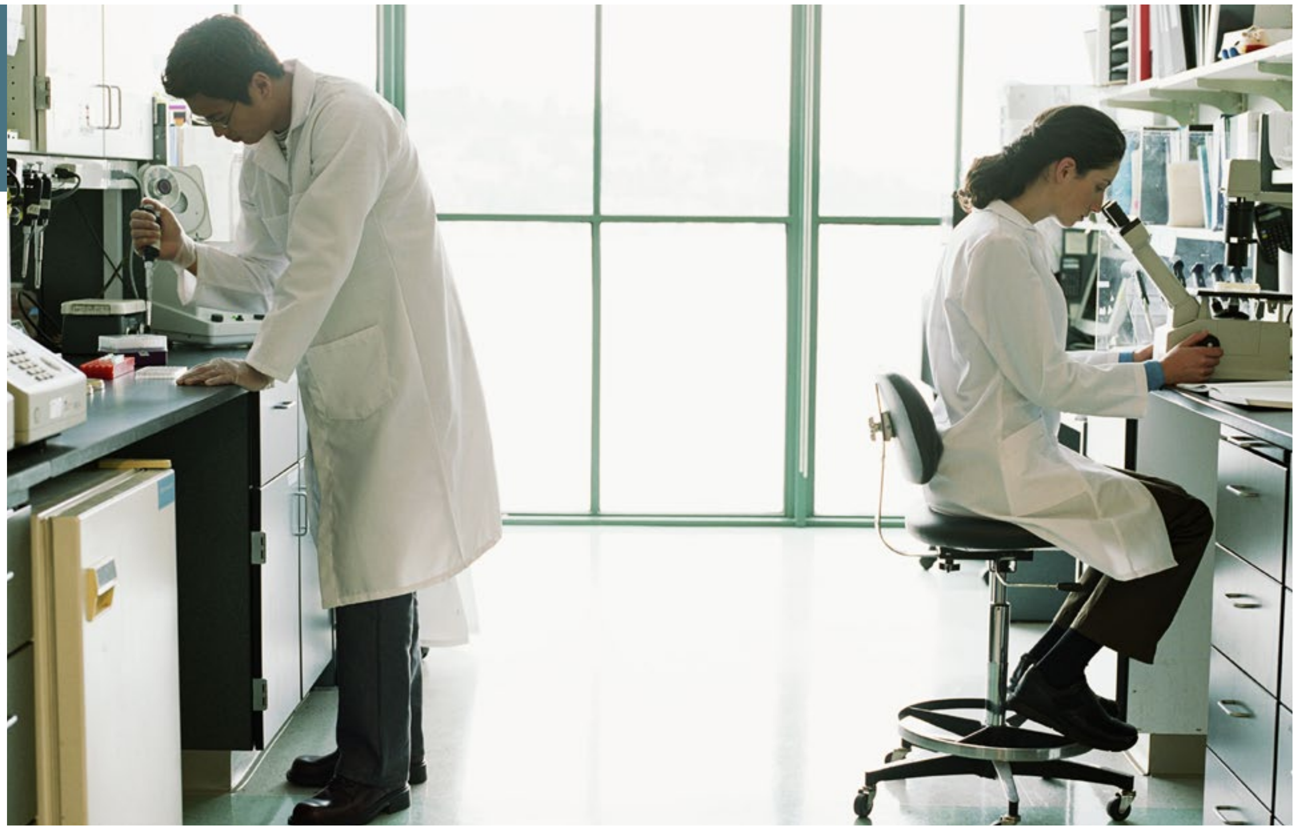
©Thinkstock/Wavebreakmedia Ltd

How has the N.ERGHY Research Grouping increased the effectiveness of fuel cell and hydrogen research in Europe?

P.L.: “ The Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is a unique public private partnership due to the fact that the research community is considered to be one of the main stakeholders in the decision-making process and is a full member of the FCH JU Governing Board. This is unique among the Joint Technology Initiatives (JTI). The reason for this is that the European research community was part of the strategic discussion at the very beginning of the process in 2002, and of the High Level Group and FCH Platform up to 2006. European research was united with one voice from the very start of the technology platform. The core group of European research and technology organisations (RTO) involved in FCH research included such famous actors as ECN (NL), CEA (FR), DLR (GER), VTT (FIN), ENEA (IT), Ciemat (SPA), FZJ (GER) and SINTEF (NOR) who succeeded in bringing together most of the European research community active in the field. From 2007 up to now N.ERGHY has brought together 64 members from 20 countries and we estimate our “workforce” to be at least the equivalent of 1500 man-years, representing probably more than 80% of the European public research effort in the sector. Over the past ten years, there has been a lot of exchange among members, including at least 2 general assemblies per year with intense discussions on priority topics, benefits for research, partnership with the business sector etc. This has resulted in an impressive number of research projects carried out over these years: in the first phase of FCH JU, 26 research projects on hydrogen production, distribution and storage; 30 projects on fuel cells and around 20 projects on transport and refuelling infrastructure were implemented, some of which are still ongoing. This continuous cooperation resulted in a very strong and coherent research community, in which professional contacts at a personal level have been established and expanded. ”

Public demand for fuel cell electric vehicles will, to a large extent, depend on their cost. How is research helping to make FCH technologies more competitive?

P.L.: “ The research carried out over the last fifteen years both in public institutions and in the private sector has allowed significant progress in most of the fields of hydrogen and fuel cells technologies. One example is a decrease in the platinum content in proton exchange membrane fuel cells (PEMFC). Less than 40 g of platinum is currently required for a full cell car - this was 10 times higher in the 2000's. Another example is the fact that a deeper understanding of the electrochemical mechanism of a fuel cell has made it possible to increase its electric efficiency up to 60%. These achievements have made it possible for us to consider the first steps in the commercialisation of products, which is always the most visual example of progress valued by customers. The launch of Mirai car by Toyota last December in Japan is a good example of this. ”



©Thinkstock/Ryan McVay

What are the main developments in recent years that have improved the performance of fuel cell technology for energy and transport applications?

P.L.: “ Over the last seven years, the platinum content for PEMFC was decreased by a factor of 3 to less than 0.8 g/kW at industrial scale and 0.2 g/kW at laboratory scale. In addition:

- Proton-exchange fuel cell (PEFC) systems are now able to operate at -20/-30 °C;
- The lifetime of stationary fuel cells has increased by at least a factor of 3;
- The reliability of small reformers for biogas has improved;
- The power density for PEFC systems for cars (volumetric & gravimetric) has increased at least by a factor of 2;
- High pressure storage at 350 and 700 bar has advanced from laboratory prototype to a qualified ready-to-deploy technology.

Many European start-up companies have stemmed from or continue to work with research organisations: The core technology of SymbioFC comes from the French Alternative Energies and Atomic Energy Commission (CEA): it produces fuel cell systems for high-power systems and range extender systems for mobility. Another example is Nedstack, a Dutch PEMFC producer that is working with different research members to improve stack components. ”

In the sphere of hydrogen production, what is currently the most efficient technology and what alternative production routes are being explored?

P.L.: “ The most mature technologies are gas reforming and alkaline electrolysis. Proton exchange membrane (PEM) electrolysers are close to the commercial market stage at large scale and solid oxide electrolysers (high temperature electrolysis) are a very promising technology with high efficiency. However, this technology needs more development to access the market.

There are a number of examples of success stories of cooperation between public research and N.ERGHY members with private companies in the field of production and storage. ITM Power is one of the world's leading PEM electrolyser manufacturers thanks to the bottom-up approach of the FCH JU. To date it has developed a number of commercial applications such as the recently deployed HFuel vehicle refuelling unit. ITM Power achieved this progress due to its participation in FP7 projects such as SafeFlame together with research partners VTT (Finland) and CESOL (Spain), as well as in FCH JU projects such as ELECTROHYPEM together with research partners CNR-ITAE (Italy), the Joint Research Centre (EU), and CNRS (France).

McPhy Energy is a dynamic start-up company (one of the Top 100 most innovative and promising companies, as evaluated by Global Cleantech) involved in coupling hydrogen production from renewable resources with innovative storage systems. It was founded as a spin-off from the CNRS and CEA (France) research centres. Starting with patents on metal hydride storage in 2008, obtained while working in the EU FP6 projects NESSHY and HYSTORY, it grew successfully in recent years and extended its product line to markets in Japan, the UK and Italy. In 2010, with a vision to develop a global renewable energies storage system, McPhy Energy delivered a prototype with a capacity of 15 kg hydrogen to the French laboratory CEA-LITEN and started its first commercial storage system with a capacity of 4 kg of H_2. McPhy will continue to be active in European research projects, namely INGRID. This project involves a system designed to produce hydrogen from renewable electricity by electrolysis, to store it in solid form and to use it via a fuel cell for power production. The system will be demonstrated in the Apulia region (Southern Italy).

A new start-up in France, SYLFEN, will develop and commercialise a reversible high temperature fuel cell/electrolyser for residential applications, able to supply heat and power or to produce syngas or hydrogen from renewable energy at 800°C. The technology was developed by NERGHY member CEA. ”

Safety is an issue of concern to consumers when it comes to hydrogen technology. What is being done to increase the safety of hydrogen production, distribution and storage?

P.L.: “ Safety is regularly addressed in our projects and is a core milestone defined in the Multi-Annual Work Programme (MAWP) 2014-2020. At the components and stack level a lot of testing has been carried out on safety issues in all incident and accident situations. For high pressure tanks, a safety coefficient of 2.35 on burst pressure has been achieved. Tanks are tested under fire, gun shot, and car accident conditions. In the fire-fighting sector, firefighters are developing specific hydrogen-oriented procedures and undergoing training. For production plant and refueling stations, feedback from around one hundred demonstration projects has resulted in a very high level of safety for regular customers when filling their tanks. ”

How does fuel cell research in Europe compare with the rest of the world? What support do European researchers need to ensure that Europe remains at the forefront of FCH technological developments?

P.L.: “ European research is at the forefront of FCH development in the world. N.ERGHY alone brings together 64 research centres and universities and we have a large platform of research expertise in all fields, and with all types of material and fuel cell technologies, ranging from low technology readiness level (TRL) and basic research to applied research and high TRL. In addition to cooperation with industry at the level of applied science, an effective funding scheme has to be ensured for basic research on clean FCH technologies at all levels, including the European. In order to preserve and extend the existing production potential in Europe, it is essential for research to keep a sustainable long-term focus on the technologies of the future. Not constrained by short-term demands regarding utility value, public research institutions have the opportunity for in-depth immersion in the research challenges that have been identified. Given that the FCH JU focuses on research at Technology Readiness Level 3 and above, it is necessary to have a coordinated effort in other Horizon 2020 initiatives and to strengthen synergies with the European Energy Research Alliance (EERA) programmes. Another unique contribution can be made by universities in this process, by educating scientists that are able to navigate existing research and/or have enough understanding to determine future successful research paths.

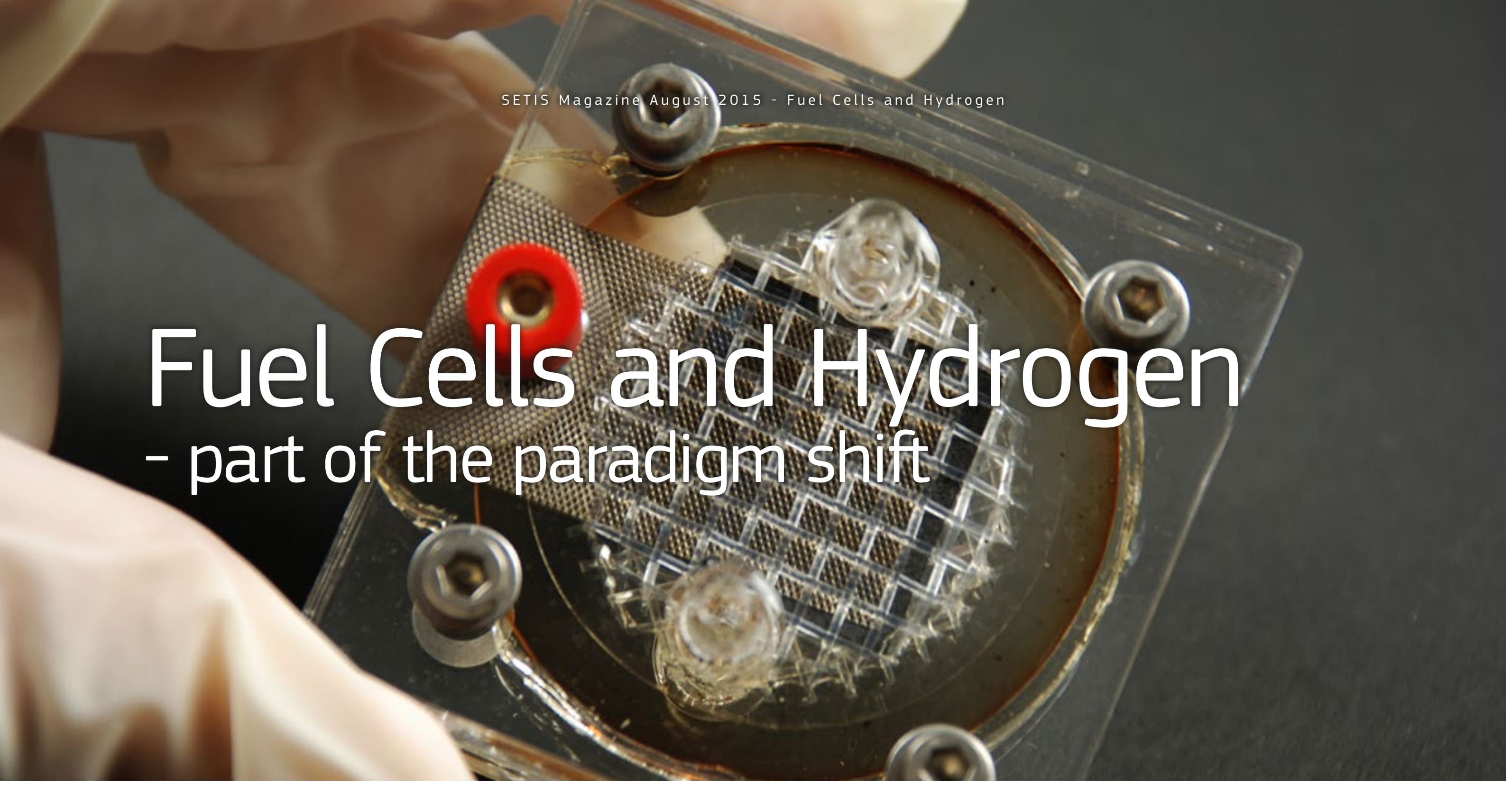
Paul Lucchese

Since 2008, Paul Lucchese has chaired N.ERGHY, the European Association on H_2 and fuel cells research, which brings together more than 65 member universities and research centres.

He is also the French representative on the Executive Committee of the Hydrogen Implementing Agreement of the International Energy Agency (IEA) and participates in the International Partnership on Hydrogen Economy. Paul received an Engineering Degree in nuclear engineering from the École Centrale de Paris (1983) and a DEA (equivalent of master) in applied chemistry (1983).

Fuel Cells and Hydrogen

- part of the paradigm shift



©iStock/albin

Europe's ambitious political agendas for both 2030 and 2050 include challenging targets for greenhouse gas (GHG) emissions reductions, renewable energy sources, and energy efficiency, thus offering interesting opportunities for low carbon innovative technologies. In particular, the Energy Union strategy, unveiled in February 2015, aims at ensuring that Europe has access to secure, affordable and sustainable energy. To make this happen, Europe will need to undergo a paradigm shift, moving towards decentralised power generation coupled with energy storage to facilitate the integration of intermittent renewable energy sources such as solar or wind power. In addition, the decarbonisation of the transport sector will need to shift into higher gear and move steadily closer towards zero local emission propulsion.

Achieving these goals will require the development of a portfolio of new technologies, to be elaborated in the imminent update of the Strategic Energy Technology Plan (SET-Plan) as well as the upcoming Strategic Transport Research and Innovation Agenda (STRIA), in which both fuel cells and hydrogen play an important role: fuel cell electric vehicles (FCEV's) will coexist along battery EV's in function of consumer needs, surplus renewable energy will be converted into hydrogen to power both transport and energy needs, and stationary fuel cells will play an increasing role in boosting the energy efficiency of power generation across Europe.

The EU role in reinforcing the Fuel Cells and Hydrogen sector – FCH JU

Recognising their potential to contribute to the decarbonisation of both transport and power generation, the EU has been supporting research on fuel cells and hydrogen technologies since the 4th Framework Programme (1994-1998) with ever-increasing intensity. In 2008, this led to the establishment of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a public-private partnership bringing together the European industry and research entities and the European Union. The overarching objective was to make Europe a worldwide leader in FCH technologies. With a total budget of €940 million, the FCH JU has proven itself highly successful in reinforcing collaboration and growing the sector amidst a shrinking market, hit by the economic crisis. This growth since 2008 is testified by, for example, a 6% increase in jobs, a 10% average boost in turnover and no less than 16% rise in the number of patents – more than 10 times higher than the average!

By co-financing 155 projects with well over 550 unique participants from Europe and beyond, the FCH JU has not only achieved significant technological progress at components and systems level, but it will also have put more than 260 fuel cell vehicles on the road, demonstrated more than 400 material handling vehicles, and installed more than 20 hydrogen refuelling stations (HRS). This effort led to a number of remarkable breakthroughs, notably in the area of FC buses, where Europe is now firmly in the lead: over 70 buses have been and are still being tested in various European cities, gathering a wealth of real-life usage data. In addition, hydrogen consumption of FC buses has been cut by half compared to previous generations over the FCH JU lifetime.

In the energy sector, similar efforts have taken place, which will culminate in the demonstration of more than 1000 micro-combined heat and power (µCHP) units for residential installation across 12 Member States by 2017, representing a significant step towards commercialisation of the technology. The units, with a system efficiency of >95%, help reduce CO_2 emissions but also decrease the load on the electricity grid through distributed generation of electricity and heat.

Continuing the integration – FCH 2 JU

Given the successes achieved by the FCH JU, the decision was made in 2014 to extend the duration of the public-private partnership through the establishment of the FCH 2 JU, which will remain in operation until 2024. The 40% budget increase compared to its predecessor underlines the growing support for the sector, both from public and private side. The focus of this new JU has shifted firmly towards commercialisation of the technology and therefore 60% of the budget will be allocated to supporting close-to-market activities, including large-scale demonstrations exploring business models, financing options and tackling social acceptance, both in transport and energy applications.

Importantly, the FCH 2 JU will, among other activities, establish synergies with various H_2 Mobility initiatives across Europe that look into deploying hydrogen as transportation fuel and thus pave the way for large-scale roll-out of FCEV's. It will also continue to support the build-up of production capacities of µCHP's with the aim of boosting Europe's competitiveness in this sector. Another area of interest is power-to-hydrogen and storage in support of renewable energy integration.

It is also important to note that the FCH 2 JU will broaden its activities via links with other relevant EU initiatives: a very concrete example is a joint Workshop with the Clean Sky JU on aeronautical applications of fuel cells and hydrogen technologies hosted by DLR 15-16 September 2015, but future collaborations with the Bio-Based Industries JU on hydrogen production, or the Shift2Rail JU on rail applications for fuel cells are also under consideration.

Unlocking the potential – the way forward

Before the market potential for FCH technologies can be tapped, some important barriers must be overcome.

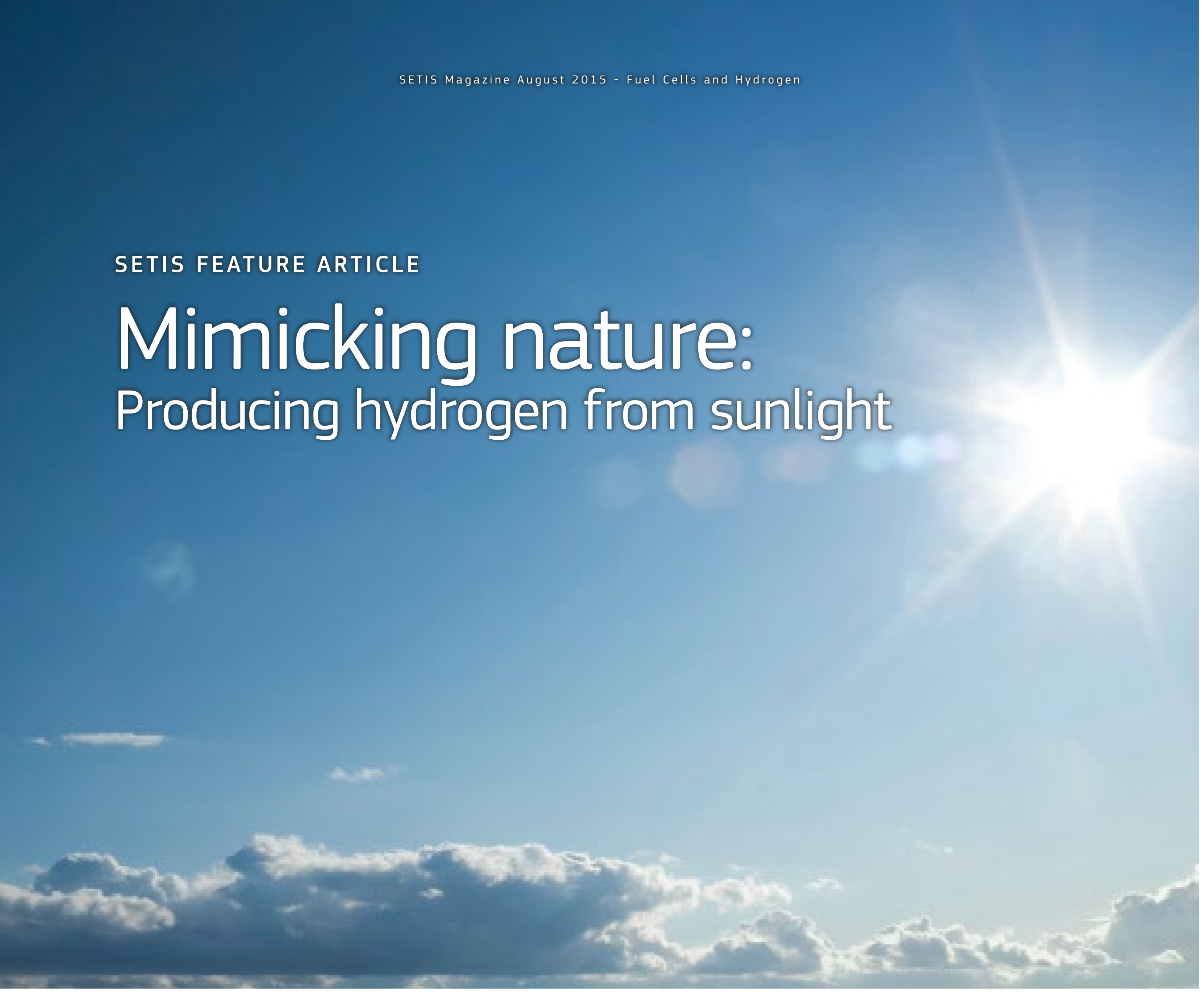
An obvious requirement is that products must be available, reliable and affordable, and that the necessary infrastructure for distribution and refuelling of hydrogen is in place. The related investments are huge and require a stable and supportive regulatory framework to build investor confidence in the market, and to ensure that business cases can emerge.

As successfully demonstrated in Japan, where government is strongly backing the deployment of FCEV's, refuelling infrastructure and has subsidised the installation of more than 100.000 domestic µCHP-units, a strong commitment is also needed in Europe to achieve a comparable result. The recent launch of the InnovFin Energy Demonstration Projects facility by the European Investment Bank and the European Commission is just one example of how investments can be financed in the pre-commercial stage.

Finally, and most importantly, it will be necessary to convince the end users that hydrogen is safe, and to demonstrate the benefits of using it on a daily basis. A very effective way to achieve this is to stimulate the deployment of fuel cell buses in European cities: moving quietly, reliably and safely, emitting nothing but water vapour, they are a perfect illustration of the many benefits fuel cells and hydrogen have to offer all of us.

Johan Blondelle

Johan Blondelle is currently Policy Officer in the Advanced Energy Production Unit of DG RTD, where his main activity is to liaise with the Fuel Cells and Hydrogen Joint Undertaking. Before that, he has contributed to the setting up of the Clean Sky JU and worked in rail research. He trained as an electrical engineer and holds a doctorate in opto-electronics from the University of Ghent, Belgium.



SETIS FEATURE ARTICLE

Mimicking nature:

Producing hydrogen from sunlight

©iStock/loongar

When Daniel Nocera of the Massachusetts Institute of Technology (now at Harvard University) demonstrated his 'artificial leaf' in 2011,[1] he made headlines with promises of a breakthrough technology that could mimic photosynthesis, using sunlight to split water into hydrogen and oxygen at room temperature. Just sixteen years earlier, this kind of artificial photosynthesis had been called the 'Holy Grail of science'.[2] However, while the postage stamp-sized 'artificial leaf' works in a small beaker of water in the lab, major challenges need to be overcome before it can be scaled up for commercial use.

As an excellent energy carrier, hydrogen has been a prime candidate for renewable power and energy storage for many years. But hydrogen is rarely found in its pure form in nature, as it is lighter than air and quickly rises into the atmosphere. Rather, hydrogen is a constituent of a multitude of naturally occurring molecules, like water, from which it has to be separated.

The principle of mimicking photosynthesis to produce hydrogen using solar energy was first described over 100 years ago. Then a team of Japanese researchers published a description of a functioning prototype in the journal *Nature* in 1975. In this process, a photovoltaic wafer comprising two electrodes separated by a membrane is immersed in an electrolyte solution - in this case, water. Each electrode is made of a photosensitive semiconductor material, coated in a catalyst that helps to generate oxygen (at the anode) and hydrogen (at the cathode). Once the water has been split, the hydrogen can be recovered.

Using these principles, Nocera's 'artificial leaf' consists of a thin sheet of semiconducting silicon, onto which is bonded a layer of a cobalt-based catalyst, which releases oxygen in the presence of sunlight. The other side of the silicon sheet is coated with a layer of a nickel-molybdenum-zinc alloy, which releases hydrogen from the water molecules. What makes his 'artificial leaf' different from other attempts to produce hydrogen using sunlight is that it uses abundant and generally inexpensive materials instead of corrosive solutions or relatively rare and expensive materials, such as platinum. The main challenge for the technology to be really useful is scale and further developing the catalysts.

Large-scale solar production of hydrogen

While there are several potential technologies for producing hydrogen using solar energy, only a few are feasible on a large scale. One currently under development is looked into by the FCH-JU co-funded CoMETHy project that uses molten salts to store heat derived from a number of renewable energy sources, including solar energy from concentrating solar plants. This heat is then used to convert a range of possible fuels to produce hydrogen. This is a 'greener' variant of a more mature technology that involves reforming methane or natural gas at high temperatures. The gases react with steam in the presence of a catalyst to produce hydrogen, along with carbon monoxide and some carbon dioxide - so they are not completely 'carbon free'.

One of the most promising technologies to produce hydrogen on a large scale is the so-called hybrid-sulphur cycle (or Westinghouse cycle). In this process, both thermochemical and electrochemical cycles are used to split water by the reduction and oxydation ('redox') of sulphur compounds, often recycled from metallurgical industries. The net result is hydrogen and sulphuric acid, which is also marketable.

Whereas nuclear energy is often used to provide the high temperature heat for the thermochemical cycles, the SOL2HY2 project, which is part of the European Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) public-private partnership, is exploring the use of solar energy for both the electrolysis cycles and, using molten salts, also for the thermochemical cycles. Another innovation being explored in SOL2HY2 is to integrate the hydrogen production process with existing sulphuric acid production plants. According to a SOL2HY2 report, the "...highly efficient co-use of existing plants drops H_2 costs by about 50-70 % compared to traditional HyS process designs."

Another FCH co-funded project, HYDROSOL-3D, which follows on from the successful HYDROSOL and HYDROSOL2 projects, aims to exploit solar energy for the catalytic dissociation of water and the production of hydrogen. One of the main technical obstacles to producing hydrogen by splitting water is the high temperature needed. To get around this, catalysts are used to lower the reaction temperature. The project is preparing to build a 1 MW demonstration plant at a site in Spain for the thermochemical production of hydrogen using a solar monolithic reactor, with on-site storage.

In an earlier phase, the team developed an innovative solar reactor to produce hydrogen by splitting steam at moderate temperatures (800-1200°C) using solar energy. This used special refractory ceramic, thin-wall, honeycomb monoliths, optimised to absorb solar radiation. The monoliths are coated with special, highly-active oxides with redox properties that trap oxygen and split water. HYDROSOL-3D now intends to carry out all the remaining steps to build the 1MW solar demonstration plant using this technology in order to ensure long-term, reliable solar-aided hydrogen production at industrially attractive yields.

The SOPHIA project, also part of FCH-JU, is exploring another high temperature path to the dissociation of water using solar energy, namely high temperature steam electrolysis (so-called HTE or SOE for Solid Oxide Electrolysis). This process involves the joint electrolysis of CO_2 and H_2O to produce syngas (H_2+CO), which is the standard intermediate for the subsequent production of methane or other gaseous or liquid fuels after an additional processing step. The main goal of SOPHIA is to develop and operate a 3 kWe pressurized HTE system, coupled to a concentrated solar energy source for proof of principle. A secondary aim is to prove the concept of co-electrolysis at the stack level.

Mimicking nature: scaling up the artificial leaf

There is now considerable R&D activity to try to overcome the limitations of scale and catalyst materials encountered when mimicking nature to produce hydrogen via artificial photosynthesis. In Europe, under the FCH-JU initiative, the ArtipHyction project is using artificial versions of enzymes involved in photosynthesis in the leaf, in particular hydrogenase and so-called Photosystem II (PSII). These serve an equivalent function to the catalysts used in other processes. The aim is to develop an artificial device to convert solar energy into hydrogen with close to 10% efficiency, by splitting water at ambient temperature.

This version of the 'artificial leaf' uses an electrode (anode) exposed to sunlight, carrying a PSII-like chemical mimic deposited on a suitable transparent electron-conductive porous electrode material. A membrane enables the transport of protons through a pulsated thin water gap. On the other side of the membrane is a cathode carrying a mimic of hydrogenase coated onto a porous electron-conducting support. Meanwhile, an external wire conducts electrons between the electrodes. At the cathode, protons and electrons are combined into pure molecular hydrogen. The goal is to assemble and test a proof-of-concept prototype of about 100 W (3 gr H_2/h) by the end of the project, for a projected lifetime of over 10,000 hours.

Meanwhile, PHOCS (Photogenerated Hydrogen by Organic Catalytic Systems), a three-year EC FP7 project due to end in November 2015, has successfully developed a hybrid photoactive device that combines organic semiconductors and inorganic materials to convert water into hydrogen using sunlight. Unlike other attempts to produce hydrogen using organic semiconductors, PHOCS places layers of nanometric titanium oxide as a physical barrier between the photovoltaic part of the cell and the catalyst that stimulates the hydrogen generation reaction. This technique overcomes problems of corrosion and stability usually associated with organic semiconductors.

In another FCH-JU initiative, PECDEMO will make hydrogen using the theoretically simple process of photo-electrochemical (PEC) water splitting. In this process, light is absorbed by a semiconductor photo-anode and/or photocathode, and converted into energetic electron-hole pairs. The electrons reduce water to form hydrogen gas at the cathode, while the holes oxidise water to form oxygen at the anode. The main focus for innovation in PECDEMO is to design earth-abundant photo-electrode and catalyst materials that are both highly efficient and chemically stable.

Building on impressive breakthroughs in the EU-funded NanoPEC project, which ran from 2009 to 2011, PECDEMO will use a chemically stable metal oxide-based photo-electrode, combined with an efficient photovoltaic (PV) solar cell in a hybrid device. The next step will be to scale up the electrode areas from a few square centimetres to 50 cm^2 within three years, with the ambition to demonstrate an 8% efficient device that is stable for more than 1000 hours.

The last word?

All of these technologies seem elaborate, though, compared to the natural simplicity of photosynthesis. But now a group of researchers at the Max Planck Institutes for Chemical Energy Conversion and Coal Research in Germany has found a way to exploit the capacity of hydrogenase enzymes in microalgae to produce hydrogen naturally, as part of the complex processes of photosynthesis. The problem with using microalgae has always been the vast surface areas required to produce hydrogen in useful volumes. But by modifying key amino acids and an enzyme in the microalgae cells, the researchers have been able to multiply the volume of hydrogen produced by hydrogenases by a factor of five. A multiplication of 10 to 100 will be needed for commercial exploitation and, even so, tanks of microalgae cultures covering huge areas will be required. But it may be as close to nature as the technology will get.

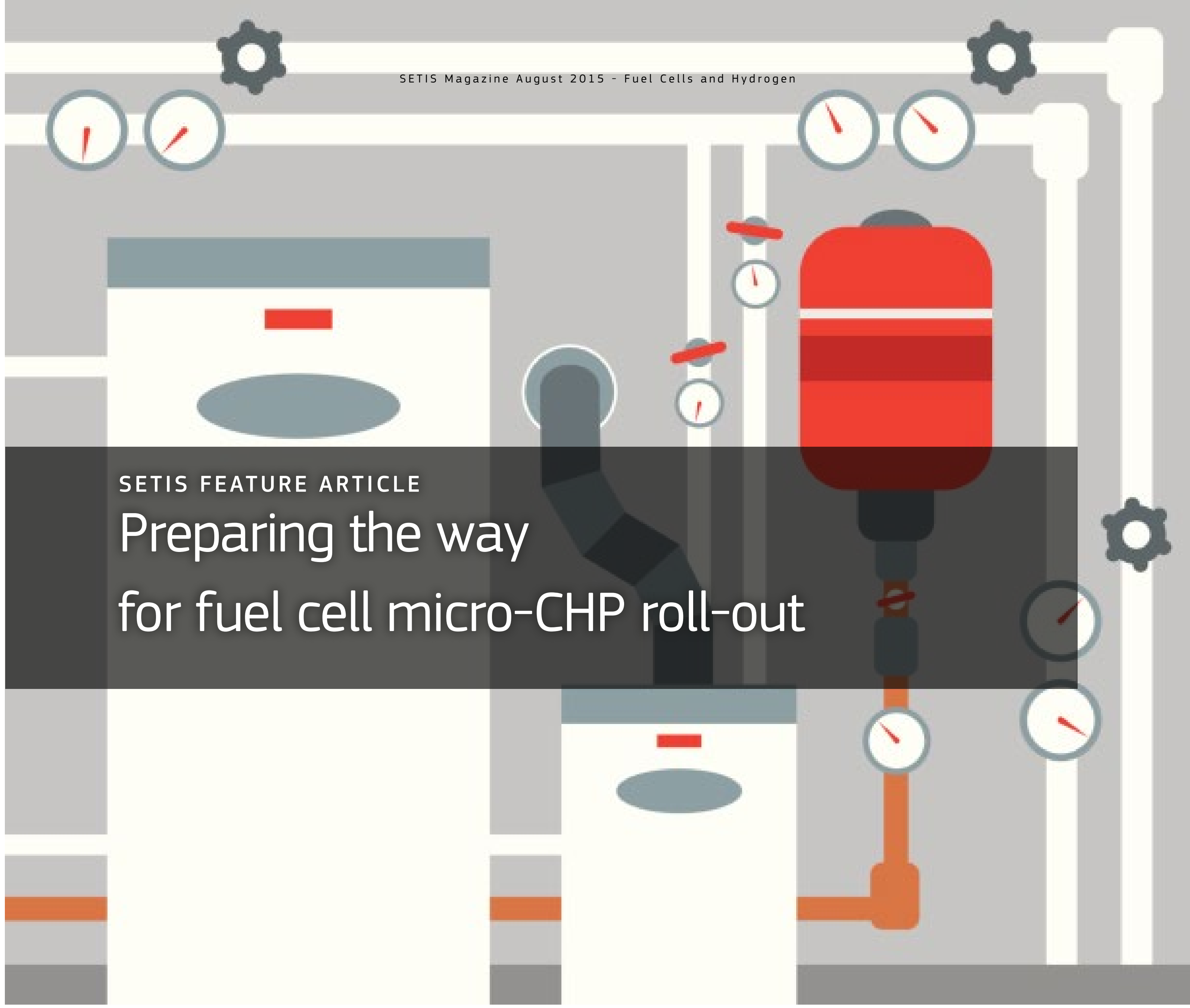
For more information:

http://www.fch.europa.eu/publications/programme-review-report-2014

©iStock/Upyanose

---

1. Science 4 November 2011. Vol. 334 no. 6056 pp. 645-648
2. Allen Bard and Marye Fox Accounts of Chemical Research 1995, 28 (3), pp 141–145



SETIS FEATURE ARTICLE

Preparing the way for fuel cell micro-CHP roll-out

©iStock/AANaAA

Hydrogen has the potential to become a significant source of power and heat for Europe's homes and industries. Stationary fuel cells are emerging as a viable alternative to combustion engines for the production of electrical power and the co-generation of heat as part of micro combined heat and power systems. According to a study conducted on behalf of COGEN Europe, micro-CHP has a number of key benefits that will ensure it plays an increasing role in the EU energy mix: it empowers energy consumers, it offers the potential to balance renewables and it decarbonises heat and electricity production, in addition to contributing to energy security and adding value to the EU economy. Furthermore, fuel cell micro-CHP has a low 'heat-to-power ratio', which means that it is well suited to the evolving trend in buildings towards higher electricity use and low space heating demand.

These benefits are also highlighted in a recent study by the Fuel Cell and Hydrogen Joint Undertaking, outlining a pathway for the commercialisation of stationary fuel cells in distributed generation across Europe.

Given these benefits, there has been sustained commitment at EU level to support field trials for emerging high efficiency technologies like fuel cell micro-CHP. One of the objectives of the Fuel Cell and Hydrogen Joint Undertaking's (FCH JU) energy pillar is to accelerate the commercialisation of FCH technologies that use fuel cells in stationary applications. The aim is to advance fuel cell stacks, balance of plant (BoP) and complete systems to the point where they are able to compete effectively with current power and heat-generation technologies.

With respect to the stationary power and CHP applications of fuel cells, the FCH JU's energy demonstration activities have focused on field demonstrations of micro-CHP and larger-scale power and CHP units. The aim here has been to establish a demonstration programme within Europe, alongside programmes supported by the Member States. Efforts have also focused on proof-of-concept of fuel cell systems and BoP components, and diagnostics and monitoring subsystems, with a view to supporting technologies through a programme of activities for proof-of-concept and validation projects. Another focus has been the demonstration of small-scale fuel cell systems to supply power for a range of back-up solutions and in remote locations.

The largest field trial currently underway in Europe is the FCH JU-co-financed ene.field project, which brings together nine mature European micro fuel cell-CHP manufacturers to deliver trials across all of the available fuel cell CHP technologies. As part of the project, fuel cell micro-CHP trials will be installed and actively monitored in dwellings across a range of European domestic heating markets, dwelling types and climatic zones, as a result of which an invaluable dataset on domestic energy consumption and micro-CHP applicability across Europe will be complied.

Ene.field will deploy and monitor approximately 1,000 new installations of residential fuel cell CHP across 12 key Member States. By learning the practical implications of installing, operating and supporting a fleet of fuel cells with real world customers, ene.field will demonstrate the environmental and economic imperative of micro FC-CHP, and lay the foundations for market exploitation.

One of the main objectives of the project is to remove barriers to the roll-out of technically mature fuel-cell micro-CHP systems through their large-scale deployment. It is hoped that this will trigger important first steps in the establishment of genuine product-support networks, well-developed supply chains and the growth of new skills to support commercial micro-CHP roll-out. The deployment of large numbers of micro-CHP devices will also help drive down costs, increase consumer awareness and establish new routes to market, in preparation for commercial roll-out.[1]

The field trials started in September 2013 with deployments to date in Austria, Belgium, Denmark, France, Germany, Luxembourg, Ireland, Italy, Netherlands, Slovenia, Spain and the UK. A report has been drawn up on the state-of-the-art with regard to field support arrangements, training and certification, in addition to an EU supply chain report. A working group for utilities has been set up, and another for regulations, codes and standards (RCS). Data from the first trials report is currently being analysed and an environmental life-cycle and costs assessment is to be developed this year, with establishment of a commercialisation framework planned for 2016.

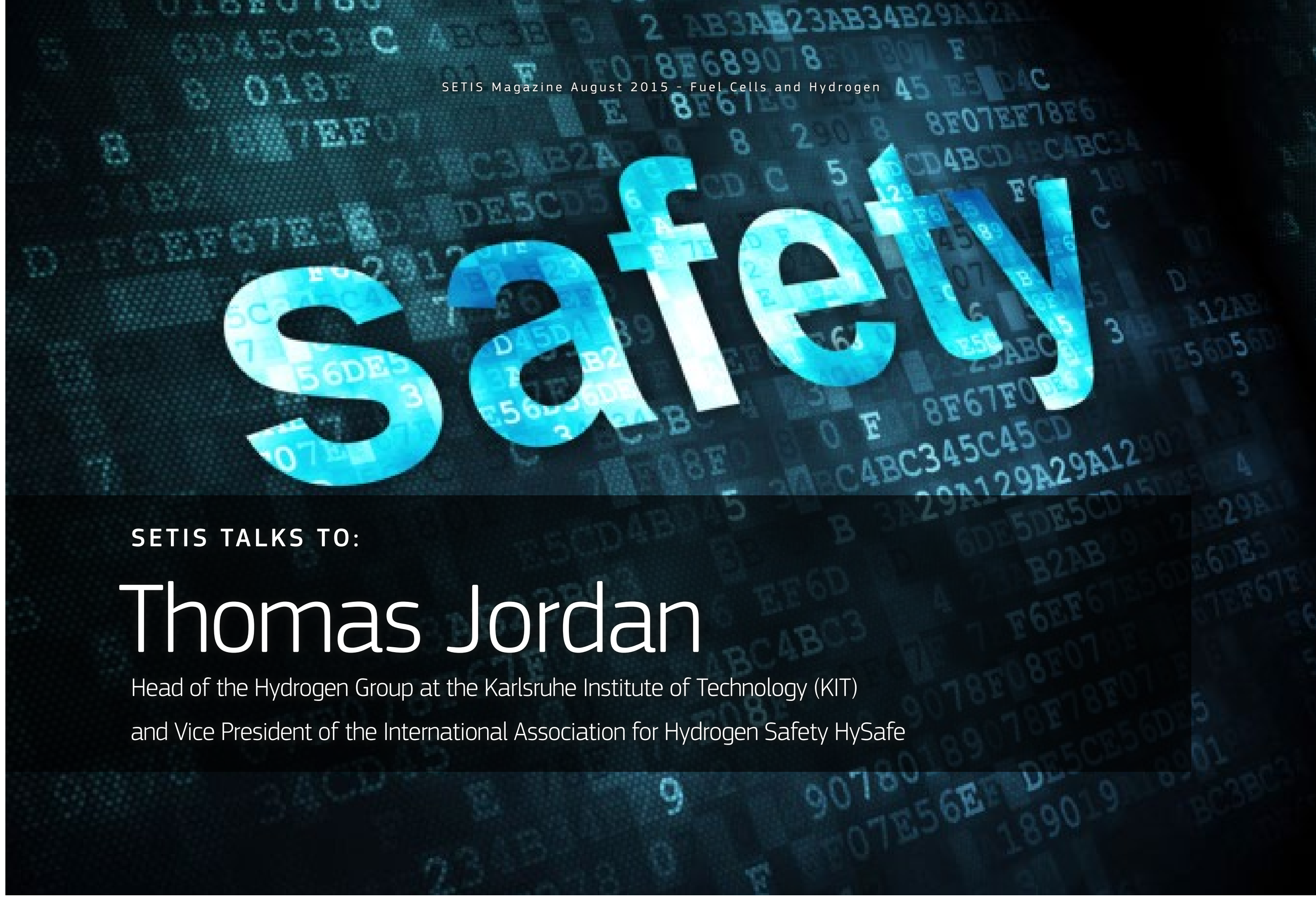
The ene.field European Supply Chain Analysis Report published last year analysed the European supply chain for fuel cell micro-CHP and identified three main barriers. According to the report, the most seriously limiting factor for the successful development of the supply chain is production volume, which is the key driver towards reducing system costs. The second challenge identified is the need to reduce system complexity, and to reduce the cost of individual components and develop collaborative strategies between key players, which is of paramount importance if the price of the final end product is to be reduced. Finally, there is a need to plan large scale public deployment projects in order to support wide distribution of the systems.

The ene.field project will contribute to the strategic objectives of the FCH Joint Technology Initiative to boost the share of FCH technologies in a sustainable, low-carbon energy and transport system and ensure a world-leading competitive FCH industry in Europe by demonstrating the market potential and environmental benefits of micro FC-CHP, elaborating market-focused product specifications and harmonised codes and standards, and helping to create a more mature supply chain capable of deploying micro FC-CHP in 12 Member States. The project will also generate an evidence base on cost and environmental performance that can be used to accelerate policy support from governments and market adoption of the technologies.

For more information:
http://www.fch.europa.eu/projects/fp7/stationary-power-production-and-CHP
http://enefield.eu/
http://www.fch.europa.eu/publications/advancing-europes-energy-systems-stationary-fuel-cells-distributed-generation

---

[1] FCH Programme Review 2014



SETIS TALKS TO:

Thomas Jordan

Head of the Hydrogen Group at the Karlsruhe Institute of Technology (KIT) and Vice President of the International Association for Hydrogen Safety HySafe

©iStock/maxkhabakov

Public concerns over hydrogen safety represent a barrier to the large-scale market uptake of hydrogen technologies. What are the main safety issues involved with the use of hydrogen as an energy carrier?

T.J.: “With the required new solutions for hydrogen as an energy carrier and energy storage medium, new operational conditions are implied. Pressure of around 70 MPa is applied for on-board storage in hydrogen-powered vehicles and large-scale distribution of hydrogen seems to be most economical in the liquid state at -250°C. From this, we can easily derive that the safety of light pressure vessels, the behaviour of cryogenic hydrogen releases and mass storage of hydrogen in general, including material compatibilities at these conditions, are the main safety issues.

However, as long as the accidental scenarios are located in the free environment the intrinsic properties of hydrogen show considerable advantages with regard to safety compared to conventional fuels or energy carriers. Only in combination with enclosure, e.g. use of hydrogen indoors, such as in tunnels, garages etc., the above issues may result in more severe hazards.

For more details, I recommend taking a look at the document “STATE-OF-THE-ART AND RESEARCH PRIORITIES IN HYDROGEN SAFETY” edited and periodically reviewed by the International Association for Hydrogen Safety HySafe in close cooperation with the European Commission's Joint Research Centre (JRC) and industry representatives. An updated version of this document will be presented at the International Conference for Hydrogen Safety in Yokohama, Japan, on 19-21 October this year.”

What projects are being implemented in the European Union to address these issues and to increase public acceptance of hydrogen?

T.J.: “In the previous Framework Programmes there were several projects addressing safety, standards and regulation, and awareness (at least partially). Some examples are EIHP, NaturalHy, HYTHEC, HarmonHy, HySociety, HYPER, and HyApproval. However, in 2003 with the Network of Excellence (NoE) instrument, a unique effort to integrate the fragmented work on hydrogen safety was initiated by the EC through the NoE HySafe.

Now, within the framework of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) several projects again address safety and acceptance-related issues. The most relevant are H2TRUST, HyTransfer, HyFacts, HyIndoor, FireComp, HyPactor, HySEA, as well as the research infrastructure project H2FC, supported by the FP7 Capacities program.

In my personal view, the cross-cutting nature of the safety, awareness and acceptance topics is not fully met through such a

©iStock/ChristianChan

project-based approach. What is required is a real cross-cutting, holistic approach to exchange and sustainably maintain experience and to continue to improve the state-of-the-art. In this regard, the JRC and IA HySafe are currently investigating measures to enable extracting relevant information from projects, feeding valuable experience back into new projects and disseminating knowledge and expertise in a consolidated way to the public via a Hydrogen Safety Expert Panel. Incidentally, the US Department of Energy (DoE) successfully established a similar group in the US several years ago. ”

What have been the main achievements in recent years towards creating a culture of safety in the hydrogen sector, and what are the main challenges remaining?

T.J.: “ Besides the important results of the above mentioned EC-funded projects and national projects, including also US and Japanese work, the safety community has fostered its links via common efforts regarding new international standards in ISO TC 197. In particular, there will be a new standard for refuelling stations, which is based on broad international consent and will refer to new commonly developed tools for risk assessment (e.g. HyRAM).

The corresponding European research community, established by the NoE HySafe, is being further integrated by the joint research work of the H2FC project and its support of highly relevant user projects at the partners' facilities.

Another important building brick for a safety culture is open communication within the recently formed safety task (Task 37) of the International Energy Agency Hydrogen Implementing Agreement (IEA HIA), which focuses international research cooperation on the most critical issues.

Lastly, but no less importantly, IA HySafe provides further critical elements with the:

- International Conference for Hydrogen Safety,
- Research Priorities Workshops,
- HIAD incident database (in cooperation with the JRC), and
- several educational activities.

One element that is missing in the European context is a service for the provision of consistently updated state-of-the-art information on safety issues to any projects dealing with hydrogen physically. This would mainly support new players and SMEs, which are the key drivers of innovation in the hydrogen and fuel cell field. Additionally, an obligation to report incidents and accidents in EC co-funded work would help to build-up a knowledge base and a statistical resource. I consider sharing critical safety information to be a key to improving overall learning and to ensuring public and private investments in these new technologies. ”

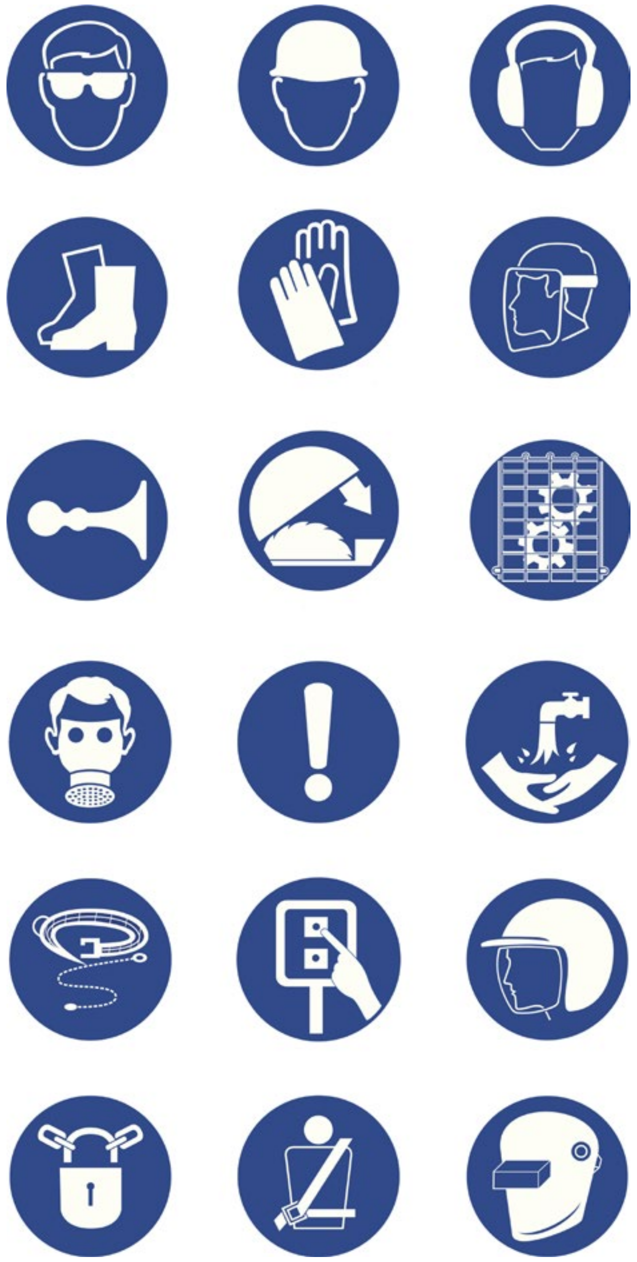
What is the current focus of hydrogen safety research?

T.J.: “ Efforts are currently directed at multiphase effects, in particular with liquid hydrogen releases, hydrogen blended to other fuels, fire safety of pressure vessels and associated testing procedures, quantitative risk assessment procedures, and human effects. In addition, the more fundamental issues of flame acceleration and deflagration-to-detonation transition continue to be further investigated, particularly for more realistic settings. On a more applied level, the risk reducing effectiveness of mitigation measures, like ventilation, represents another important focus ”

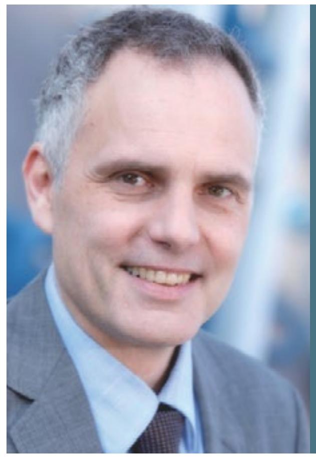
How does the safety culture in the hydrogen sector in Europe compare with that in the rest of the world? Are there any best practices that Europe can learn from international experience?

T.J.: “ We are seeing quite strong and strategic activities in US, driven by the US DoE, and in Japan, driven mainly by a strong belief in the hydrogen economy there. The central funding agencies there simply call for the required cross-cutting actions and mandate qualified and independent organisations to ensure consistent application of harmonised safety-related procedures and reporting. Consequently, one might expect the safety culture to be more mature in these regions, which are more hierarchically driven.

However, in a considerable number of technology fields associated with hydrogen and fuel cells European industry was and still is in a leading position, which is also due to the very highly-developed safety culture among European companies. The spread of this culture beyond the companies in question through a cross-cutting effort will further improve the overall situation in Europe. However, this has to happen based on a top-down approach, going beyond typical project limitations, making best use of existing infrastructures and communities that are ready to deliver. ”



©iStock/icedea



Dr Thomas Jordan

Thomas Jordan is a senior scientist at the Karlsruhe Institute for Technology KIT. He is an expert in object oriented programming, plasma physics, structural and continuum damage mechanics and computational fluid dynamics. He coordinated the EC NoE HySafe, acts in the corresponding follow-up IA HySafe as vice president and represents Germany in the IEA HIA Safety Task since 2005. He is teaching "Hydrogen Technologies" at the university branch and the international department of KIT and since 2009 he is heading the hydrogen group at the Institute for Nuclear and Energy Technologies. Thomas has a PhD in mechanical engineering.

10 years of JRC activities on Fuel Cells and Hydrogen

©iStock/karitap

As of the publication of the Vision Report[1] by the High Level Group established in 2003, JRC has been actively involved in hydrogen and fuel-cell related activities. Just over ten years ago, in July 2005, the hydrogen storage and fuel cell test facilities in Petten have been officially opened. In line with the JRC mission statement, the research performed in these state-of-the-art facilities targets pre-normative research in support to European and international standardization and regulatory activities. In parallel, and complementing the experimental work, JRC contributes to the SETIS deliverables Technology Maps, Capacities Maps and ETRI Database. Also, JRC has facilitated the Secretariat of the European Hydrogen and Fuel Cell Technology Platform, from where the public-private partnership European Joint Undertaking on Fuel Cells and Hydrogen (FCH-JU) was established to implement the related Joint Technology Initiative in collaboration between European industrial and research partners.

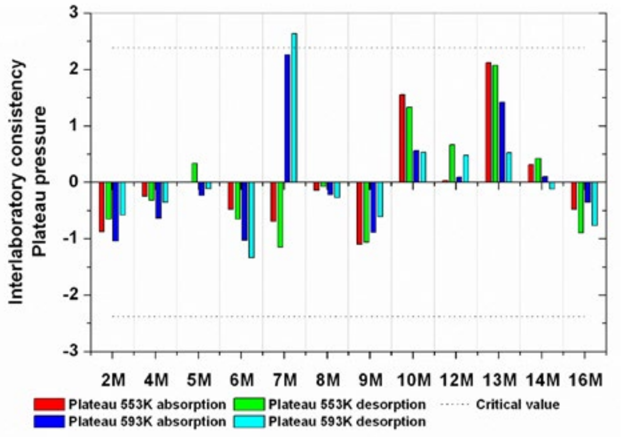


Fig. 1: Inter laboratory consistency: plateau pressure values measured at a given wt.% hydrogen.

As an industry-led PPP according to Article 187 TFEU, FCH-JU has a ring-fenced budget to implement consecutive annual work plans to address research and innovation priorities that have been agreed between the FCH-JU members: the industry grouping, the research grouping and the Commission. Being part of the Commission, JRC has oriented its work on fuel cells and hydrogen to comply with and complement the R&I topics prioritized by the European industry. In line with the JRC mission, JRC activities target public goods such as safety, security and sustainability. In doing so, particular emphasis is placed on establishing EU-wide consented science-based approaches and methodologies for evaluating and quantifying the performance of FCH technologies under service-representative conditions in terms of safety, (resource) efficiency, reliability, durability, emissions, etc. The output of the JRC work feeds into European and international standardization. In both ISO TC 197 on Hydrogen Technologies and IEC TC 105 on Fuel Cell Technologies JRC has liaison-A status on behalf of the Commission which allows it to contribute to defining the scope and schedule of international standardization activities to best meet European priorities and interests.

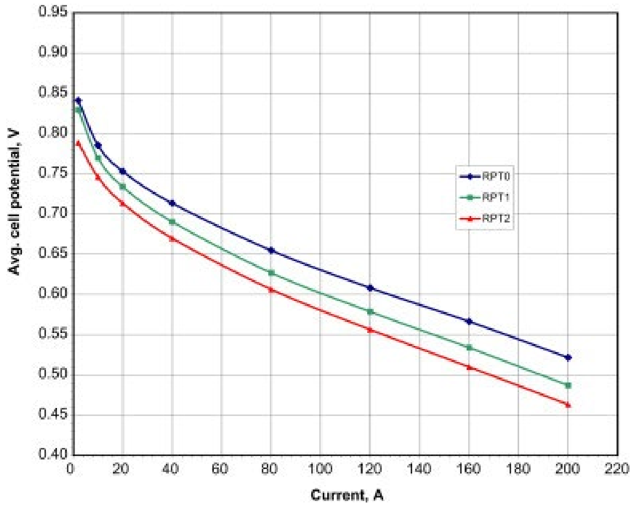


Fig. 2: Average cell potential vs. total current and time for the stack cycled using the New European Driving Cycle protocol at JRC-IET , RPTs curve after successive 100 hours test duration

Successful examples of JRC pre-normative and pre-regulatory work cover

- the input to European and international standards and regulations (table 1),
- the organization and evaluation of international inter-laboratory tests to identify and quantify test parameters and external factors that affect the accuracy, repeatability and reproducibility of the measurement result (e.g. hydrogen solid state storage (fig. 1 from[2]) and polarization curves for fuel cell stacks; (fig. 2 PEMFC with ANL + reference[3]),
- multi-criteria performance assessment of hydrogen detectors (fig. 3 from[4]) to enable selection of which type of sensor best fits a given application,
- data generation of high-pressure fast filling of hydrogen tanks for subsequent use for modelling purposes (fig. 4 from[5]),
- validation of CFD-models for fast filling of tanks (fig. 5 from[6]) to enhance confidence in numerical models applied for safety investigations,
- co-organisation on a 2-yearly basis of the leading International Conference on Hydrogen Safety (fig. 6 - photo ICHS-2013).

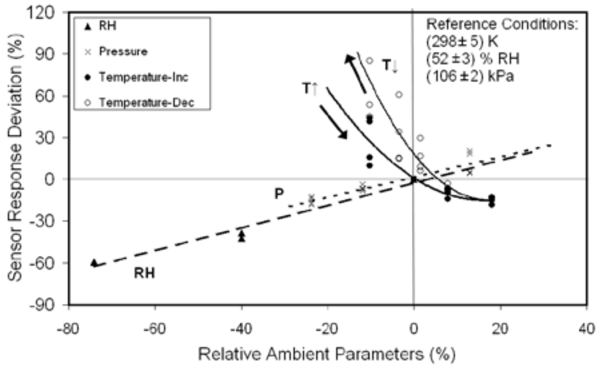


Fig. 3: MOx sensors: deviation of response to hydrogen from the response at the reference conditions as a function of changes in ambient temperature, pressure and relative humidity.

Recently, JRC has also organized an international workshop in the Science-for-Standards series on Power-to-Hydrogen which has meanwhile led to the setting up of a dedicated CEN-CENELEC Working Group under the Sector Forum Energy Management on the topic. Also a number of international workshops under the frame of the JRC Enlargement and Integration Action have been organized; some of these figuring as milestone in the Fuel Cell and Safety, Codes and Standards sub-programmes of the US-DoE Hydrogen and Fuel Cell Programme.

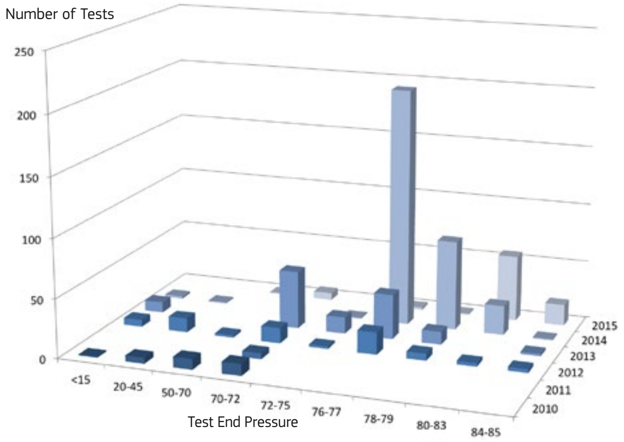


Fig. 4: Data from 133 fast-filling tests on Type-IV tanks

Table 1: JRC has contributed to the formulation of the following standards and regulations

Standards	IEC TC 105	IEC TS 62282-7-1:2010 Single cell test methods for PEFC IEC TS 62282-1:2013 Fuel cell technologies Part 1: Terminology IEC TS 62282-7-2:2014 Test method - single cell and stack performance test for SOFC IEC-62282-4-101:2014 Safety of electrically powered industrial trucks
	IEC TC 105 On-going	IEC-TS 62282-7-1:2016 Single cell test methods for PEFC
		IEC-62282-4-102:2017 Performance test methods for electrically powered industrial trucks
		NWIP on electrolysis standardisation
	ISO TC 197	ISO 14687-2:2012 Hydrogen fuel - Product specification - Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles
		ISO 26142 Hydrogen detection apparatus - Stationary applications
		Still on-going: ISO 19880-1 Gaseous hydrogen - Fuelling stations
	CENELEC	Workshop Agreement 50611 Flow batteries - Guidance on the specification, installation and operation
Regulations	Commission Regulation	EU No 406/2010, implementing Regulation (EC) No 79/2009 of the European Parliament and of the Council on type-approval of hydrogen-powered motor vehicles
	UNECE WP.29 GTR 13	Global technical regulation on hydrogen and fuel cell vehicles

As for other activity areas, JRC research on hydrogen and fuel cells is performed in close collaboration with European and international partners. Within the EU, JRC partners with the members of the FCH-JU industry and research grouping and has established a number of collaboration agreements with leading national research centres. At the international level, JRC is involved in the activities of the EU-US Energy Council, where hydrogen and fuel cells are identified as priority transatlantic collaboration topic. In this context, JRC teams up with the US Department of Energy by acting as co-chair to the Regulations, Codes and Standards Working Group of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and by collaborating in specific topics with a number of DoE national labs, JRC also represents the Commission in the Executive Committee of the Hydrogen Implementing Agreement of the International energy Agency (HIA-IEA) and participates to some of the HIA tasks.

Photo courtesy of ICHS

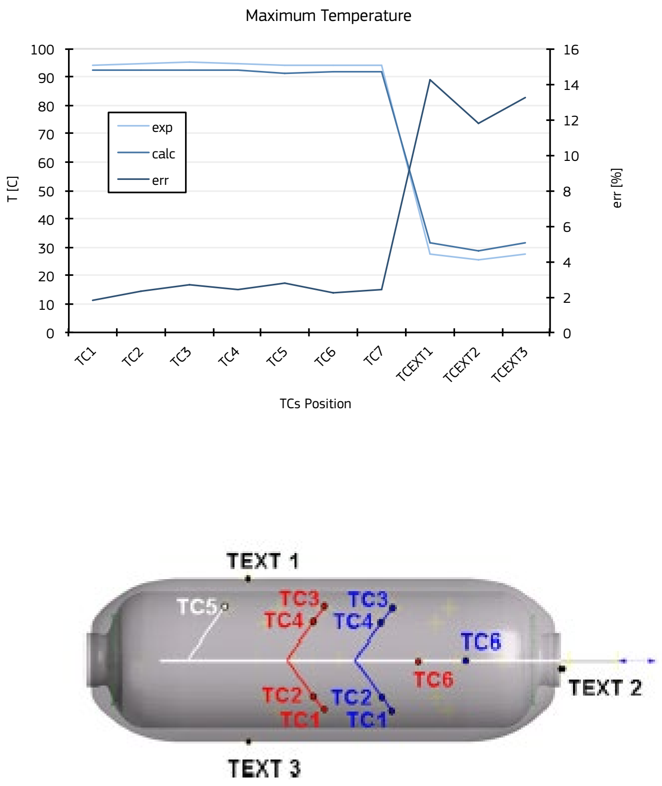


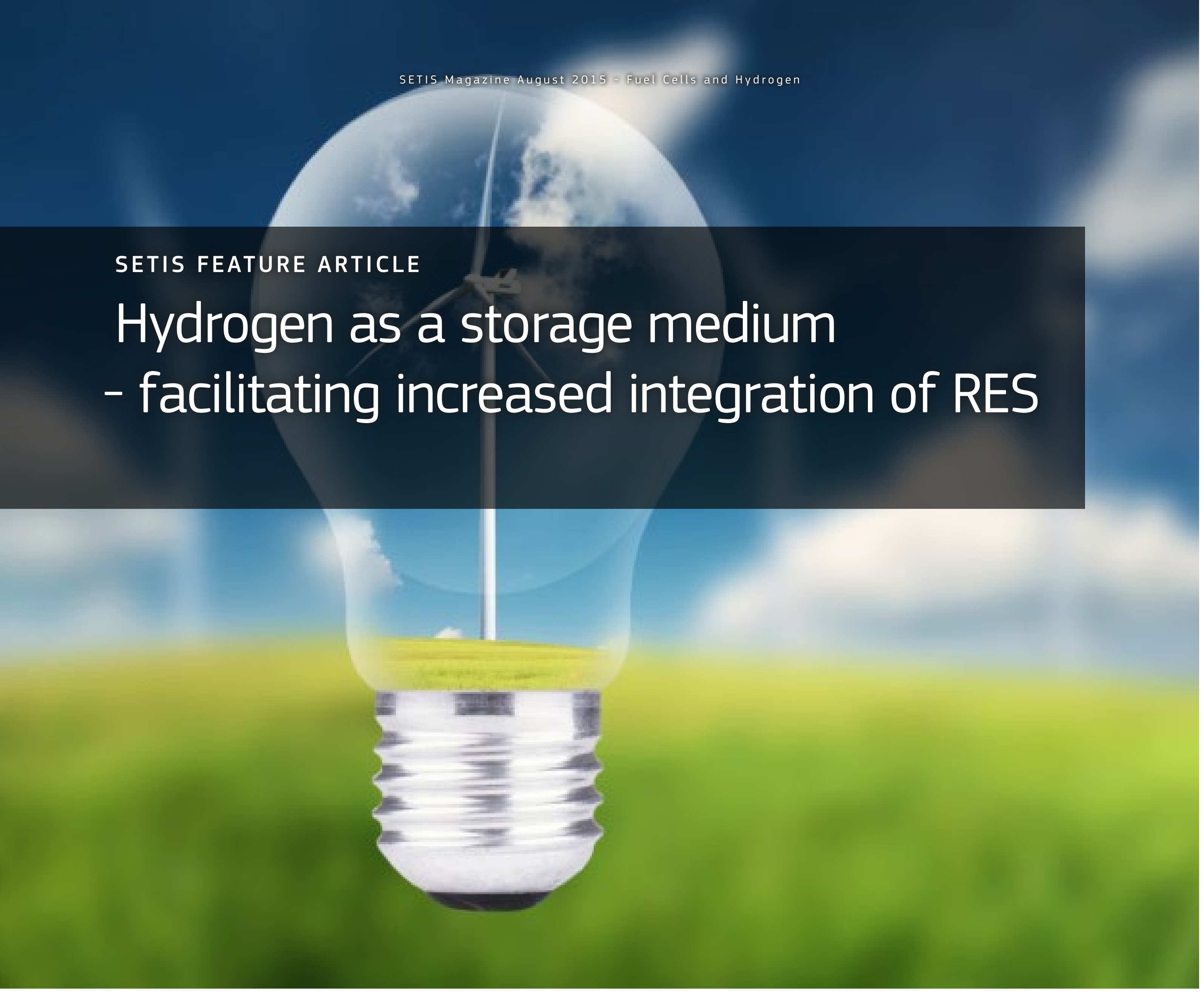
Fig. 5: Accuracy of calculated maximum temperature at different thermocouple positions

Next to continuing the pre-normative research, future JRC work on hydrogen and fuel cells will increasingly look into identifying and facilitating the necessary actions for enabling the deployment of FCH technologies in the EU. From this point of view, based on its impartiality and expertise, JRC will step up its support to FCH-JU in technology monitoring and assessment and in tailoring and coordinating the FCH-JU Regulations, Codes and Standards Coordination Strategy.

1. Hydrogen Energy and Fuel Cells – A vision of our future, Final report of the High Level Group, EC,EUR20719EN, 2003
2. Moretto et al., A Round Robin Test exercise on hydrogen absorption/desorption properties of a magnesium hydride based material, international journal of hydrogen energy 38 (2013) 6704-6717
3. Bloom et al., A comparison of Fuel Cell Testing protocols - A case study: Protocols used by the U.S. Department of Energy, European Union, International Electrotechnical Commission/Fuel Cell Testing and Standardization Network, and Fuel Cell Technical Team, Journal of Power Sources 243 (2013) 451-457
4. Boon-Brett et al., Reliability of commercially available hydrogen sensors for detection of hydrogen at critical concentrations: Part II – selected sensor test results, International journal of hydrogen energy 34(2009), 562-571
5. Acosta et al., JRC reference data from experiments of on-board hydrogen tanks fast filling, International Journal of hydrogen energy 39(2014)20531-20537
6. Galassi et al Assessment of CFD models for hydrogen fast filling simulations, International journal of hydrogen energy 39(2014)6252-6260

Marc Steen

Marc Steen leads the Energy Conversion and Storage Technologies Unit of the Joint Research Centre of the European Commission. Activities of the unit focus on experimental assessment of hydrogen, fuel cell and battery technologies in terms of performance and safety, supported by numerical simulation. The unit activities provide support to industry-led public-private partnerships, namely the European Fuel Cells and Hydrogen Joint Undertaking (FCH-JU) and the European Green Vehicle Initiative (EGVI).



SETIS FEATURE ARTICLE

Hydrogen as a storage medium - facilitating increased integration of RES

©iStock/powerofforever

The share of RES in the European electric power generation mix is expected to reach about 36% by 2020, 45-60% by 2030 and over 80% in 2050. In some scenarios, up to 65% of EU power generation will be covered by solar photovoltaics as well as onshore and offshore wind. Due to the highly variable nature of these renewable energy sources, where production is subject to both seasonal and hourly weather variability, new systems and tools will be required to ensure that this renewable energy is effectively integrated into the power system.

There are four main options for providing the required flexibility to the power system: dispatchable generation, the expansion of transmission and distribution, demand side management, and energy storage. With regards to storage, a number of options are available, from power to power (P2P) solutions such as pumped hydro, compressed and liquid air, Li-ion, flow and lead-acid batteries, and electrolytic hydrogen production and re-electrification. Power can also be converted to heat and stored for final consumption, or it can be converted to hydrogen for use outside the power sector - as fuel for vehicles or in industry.

Currently the only fully-mature technology is pumped hydro, and this accounts for a large share of the energy storage capacity in the EU. However, there are geographic restrictions on this technology, which limit its widespread use. Other large-scale storage options such as batteries, compressed air storage and hydrogen storage are currently at various stages of development. Hydrogen is widely seen as the most versatile means of energy storage: it can be produced and stored in all scales and used as a fuel or as a raw material in the chemical industry. Hydrogen can be produced from a variety of feedstock, including electricity, and stored in many different ways. Hydrogen gas has the largest energy content per unit mass of any fuel, making it a very good vehicle for holding and distributing energy. With the ability to hold 120MJ/kg, a relatively small amount of hydrogen is needed to store significant amounts of energy. Consequently, conversion of electricity to hydrogen and use of this hydrogen in the gas grid (P2G), in the transport sector or in industry can contribute to the decarbonisation of these sectors and help level out the peaks and troughs inherent in the temporal and geographical variability of RES.

©iStock/jackstudio

The Fuel Cell and Hydrogen Joint Undertaking (FCH JU) supports a number of projects aimed at demonstrating technologies capable of storing hydrogen at a range of scales from small tank storage to large-scale underground storage, and in a variety of forms: gaseous, liquid and solid. The BOR4STORE project focuses on solid-state storage of hydrogen using boron-hydride based materials, while the EDEN project is developing an integrated system for solid-state H_2 storage through an optimised fast-reacting magnesium-based hydride. This system will be interlinked to an energy supply system able to match intermittent energy sources with local energy demand (buildings, small dwellings) in stationary applications. The IDEALHY project (see the liquefaction article in this issue) aims to develop an economically viable hydrogen liquefaction capacity in Europe, while the objective of the HyUnder project is to support the deployment of large-scale H_2 energy storage in underground caverns.

One of the conclusions reached by the HyUnder project was that, while underground storage of hydrogen in salt caverns is technically feasible for large-scale storage of electricity, hydrogen energy storage as a means to store renewable electricity via electrolysis and underground storage is economically very challenging. Consequently, under the given policy framework, the transport sector is currently the only market expected to allow a hydrogen sales price that may enable the commercial operation of an integrated hydrogen electrolysis and storage plant.

The FP7-financed INGRID project aims to combine recent advances in smart grids and hydrogen-based energy storage with a view to matching energy supply and demand and optimising the integration of electricity generated by intermittent RES. The main innovation of the INGRID project will consist of combining solid-state high-density hydrogen storage systems and electrolysis with advanced ICT technologies for smart distribution grids monitoring and control in a scenario of high penetration of renewable energy sources.

To assess the role and commercial viability of energy storage (both P2P and conversion of power to heat and hydrogen), the FCH JU has supported a study on the Commercialisation of Energy Storage in Europe. This study found that very large amounts of energy storage would be required to significantly reduce the required fossil backup even in the case of high RES penetration. Given the scale involved, it is likely that nearly all of the technologies concerned will start running into constraints regarding locations (suitable high-capacity hydrogen storage, elevations for pumped hydro, etc.), and their capex costs will start to rise as they are placed in ever less favourable locations. Of the technologies surveyed, the report found that only chemical storage (notably hydrogen storage) could potentially achieve acceptable economics at this scale.

For this to happen, the necessary regulatory framework will have to be put in place. However, the study also identified some key regulatory obstacles to energy storage, such as a lack of clarity on the rules under which storage can access markets – in particular the inability of transmission system operators (TSOs) and distribution system operators (DSOs) to own and operate storage or purchase transmission and distribution deferral as a service in some countries, or the lack of rules concerning the access of storage to the ancillary services market. Other obstacles include the application of final consumption fees to storage (including P2G), even though storage does not constitute final use of the energy, and payments for curtailment to RES producers, removing an incentive for productive use of the curtailed electricity. That said, the researchers believe that these obstacles can be removed by fair consideration of the role of storage in the electric power value chain.

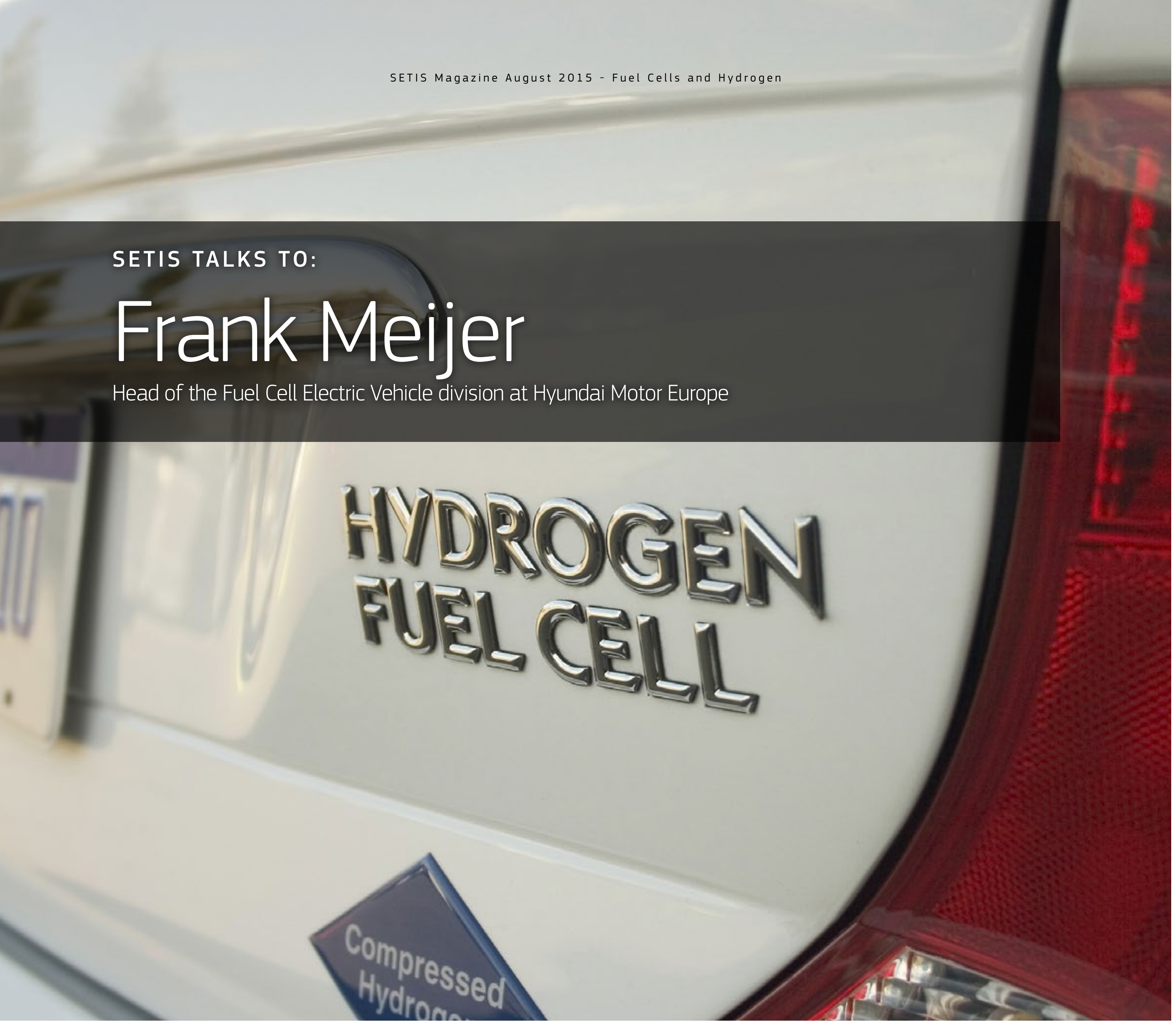
For more information:

http://www.fch.europa.eu/sites/default/files/FCH-PPR14-17Mar2015-web%20%283%29.pdf
http://www.fch.europa.eu/sites/default/files/CommercializationofEnergyStorageFinal_3.pdf
http://bookshop.europa.eu/en/workshop-putting-science-into-standards-power-to-hydrogen-and-hcng--pbLDNA26984/

SETIS TALKS TO:

Frank Meijer

Head of the Fuel Cell Electric Vehicle division at Hyundai Motor Europe



©iStock/gchutka

What is the current status with the development and deployment of fuel cell cars and buses in Europe? What needs to be done to ensure a wider market share for these vehicles?

F.M.: “ Hyundai has taken the challenging role to be the first to bring a mass production Fuel Cell car to the market, meaning that our cars are available for all types of customers. We have now delivered vehicles in 11 countries and we are aiming to add 2 more countries by the end of the year. Infrastructure remains the top priority to get a wider acceptance. ”

Is the development of refuelling infrastructure keeping pace with the deployment of the electric fleet? What are the main challenges that need to be overcome to put the necessary infrastructure in place?

F.M.: “ There are big differences in the deployment of hydrogen refuelling infrastructure per country. The largest European initiative is in Germany, on track to have 50 Clean Energy Partnership stations ready by the beginning of 2016.

Another best-practice country, Denmark, has five stations operational, three under construction to be ready very soon, and three more expected to be ready by the beginning of 2016. What makes the Danish example a best practice is the parallel rollout: commitment for a minimum number of cars at the time the decision is made for a new refuelling station.

This parallel rollout is an important consideration. There are some stations in Europe that are built without planning for users – a situation that is also seen with charging stations being installed for electric vehicles that are simply not being used. To avoid this, we are cooperating on a daily basis with infrastructure providers and hydrogen producers to plan our approach to bring cars where the stations are being built. ”

At a policy level, does the fuel cells and hydrogen sector in Europe receive sufficient support to ensure that it reaches its full potential, or are there other policy measures that need to be considered?

F.M.: “ The EU has several demonstration and research projects in place, not only for vehicles but also for stationary units, all to have less pollution and, equally important, to become independent from fossil fuels.

Under several EU Framework Programmes there has been a commitment made to invest almost EUR 17 billion in hydrogen-related projects.

Cost is a key issue for the market-uptake of fuel cell-powered vehicles. What is needed to make fuel cell technology competitive?

Like with all new technologies, production cost can be successfully reduced in line with lower costs in the supply chain, which in turn come from increased volumes. The cost of the ix35 Fuel Cell is already quite competitive, which is helping to attract new customers to consider choosing fuel cell technology.

Our car works just like any other car: users tell us that they are very surprised how easy it is to drive the ix35 Fuel Cell, especially as they don't have the same anxiety as with electric cars regarding driving range.

But still the most important factor is the infrastructure. This cannot be resolved overnight, and we are realistic, acknowledging that it will take several years to have a sufficiently widespread network of European refuelling stations. ”

In terms of cost and efficiency, how does hydrogen compare to battery technology for powering electric vehicles?

F.M.: “ The most important difference for users in real-world terms is that the Fuel Cell car avoids the limitations on driving range and charging time that are typically associated with a battery-electric vehicle. We believe that there will be a place for battery-electric cars and Fuel Cell vehicles, as well as plug-in hybrids and hybrids. Users will choose the technology that best suits their needs regarding range, vehicle type, cost, and so on.

It is sometimes argued that battery-electric vehicles use electricity more efficiently in transportation. But this does not take into account the energy used to generate the electricity for the battery-electric vehicle. A more accurate comparison would consider total well-to-wheel energy efficiency.

Although generating hydrogen through electrolysis and renewables could be a less efficient pathway, it offers a greater possibility to use otherwise curtailed renewable energy via the inherent storage in the hydrogen delivery system. In this scenario, supply and demand for hydrogen need not be perfectly matched to energy production at all times. Battery energy storage on the grid could alleviate some of this problem, but hydrogen storage inherently provides this function through the delivery system. ”

The transport sector is a major emitter of greenhouse gasses. How significant a contribution can hydrogen make to the fight against climate change?

F.M.: “ Driving a hydrogen-powered car does not emit any greenhouse gases. And there are efforts in place to encourage hydrogen to be made completely from renewable energy sources.

According to forecasts, by 2020 there will be approximately 190 GW of clean wind energy – an increase of 64% compared to 2014. To make optimal use of this, energy storage will play an important role, enabling wind power to be used when it is needed and at the same time provide a 100%-clean source of hydrogen. ”

Frank Meijer

Born in the Netherlands, Frank Meijer has 10 years of experience in automotive retail sales and 13 years in business-to-business sales.

Meijer joined Hyundai Motor Europe in 2012 as European Fleet Sales and Remarketing Manager, before becoming responsible for sales and marketing activities for the Hyundai ix35 Fuel Cell Electric Vehicle in Europe.

On-board hydrogen storage

©iStock/aprott

By next year (2016), an interested environmentally conscious consumer will already be able to choose between three different models of fuel cell vehicles, as Hyundai, Toyota and Honda are bringing hydrogen powered cars to the market. Several other major automakers, including Mercedes, Nissan, Ford and BMW are also developing zero-emission fuel cell electric vehicles (FCEV). The biggest challenge faced by the vehicle manufacturers is to ensure a driving range able to meet customer expectations, with above 500 km driving autonomy and refuelling times and costs similar to those of conventional ICE cars.

Due to the size and weight constraints in vehicles and the physical properties of hydrogen, on-board hydrogen storage is particularly challenging. Although hydrogen has a high gravimetric energy density (120 MJ/kg), its volumetric energy density is the lowest of all common fuels. To increase its volumetric energy density, hydrogen is compressed and/or cooled down, both for transport and storage purposes. Another characteristic of hydrogen is its small molecular size, which allows permeation through most materials. Selection of the right material for the storage system is therefore also challenging and needs further research.

For fuel cell cars to achieve a driving range above 500 km, similar to today's passenger vehicles, around 5 kg of hydrogen should be stored on-board. As mentioned above, in order to store this amount of hydrogen in a reasonable volume, the density of the gas has to be increased. Currently, the most mature technology for storing hydrogen is in compressed form, within high-pressure steel cylinders at around 20 MPa and 50 L volume, but these tanks would be far too heavy and bulky for on-board storage.

The highest gravimetric energy storage densities can be achieved through liquefaction or cryo-compression of hydrogen; however these storage solutions have a high technical complexity and boil-off losses may be incurred. Therefore compressed hydrogen (CGH_2) has become the industry standard for on-board storage. 70 MPa high pressure systems are the most common solution in light-duty vehicles, whereas 35 MPa systems are used for buses. Research is being carried out to optimize the on-board storage system, so that customers can be offered a compact, safe, reliable, inexpensive and energy efficient method of hydrogen storage.

The tanks for CGH_2 have cylindrical shape and are made of carbon fibre reinforced epoxy resin (CFRE) with an internal liner made of steel or aluminium (type 3) or plastic (type 4). The type 4 vessels are cheaper and lighter than type 3 tanks, but they have relatively low thermal conductivity, which is an issue during fast refuelling (5 kg H_2 in 3-5 minutes) since the heat released due to compression during refuelling increases the temperature of the gas inside the tank. The temperature should be kept below 85°C to avoid overheating the liner and the composite wrapping. Overheating can reduce the structural resistance of the tank and thus jeopardise the safety of the storage system. The FCH JU funded HyTransfer project aims to develop and experimentally validate a practical approach for optimizing means of temperature control during fast transfers of compressed hydrogen to keep the gas temperature below the specified temperature limit (gas or material) taking into account the container and system's thermal behavior.

Several projects of the FCH JU have the aim to reduce costs and ensure safety of composite tanks. The project HyComp conducted research on whether it is possible to reduce the safety factor of these vessels, which could help make this technology cheaper. In addition they proposed testing procedures adapted to specific features of composite materials, for type approval, manufacturing quality assurance and in-service inspection. Pre-normative research on resistance to mechanical impact of composite-overwrapped pressure vessels is being conducted by the consortium of the project HyPactor. The project aims at strengthening the knowledge on the influence of mechanical impact with respect to full composite (type-4) high pressure cylinders integrity. The COPERNIC project aims at increasing the maturity and competitiveness of CGH_2 tank manufacturing processes evolving from classical automotive manufacturing technologies or concepts. It also targets costs while improving composite quality, manufacturing productivity and using optimized composite design, materials and components. The project Mathryce focusses on hydrogen compatibility of materials and the development of a methodology for the design and lifetime assessment of hydrogen high pressure metallic vessels that takes into account hydrogen-enhanced fatigue.

Liquid hydrogen storage

Hydrogen in liquid form has a much higher energy density than in its gaseous form at ambient temperatures, even when at high pressures. Liquid hydrogen can be stored at ambient pressures, but the process of liquefaction is energy intensive as it currently consumes more than 30% of the energy content of the liquefied gas. Further optimisation is however possible, as proven by the project IdealHy which developed a highly efficient liquefaction plant concept. In a liquefaction plant, hydrogen is compressed and cooled in a multi-step heat exchange process. Liquid hydrogen (LH_2) is formed below 21.2K, therefore special cryogenic tanks are needed for storage in stationary tanks, for example at a refuelling station, or for distribution of liquid hydrogen in tankers. Liquid hydrogen storage is also implemented for industrial use, and maritime large scale transport of liquid hydrogen is being considered. BMW's prototype hydrogen 7 series vehicles were equipped with a specially designed tank for liquid hydrogen as well as regular gasoline, with a capacity of eight kilograms of hydrogen. Liquid on-board storage in passenger vehicles is no longer being developed by the automotive industry, mainly due to high venting losses associated with boil-off and limited availability of liquid hydrogen.

Cryo-compressed hydrogen storage

Higher density hydrogen storage at lower pressures can be achieved with cryogenic gaseous hydrogen. Thermally insulated pressure vessels with an operating pressure of up to 32 MPa have been developed for hydrogen. Because of the higher maximum pressure, venting losses are much lower than those encountered for liquid hydrogen storage. This storage technology has a high system complexity and additional monitoring of vacuum stability of the thermal insulation is needed to assure continuous performance. Tests are continuing to establish the technical feasibility and safety of this storage technology. Several projects have been supported in Germany by NOW for the validation of this technology.

Materials based hydrogen storage

Hydrogen can be stored in a variety of materials and liquids, based for example on metal hydrides, complex chemical compounds such as sodium boron hydride or liquid organic hydrogen carriers, such as N-ethylcarbozol. Daimler had been investigating another type of storage material, metal organic frameworks, which offer a large surface on which hydrogen can be adsorbed at low temperature. The advantage of chemical storage is that these systems operate at much lower pressures than conventional gaseous hydrogen storage, thereby improving the fundamental safety of the storage system. At present, no solid storage material fulfils the typical targets set for automotive applications. The main issues linked to solid state hydrogen storage solutions are a significant penalty in terms of gravimetric density, poor reversibility, costs, unfavourable kinetics and thermodynamic properties. Some classes of materials perform better than others in different fields, but no material is able to fulfil all the requirements for on-board storage. Reversibility in particular

©iStock/Ics813

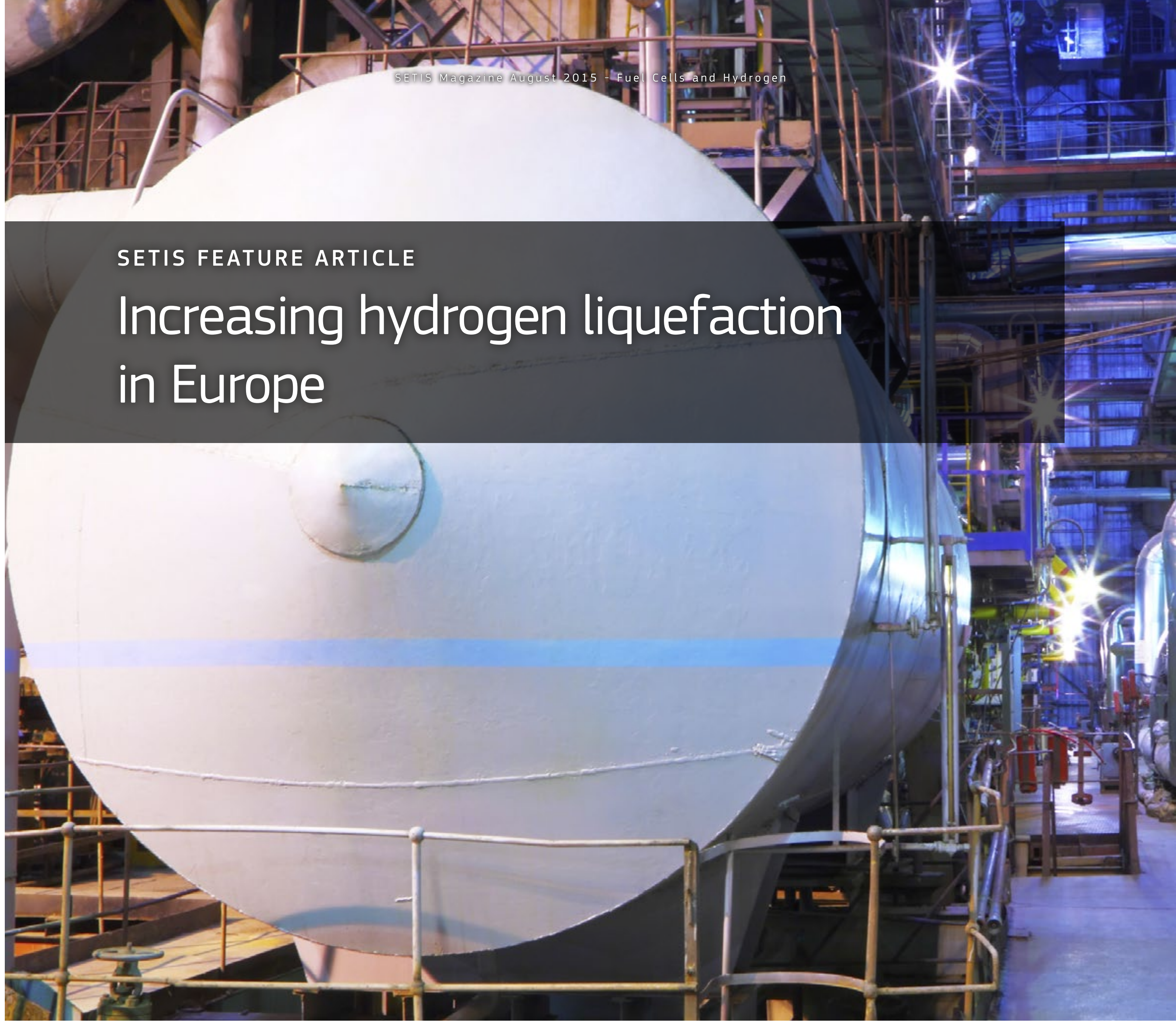
is the biggest discriminating factor in practical applications of solid state hydrogen storage materials. This field remains an active area of academic research. Whereas the goal of finding a solid state material suitable for on-board storage on a car seems elusive, other applications have been identified. The FCH JU has supported research into solid hydrogen storage (a magnesium amide/lithium hydride mixture) to power a 5 kW auxiliary power unit in the project SSH2S. There are few commercially available products utilizing solid state storage and these are commonly based on metal hydrides. Metal hydrides tend to have low gravimetric density, but this is not necessarily a drawback for some uses, such as supplying hydrogen to materials handling vehicles and stationary storage systems. A magnesium hydride (MgH_2) based system has been deployed by the French company McPhy; higher efficiency is achieved due to the use of a phase-change material, which utilizes the heat released during hydrogenation. Small scale storage cartridges are also available for specific portable applications, for example for military use, which the FCH JU project Hyper is developing further. Storage in liquid organic compounds has also been proposed for the distribution of large quantities of hydrogen over long distances with active research being conducted in Germany and Japan by the Chiyoda Corporation.

The on-board storage of hydrogen as a compressed gas can be considered a safe and mature technology, but the biggest obstacle to fuel-cell vehicles deployment remains the lack of hydrogen filling stations. Automakers have signed a joint letter of understanding, addressed to the oil and energy industries, and government organisations, urging for the development of hydrogen infrastructure to allow for a market introduction. There are plans in place to open a signification number of refuelling stations in the next few years, and by 2020 it may well be possible to drive a FCEV all the way across Europe.

Article contributed by

Rafael Ortiz Cebolla
Nerea de Miguel Echevarria
Francesco Dolci
Eveline Weidner

from the Institute for Energy and Transport
of the European Commission Joint Research Centre.



SETIS FEATURE ARTICLE

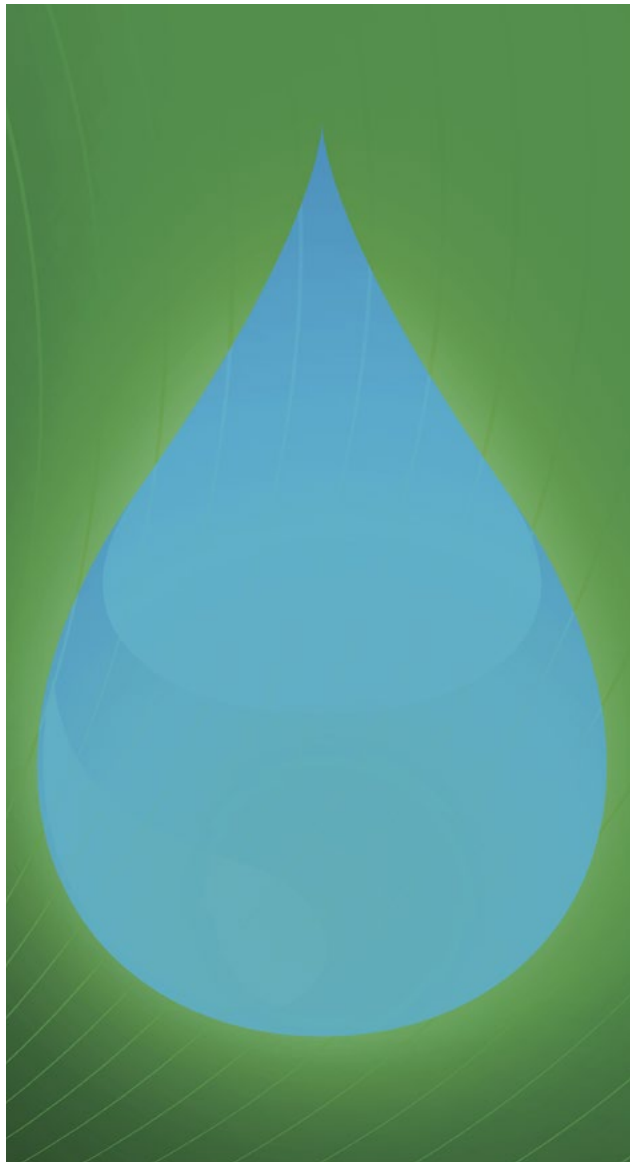
Increasing hydrogen liquefaction in Europe

©iStock/Hramovnick

An excellent energy carrier with respect to weight, hydrogen is widely considered to be the transport fuel of the future. One kilogramme of hydrogen contains 33.33 kWh of usable energy, compared to about 12 kWh/kg for petrol and diesel. In terms of volumetric energy density however, hydrogen is outperformed by liquid fuels. This poses a challenge when transporting hydrogen from where it is produced to the refuelling stations from which it will be distributed to consumers.

In the absence of a pipeline network, liquefaction may be the most economical way of distributing large quantities of hydrogen fuel. However, current H_2 liquefaction technology lacks the necessary capacity and infrastructure to meet potential demand. Funded under the European Union's Seventh Framework Programme, the Integrated Design for Demonstration of Efficient Liquefaction of Hydrogen (IDEALHY) project, which ran from 2011 to 2013, aimed to enable the development of an economically viable hydrogen liquefaction capacity in Europe.

The IDEALHY project brought together world experts to design a generic hydrogen liquefaction process and plan for a large-scale demonstration of efficient hydrogen liquefaction in the range of up to 200 tonnes per day. This represents a substantial scale-up compared to existing and proposed plants worldwide. One drawback of hydrogen liquefaction is the amount of energy the process requires. This is partly due to the very low temperatures required to condense it into its liquid state (about -253°C). The IDEALHY project investigated the various steps in the liquefaction process in detail, using innovations and greater integration in an effort to roughly halve the specific power consumption for hydrogen liquefaction compared to the state of the art (i.e. reduce it to about 6 kWh/kg) while simultaneously reducing investment costs. Essentially, the project aimed to support a viable, economic liquefaction capacity in Europe, to increase economic transportation of hydrogen to refuelling stations and, in so doing, to accelerate investment in hydrogen infrastructure.



©iStock/bmelofo

The IDEALHY liquefaction process uses two successive Brayton cycles[1] with a common compressor train. The refrigerant is a helium/neon mixture ('nelium') selected for optimum compressibility and refrigeration efficiency. The hydrogen is pre-cooled to 130K using a mixed refrigerant (MR), and this MR cycle provides the additional cooling needed for the two Brayton cycles. The current state of the art hydrogen liquefaction technology has a power consumption of 12 kWh/kg, which is equivalent to 36% of the useable energy contained in 1 kg of hydrogen. Based on technology analysis, conceptual work and process optimisation, the IDEALHY project has showed that 6.4 kWh/kg can be achieved, but there is potential to further reduce specific power consumption, pending tests of appropriate components, such as turbo machinery, and operation of a demonstration plant.

The task of the IDEALHY project was to identify the best process for the liquefaction of hydrogen and the components needed to build a high-efficiency large-scale plant. This plant should have a low investment cost, be safe and easy to operate and have a positive cash flow over its life cycle. The project benchmarked existing and proposed processes for hydrogen liquefaction at large scale (>50 tonnes per day) via detailed simulations. The most promising concept was developed further, during which the process was optimised to ensure the lowest possible energy consumption. Investment cost was a consideration, so the amount and complexity of equipment was kept to a minimum, without compromising efficiency. In parallel with this work, discussions were held with equipment manufacturers to ensure the availability of components. The researchers stressed that close cooperation with manufacturers was crucial if the right equipment is to be available for plant construction at a later date.

According to a report produced as part of the project, currently about one commercial hydrogen liquefier is built per year worldwide with a capacity of 5-10 tonnes per day (tpd). Plants with a capacity of up to about 20 tpd will probably be built in the foreseeable future, and will be based on the technology currently available. The lowest capacity for which the IDEALHY technology would be fully usable is about 40 tpd. There is currently no market for a liquid hydrogen production rate in this order of magnitude. Such a plant would however have a lifetime of at least 30 years, during which time the market size will grow. In the meantime, the part-load efficiency of the proposed IDEALHY process means that production will be profitable down to about 25% of the nominal capacity.

According to conclusions reached in the Assessment of Complete Plan report, the area which has seen least discussion in the project, and in which the most work remains to be done, is in the trade-off needed between capital expenditure, operating expenses and efficiency advantages. For future work leading to an actual plant design, it will be crucial to carry out detailed cost engineering on the proposed design and to ensure that the process ultimately selected is economically feasible. Plans are already underway to implement a hydrogen refuelling infrastructure in Europe in preparation of the commercialisation of fuel cell vehicles, and the research conducted as part of this project will make a significant contribution towards the roll-out of this infrastructure.

For more information:

http://www.idealhy.eu/

---

[1] A thermodynamic cycle composed of two adiabatic and two isobaric changes in alternate order. Fuel and a compressor are used to heat and increase the pressure of a gas; the gas expands and spins the blades of a turbine, which, when connected to a generator, generates electricity.

SETIS

Information For Decision-making

http://setis.ec.europa.eu