FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

FUEL CELL AND HYDROGEN TECHNOLOGY: EUROPE'S JOURNEY TO A GREENER WORLD

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10TH EDITION

STAKEHOLDER FORUM

FUEL CELL AND HYDROGEN TECHNOLOGY: EUROPE'S JOURNEY TO A GREENER WORLD

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JOINT UNDERTAKING


Hydrogen
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INTRODUCTION

In 2015, the European Union became a signatory to the landmark Paris climate accord on greenhouse gas emissions mitigation, committing Europe to concrete measures on alleviating global warming. The Paris Agreement was rightly welcomed as a breakthrough in recognising and addressing the threat posed by climate change.

The significance of this should not be underestimated; the European Union, in line with many other signatories, is a modern, industrialised economy that has depended on fossil fuels for power and energy since the Industrial Revolution. The Paris Agreement highlights the dramatic and substantial shift to embracing cleaner, greener fuels and energy technologies. It also signals that the EU is confident in its ability to prosper in this new energy environment.

One of the reasons that the EU can be confident in a clean energy future is because it has pursued a long term strategy to stimulate clean fuel technologies. Initially through the European Hydrogen and Fuel Cell Technology Platform, and more recently with the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), the European Union has committed to supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies.

The technologies are not new; the science behind them is well understood. But, the widespread availability of cheap fossil fuel meant there was little incentive to develop their potential. However, times change and the remarkable work undertaken in the FCH JU is demonstrating the feasibility and viability of these technologies, and helping to bring them to the market.

Although there have been many EU-funded research success stories over the years, the decision to accelerate the development of fuel cell and hydrogen technologies showed remarkable foresight. Conceived when Europe's energy market was dominated by conventional, carbon-intensive technologies, the FCH JU's aims mirror the EU's ambitions to reduce its energy dependency, cut emissions and embrace clean energy sources.

This book sets out the story behind both the FCH JU and fuel cell and hydrogen technology in Europe. It reviews the events leading to its creation and examines the achievements that have allowed Europe to take a leading role in fuel cell and hydrogen excellence.

It will also look at what this investment in fuel cell technology will mean for the EU in the coming years.

ROBERT-JAN SMITS

European Commission – Director-General for Research and Innovation

> I am truly impressed by the hundreds of projects that have been supported so far, and especially by the groundbreaking results coming out of this investment in research and innovation.

It is no exaggeration to say that our future prosperity depends on developing new methods of generating and using energy in a more efficient, sustainable and, above all, environmentally friendly way. This is an enormous challenge, but one that we must fully embrace before it becomes too difficult to deal with the consequences of our reliance on current sources of energy. In fact, we need an energy revolution akin to the invention of the steam engine — but one not dependent on fossil fuels. This will require groundbreaking technologies, which is why research and innovation is at the heart of the European Energy Union.

Some of the seeds of this energy revolution have already been sown. In 2008 the European Commission, working in partnership with key players from a broad range of industrial sectors, launched the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). To date the European Union has committed more than €1 billion to this public–private partnership, and there have been matching contributions from industry. Next year the partnership will celebrate its tenth anniversary, and so now is a good time to take stock of the progress that has been made. It is an ambitious initiative, as the pages ahead will reveal.

I am truly impressed by the hundreds of projects that have been supported so far, and especially by the groundbreaking results coming out of this investment in research and innovation. This joint undertaking has put Europe at the forefront of technology development in key areas, such as fuel cell electric buses, hydrogen refuelling infrastructure, and renewable hydrogen production. The progress set out in this book clearly demonstrates that, with sufficient determination — and investment — it is possible to move towards clean energy solutions that will generate new jobs and stimulate economic growth.

The FCH JU is one of a number of such public–private partnerships supported by the European Commission and exemplifies what can be done by working together across industrial sectors and across Europe. It has contributed to overcoming the fragmentation of the European 'hydrogen community' and is drawing in new players from other sectors.

I congratulate the partners in this initiative for demonstrating that hydrogen-based technologies can offer a viable pathway for the European transition towards a sustainable, low carbon economy, and for bringing us one step closer to realising Jules Verne's 1874 prophecy that hydrogen and oxygen will one day replace coal.

The FCH JU's innovative public-private partnership model demonstrates that Europe is positioned to be a leading player in the coming hydrogen economy.

BENOÎT POTIER
Chairman and Chief Executive Officer of Air Liquide

For economies and energy systems alike, hydrogen energy's benefits and potential are increasingly clear. Some of the world's leading companies now trust, and are using, hydrogen technologies. In Europe, the FCH JU has played a major role in promoting this development. Pursuing a two-pronged strategy, the joint technology initiative helped lay the groundwork for a future hydrogen economy. Firstly, it has consistently channelled its efforts into hydrogen research and innovation in order to improve existing technologies and develop new ones. Secondly, it has supported the deployment of the early phases of the hydrogen infrastructure, with respect to both vehicles and recharging stations.

The projects carried out through this programme demonstrate the technical and early economic feasibility of the hydrogen solution. Through subsidy programmes, they have also enabled key players to start first series production, allowing for a reduced-risk market deployment. In the field of mobility, the HYPE hydrogen taxi fleet in Paris, the first initiative of its kind in the world, which was rolled out under the auspices of the FCH JU's H2ME project, is one example. The substantial support for the H2 MOBILITY German infrastructure project is another. But fundamental steps are also being supported in the field of energy storage, power to gas, and stationary projects. There are too many successful projects to list them all, but here are a few: the HyFIVE and H2ME transport projects; the ene.field and PACE projects, which deployed the first residential fuel cell units for home heating and power; the HYDROSOL-PLANT project for hydrogen production and energy security; and the more recent H2FUTURE project, which is making the case for green industrial hydrogen.

In fact, more than 203 projects have been funded, involving several hundred partners from research and industry, in just ten years. Together, they represent a European effort of more than € 1.5 billion, evenly distributed between public and private sectors.

The FCH JU's innovative public–private partnership model demonstrates that Europe is positioned to be a leading player in the coming hydrogen economy. Along with Japan, Europe has spearheaded the deployment of hydrogen to serve the energy transition. In the ten years since its inception, the FCH JU has proven to be a successful model of cooperation and interconnection between European industrial companies and public authorities. The FCH JU has brought together leading players with a common vision and the technological and financial resources to achieve it, and has made a significant contribution by combining the forces of industry and research into the Hydrogen Europe association, which now has more than 100 members of all sizes, representing every sector and nationality in Europe. The ecosystem created by the model provides a viable environment for industrial investment that would never have formed spontaneously, offering the support and security that has encouraged all stakeholders to participate. The challenge we face now involves intensifying our efforts to enable the large-scale deployment of hydrogen technologies. This will require new regulatory and financial tools to accelerate the uptake of hydrogen and reap the associated benefits. To face the challenges ahead, particularly in research, we must adopt a new financial approach and, as we move towards the industrialisation phase and our ambitions for the future, we must also take into account the achievements of the past ten years.

The establishment of a viable clean energy programme that improves, promotes and deploys fuel cell and hydrogen technologies throughout Europe is proof of the European Union's admirable foresight.

We can and should approach this new opportunity with optimism, positioning Europe and European companies as leaders in clean technology. But we must not forget that this has been, and will continue to be, a long journey and one that, for everyone who has (and will have) played a role in its success, is a justifiable source of pride. After all, we are taking part in nothing less than an energy revolution. Efforts must continue to be made from both sides, but the results achieved so far are an illustration of the virtuous power of a common vision, shared by industry, research and the European Union, serving the major societal goals that lie ahead.

BART BIEBUYCK
Executive Director Fuel Cells and Hydrogen Joint Undertaking

> **We need to keep working together, to keep seeking improvements and innovations, and to make these technologies mainstream.**

The 10th edition of the FCH JU Stakeholder Forum is more than just a milestone, it provides us with an opportunity to take stock, examine where we have come from and take account of how much we have achieved over the last decade. This book is our contribution to capturing the highlights and pivotal moments in our journey. It will provide recognition for the people and the events that have brought us to where we now stand.

Inevitably, we need to start with our roots, the High Level Group on Hydrogen. It was this initiative, conceived by Romano Prodi and former European Commissioners Loyola de Palacio and Philippe Busquin, that planted the seed for the FCH JU. In any retrospective account of this subject, it is vital to give recognition to them for their foresight in identifying how pivotal green energy sources would become and the role of hydrogen technology in making clean energy a reality.

It's easy to forget how different the political landscape was a decade ago at the launch of the FCH JU. Climate change was a concern, but there was nothing like the ubiquitous recognition of the need to act that we see today. The 2015 Paris Agreement on tackling climate change and the EU's Energy Union plans would have been difficult to envisage at that time. Yet the last ten years have demonstrated that the FCH JU model has been the ideal vehicle for converting these once marginal technologies into applications set to drive Europe's transition away from fossil fuels, addressing the ambitions of Europe's politicians and the needs of its citizens. In doing so, the EU has taken a sector that was neglected and under-exploited, and made Europe a global leader in the field and a beacon for green hydrogen and fuel cell technologies.

It also needs to be remembered that the FCH JU has helped to pioneer new kinds of public–private partnerships. The first FCH JU created a community that allowed the innovation inherent in SMEs to thrive while working with, and benefiting from, interaction with large organisations. The second iteration saw us turn that enthusiasm and effort into real solutions to real challenges.

However, as well as celebrating past achievements, we also need to look to the future. This is not the end; the next step must be to use what we have all achieved in FCH JU 1 and 2 to drive the changes that we sought at the outset. Having worked hard to get the blend of energies correct, we need to keep working together, to keep seeking improvements and innovations, and to make these technologies mainstream.

We hope you enjoy our book as much as we have enjoyed the last ten years of the FCH JU.

01 FUELS CELLS AND HYDROGEN – LEARNING FROM HISTORY

The Fuel Cell Hydrogen Joint Undertaking (FCH JU) is a flagship initiative for Europe, placing it at the cutting edge of clean, sustainable energy sources for transport and energy for the foreseeable future.

Yet despite the 21st-century technology, the historical roots of the FCH JU vision can be traced back more than 40 years. Events at that time changed how governments around the world viewed their dependence on fossil fuels. Ultimately, this led to Europe taking the leadership in developing fuel cell technology.

In the early 1970s there seemed to be boundless optimism around what science could achieve. The global economy was booming, while technological change was happening at an unprecedented rate; men were walking on the moon, spaceships were travelling to the outer reaches of the solar system. Consumer goods were increasingly affordable; air travel was opening up to the mass market – even supersonic aircraft were a reality. It seemed the world was shrinking and potential was endless.

Almost overnight, that optimism disappeared, replaced by an energy security crisis. In 1973 the Organization of Petroleum Exporting Countries (OPEC) announced an embargo and the price of a barrel of oil rapidly quadrupled. The economic and technological boom came to a juddering halt.

For governments, the OPEC embargo was a major wake-up call, forcing a change in their energy strategies. Many realised that relying on sources that they could not control or secure could lead to a recurrence of the crisis. Inevitably, this provided a stimulus for identifying and developing alternative energy sources. Domestic fossil fuels, nuclear power and renewable sources such as wind and solar energy became increasingly important.

Different countries and areas adapted according to their available resources and ability to meet the challenges. The US, with sizeable indigenous supplies of crude oil, was less reliant on OPEC. Other regions and countries took different paths.

European countries lacked access to such natural resources. However, the then European Economic Community (EEC) took its own steps to reduce oil dependence, developing expertise in building fuel-efficient engines and vehicles. The European Commission also realised the potential offered by the existing, but underdeveloped, fuel cell and hydrogen technologies.

The EU's decision to implement the European Hydrogen and Fuel Cell Technology Platform and subsequently the Fuel Cells and Hydrogen Joint Undertaking has proved a game-changer. These initiatives have taken Europe to the forefront of fuel cell and hydrogen technology. The projects sponsored by the FCH JU over the last ten years have addressed the activities necessary to take these technologies from laboratory benches to real-world applications on the threshold of mass-market production. It has also helped Europe to establish world-leading expertise in developing better and more efficient fuel cells and green hydrogen production.

Europe's decision to pursue these technologies has proved a prescient one. Not only has it delivered major strides towards guaranteeing the EU's future energy security, it has also provided the tools to meet future commitments to emission-free energy production. In so doing, it has created a strong and thriving industry sector, from SMEs to European multinationals that stand to benefit from a growing market.


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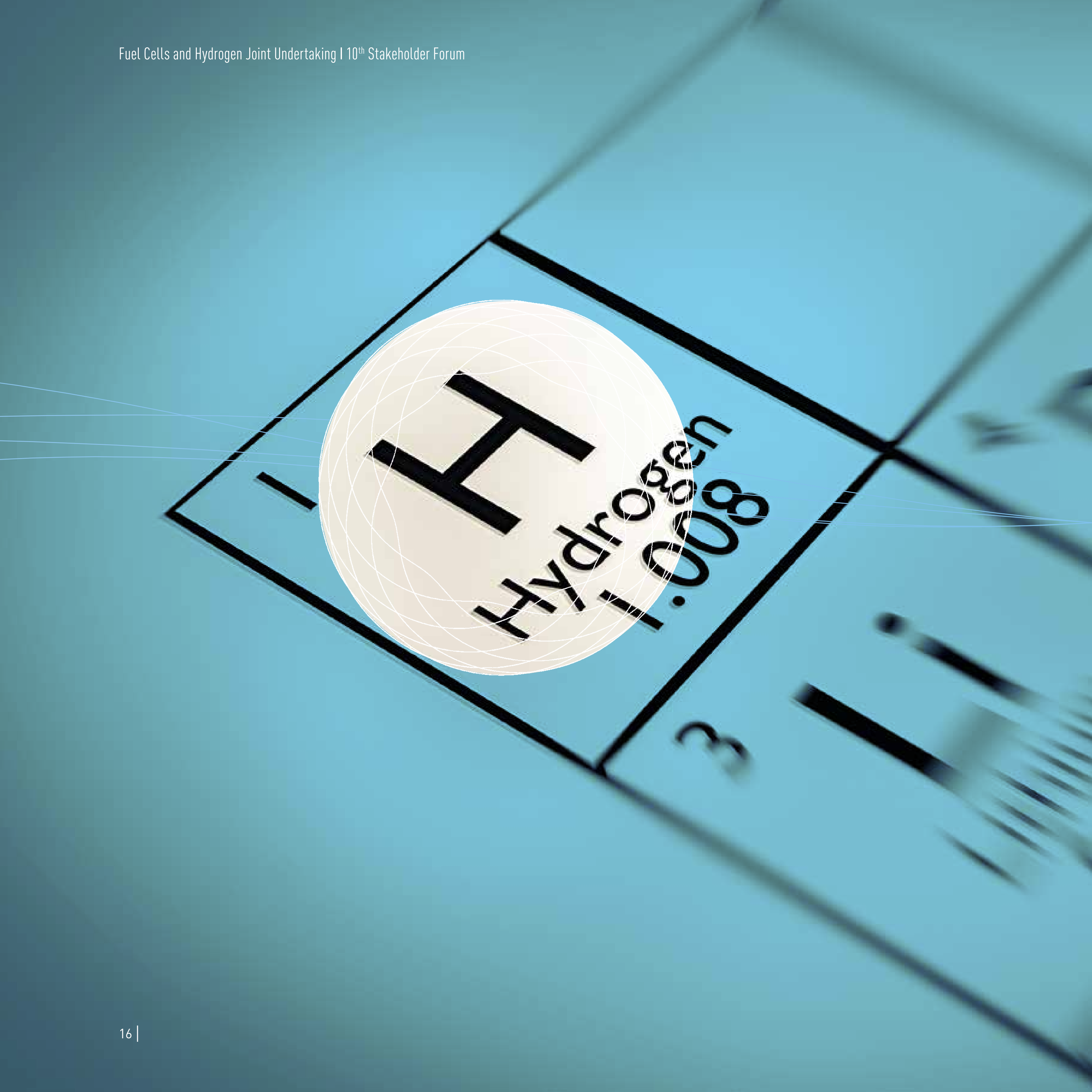
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02

MAKING THE VISION A REALITY: ORIGINS OF THE FCH JU

The clean energy transition is likely to be more technologically disruptive and globally transformative than any previous industrial change. US economic and social theorist, Jeremy Rifkin, chose his words well when he termed the world's post-carbon future as 'the third industrial revolution'.

At the heart of Rifkin's revolutionary vision was a hydrogen-based economy. Clean, abundant and infinitely renewable, the merits of hydrogen and fuel cell technologies were well known for decades. Despite this, the first hydrogen pioneers worked alone or in small groups, often struggling for recognition.

However, the oil crisis of the 1970s transformed attitudes to energy overnight, catalysing Europe's five-decade long transition towards clean energy. That journey – in many ways as much an energy evolution as a revolution – highlighted the potential of hydrogen and fuel cells as a bridge to realising Europe's sustainable energy future, in which electricity and hydrogen would be the dominant energy carriers.

By the 1990s, Europe was increasingly dependent on fossil fuel imports. Concerns that this could seriously undermine the European economy, led to then European Commission President Romano Prodi taking a personal interest in fostering the political will to invest in fuel cell and hydrogen solutions as enablers of a clean energy system.

The European Commission's Green Paper of November 2000 entitled, "Towards a European Strategy for the Security of Energy Supply", outlined the twin challenges facing Europe in safeguarding its energy supplies and in tackling climate change. This crucial consultation paper helped define the EU-level debate on the need for an active energy policy, the role of renewable clean energy and the threat posed by global warming.

We are on the cusp of a third industrial revolution and a new energy era. Hydrogen is our common future. *Jeremy Rifkin*

Our goal is for sustainable and clean energy to be the inheritance of all the world's people by the middle of this century. By achieving that goal we shall contribute to quality of life, peace and stability the world over. *Romano Prodi*

HYDROGEN'S POTENTIAL: "A NEW UNIVERSAL ENERGY CARRIER"

Included in the Green Paper were proposals to intensify hydrogen research. Even at this early stage, hydrogen was recognised as a priority solution, as "fuel for vehicles of the future", and for clean urban transport. The then European Commissioner for Transport and Energy Loyola de Palacio, announced that, "Hydrogen as a potential new universal energy carrier has attracted our special attention."

Much like Romano Prodi, de Palacio became an enthusiastic supporter of hydrogen and fuel cell technologies, particularly the uptake of hydrogen-fuelled transport.

Just a few years after the turn of the century, the EU was funding around 70 research and development projects, among them the CUTE demonstration project trialling a fleet of hydrogen fuel cell buses across nine European cities. De Palacio was immensely proud when her hometown, Madrid, began operating these first buses in June 2003.

Yet despite EU success stories like the CUTE project and increasing investment through the four-year EU Research Framework funding programmes, support was disparate and often solely for individual projects. This meant that, when potential discoveries and breakthroughs emerged, their developments were not always realised.

As new and emerging technologies, hydrogen and fuel cells face a complex system of interconnected barriers involving the market, technology, financing and public perceptions. Even where a major milestone is reached in one area of hydrogen and fuel cell development, there is often a long way to go before it can be effectively deployed. The cause-and-effect dilemma of building hydrogen fuelling stations and developing hydrogen-powered cars was a clear case in point. The public weren't going to buy a car that is inconvenient

> **Europe's society deserves the best. Therefore we seek to develop and deliver world class technology meeting ambitious objectives for sustainability.** *Philippe Busquin*

or impossible to refill, while private businesses were not willing to invest in installing hydrogen fuelling stations until the public were driving hydrogen vehicles.

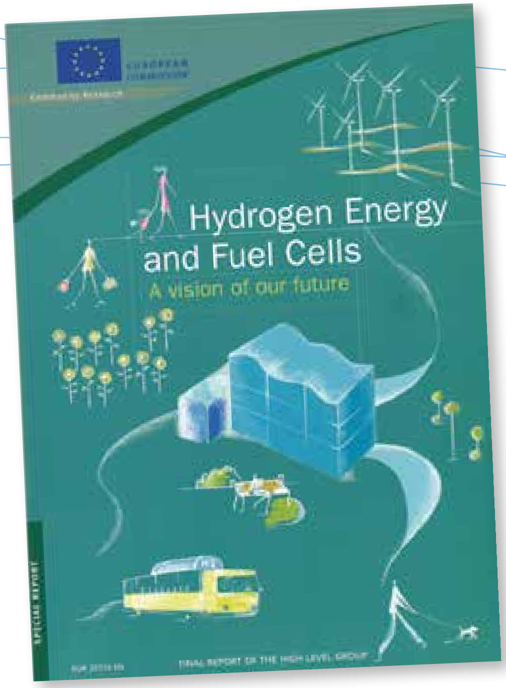
EU policymakers realised that until they could achieve sufficient number of adopters, developers or innovators, hydrogen energy would not gain traction in energy and transport systems. This notion of reaching a self-sustaining 'critical mass' became increasingly important as the EU's energy research and development architecture evolved.

COLLABORATION TO MAKE THE STRATEGIC VISION A REALITY

For the EU's hydrogen ambitions to be fulfilled, innovative collaboration between sectors and a clear strategic vision were essential. De Palacio recognised that a traditional research and development approach was just not going to work, arguing that: "An integrated development for energy and transport sectors is particularly important."

Step forward Philippe Busquin, the then European Commissioner for Research, who also recognised that collaboration was the key to successfully delivering hydrogen and fuel cell technology. "The challenge before us is a substantial one," said Busquin, adding, "We must set up structures and partnerships capable of developing and implementing future hydrogen and fuel cell energy systems: systems that will eliminate or substantially reduce the negative aspects of those we rely upon today."

Thanks to Busquin and de Palacio's prescience, a High-Level Group for Hydrogen and Fuel Cells Technologies was established in 2002. That decision not only paved the way for the eventual creation of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) but was also a turning point in Europe's recognition of the potential of hydrogen as a clean energy for the future.



"The Vision Report in 2003 defined the importance and the relevance of hydrogen and fuel cells for a sustainable energy system. This was the first milestone; the first time that hydrogen and fuel cells were treated as a single important topic by the Commission."
Joaquin Martin-Bermejo, former Policy Officer, DG Research and Innovation, European Commission

Addressing the High-Level Group's inaugural meeting, Busquin said, "Fuel cell technologies are expected to play a key role in a future economy in which electricity and hydrogen become principal and interchangeable energy carriers."

The High-Level Group involved nineteen hydrogen-power stakeholders and included representatives of the research community, industry, public authorities and end-users. They were asked to outline the steps needed to enable a sustainable hydrogen-oriented economy. Within six months, the group had prepared its outline on how hydrogen and fuel cell technologies could help Europe to meet its sustainable energy aspirations.

Its key recommendations included the creation of a Hydrogen and Fuel Cell Technology Partnership, a strategic Research Agenda, a Deployment Strategy and a European Roadmap.

The fundamentals of the High-Level Group's recommendations were that together, hydrogen and fuel cells could open the way to integrated 'open energy systems', capable of addressing energy and environmental challenges and adapting to a variety of intermittent renewable energy sources.

Through strategic planning and increasing effort in the research, development and deployment of hydrogen and fuel cell technologies, a more structured approach to energy policy, research, education and awareness could be developed. Coordination was the essential buzzword: coordination in balancing the interests of all stakeholders and in generating that all-important critical mass, deemed essential for market entry.

"By their very nature hydrogen and fuel cell technologies were disruptive — so, it's not as simple as just saying, 'This is an evolution; this is a new technology; just change one bit with another one that performs better' — it's the whole transformation of a sector."

Agustin Escardino Malva, Deputy Head and Acting Head of Renewable Energy in DG Research and Innovation, European Commission and former member of executive group in the FCH Technology member

"It wouldn't have happened without a European strategy. The main target was to overcome fragmentation and to achieve something in a coordinated way."

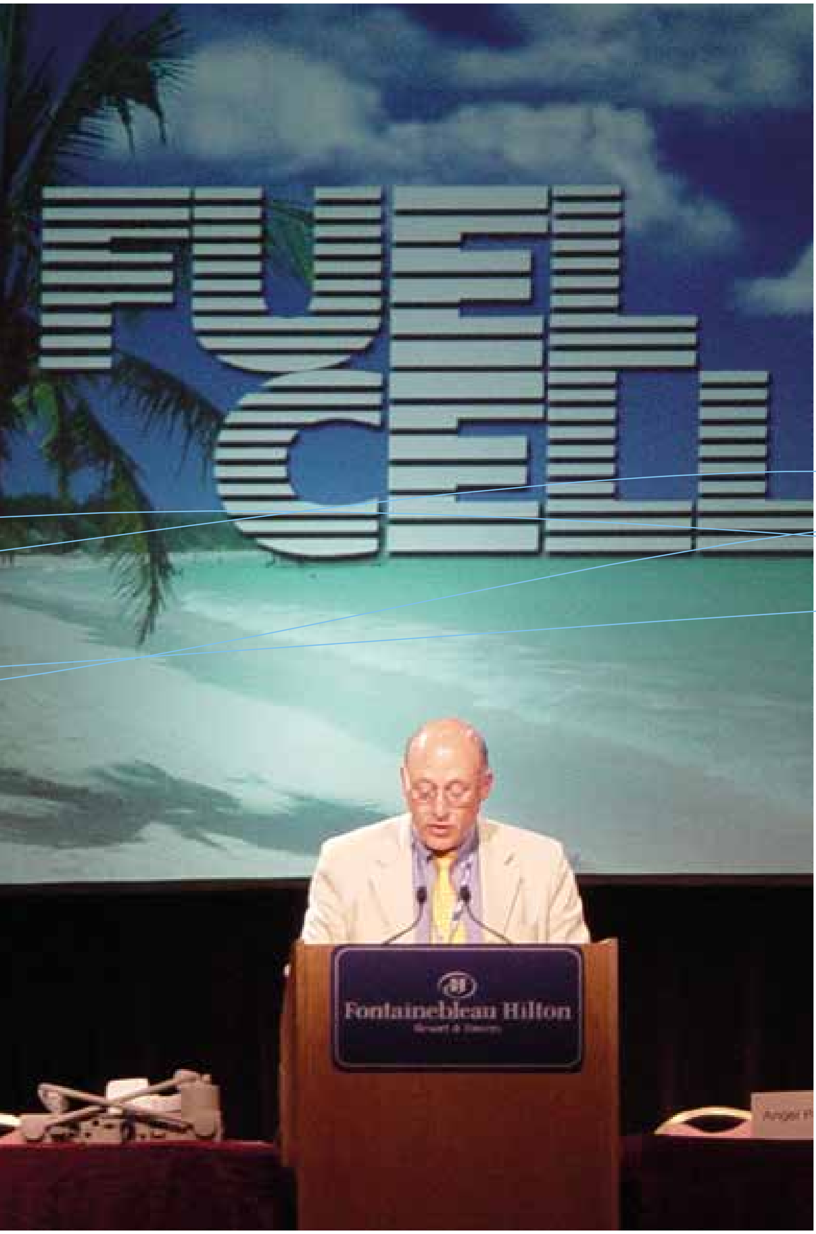
Professor Detlof Stolten, former member of the Hydrogen and Fuel Cell Technology Platform

The High-Level Group also emphasised the sizeable investment and potential risks inherent in delivering the advanced research, development and deployment that would be required to mobilise a hydrogen-based economy. The key to tackling these barriers lay in cross-business and cross-border cooperation, and these would need to be supported by public agencies.

They believed these efforts could be underpinned through an EU plan, a Strategic Research Agenda with the aim of focusing research resources more efficiently on the most promising solutions. By bringing together top research groups in Europe, the strategy would achieve much more than many projects carrying out uncoordinated research.

The final report of the High-Level Group made it clear that their hydrogen vision could not materialise by itself and would depend on a complex interaction of policy, business and academia. "Europe must substantially increase its efforts and budgets to build and deploy a competitive hydrogen technology and fuel cell industry. This should not be left to develop in an uncoordinated fashion, at the level of individual Member States. Gaining global leadership will require a coherent European-level strategy, encompassing research and development, demonstration, and market entry".

The Group called for the urgent formation of a public-private partnership that should include the most important and innovative companies working on hydrogen and fuel cells in Europe as well as hydrogen experts, policymakers and other stakeholders.



"The High-Level Group was set up to assess the feasibility of hydrogen as an energy vector for complementing electricity. Hydrogen was very promising in this regard – plus clean vehicles, clean energy production, democratisation of energy – and a lot of beautiful things."
Angel Perez Sainz, former Head of unit, DG Research and Innovation, European Commission

Synchronising business and policy interests would be the key to supporting a hydrogen economy. Steered and monitored by an advisory council, these actors should work together to set out clear and harmonised objectives and commercialisation targets, create policies, business developments, demonstrations, educational initiatives and recommendations that would benefit all actors in hydrogen and fuel cell technology.

FUEL CELL TECHNOLOGY PLATFORM

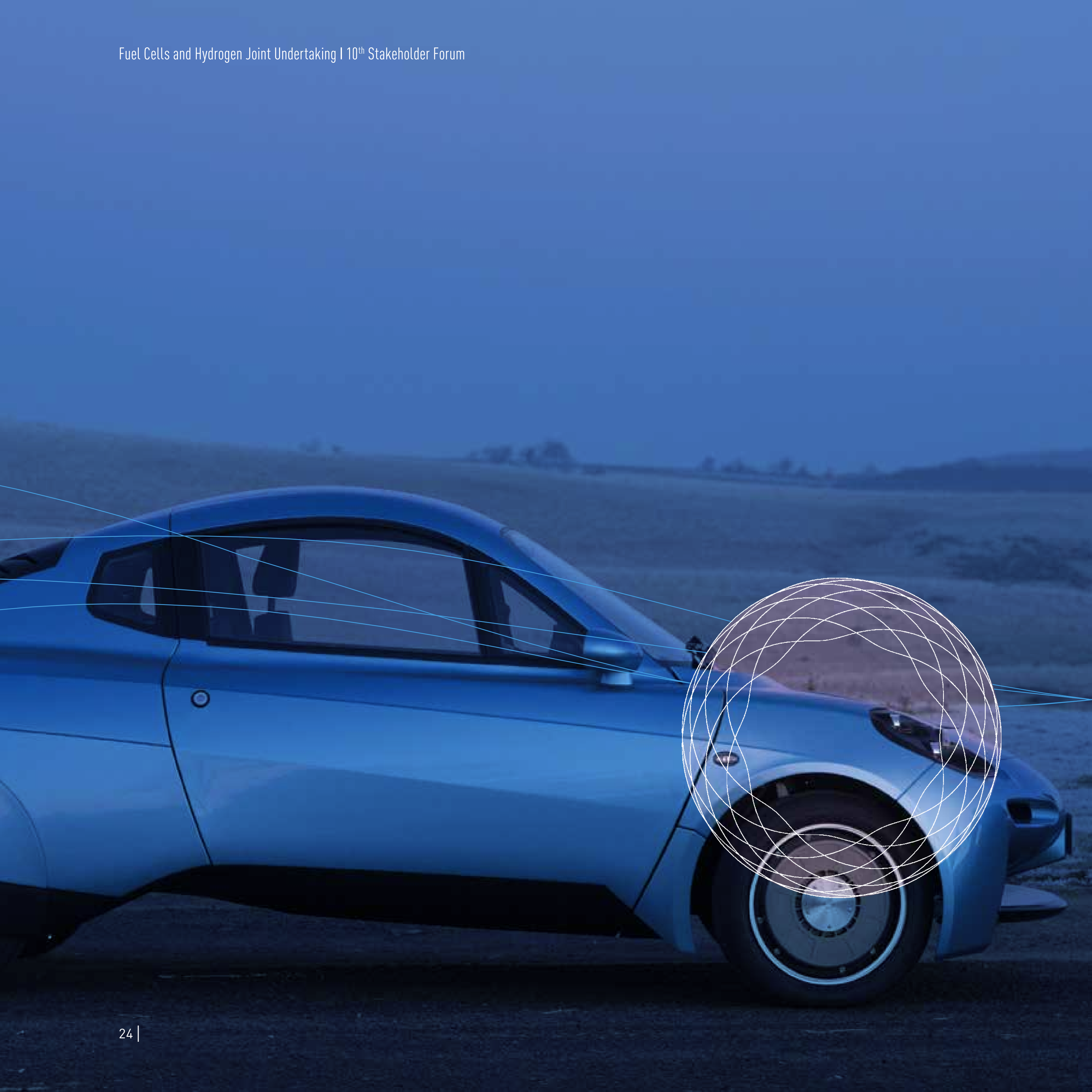
In January 2004, the first steps towards the Joint Undertaking began, with the launch of the European Hydrogen and Fuel Cell Technology Platform. Announcing the platform's launch, Romano Prodi said, "Our objective is to realise a step-by-step shift towards a fully integrated hydrogen economy, based on renewable energy sources, by the middle of the century. To turn this vision into reality, however, Europe needs more research, larger demonstration and deployment projects, and regulations and standards appropriate to the future hydrogen economy. These efforts will be successful only if national and European resources, both public and private, are pulled together in a co-ordinated way. This is why we are launching the European partnership for the hydrogen economy."

Joaquin Martin-Bermejo, who acted as secretary for the European Hydrogen and Fuel Cell Technology Platform member states Mirror Group, says the platform was considered the best way to move things forward. "The existing research and technological development approach within the then EU 15 as well as separate industry efforts were just not sufficient in providing the minimum critical mass needed to take the technologies to market and to compete against more advanced regions such as the US and Japan."

As Prodi had hoped, the Platform brought together, for the first time, the European Commission, industry and other stakeholders from across the fuel cell and hydrogen energy supply chain — all committed to putting hydrogen on the clean energy map.

The Platform's task was to identify the triggers for 'disruptive' technologies, and incorporate them into an overall plan. Early markets would need to be consciously identified and targeted with appropriate market strategies, and large-scale demonstration projects would be used to enter the public sphere and accelerate market entry.

The Platform played a key role between 2004 to 2007 in laying the groundwork for hydrogen development – just as the EU took the decisive step to develop a common energy policy. The Platform also set the stage for the creation of the Fuel Cells and Hydrogen Joint Undertaking.



PROGRESS

03

From the High-Level Group to the FCH JU


New Energy World
JTI

THE FOUNDING OF THE FCH JU

The European Hydrogen and Fuel Cell Platform (HFP) was tasked with coordinating a European strategy to develop and exploit the potential of a hydrogen-based economy.

Following the positive reception of several strategy papers, in particular the Strategic Research Agenda, the Deployment Strategy and the Implementation Plan – Status 2006, the HFP concluded that fuel cells and hydrogen could play a key role in Europe's shift towards new and clean energy technologies.

But to break into the mainstream transport and power generation markets, a set of common research, development and deployment strategies, and objectives for fuel cells and hydrogen would need to be developed.

This heralded the creation of the Fuel Cells and Hydrogen Joint Undertaking, established by a Council Regulation on 30 May 2008 as a public-private partnership between the European Commission, European industry and research organisations, with the objective of accelerating the development and deployment of fuel cell and hydrogen technologies.

With an industry-led implemented structure, the FCH JU synchronised public and private interests, reinforcing the industrial commitment to move forward with this technology.

OBJECTIVES

GREEN HYDROGEN PRODUCTION
Increase efficiency and reduce costs of hydrogen production, mainly from water electrolysis and renewables

CLEAN TRANSPORT
Reduce fuel cell system costs for transport applications

MINIMAL USE OF CRITICAL RAW MATERIALS
Reduce platinium loading energy system

H2 STORAGE FOR GRID BALANCING
Demonstrate on a large-scale hydrogen's capacity to harness power from renewables and support its integration into the energy system

HEAT & ELECTRICITY PRODUCTION
Increase fuel cell efficiency and lifetime

STRUCTURE, FUNDING AND MISSION

Initially operating under the Seventh Research Framework Programme (FP7) with a budget of €940 million, the first phase of the FCH JU ran for six years until 2014. Its success in supporting research, technological development and demonstration activities in fuel cell and hydrogen energy technologies in Europe was recognised by the decision to continue and extend funding under the EU Horizon 2020 Framework Programme.

This latest phase, which will run until 2020, has a total matched budget of at least €1.33 billion provided by the public-private trio involving the European Commission, the industry grouping Hydrogen Europe and the research grouping Hydrogen Europe Research.

Unique among the EU's Joint Undertakings, the FCH JU's three-way public-private partnership approach to the development and deployment of fuel cell and hydrogen technologies extends beyond the capacity of single companies or public research institutions in terms of financial commitment, resources and capability.

The FCH JU programme is built around two main research and innovation pillars. Pillar one – energy systems – covers fuel cells for both power and combined heat and power generation, hydrogen production and distribution and hydrogen for renewable energy generation. The second pillar covers transport, specifically covering road vehicles, non-road mobile vehicles such as construction and material handling vehicles, refuelling infrastructure and maritime, rail and aviation applications.

STRUCTURE

ENERGY

- Fuel cells for power and combined heat and power generation
- Hydrogen production and distribution
- Hydrogen for renewable energy generation (and blending in natural gas grid)

CROSS-CUTTING ISSUES (STANDARDS, CONSUMER AWARENESS, MANUFACTURING METHODS, STUDIES)

- Road vehicles
- Non-road mobile vehicles and machinery
- Maritime, rail and aviation applications
- Refueling infrastructure

TRANSPORT

BUDGET

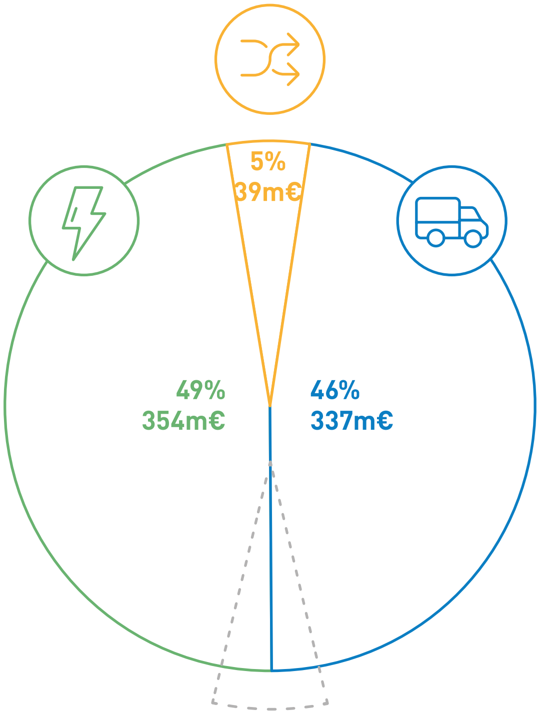
34 CROSS-CUTTING PROJECTS
(e.g. standards, safety, education, consumer awareness, ...)

114 ENERGY PROJECTS

Hydrogen production and distribution

Hydrogen storage for renewable energy integration

Fuel cells for power & combined heat & power generation



52 TRANSPORT PROJECTS

Road vehicles

Non-road mobile vehicles and machinery

Refueling infrastructure

Maritime, rail and aviation applications

3 OVERARCHING PROJECTS

As of 1 January 2017

Complementing and supporting these two main pillars is a third, which encompasses cross-cutting activities including safety issues, standards, consumer awareness, manufacturing methods and studies.

The overarching aim of the FCH JU is to build bridges between today's advanced technology and tomorrow's widespread deployment, by ensuring that its annual competitive open calls for proposals are determined solely by genuine market needs.

FUNDING FOR RESEARCH AND DEVELOPMENT

The FCH JU provides financial support in the form of grants for promising research and demonstration project proposals. These have to obtain the highest scores against a range of selected criteria in a rigorous independent evaluation procedure.

Since 2008, more than 200 research and demonstration projects have benefited by sharing in approximately €730 million of funding from the European Union. This FCH JU funding 'bridge' enables some of Europe's top-ranked research teams to dedicate their expertise to advancing technology and reducing costs in these key technologies, by delivering real-life testing of hydrogen and fuels cells and ensuring that users have the opportunity to experience the benefits of hydrogen and fuel cell technology.

A core advantage of the FCH JU's public-private triumvirate structure is the ability to ensure that the most promising projects stimulate industry to invest further in development and production. By bringing these technologies to the point of market breakthrough, the FCH JU plays an essential role in delivering on the potential of hydrogen and fuel cell technology.

PROGRESS IN EUROPEAN POLICY

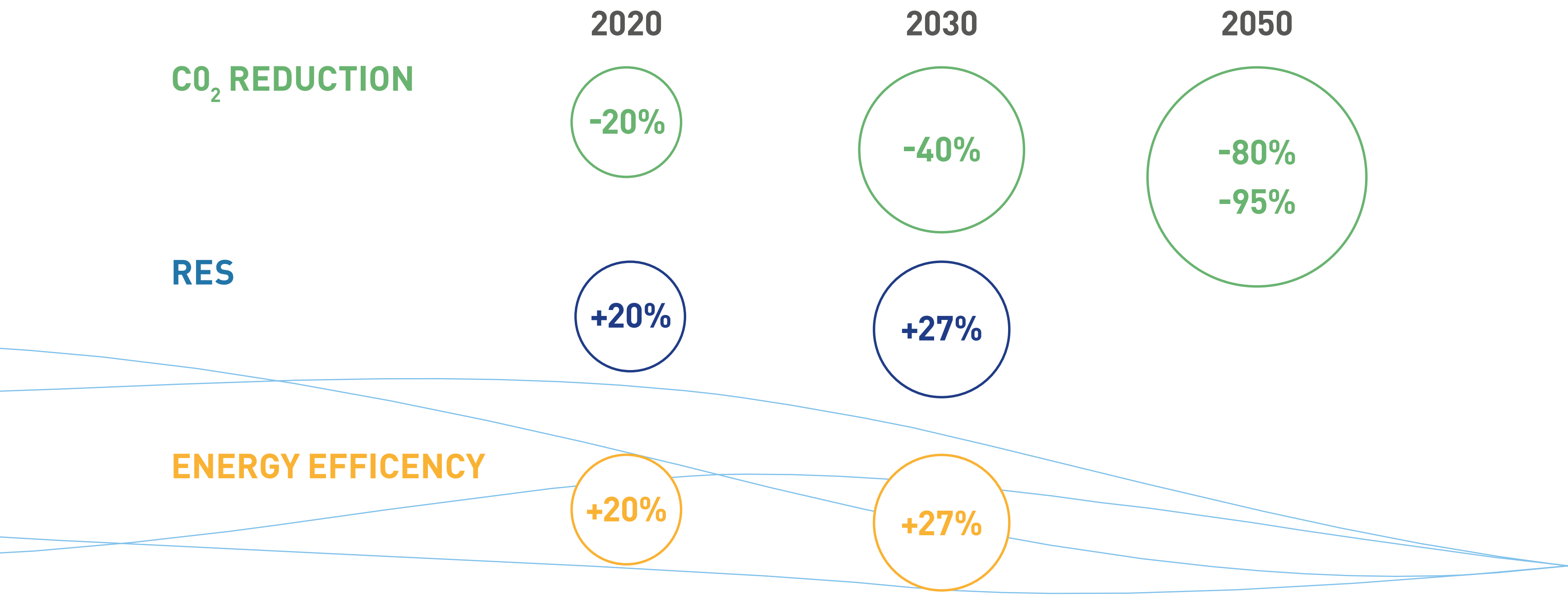
The first recognition of fuel cell and hydrogen technologies in European energy policy was in the European Strategic Energy Technology Plan (SET-Plan) in 2007, referring to the commercialisation of hydrogen fuel cell technologies as a 'key EU technology challenge for the next ten years'.

The SET-Plan called for a change in how research funding programmes were delivered, citing the forerunner of the FCH JU, the 'Fuel Cell and Hydrogen Joint Technology Initiative', as a 'prime example of such a change, [...] a programme of research and demonstration with industry in a new, European public-private partnership'.

Since then, subsequent energy and climate policies have emphasised energy efficiency, energy security and a decarbonised energy system – priorities that can be addressed using fuel cell and hydrogen-based technologies.

Significantly, the 2016 Sustainable Energy Security Package highlighted the importance of gas in Europe's energy transition and included the EU's first-ever heating and cooling strategy, identifying 'stationary fuel cells' as innovative and highly efficient technologies near market readiness.

The November 2016 Clean Energy for all Europeans policy package highlighted the role of renewable gas, including green hydrogen, in renewable energy targets. The FCH JU has supported green hydrogen production and the development of hydrogen production and storage. However, energy storage, including hydrogen, has not yet been developed to its full potential, an issue highlighted in the European Commission's 2017 Staff Working Document on energy storage that prioritised the development of affordable and integrated energy storage solutions.



Fuel cell and green hydrogen-based technologies can contribute towards reaching the 2050 target of 60% reduction in transport greenhouse gas emissions. Goals for 2020 include a 10% share of renewable energy in transport – a target that could be met by in part by clean, green, renewable hydrogen. And the ongoing review of the CO_2 standards directive is driving carbon limits down to such an extent that innovative fuel cell electric vehicles powertrains are fast becoming commercially viable. Meanwhile the 2014 alternative fuels infrastructure directive has fostered the inclusion by several EU Member States of hydrogen in their national planning, including the deployment of new hydrogen refuelling stations.

Fuel cell and hydrogen-based technologies can play a part in transforming the transport sector's three key domains; energy, powertrains and infrastructure – if supported by the right policy framework and supported by Member States.

The EU's environmental policies have been another factor in driving the uptake of fuel cell and hydrogen-based technologies and highlighting the work of the FCH JU, with the 2013 Clean Air policy package proposing reductions and limits of certain atmospheric pollutants.

A recent International Energy Agency 'technology roadmap' report concluded that hydrogen can help achieve low-carbon transport; help integrate renewable energy into the energy system, and contribute to decarbonisation across several industry sectors.

No longer on the edge of the political and legislative debate, fuel cell and hydrogen-based technologies are now recognised for what they are, key enablers for Europe's low-carbon transition.

EMITS ONLY H_2O	NO MOVING PARTS	NO COMBUSTION	VERSATILE

HOW THE TECHNOLOGY WORKS

WHAT IS A FUEL CELL?

In simple terms, a fuel cell is a device that generates electricity through a chemical reaction between hydrogen and oxygen. Unlike batteries, fuel cells can produce power continuously as long as fuel and oxygen are available. The fuel cell is not a recent invention; it was first described by the Welsh scientist William Grove in 1838.

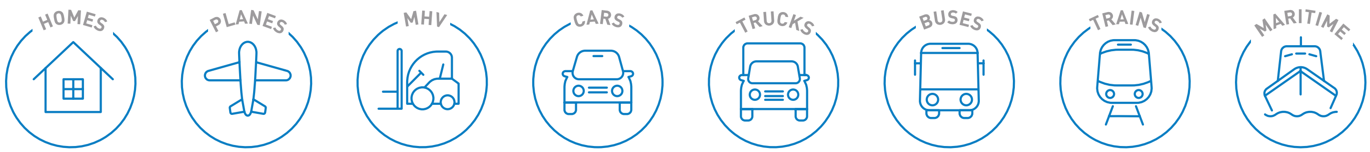
The abundance of cheap oil meant the potential of fuel cells as a power source was almost forgotten; they did not see a renaissance until more than 100 years later. The first practical application of fuel cells was on NASA's Gemini space programme in the 1960s. The technology was light and reliable, and both hydrogen and oxygen were already available in the spacecraft. In addition, the fuel cells even produced drinking water as a by-product.

Modern fuel cells are increasingly reliable and flexible, with different technology types for different applications; small enough to install in a family car or large enough to provide the power needed for steel production.

THE ADVANTAGES OF FUEL CELLS

- Fuel cells emit only water. They produce no CO_2 emissions, which are largely responsible for global warming, nor atmospheric pollutants such as NOx, SOx, or particulate matter.
- They have no moving parts, making them quiet and reliable.
- They do not rely on combustion to release energy; this makes them highly efficient, as little energy is wasted in heat.
- They are versatile: fuel cells can be tailored to produce energy (electricity and/or heat) in different amounts, and can be used in applications ranging from vehicles to actual power generators, be it at domestic or industrial levels.

Applications Area

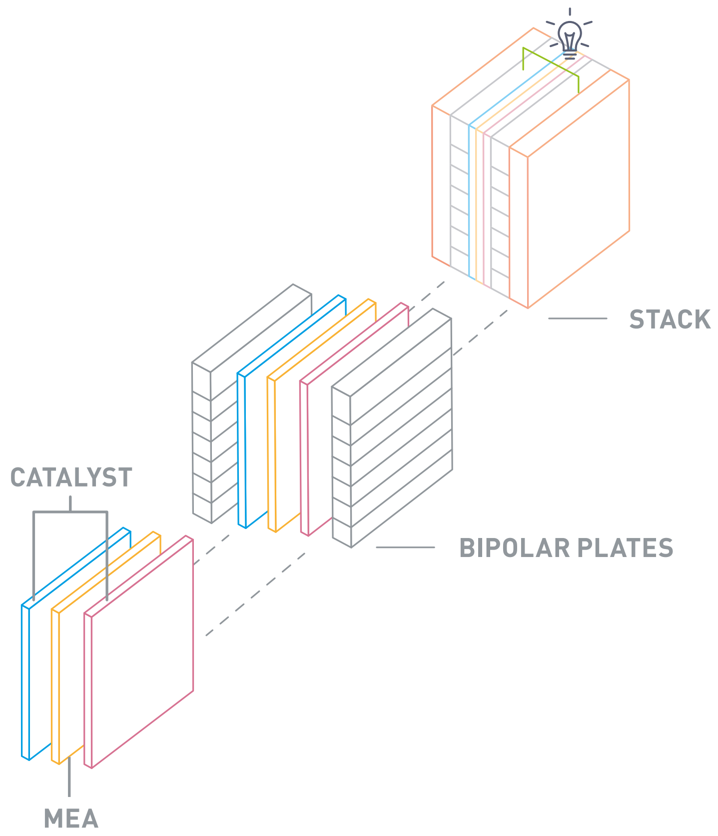


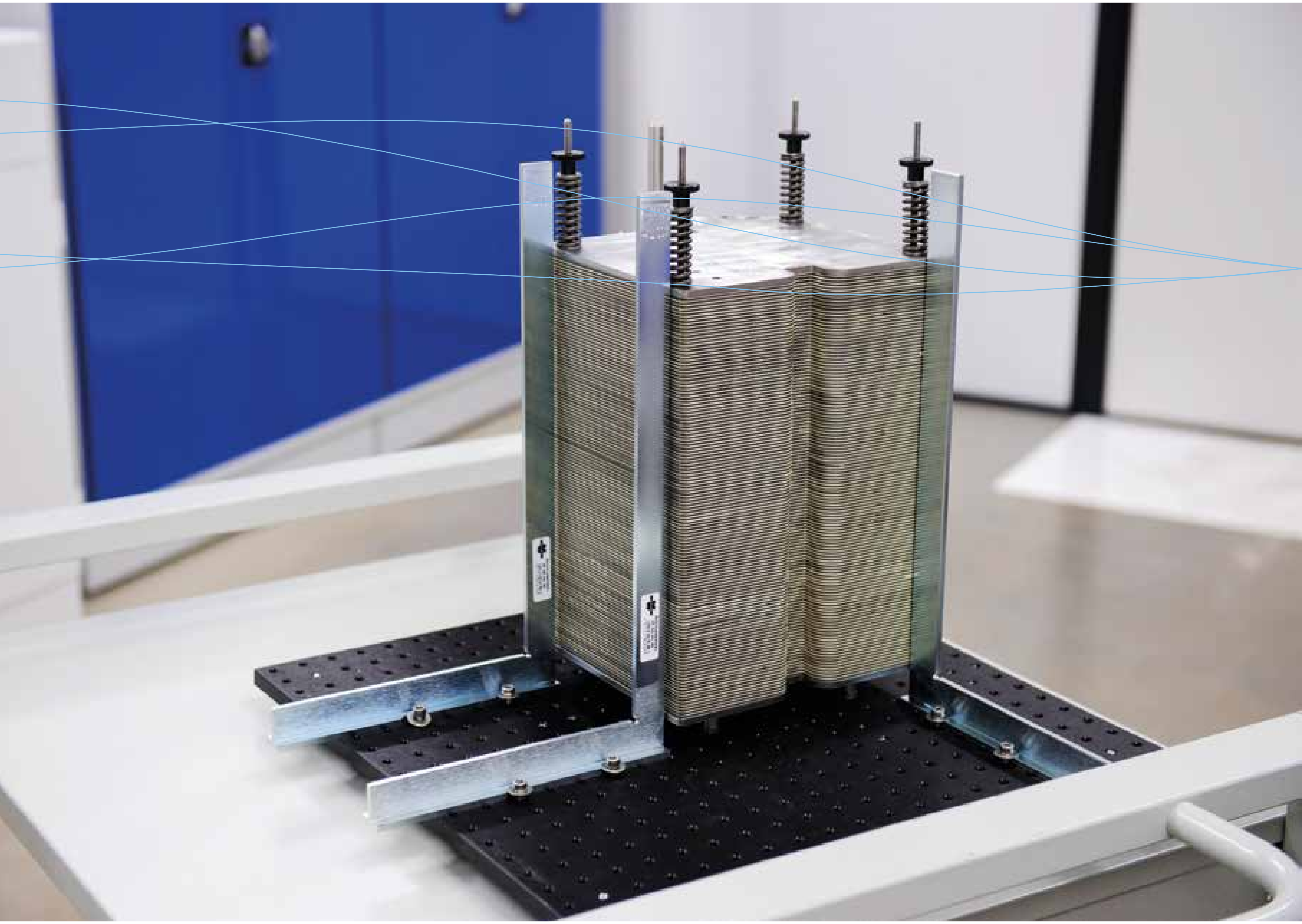
WHAT ARE THE COMPONENTS OF A FUEL CELL?

Electrodes and an electrolyte
Each fuel cell has two electrodes and an electrolyte to carry the ions from one electrode to the other. The basic reactants — hydrogen and oxygen — power the chemical reaction. To do so, fuel cells also contain a catalyst to stimulate the reaction.

Membrane electrode assembly
The membrane electrode assembly (MEA) is a vital component standing at the heart of every fuel cell. An MEA forms the core of the fuel cell and determines the performance and longevity of the device.

Stack
Just like batteries, individual cells are stacked to achieve a higher voltage and power. This assembly of cells is called a fuel cell stack, or just a stack. A single fuel cell generates a tiny amount of direct current (DC) electricity. In practice, many fuel cells are usually assembled into a stack. This allows the overall power output to be tailored according to the application's needs. As demand for fuel cells grow, so the 'stack' will become standardised and easier — and cheaper — to mass produce. The FCH JU has supported a number of initiatives geared towards high-volume fuel cell stack production.


STACK
CATALYST
BIPOLAR PLATES
MEA



THE DIFFERENT TYPES OF FUEL CELL

There are four main types of fuel cell, each of which works on the same principle and performs the same purpose — converting hydrogen and oxygen into electrical power and sometimes heat.

The type of electrolyte a fuel cell employs is usually used to classify them, as the electrolyte determines the kind of chemical reaction taking place. The most important types are the alkaline fuel cell, the proton exchange membrane fuel cell, the solid oxide fuel cell, and the molten carbonate fuel cell.

Alkaline fuel cells
The alkaline fuel cell (AFC) was historically the first fuel cell technology developed and deployed; this is the model used in the US space programme. They use a solution of potassium hydroxide as the electrolyte and operate at about 150–200 °C. Their electrical efficiency is about 70% and depends on a platinum catalyst on one electrode.

Proton exchange membrane fuel cells
The proton exchange membrane (PEM) fuel cell uses a polymer electrolyte, normally in the form of a thin, permeable sheet that looks like a sheet of cling film. They require a platinum catalyst on each side. Although not as efficient as an AFC — normally around 40–50% — they have a lower operating temperature, making them ideal for use in domestic settings, or in cars that need to be operational soon after being turned on. Also — unlike AFCs — they are not liquid and therefore can avoid electrolyte leakage.

Solid oxide fuel cells
The solid oxide fuel cell (SOFC), as the name suggests, relies on a solid electrolyte, usually a metal oxide. These cells are very efficient — usually around 60% — with an operating temperature of around 500–1000 °C. This high temperature means they do not require a platinum catalyst to activate the reaction. The waste heat can also be exploited to create more electrical power via steam generation. They are clean and quiet, ideal for urban locations.

Molten carbonate fuel cells
Molten carbonate fuel cells (MCFCs) use an electrolyte made of a molten carbonate salt mixture, which is suspended in an inert ceramic matrix. Like SOFCs, they operate at high temperature — around 650 °C — and thus do not require a platinum catalyst, bringing down the price of production. MCFCs are efficient, and can run on natural gas or biogas, the by-products of which can act as a poison to catalysts in other fuel cell types.

WHAT IS AN ELECTROLYSER?

Hydrogen, although one of the most common elements available in nature, is almost never found in its pure form. It 'burns' spontaneously in the presence of oxygen, to form water.

It has to be extracted from other molecules in order to be used as an energy carrier. Once stored in hermetically sealed containers, it can be used to power hydrogen fuel cells, or can be added to existing gas networks.

The most widely available source of hydrogen is water. By applying an electric current, the hydrogen and oxygen can be separated and collected. This process is known as electrolysis and the equipment that performs this function is called an electrolyser.

HOW DOES AN ELECTROLYSER WORK?

An electrolyser is a fuel cell operating in reverse. Rather than combining hydrogen and oxygen to produce electrical power and water, it uses electrical power to separate water into its component parts. Although it requires a relatively high level of energy to perform the conversion, the increasing availability of renewable sources of electricity is making it less and less expensive. Using spare capacity to create hydrogen is an excellent energy capture and storage method.

TYPES OF ELECTROLYSER

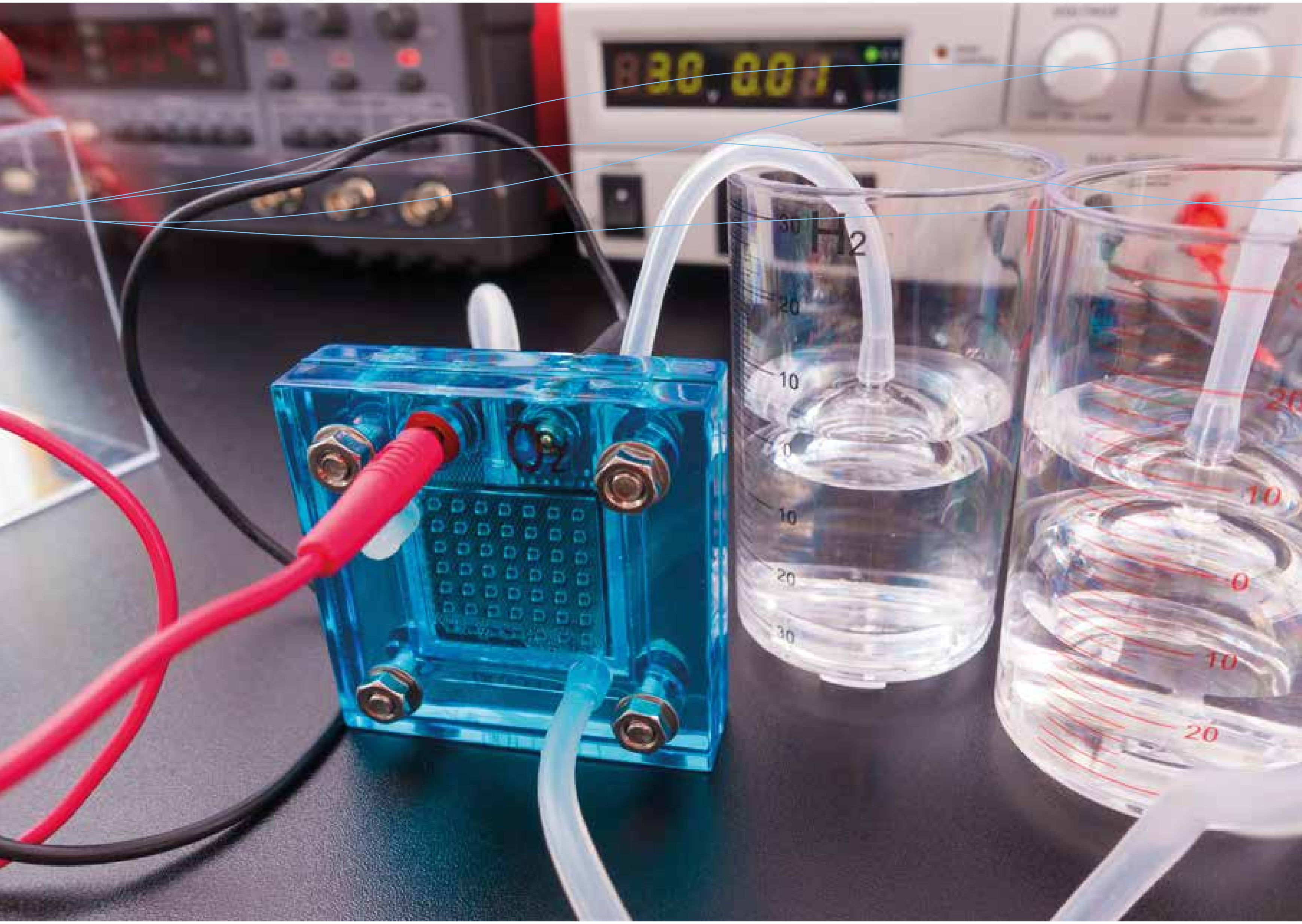
As with fuel cells, there are different types of electrolysers. The most important of these are the alkaline water electrolyser, the polymer electrolyte membrane electrolyser and the solid oxide electrolyser.

The alkaline water electrolyser, like the fuel cell, uses a liquid alkaline solution. A diaphragm separates the two electrodes in order to split the two gases produced. They do not require pure water to operate; some minerals need to be present for the electrolysis reaction to occur.

The polymer electrolyte membrane (PEM) electrolyser was developed in the 1960s. The main advantage of PEM electrolysers is their compatibility with dynamic energy sources such as wind or solar power (i.e. they can easily operate with more or less electricity input). They are well-suited to capturing the energy from sudden spikes in power production.

A PEM electrolyser produces very pure hydrogen; however, at the same time, it relies on highly purified water.

Solid oxide electrolysers are made of ceramic. They are highly efficient and stable but require high operating temperatures.


H2
O2

HYDROGEN AND ENERGY STORAGE

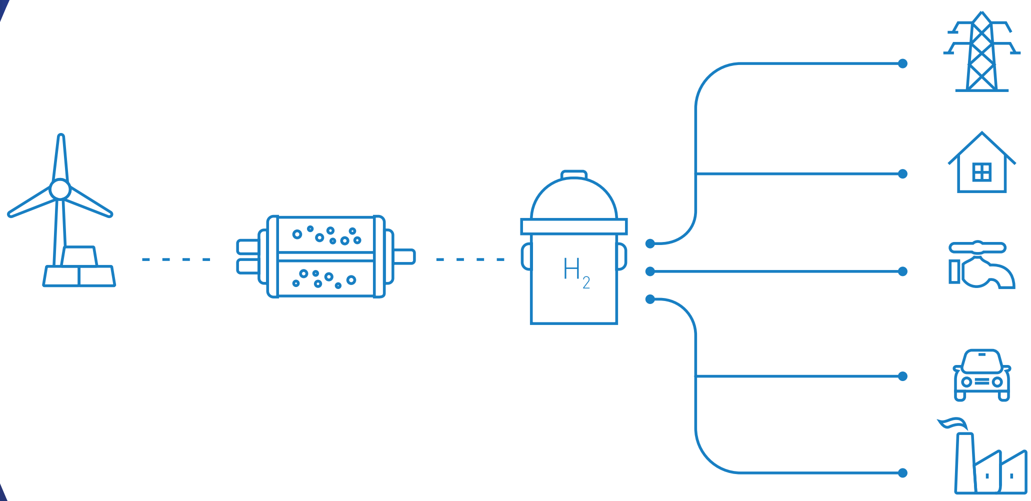
Shifting towards the use of renewables requires an efficient way to collect and store energy during those times when the sun is not shining and the wind is not blowing. Storage is one of the main technological barriers to the mass adoption of renewable energy. Hydrogen can play a key role in this respect, providing a way to store energy.

When there is excess renewable electricity available, this excess can be used to electrolyse water and produce hydrogen. The hydrogen then stores the surplus energy, which can be converted back to electricity when renewable sources are not active, or are insufficient to meet demand. In this way, hydrogen allows the exploitation of power that otherwise would have been lost.

The hydrogen produced can also be used to power fuel cell appliances, such as vehicles, or as a calorific value booster in the natural gas grid.

Energy storage will play a key role in enabling the EU to develop a low carbon electricity system. Hydrogen, when used to store energy, can supply more flexibility and balance to the grid, providing a back-up to intermittent renewable energy.

HYDROGEN AND ENERGY STORAGE



TECHNOLOGY READINESS LEVELS

TRL 1
Basic principles observed

TRL 2
Technology concept formulated

TRL 3
Experimental proof of concept

TRL 4
Technology validated in lab

TRL 5
Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 6
Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

TRL 7
System prototype demonstration in operational environment

TRL 8
System complete and qualified

TRL 9
Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

TECHNOLOGY READINESS LEVEL EXPLAINED

The public concept of new technology is normally one of a finished, ready to use product; think of a new electric car or smartphone. This is technology that is already reliable and easy to use, with the user experiencing few bugs or glitches.

However, consumer-ready technology has inevitably been through a series of assessments to define how close it is to deployment. These are defined as a technology readiness levels (TRLs), a concept originally developed by NASA in the 1970s. TRLs allow comparisons between the maturities of various technologies.

TRLs cover the entire process of development, beginning with assessing whether the basic principles underpinning the concept have been observed, through the proof of concept, prototyping, and up to demonstrating operational effectiveness.he European Commission uses nine levels of technology readiness:

- **TRL 1** — basic principles observed
- **TRL 2** — technology concept formulated
- **TRL 3** — experimental proof of concept
- **TRL 4** — technology validated in lab
- **TRL 5** — technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL 6** — technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- **TRL 7** — system prototype demonstration in operational environment
- **TRL 8** — system complete and qualified
- **TRL 9** — actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

TECHNOLOGY BREAKTHROUGHS

FUEL CELL RESEARCH FOR INDUSTRY UPTAKE

Although the potential of fuel cells and hydrogen had been clearly established, fully realising their promise required a careful research orientation. Therefore, one of the main tasks for the FCH JU was to develop a clear path to ensure the technologies could progress steadily towards commercial viability and, in the long term, widespread uptake.

Although full-scale commercialisation would ultimately be a task for industry, the FCH JU realised it would play a key role in building the connections that would make this possible. It had to ensure that industry was aware of, involved with, and participated in advancing fuel cell and hydrogen technologies to the point where they could be deployed.

To address this, the FCH JU established a clear roadmap to advance each of the core technologies to the point where they were sufficiently mature from a technology readiness perspective, to attract interest from the relevant industries. This began with fundamental, fact-finding research.

The first step was to determine what industry's expectations were along basic parameters, such as required power outputs, expected longevity and reliability, cost thresholds and demand. Armed with this information, the FCH JU was able to design the research projects necessary to advance the technologies sufficiently to meet these expectations. This took many of the technologies from the laboratory bench to situations where they could be tested and improved. Incremental improvements to the lifespan and reliability of fuel cells, or greater outputs from electrolysers, were key to increasing their commercial potential.

The FCH JU established a series of projects that would further advance the technologies, ideally to a stage where manufacturing could be partially automated. This would allow production to be scaled up and lay the groundwork for mass production. At the same time, it also promoted demonstration projects that would showcase the technologies in action. As the technology readiness levels (TRLs) increased, larger manufacturers could envisage applications, and become increasingly involved in late stage projects. The unique appeal of the FCH JU was pivotal in both shaping and encouraging this productive, targeted collaboration between research and industry.

Breakthrough areas of research

MEMBRANE ELECTRODE ASSEMBLY

At the heart of every fuel cell is a vital component, the membrane electrode assembly or MEA. The reason that MEAs are so important is that as they form the core of the fuel cell, they determine the performance and longevity of the fuel cell. Clearly, improved performance and extended longevity will contribute to the overall attractiveness of fuel cells. This is why FCH JU has invested significant funding in finding ways of improving MEAs. In particular, it has focused on the MEAs used in PEM electrolysers and fuel cells. These MEAs are made up of a polymer electrolyte membrane (PEM), catalyst layers (CLs) and gas diffusion layers (GDLs). These elements are arranged in series to form a fuel cell 'stack'.

A particular focus of research has been on catalysts. Currently, the catalysts for most fuel cells are platinum-based, which has significant cost implications. Finding a way to use less platinum, or identifying alternatives, could greatly reduce manufacturing costs.

The research activities on catalysts have been successful as a result of the effective cooperation between research and industry. This has been particularly beneficial for organisations like the CNRS (Centre National de Recherche Scientifique) and Johnson Matthey Fuel Cells, which worked through a series of FCH JU projects of increasing technology readiness levels (TRLs). These projects included MAESTRO (2011-2014), which aimed at improving the mechanical properties of the MEA and thus increasing its longevity, and CATAPULT (2013-2016), which investigated MEA catalysts with lower platinum or non-platinum group metals. Johnson Matthey Fuel Cells was involved in the project IMPACT (2012-2016), which examined how to increase the lifespan of fuel cells with ultralow platinum, and CNRS took part in the project IMMEDIATE (2013-2016), which set out to create a PEM fuel cell capable of operating at greater than 100 °C with minimal rhodium or platinum loadings.

These FCH JU-funded projects were instrumental in laying the groundwork for developing better and lower cost components. This in turn made it attractive for manufacturers to pick up the results of this research with a view to commercialisation. In the case of the CNRS and Johnson Matthey Fuel Cells projects, this led to BMW becoming part of subsequent projects with an interest in adopting the products developed for their automotive stacks.

Projects with higher TRL levels involving all three organisations followed, aiming at increasing the manufacturing readiness level, with a view to mass production. The Volumetriq project, running from 2015 until 2019, is examining PEM fuel cell components capable of high power density and with volume production capability along with embedded quality control. Meanwhile, another FCH JU-funded project, Inspire (2016-2019) is looking to develop a stack with reduced power degradation over time, at a cost of less than €50/kW for a 50,000-unit annual production.

In addition, the FCH JU is encouraging research to find ways to simplify the manufacturing process. Currently, many MEAs are assembled by hand in laboratories; shifting this to semi-automated or ideally fully-automated manufacturing and assembly would deliver substantial economies of scale.

PEM fuel cells are finding applications in both stationary and transport applications; however, they are proving particularly interesting to the automotive industry as they move to develop fuel cell-powered vehicles.


Fuel Cells

AUTOMOTIVE FUEL CELL STACKS

One of the core ambitions of the FCH JU was to encourage the development of hydrogen fuel cells for transport applications. Fuel cells produce little power individually but, by combining them into layers or 'stacks' of cells, they can be scaled up to produce sufficient power to drive vehicles. A shift to fuel cell-powered transport would help Europe reduce its reliance on imported energy and make a major contribution to reducing damaging emissions from transport.

However, for many years, Europe had lagged behind other regions in developing hydrogen fuel cells for automotive applications. Industrial fuel cell development in Europe lacked both, state-of-the-art stack products, and competitive stack suppliers for automotive application. Vehicles on European roads using fuel cells were reliant on technology from Japan or North America. Therefore, developing the technology to produce fuel cell stacks was an early priority for the FCH JU.

As early as 2009, the FCH JU began to lay the foundations for this, establishing the AUTO-STACK project as a cluster initiative for automotive fuel cell stack in Europe. The most recent project, AUTO-STACK CORE, has established a platform for developing best-of-its-class automotive stack hardware with superior power density and performance while meeting commercial target cost. The project combines the collective expertise of automotive OEMs, component suppliers, system integrators and research institutes and thus removes critical disconnects between stakeholders.

Attracting a contribution of almost €8 million from the FCH JU, AUTO-STACK CORE acted as a platform concept to substantially improve economies of scale and reduce critical investment cost for individual OEMs by sharing the same stack hardware for different vehicles and vehicle categories.

The project has seen the weight and size of stacks fall while power increases. While there is still room for further improvements, the collaboration promoted by the FCH JU is bringing European fuel cell stacks ever closer to market.

The project has developed successive generations of stacks, the last version of which has achieved high performance results, high power density at lower costs in compliance with the demanding expectations of car OEMs. These successful developments were recognised in the community, results have been exploited by the car OEMs and a limited production of stacks has started.

Based on these successes, in July 2017, a German "Autostack industry" project was launched as the natural follow-up of the FCH JU projects. With a €60 million project, and a project duration of three years, this consortium of leading industrial companies will enable the transition to automated assembly of high quality, high performance stack, which is a prerequisite for a broad market launch of fuel cell vehicles.

With this new project, all the jigsaw pieces will be put into place to industrialise the production of fuel cells for automobiles. The thrust of this effort is to boost fuel cell performance, service life and reliability while cutting costs. The project is part of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) coordinated by the National Organisation for Hydrogen and Fuel Cell Technology (NOW).

This highlights how European research projects can inspire and support national initiatives, where industry collaborates with research, harnessing European research and innovation.

SOLID OXIDE FUEL CELLS

Among the different types of fuel cells being developed, the Solid Oxide Fuel Cell (SOFC) offers high potential for a number of applications, most notably in the areas of stationary power generation, and in particular, for micro combined heat and power (µCHP) fuel cells.

SOFCs are very efficient, highly stable and offer flexibility on the fuels they can use. In addition, as they routinely operate at very high temperatures – between 500-1000 °C – solid oxides do not need platinum as a catalyst, unlike other fuel cells. This potentially reduces the cost of manufacture.

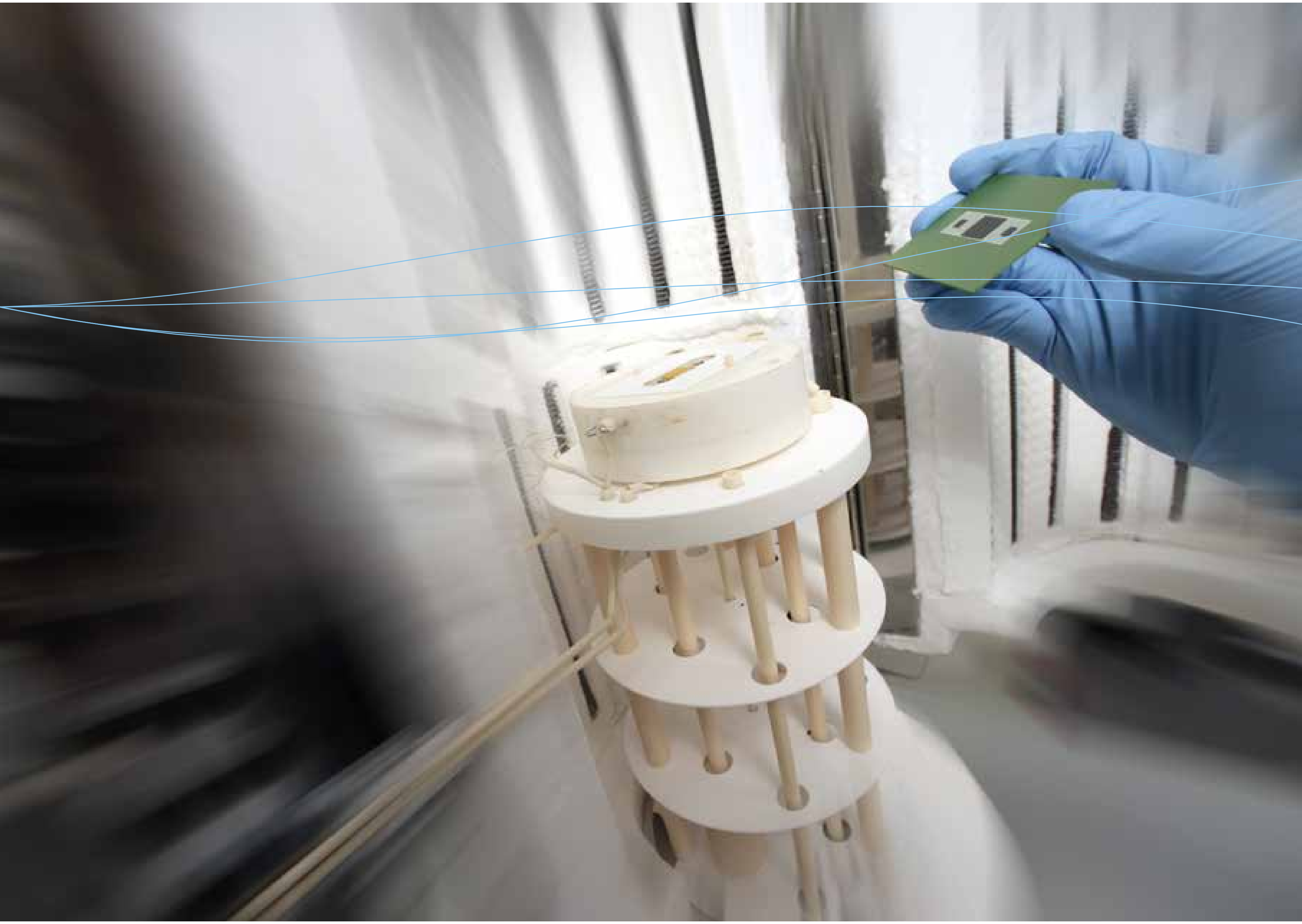
The FCH JU made it a priority to take SOFCs through a range of technology readiness levels (TRLs) from research to becoming a commercially viable product. The objectives were to increase their longevity and to reduce production costs.

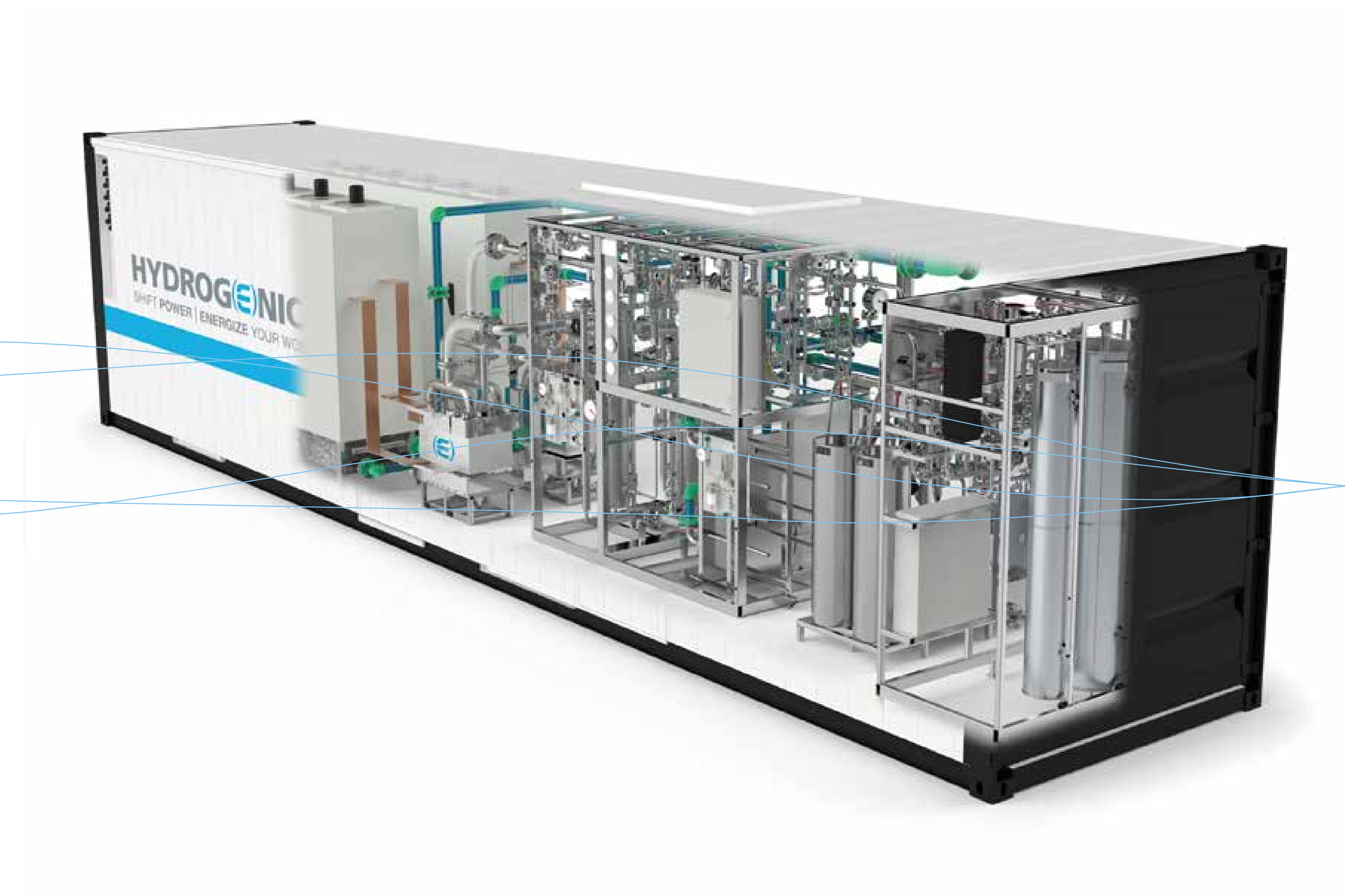
Initial work focused on extending the lifespan of SOFCs, especially on the stacks, a crucial factor in their technical and economic viability. Fuel cells naturally degrade over their lifespan, so slowing the degradation process extends their longevity. Initial projects aimed at a lifespan of 40,000 hours, a target that has been achieved. The goal now is to extend this to 80,000 hours.

One project, aptly named ENDURANCE, launched in 2014 with €2.5 million funding from the FCH JU and led by the University of Genoa, is developing models that will detect the earliest signals of fuel cell stack failure, propose new materials for the stack and extend their lifespan.

The next research objective was to identify ways to develop SOFCs, from functional but experimental designs in the laboratory, to using semi-automated manufacturing lines. A number of FCH JU-funded projects are addressing this transition by validating the suitability of materials and methods for improved manufacturing processes. Following the results of these projects and a large-scale field trial supported by the FCH JU, manufacturers are taking the initial steps to move towards fully-automated manufacturing and mass production. Some manufacturers are planning expansion of their manufacturing facilities to 50 MW per year in the short to medium term.

Once this has been achieved and production volumes are sufficient, the final transition to a wider commercial uptake and deployment should be only a short step away. However, it is the steady encouragement of FCH JU projects that have contributed to realising the potential of SOFCs and to helping bring affordable mass production within reach.




HYDROG(E)NIC
SHIFT POWER | ENERGIZE YOUR WO

ELECTROLYSERS

With the uptake of green hydrogen as a clean energy carrier, the FCH JU has played a crucial role in driving the development of technology needed to ensure a steady reliable supply. This places a focus on the development of effective electrolysers as the core production technology.

The FCH JU set out to improve electrolysers in a number of ways, looking to develop existing technology to improve reliability, and exploring the potential of newer techniques such as proton exchange membrane (PEM) electrolysers. These offered the potential for improved dynamic operation performance, making them more suitable for integration with renewables.

A series of FCH JU-funded projects have seen power yields rise dramatically, from outputs of a few tens of kilowatts. The HyBalance project, which began in 2015 and attracted €8 million in FCH JU funding, sought to prove the feasibility of using central large-scale electrolysers to supply grid services, as well as hydrogen for high-value markets. HyBalance proved that outputs of more than 1 MW were perfectly feasible for PEM electrolysers. The unit was developed by Hydrogenics.

Building on this, the 2016 project, H2Future, is now developing a 6 MW PEM power plant. This project, which attracted €12 million in FCH JU funding, is coordinated by Verbund, Austria's largest electricity provider. The PEM electrolyser, manufactured by Siemens, is being installed at the Linz production facilities of Austrian steel manufacturer voestalpine. This should demonstrate not only the benefits of the 6 MW capacity, but also the increasing flexibility of the technology. It will also provide affordable hydrogen for use in steel-making processes and will provide electricity grid balancing services.

The FCH JU is in the process of signing a grant agreement for the 2017 REFHYNE project where a 10 MW electrolyser developed by ITM will be installed in a refinery. The hydrogen produced will displace grey hydrogen used in the refining process.

To maximise the efficiency of energy storage, future projects will examine ways to further increase the technology efficiency, producing greater quantities of hydrogen for the same amount of electricity used, with improved reliability and reduced capital costs.

The FCH JU has also supported the development of Solid Oxide Electrolyser Cells (SOEC) from laboratory prototypes to practical application. This type of 'high-temperature electrolysis' (the cells run at temperatures of more than 500 °C) is highly efficient and offers potential in cases where energy input comes as heat as well as electricity.

This technology is being trialled in another FCH JU demonstration project, GRINHY (Green Industrial Hydrogen via Reversible High-Temperature Electrolysis), and is being run at an integrated iron and steel works, providing the necessary waste heat, and using the hydrogen in the surface treatment of steel.

From the low power output levels seen only ten years ago, the FCH JU has helped encourage projects that have increased power outputs exponentially. With a 20 MW PEM and 1 MW SOE on the horizon, the barrier to the availability of bulk quantities of green hydrogen is fast disappearing.

COMMITMENT FROM RESEARCH AND INDUSTRY

This progress, and the technological breakthroughs described here, would not have been possible without the strong commitment of the FCH JU industry and research members, namely: Hydrogen Europe and Hydrogen Europe Research.

Hydrogen Europe (formerly known as NEW-IG) is the leading industry association representing almost 100 companies, both large companies and SMEs, working to make hydrogen energy an everyday reality. Hydrogen Europe partners with the European Commission and the research community to accelerate the market introduction of these clean technologies in the energy and transport sectors.

Hydrogen Europe Research is a research grouping that gathers more than 60 research institutions (universities and research centres), to support and promote research interests in the FCH JU, and creates a framework for the cooperation of science and industry in Europe.


TAXI
PARISIEN

BENEFITS

THE IMPORTANCE TO EUROPE'S KEY INDUSTRIES

Less emissions in the air we breathe, quieter vehicles on our streets, cleaner and more secure energy warming our homes and offices and innovative and high-tech jobs in our business parks. The socioeconomic benefits of the hydrogen economy have never been clearer, and thanks to the driving force behind the FCH JU, hydrogen is increasingly considered as an asset for both delivering energy security and boosting European competitiveness.

Europe's upcoming mobility package aspires to reduce CO_2 emissions in the transport sector, while the recently announced industrial policy strategy aims to empower European businesses to continue delivering sustainable growth and jobs. Both are initiatives where the FCH JU's stable of smart, innovative and sustainable project partners are well placed to make a substantial contribution.

Europe is also well placed to gain from its position as a leading high-tech component and system manufacturer and from the complementary aspects of the emerging energy and transport transition. These are areas where the FCH JU is already strategically active, and positions Europe to profit from European component and system manufacture, for deployment domestically and for export.

Europe's key industries benefit strongly from the inherent expertise within and around those involved in the FCH JU. This will become increasingly apparent as Europe continues to progress along other parallel energy system development tracks such as renewables market penetration, battery electric vehicles and energy storage solutions.

In addition, reliable power has become a mission-critical requirement for many of Europe's key industries and business sectors. Banks, hospitals, data storage centres, telecoms companies and supermarkets and utility infrastructure are all reliant on constant power to maintain operations. As 'smart' technology continues to permeate our daily lives, this will only increase.

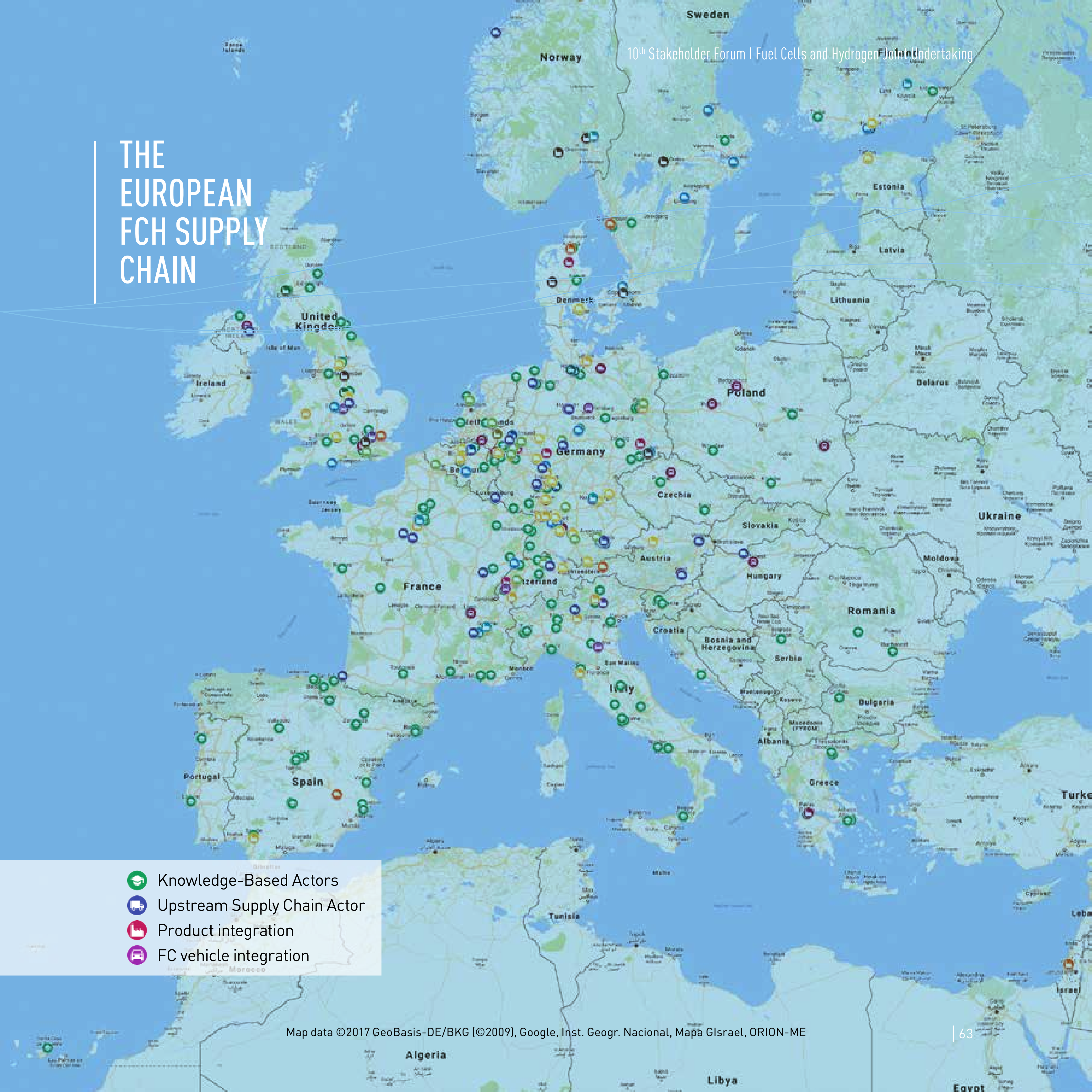
Hydrogen and fuel cell technologies developed through the FCH JU, such as micro combined heat and power, work independently from the electricity grid. This 'fuel flexibility' as well as the inherent scalability of fuel cells, their reliability and low-zero emissions offers Europe's key industries a unique and potentially irresistible combination of benefits.

This map shows the breadth of knowledge-based actors along the European supply chain for fuel cell and hydrogen technology. Products include micro CHP, large CHP, fuel cell electric vehicles, fuel cell buses and forklifts, trucks, electrolysers, compressors and hydrogen storage.

More than 400 companies are active in the field, and 75% of these companies have been, or are, involved in the FCH JU.

As the FCH JU enters its second decade, its portfolio of clean, efficient and ever-more affordable fuel cells and hydrogen technologies can be expected to help Europe sustain and grow its international competitiveness in a vitally strategic sector.

THE EUROPEAN FCH SUPPLY CHAIN



Map data ©2017 GeoBasis-DE/BKG (©2009), Google, Inst. Geogr. Nacional, Mapa GIsrael, ORION-ME

SUPPORTING EUROPE'S SMES

One of the FCH JU's top strategic priorities is to ensure that the SME sector remains a key player in hydrogen and fuel cell development. The unique public–private partnership structure has made it possible to develop a network of partners to nurture SMEs. With this support, the sector has grown into the backbone of the early FCH community, helping to push hydrogen and fuel cell technology to the cusp of widespread uptake.

With 27% (€77.7 million) of its financial programme dedicated to smaller businesses, the FCH 2 JU has already exceeded the Horizon 2020 target of ensuring that at least 20% of its funding is allocated to SMEs. Companies receiving FCH JU grant support are regularly involved in groundbreaking ventures with high market potential, including the deployment of hydrogen and fuel cell technologies.

The benefits that the FCH JU can deliver in leveraging collaboration and optimising funding for SMEs have been clearly demonstrated by the experience of FCH JU participant, **H2 Logic**.

Set up in 2003, the Danish SME anticipated the need for low cost, reliable and user-friendly hydrogen refuelling stations (HRSs). With FCH JU finance behind their HRS demonstration projects, H2 Logic had the opportunity to field test their products. Following the company's successful participation in several FCH JU-funded projects including H2moves, HyTEC, HyFIVE and H2ME, H2 Logic quickly grew from its initial three co-founders to a team of 77 people.

In 2015, NEL acquired H2 Logic and became NEL Hydrogen, a new company currently employing 200 people and with a presence in both Europe and the US. It recently invested €9 million in a manufacturing plant in Denmark with the capacity to build around 300 HRSs a year, enough to fuel 200,000 hydrogen vehicles.

The FCH JU's requirement to address technological improvements and reduce costs on electrolysers, led it to offer support to UK-based SME, **ITM Power.** The programme provided ITM Power with the funding to grow their energy- and transport-related products from proof of concept to large-scale integration, enabling them to expand swiftly. The company found its relationship with the FCH JU to be fundamentally constructive.

The FCH JU contributed to the growth of Italian microgrids in general and energy storage company **Electro Power Systems (EPS)** in particular, by offering support for its technology incubation phases via two of its projects: FITUP and FluMaBack. The company's involvement with the FCH JU had a significant impact on developing technology improvements, leveraging the initial public offering process and increasing the visibility of results. EPS' innovative power-to-power technology energy storage solution in off-grid and isolated microgrid applications has attracted the interest of major EU and global utilities. Today, thanks to the backing of the FCH JU, EPS belongs to a select pool of global players, able to deliver utility-scale storage systems on a turnkey basis to the world's leading energy companies.

Once a small start-up, the Estonian enterprise **Elcogen** is now the manufacturer of the world's most efficient solid oxide fuel cell (SOFC) technology and has more than 60 customers globally. Backed by the conviction that fuel cells would play a role in a future of decarbonised energy, Elcogen has developed ceramic SOFC and stack technology with a high electrochemical performance and efficiency combined with the lowest possible operating temperatures (as low as 650 °C).

The FCH JU enabled Elcogen to finance R&D work with leading European institutes, such as VTT in Finland, Jülich in Germany, KBFI in Estonia, CEA in France and ENEA in Italy. The support has meant that Elcogen could develop products and production processes with top technology companies, such as ElringKlinger, Flexitallic, Convion and Sylfen. Elcogen's stacks recently achieved a world record 74% primary energy conversion efficiency.

French company Sylfen has created breakthrough technology that can facilitate the decentralised production and management of energy. It solves the problem of energy spikes encountered in renewable energy production, by offering local, high capacity storage in the form of hydrogen, leading to more resilient grids and lower CO_2 emissions. **Sylfen** now has a worldwide exclusive license on the technology.The young company is a spin-off from the research institute CEA — one of the main research bodies in the FCH JU programme. Sylfen's game-changing technology, which holds 30 patents, builds on ten years of R&D by the CEA-Liten institute of Grenoble, has received €40 million in investment, and, in 2014, demonstrated the best efficiency in solid oxide electrolyser cells (SOECs) worldwide. The institute has developed strong expertise in building reversible solid oxide cell (rSOC) stacks, and operating them under the best temperature conditions. This is the result of various initiatives, mainly FCH JU projects such as RelHy, SOPHIA, and ECo. This knowledge is now being put to good use by Sylfen. With operational support from CEA, the spin-off is setting up the first stack manufacturing line, and will become fully operational in 2018. The company plans to increase its staff from seven to 20 by 2018.

FCH JU has also supported **SOLIDpower,** who is developing, manufacturing and marketing fuel cell systems for generating power and heat (micro CHP) in residential and commercial buildings. Started in 2006, the company employs 220 people at four locations. SOLIDpower recently closed a financing round of €40 million, providing the capital to become an industrial company.

These collaborations exemplify how networks and partnerships create the possibilities to upscale systems.

"The FCH JU offers more than just financial support; the networks and opportunities it provides are also invaluable." *ITM Power*

"Support from the FCH JU has been paramount in the development of fuel cell and hydrogen technologies in Europe." *Elcogen*

"Many of our suppliers and customers were found through FCH projects." *SOLIDPower*

"FCH JU projects are key to support the development and deployment of breakthrough technologies, by gathering complementary competencies from all over Europe. In parallel they also offer the possibility to perform R&D to improve materials, performance, durability etc... it needs to be continued!" *Sylfen*

COPERNIC: MAKING SMES GLOBALLY COMPETITIVE

The FCH JU-funded COPERNIC aimed at reducing the cost of hydrogen cars, making them a more viable and competitive option. COPERNIC's success saw many of the SMEs involved grow into globally competitive companies.

> Always more than just a funding programme, the work of the FCH JU has helped Europe's SMEs flourish, and it will continue to do so.

Optimum CPV, one of the partners of the COPERNIC Project, was encouraged to extend its skill sets on the developing, manufacturing and testing of composite pressure vessels (CPVs) for high-pressure applications related to hydrogen storage. In response to market demand, Optimum CPV hired additional technicians and engineers, increasing their turnover by 50% and finalising marketing/representation agreements in the US, South America, Japan, South Korea and China.

As a direct result of the COPERNIC Project, German engineering company Anleg is now known worldwide for its work as a manufacturer on hydrogen applications. The COPERNIC Project facilitated Anleg's development of a completely new on tank valve with integrated regulator (OTV-R). This resulted in increased turnover and strong client interest, generating new jobs and new business opportunities in the aerospace and car manufacturing industries. **Anleg** invested approximately €200,000 in hydrogen infrastructure and production, including a testing facility for its OTV-R business branch.

Thanks to COPERNIC, project partners, **CEA, RAIGI, OCPV** and **WUT** are now engaged in a new project and will work at developing and certifying a composite overwrapped pressure vessel (COPV) dedicated to fuel cell electric vehicles (FCEVs) based on COPERNIC results and previous experiences.

CONTRIBUTING TO ENERGY SECURITY

Security of energy supply presents a major challenge, as the European Union imports over half of all energy consumed, including more than 90% of crude oil and 66% of natural gas. Over-reliance on importation of gas and oil from a limited number of supplier countries leaves member states vulnerable to the effects of power-supply disruption. Fuel cell and hydrogen technology has a vital part to play in increasing Europe's energy independence and energy security.

The EU published its Energy Security Strategy in May 2014, which set out to ensure that European citizens and the EU economy had a stable, abundant and reliable supply of energy. Along with short-term measures aimed at dealing with dramatic shortages, the strategy addressed the long-term challenges of securing supply. Increasing energy efficiency and reliance on renewable energy sources were of central importance. The efforts of the FCH JU in bringing fuel cell and green hydrogen production technologies to maturity will make a major contribution to this particular objective in two ways.

One of the problems with the efficiency of renewable energy sources is the intermittent nature of the energy produced and the difficulty of storing electricity for when it is needed. FCH offers a solution to this by using the electrolysis of water to convert excess electricity into hydrogen, which can store the energy until it is needed, or supply fuel cells – high-efficiency conversion devices – directly, for example in vehicles, thereby reducing consumption of fossil fuels.

The storage potential of hydrogen will be increasingly important to the penetration of renewables, and the EU's transition to a low-carbon economy, as it will allow more renewables to come onto the grid. Indigenous excess renewable electricity can then be exported to other sectors, such as gas, industry and transport, thereby reducing each country's reliance on imported fossil fuels.

An example of FCH technology being applied to this end is in Denmark, which aims at eliminating the use of fossil fuels for heat and electricity production by 2035, and to attain independence from fossil fuels by 2050. Hydrogen technology is key to their efforts, and several FCH JU projects are being developed there. These include HyBalance, a €15 million project to establish one of Europe's largest plants for the production of hydrogen based on wind power, and HyFIVE, the FCH JU project that has enabled the rollout of hydrogen cars in Denmark through the opening of hydrogen refuelling stations across the country – most recently in Aarhus in January 2017.

CLEANER AIR

Air pollution has become the world's biggest environmental health risk. Urban smog, particle pollution, and toxic pollutants pose serious health concerns. The increase in greenhouse gas emissions, commonly referred to as GHGs, has a direct impact on global warming. Cleaning the air and reducing the impact of global warming are therefore crucial. Innovative clean technologies, such as fuel cells, and hydrogen can play a significant role in that battle.

Fuel cells and hydrogen can help to reduce ...

- **Carbon dioxide**

There are a number of GHGs; the most important of these is carbon dioxide (CO_2). Levels of CO_2 emissions have risen substantially in the last few decades, due to increased industrialisation. At the same time, changes in land use, such as deforestation, are reducing the capacity of the planet to absorb this CO_2.

The vast majority of CO_2 emissions are a result of the exhaust gases from burning fossil fuels such as coal and natural gas, and from oil-derived fuels such as gasoline, diesel and kerosene. This is why there is a growing interest in reducing reliance on internal combustion engines. A switch to battery and fuel cell electric vehicles, which produce no GHGs, would make a major contribution to reducing atmospheric CO_2 levels.

- **Nitrous and sulphur oxides**

GHGs are not the only problems caused by exhaust gas emissions. Nitrous and sulphur oxides (NOx, SOx) are also an issue. On a per-molecule basis, NOx has an even greater potential to increase global warming than CO_2. Fortunately, current atmospheric concentrations of NOx are much lower than those of CO_2. However, these levels are rising. NOx is also implicated in the thinning of the ozone layer.

SOx is not a GHG, however it can cause health problems, particularly respiratory issues. Children, the elderly and those suffering from asthma are the most sensitive to its effects.

- **Particulate matter**

Internal combustion engines produce particulate matter (PM). This consists of microscopic solids or liquid droplets that are small enough to be inhaled, causing respiratory problems. Diesel-powered engines are known to produce more PM than petrol engines.

As well as reducing GHGs, a switch to battery and fuel cell electric vehicles would help reduce NOx, SOx and PM levels.

HELPING TO MEET EUROPE'S CLIMATE AND ENERGY GOALS

The COP21 UN Climate Change Conference in Paris in 2015, culminating in the Paris Agreement, sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C.

Following the Conference, the European Commission presented its plan on how the EU could ratify the Paris Agreement. The measures proposed included reducing transport emissions and an ambitious renewable energy policy. Overall, the Commission's blueprint commits the EU to reducing greenhouse gas (GHG) emissions by at least 40% within the next fifteen years.

Meeting these ambitious targets will be challenging. The maturing fuel cell technology, supported by the FCH JU, will have a considerable role to play. For example, hydrogen fuel cell-powered buses can contribute to reducing transport emissions. These buses are not powered by combustion and produce no CO_2, reducing GHG emissions by as much as 85% compared to existing diesel models.

In addition, fuel cell cars are on the verge of penetrating the mainstream market. Hydrogen infrastructure is expanding, and the latest models have reliability and ranges comparable to conventionally powered cars. Fuel cell taxis are in use in larger cities. Using hydrogen from wind power, a global warming potential reduction of up to 83% is possible for a fuel cell taxi compared to a diesel taxi.

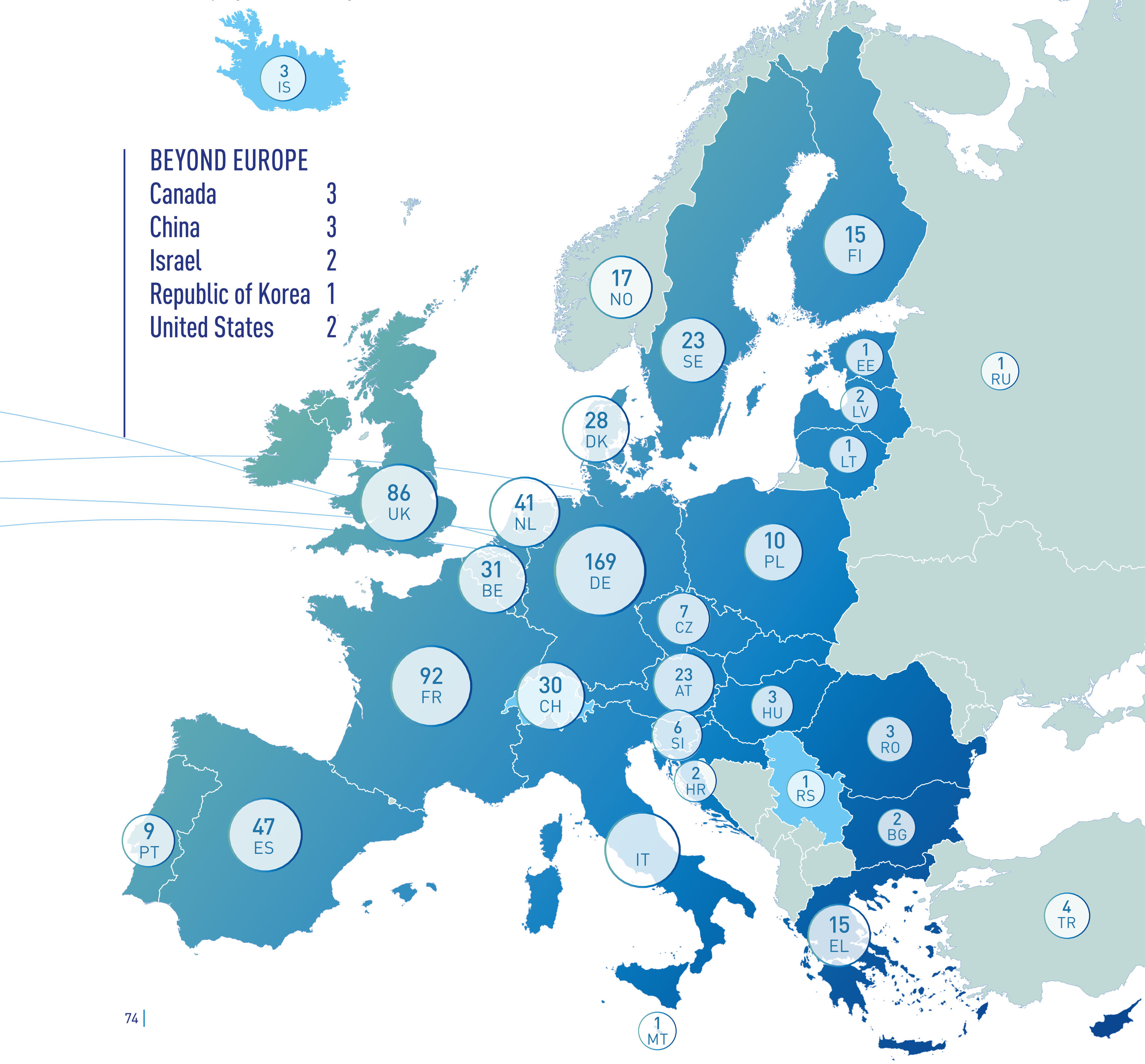
Meanwhile, fuel cell technology is contributing to emissions reduction in other sectors. Domestic fuel cells – known as micro combined heat and power (µCHPs) – provide electricity and heating in homes and small offices, using natural gas as a fuel source. Highly efficient and reliable, micro CHPs produce no GHGs while reducing electricity demand compared to conventional technologies: 30% immediate CO_2 savings relative to gas boiler and grid electricity supply, and up to 80% depending on local conditions.

With upfront capital costs falling and few technical barriers to deployment, rapid market uptake of µCHP is predicted and can make significant contributions to meeting Europe's ambitious emissions reduction targets.


hype
hype
TAXI

BEYOND EUROPE

Canada	3
China	3
Israel	2
Republic of Korea	1
United States	2



HIGHLIGHTS

"By pooling resources and creating a common platform where policymakers, industry and research come together, the FCH JU underpins confidence and continued crucial investment."

Mirela Atanasiu, Head of Unit Operations and Communication FCH JU

RESEARCH AND DEVELOPMENT ACROSS EUROPE

Hydrogen fuel cells are entering the power generation market as well as the transport, industrial and residential sectors, thus playing a significant role in reducing emissions and enhancing energy security. However, this continues to require extensive public and private research and development (R&D) efforts to achieve technology breakthroughs and bring these technologies to commercial maturity.

The FCH JU has played a leading role in actively shaping the priority R&D agenda, focusing on the most critical actions, within and across sectors and applications, and assigning funding based on Return on Investment (ROI) criteria.

The map on page 74 shows the breadth of activity of R&D in fuel cell and hydrogen technology according to the participation level in each Member State.

CELEBRATING A DECADE OF COLLABORATION BETWEEN THE PUBLIC SECTOR, INDUSTRY AND RESEARCH

The relevance of the FCH JU research is now becoming ever more apparent, and significant investment by governments has contributed to recent rapid breakthroughs. Looking back on the last ten years, Mirela Atanasiu, formerly project manager in the European Commission, now Head of Unit Operations and Communication at the FCH JU, attributes the FCH JU's success in advancing the research agenda to the organisation's public-private partnership structure.

This has allowed for research of sufficient scale and scope in the development and deployment of FCH technologies. By pooling resources and creating a common platform where policymakers, industry and research come together, the FCH JU underpins industry confidence and continued crucial investment. The creation of a community with a joint roadmap has enabled the acceleration of FCH technology development, with the FCH JU acting as a catalyst. Atanasiu points out the diverse application of its research results also: "it's the only JU that is a transectorial JU."

Since its establishment in 2008, the FCH JU industry membership has grown from a base of about sixty companies from twenty countries to 110 companies today. Importantly, this expansion also relates to the nature of the companies, which now include companies whose main activity is not FCH, but are expanding their technology portfolios. Half of the industry grouping, Hydrogen Europe, is however made up of SMEs, as this is a young technology. The FCH JU has proved a key instrument for SMEs, providing a stable regulatory environment, as well as the long-term stability offered by public sector funding. The leverage effect has also been very important – with public money triggering additional private investment.

In the first phase under FP7, the primary role initially was to unify what was previously a fragmented research landscape. Now in its second phase under Horizon 2020, it has succeeded in bringing products onto the market. The challenge remains in making these products commercially viable by being competitively priced with carbon-emitting technology. There is huge public interest in the technology from companies and individuals, and the FCH JU is tapping into this by approaching cities and regions to build on the appetite that has been created for the products, some of which, for example buses, are at the pre-commercialisation phase.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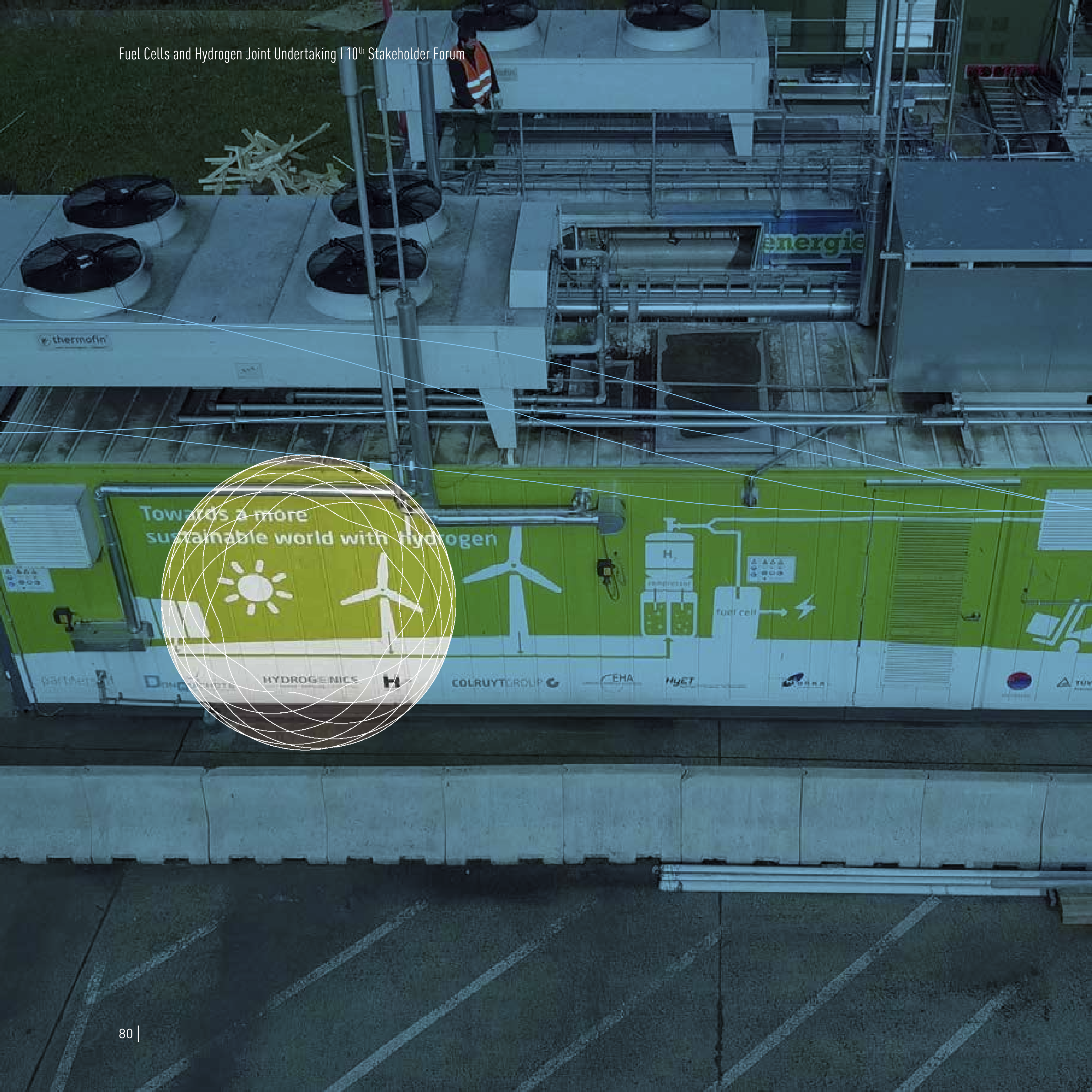
H2


Hydrogen Fuel Cell
LJ13 JZO

CASE STUDIES

04

Hydrogen technology will help to capture the surplus electricity created by renewable sources, and decarbonise Europe's energy and transport systems.


Towards a more
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thermofin
fuel cell
HYDROGENICS
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GREEN HYDROGEN AND ENERGY STORAGE

1

Green hydrogen has huge potential as a clean energy carrier. The FCH JU is playing an important role in its establishment as a viable approach to energy storage and clean fuel. Once in place, hydrogen technology will help to capture the surplus energy created by renewable sources, decarbonise Europe's energy and transport systems, help to reduce dependence on external supplies, and aid green industrial processes.

ABOUT GREEN HYDROGEN

Hydrogen is commonly produced through steam methane reforming (SMR). This enables the production of hydrogen in bulk, which can be transported by tanker or by pipeline and used for commercial and industrial purposes. This method is inexpensive and efficient, but is not environmentally friendly. Producing hydrogen via electrolysis fed by renewable electricity allows for a carbon-free process that entirely avoids GHG emissions and results in green hydrogen. Progressively replacing SMR hydrogen with this sustainable gas would allow industry to go green. The green hydrogen has two further advantages: it can be used to rapidly balance the grid at times of high demand, and for decarbonising transport when used in fuel cell vehicles.

CHALLENGES

The science behind making hydrogen through electrolysis based on alkaline technology is 100 years old. However, using electrolysis to produce hydrogen as a clean-energy storage solution and as a fuel for transport is a more recent concept. As soon as this potential was identified, these applications began to be explored.

The technology needed to become flexible enough to adapt to the use of renewable energies, while reducing costs, and providing electricity grid services. It was important to show that production methods were technically feasible, could be adapted to real world conditions, and were financially viable. During the process of harnessing hydrogen as a clean fuel it became immediately apparent that electrolysis methods had to be improved.

To meet these demands, the FCH JU followed two distinct strands. One would support a series of projects to examine the development of more powerful and more efficient electrolysers. The other would open up new markets by financing field demonstrations for transport technologies and industrial applications.

SOLUTIONS

The FCH JU activities worked at improving the initial alkaline electrolysers, but also at delivering advances in other types, including polymer electrolyte membrane (PEM) and solid oxide (SOEC) electrolysers.

PEM electrolysers are highly efficient and produce very pure hydrogen. PEM electrolysis is now targeting the renewable energy storage market, supplying hydrogen to FCEV service stations, industry, and natural gas networks. Meanwhile, the SOEC electrolyser is efficient at very high temperatures, making it useful for industrial processes that deliver heat as a by-product. Existing alkaline models are also being substantially improved to offer grid support services.

FCH JU energy projects have demonstrated the increasing power of electrolysers. In 2011 the Don Quichote project produced a capability of 100 kW, by 2016 this had risen to 6 MW under the 2016 H2FUTURE project. The increasing power will make electrolysers suitable for a growing range of applications. This is attracting a broader base of end users, including heavy industry. The H2FUTURE project, for example, is injecting green hydrogen into steel production. Similarly, the 2016 project DEMO4GRID will store electricity as hydrogen to produce CO_2-free fuel for ovens in the food industry; it will also power a delivery fleet. Demonstrating that highly energy-dependent sectors can rely on this technology will ensure increasingly green industrial production.

The production of energy from renewable sources, such as wind or solar power, has changed the electricity market. When these sources generate large amounts of energy, there are surpluses of electricity available on the grids. Thanks to their dynamic operation characteristics, the improved electrolysers are capable of capturing this excess electricity, and can offer grid balancing services.

THE SECRET OF SUCCESS

The public–private partnership structure of the FCH JU means it plays a unique role in driving the uptake of this technology. The work programme sets out the technical specifications, which the project members have delivered — and frequently surpassed. The remaining barriers will not be overcome by individual players. This is why the FCH JU structure offers a distinctive advantage; it allows suppliers and end users to work together in a way that would not happen spontaneously.

The FCH JU structure helps smaller companies to develop demonstration projects that may otherwise be too expensive. It also permits a long term, strategic perspective on the sector.

THE POLICY DIMENSION

The FCH JU's activities also contribute to the development of policies regarding clean energy. Even with increasing access to spare generating capacity, green hydrogen from electrolysis remains relatively expensive. Nevertheless, there are growing numbers of cities and regions eager to demonstrate their commitment to clean energy technologies. Through a current study, the FCH JU is taking the lead in creating green hydrogen market certificates to satisfy this demand.

BUILDING FOR THE FUTURE

Europe has relied on fossil fuels for more than 250 years. Yet in the ten years since its inception, by supporting and promoting the use of clean hydrogen, the FCH JU has put in place many of the elements needed for the smooth transition to renewable energy sources. Indeed, FCH JU investment has increased interest in the relevant sectors and helped boost confidence in the technology.

EXAMPLES

Don Quichote — Belgium (2011)

The Demonstration Of New QUalitative Innovative Concept of Hydrogen Out of wind Turbine Electricity (Don Quichote) project, which is being run near Brussels by supermarket group Colruyt, has been an early success story for clean hydrogen.

In this project, both an alkaline and a PEM electrolyser plant were installed, producing and storing up to 120 kg of hydrogen a day, which was used to power Colruyt's forklift trucks. This provides an excellent demonstration of integrating renewable electricity sources and hydrogen production, and deploying them in transport.

HyBalance — Denmark (2014)

A project to install an innovative 1 MW capacity PEM electrolyser is currently underway in Denmark. Led by Air Liquide, one of Europe's largest industrial gases companies, hydrogen will be provided to Danish industry and transport projects. This device is a consumer, and not a generator, of energy; it takes electrical energy, equivalent to the power of 200 homes, from the grid to convert to hydrogen.

The HyBalance project is developing a model that monitors the operation of a hydrogen plant on an hourly basis, balancing the electricity grid and hydrogen demand in relation to hourly power prices. The project is expected to help determine the electricity threshold price for hydrogen production.

The FCH JU is contributing €8 million towards the total budget, with the Danish government providing a further €7.6 million.

H2Future — Austria (2016)

H2FUTURE is a European flagship project bringing together companies including voestalpine, Siemens, VERBUND and Austrian Power Grid (APG), aiming at generating green hydrogen from renewable electricity sources. The project will oversee the construction of one of the world's largest electrolysis plants.

The hydrogen it produces will be fed directly into the internal gas network, allowing hydrogen use to be tested in the various stages of voestalpine's steel production process.

DEMO4GRID — Austria (2016)

This project will store electricity as hydrogen to produce CO_2-free fuel. The DEMO4GRID electrolysis plant, located near Innsbruck, will be built in 2019 and operated by MPREIS, a regional food producer. The resulting hydrogen will be used in their production plant; they are aiming at replacing the natural gas used for heating their ovens, and producing 'zero-CO_2' or 'green' bread.

Hydrogen will also replace diesel for the MPREIS logistics fleet and power fuel cell buses in public transport.

DOMESTIC FUEL CELLS

2

BACKGROUND

Driven by ever more stringent building codes, modern homes are increasingly energy-efficient. Modern construction techniques help to ensure that they are well insulated and use less fuel for heating and hot water. However, most rely on a combustion-based domestic or communal boiler fuelled by methane gas.

Micro fuel cell combined heat and power plants (FC µCHPs) are efficient, distributed energy solutions for heat and power generation near the point of consumption. These micro-sized units are usually installed in residential or small commercial buildings and are capable of providing heating, hot water and/or cooling in buildings while generating electricity to replace or complement that supplied by the grid. Of all the solutions available, FC µCHPs offer the greatest potential due to the high fuel-to-energy conversion efficiencies that this technology can offer. Electrical efficiencies of up to 60% have been observed and overall heat and power combined efficiencies as high as 90% have been achieved.

In addition FC µCHP technology offers a highly controllable electricity generation solution. Geographically distributed units can be clustered to operate as a single aggregated source of generation. Such a virtual power plant, if controlled centrally, would allow large amounts of power generation to be modulated up or down in periods of peak demand; hence providing a solution to grid operators that have to deal with high shares of intermittent renewable generation.

BARRIERS TO UPTAKE

In theory, using fuel cells in residential settings seems eminently sensible. Rather than buy electricity from the grid, the fuel cell produces the electricity more efficiently and affordably, with minimal environmental impact. Furthermore, it produces both electrical power and heat, and hot water, ideal for flats or houses of 200m^2 or less. It would not fully replace the need for external power, but the increased efficiency sharply reduces both the need for electricity supply from the grid and primary energy needs.

Until recently, the existing fuel cell technology had a number of limitations. Historically they were large, expensive to manufacture, and required regular maintenance, making them ill adapted for home and small office environments with spikes in power demand and the need for a mix of heat and power.

However, the development of the FC µCHPs was a potential game-changer. It could transform natural gas into the hydrogen needed to power the fuel cells, making them suitable for any home connected to the gas network.

CHALLENGE

The FCH JU wanted to show that FC µCHPs are ideal for the domestic environment. Although the technology existed, it lacked wide testing in the planned environment and — at current production levels — it was prohibitively expensive, even before installation costs.

Trialling the FC µCHPs would build confidence; consumers could see the benefits, and potential manufacturers could see the size of the market opportunities.

SOLUTION

Launched in 2012, the FCH JU-funded project ene.field[1] has supported the installation of over 1,000 residential FC µCHPs in nine EU countries. The project results have allowed the participating manufacturers to gain insights to help refine their technologies and business models and to develop a track record of installations.

Following a study commissioned by FCH JU, which confirmed the achievements and the roadmap for this technology, a number of the ene.field manufacturers joined forces with other partners in PACE, a five-year project to bring FC µCHP technology closer to mass commercialisation. This endeavour is again backed by the FCH JU[2] and aims

µCHP units are already delivering primary energy savings and CO_2 emission reductions, with zero local air emissions compared to conventional technologies, and an immediate 30% reduction in CO_2 over gas boilers and grid electricity supply (rising to 80% depending on local conditions).

at installing 2,650 units with real customers. It will allow manufacturers to scale up production and improve further the durability of the fuel cells at the core of the units. The shift to large-scale manufacturing should also help reduce the cost of production by at least 30%.

The FCH JU public–private partnership model brings other benefits. As well as providing support for the investment required for domestic fuel cells — something the SMEs involved would struggle to fund — it also allows them to engage with important future partners; utilities, energy services companies, house builders, and local governments.

The importance of this cannot be overstated; SMEs can tap into the expertise, distribution networks, support, and potential customers of the larger organisations. The other partners get to understand the technology at an early stage and learn how to deploy it: standards are established, problems are ironed out before they become too big, and future ambitions are shared.

THE POLICY DIMENSION

In February 2016, when the European Commission published the first ever EU Heating and Cooling Strategy, decarbonising the heating provision in the building sector became one of the priorities of EU energy policy, as reflected later in 2016, in the Clean Energy Package legislative proposals. FC µCHPs are part of the solution — they are already capable of delivering primary energy savings and reducing CO_2 emissions, with zero local air emissions compared to conventional technologies. The FCH JU field trials have demonstrated CO_2 savings of 30% compared to gas boiler and grid electricity supply, rising to 80% depending on the energy mix of the grid. In addition, the units are completely silent and produce no other pollutants.

In the future, increasingly available green biogas and hydrogen produced with renewables will mean zero-emission heat and power for domestic applications.

1. FCH JU funding of €25 million (project total value of €54 million)
2. FHC JU funding of €34 million (project total value of €90 million)

Domestic fuel cells, coupled with the decarbonisation of the gas supply will result in CO_2-neutral heat and power solutions for homes in the future.

BUILDING FOR THE FUTURE

The domestic deployment of FC µCHPs is now a reality, in no small part due to the FCH JU's early support for research, establishing a solid EU-based industry in this sector. The largest share of the FCH JU's demonstration budget for stationary applications of fuel cells is for FC µCHPs — almost 40% of the total.

Partly building on the results achieved and experiences gained as part of the ene.field project, an incentive was launched in Germany at the end of 2016 to speed up the commercialisation of FC µCHPs. The Federal Ministry for Economic Affairs and Energy is seeking to realise sales in the region of 60–70,000 units per year. Other countries, including the UK, have a feed-in tariff scheme in place for micro generation technologies including FC µCHPs. These schemes are already helping to make the economic case for the technology, while the increased volumes are allowing manufacturers to shift to fully automated mass production, making them more affordable, reliable and accessible. To date over 2,000 FC µCHPs have been installed in Europe. This has contributed to the generation of confidence in the market, and additional private investment in the sector is starting to take place. Moreover, new business models are beginning to emerge and are starting to be implemented, offering end consumers innovative commercial propositions. Equipment manufacturers are seizing these opportunities and the sector is one step closer to achieving the mass commercialisation of the technology.

Below are some testimonials and text from FC µCHP users taken from the PACE website: http://www.pace-energy.eu/stories/

'More than 60,000 households in Europe are already reaping the benefits of micro-cogeneration, and among them, more than 3,000 chose to install an FC µCHP unit to bring sustainable, reliable and affordable energy to their home. Thanks to these units, they now can generate their own electricity, while producing heating, hot water and even cooling at the same time. By 2021, PACE aims at installing at least 2,500 units in Europe, as part of a transition to manufacturing volumes in the order of 10,000 units a year post 2020.'

'Surveys conducted under ene.field show that more than 90% of end users are pleased with the environmental performance, the comfort and warmth, reliability and running costs of their FC µCHP.'

FC µCHPs as a means to provide clean and affordable energy

'Peter installed a unit in his home that reduces his energy bill by €700 every year, saves two tonnes of CO_2 annually and helps him produce his own electricity for his washing machine, dryer and computer, and for recharging his electric car.'

Peter says, "These are excellent results, because they help us contribute to a healthier environment for our children to grow up in."

Decentralised energy systems, such as FC µCHPs, allow Europeans to become active energy 'prosumers' (producer–consumers), putting them at the heart of the future energy system. On-site generation with FC µCHPs gives consumers greater control over their energy use and production. At the same time, as well as cutting their energy bills and protecting them against rising costs, it also allows them to export their excess electricity to the grid.

According to another end user, "I chose a FC µCHP unit to reduce my energy costs and become independent from the continuously increasing prices for power from the grid."


Tower Gateway RV1
WSH62998
hydrogen bus
WRIGHT
LJ13 JZO
LD55 BEJ

BUSES

3

BACKGROUND

Transport relying on internal combustion engines is a major contributor to greenhouse gas (GHG) emissions. This is also a source of other air pollution, which is a growing threat to health in increasingly congested urban areas. Reducing these emissions will be vitally important if the EU is to meet its environmental commitments and improve the quality of life for urban citizens. Shifting public transport, particularly bus networks, to hydrogen fuel cell vehicles offers a concrete and promising solution to these issues. A fuel cell electric bus running on green hydrogen can reduce the global warming potential by up to 85% compared to an existing diesel bus.

CHALLENGES

Although hydrogen fuel cells clearly offer an obvious solution, there was very little experience in using this technology for public transport applications. Given that most urban bus fleets are bought with longevity in mind — a bus may be in operation for 10–15 years — there was a pressing need for convincing evidence that fuel cell-eezz buses were reliable and cost effective. Without this, operators, manufacturers and public transport authorities would be reluctant to invest in the technology. Another potential barrier was the need for a refuelling infrastructure. There has to be access to a reliable, local and convenient source of hydrogen; yet without demand, there was no incentive to invest in developing the infrastructure needed.

In order to make a viable case for the operators, manufacturers and public transport authorities, the FCH JU had to address these two major challenges.

The first step it took was to establish precisely what the stakeholders' expectations were. The FCH JU gathered these players, representing both the supply side and the demand side, together. Acting as a platform, the FCH JU allowed for the exchange of know-how and expertise, building further insight on what would make a fuel cell fleet viable.

Supporting the development of fuel cell buses has been a strategic journey within the walls of the FCH JU, from making a business case to proving commercial viability.

SOLUTION

In 2010, an initial project set out to demonstrate the technology readiness and flexibility of fuel cell bus solutions. Indeed, the FCH JU Clean Hydrogen in European Cities (CHIC) project,

Entreprises
Transport

Van Hool mise sur l'hydrogène

«Nous avons investi des dizaines de millions d'euros dans cette technologie. Pour nous, c'est l'avenir...»

Financement européen

Prix élevé

a flagship zero-emission bus project, was launched to deploy 56 fuel cell electric buses with the relevant refuelling infrastructure across Europe and in Canada. This involved 23 partners in eight countries, with nine operators and six bus manufacturers. The FCH JU co-financed the project, providing €26 million out of a total of €82 million. CHIC deployed several hydrogen bus fleets using urban and rural routes, within limited geographical areas. The enabled central refuelling stations to service the buses and helped to address the refuelling infrastructure issue.

Throughout its activities, CHIC successfully demonstrated that fuel cell buses could offer a functional solution for cities to decarbonise their public transport fleets, improve air quality, and lower noise levels.

Building on this initial project, the FCH JU set out to broaden uptake by identifying, initiating and coordinating a series of new clusters suitable for procuring fuel cell electric buses. Not only would this build confidence in the technology, it would help cement the commercial case. Follow CHIC, the other FCH JU projects on buses, such as High V.LO-City, HyTRANSIT and 3Emotion trialled bigger fleets (of around 20 buses) throughout European cities. The clusters identified included Benelux, Germany, France, Scandinavia and Northern Europe, and the UK. **All of these projects have proven that fuel cell buses can operate with the same flexibility as diesel buses without compromising the productivity of public transport.**

While fuel cell electric bus prices are still more expensive on a purchase price than conventional diesel buses, the FCH JU supports the realisation of business scenarios where the commercialisation of these buses is more favourable. Inevitably, the price difference will decrease as understanding of the technology in real-world situations improves and economies of scale become apparent. To allow participating clusters to make a more realistic assessment of the deployment costs, the FCH JU allocated a budget of up to €200,000 per bus. This also provided a robust indicative price at which interest in the units would be realistic.

Increasing volumes is a key solution to address cost reduction and open the gate to market deployment. For this reason, the FCH JU's latest bus project, JIVE, aims at having a massive impact on volumes. JIVE will deploy 139 fuel cell buses in Europe, helping to unlock the economies of scale required for commercialisation. This is the largest ever deployment of fuel cell buses in Europe.

REINFORCING COMMITMENT

The FCH JU's public–private partnership structure provides a unique political context. A number of regional and metropolitan authorities were interested in taking part in pilot projects to find ways to reduce their reliance on fossil fuels. The platform set up by the FCH JU facilitated these activities, helping to create stakeholder consensus.

On top of the projects it has supported, the FCH JU helped to increase the level of commitment from the supply and the demand sides. At several conferences and events, the FCH JU organised signature ceremonies involving both manufacturers and cities/operators to seal their commitment to fuel cell bus expansion. This level of commitment was absent not too long ago. This is new, and is clearly linked to the efforts of stakeholders under the umbrella of the FCH JU.

BUILDING FOR THE FUTURE

The successes of the projects in cities such as Cologne, London and Aberdeen have demonstrated that fuel cell electric buses are not only viable, but deliver the desired results. The lack of noise, and their contribution to air quality, makes them popular with the public; indeed, London is seeking to capitalise on their popularity, and is pushing for a fuel cell version of their iconic double-decker bus. Overall, the expected demand for fuel cell electric buses in the clusters was higher than expected. The initial estimate of 200–300 buses has risen to more than 900. This is driving a virtuous circle of demonstrating confidence and reducing unit costs, de-risking investment for other potential cities seeking to deploy this technology, as well as for operators and manufacturers.


eDrive
Hydrogen Fuel Cell
BMW Group Research and Technology

FUEL CELL ELECTRIC VEHICLES

4

BACKGROUND

Despite numerous incentives to reduce personal car use – road charging, congestion taxes, higher fuel duties, ecological tax exemptions or public transport contributions – the number of vehicles on our roads continues to grow. Although engine manufacturers are continuing to extract ever more power from ever smaller engines while generating less pollution, the internal combustion engine is reaching the end of its life span. Its reliance on fossil fuels prevents it from being sustainable and environmentally friendly.

As a response, a range of alternatively-powered cars is available, including battery and hybrid.

Cars powered by hydrogen fuel cells offer an ideal solution. These emit no pollutants; the only by-product is water. At the same time, they can cover far greater distances per tank – currently 500 km, and could even reach up to 800 km in the near future – with a refuelling time equivalent to that of conventional petrol or diesel cars.

THE CHALLENGE

The technology for fuel cell cars is already well established; from a driver's perspective, they are quiet, responsive and perform as well as any modern vehicle. Paris already operates a fleet of 60 fuel cell electric taxis, the largest such fleet in the world, with plans to increase the numbers to several hundred. Other car-sharing initiatives are being set up using these clean and reliable vehicles. This is the reason why car manufacturers are beginning to make fuel cell vehicles available to consumers.

However, with the cars currently built only in small numbers, the list prices remain high. The sparse refuelling infrastructure remains the other barrier for hydrogen-powered cars. Filling up with hydrogen requires dedicated service stations, capable of delivering the fuel at the appropriate pressure. There needs to be a critical density of the refuelling infrastructure in order to build consumer trust. Drivers need to be confident that the most convenient point of sale for them is operational and adequately supplied.

SOLUTION

The FCH JU sought to find ways to overcome the challenges to fuel cell electric vehicles uptake. The basic prerequisite is for car manufacturers and infrastructure providers to work hand in hand – one will not become established without the other. At the same time, along with addressing collaboration between the car manufacturing and infrastructure providers, FCH JU also focused on improving consumer confidence by encouraging the adoption of existing standards for refuelling stations.

To assemble the elements required to address these challenges, the FCH JU funded a series of projects. The largest FCEV (fuel cell electric vehicle) demonstration projects of the FCH JU are HyFIVE and H2ME. HyFIVE has already put into operation 185 hydrogen vehicles along with six hydrogen refuelling stations. The vehicles come from five leading global automotive companies: BMW, Daimler, Honda, Hyundai and Toyota. This project successfully developed a hydrogen network within three geographical clusters: London, Copenhagen and a southern area comprising Innsbruck, Munich, Stuttgart and Bolzano.

The FCH JU subsequently funded the Hydrogen Mobility Europe (H2ME) projects. These projects bring together Europe's leading initiatives in hydrogen mobility – in France, Germany the UK and Scandinavia – helping to significantly expand Europe's hydrogen vehicles and station network. H2ME is the biggest FCH car demonstration project to date, testing the latest technology from leading car OEMs of the sector and hydrogen refuelling station providers. The first project – H2ME – began in 2015, aiming to deploy 29 hydrogen refuelling stations and 325 vehicles. H2ME2, which started in 2016, is adding a further 20 hydrogen refuelling stations and more than 1,100 vehicles.

These projects will demonstrate hydrogen-fuelled road transport as a pan-European solution to the need for viable and competitive alternatives to fossil fuels. Importantly, they also incorporate a number of 'observer countries' – Austria, Belgium and the Netherlands – which will use the experience to in their own hydrogen mobility programmes.

BUILDING FOR THE FUTURE

While cars powered by hydrogen fuel cells may not deal with increasing road congestion, they will make a major contribution to making Europe's environment cleaner. As the technology continues to improve, fuel cell-powered vehicles could be set to become the core of clean transport technology. Once the technology is widely available on the market, passenger car owners will be able to switch to this technology easily without changing their habits. The driving range and refuelling times are already comparable to those of conventional cars, while mitigating the issue of air pollution.


Hydrogen
powered vehicle

CONCLUSION

The EU's decision to implement the European Hydrogen and Fuel Cell Technology Platform and subsequently the Fuel Cell Hydrogen Joint Undertaking has proved a game-changer. Over the past ten years, the FCH JU has provided a focus for European expertise in fuel cells and hydrogen to reach common goals, and taken Europe to the forefront of fuel cell and hydrogen technology.

The FCH JU's unique public-private partnership and three-way structure has ensured a stable framework to facilitate the strategic cooperation needed between public authorities, industry and research to deliver fuel cell deployment at a large scale.

Along with the SMEs and industry players gathered together in the industry grouping Hydrogen Europe, and the universities and research organisations convened in Hydrogen Europe Research, many stakeholders are involved with FCH JU on the path towards commercialisation, including NGOs, utilities, heating operators, transport operators, energy service companies, energy and mobility associations, municipalities, regional authorities, and member states.

Cooperation and cross-fertilization across the FCH JU community has enabled significant progress – with technology breakthroughs in key areas, and in terms of reduced life-cycle costs and increased overall performance, durability and efficiency. It has also helped Europe to establish world-leading expertise in developing better and more efficient fuel cells and green hydrogen production.

Thanks to these activities, hydrogen and fuel cell technology is approaching market-readiness in many sectors, including buses, passenger cars, forklift truck, combine heat and power units, and portable and back-up applications. The urgent need to decarbonise Europe's energy and transport systems has given fresh impetus to the FCH's mission: to build bridges between today's advanced technology and tomorrow's widespread deployment.

By 2020, the FCH JU aims at developing very efficient fuel cell systems; continuing the successful demonstration and roll-out of fuel cell applications for homes and businesses in many countries, and providing cleaner transport solutions.

Looking further ahead to 2030, with the support of the FCH JU, fuel cell cars, buses and generators will be an affordable and convenient option for many. With Europe's 2030 climate and energy goals in mind, fuel cell and hydrogen will make a major contribution to the targets of reducing greenhouse gas emissions by 40%, increase renewables to 27% of Europe's energy needs, and increase energy efficiency by 27%.

By 2050, we hope that the FCH JU's efforts will have led to market expansion and zero-emission transport, powered by fuel cells. Zero-carbon renewable energy from fuel cell generators and hydrogen will be an everyday reality, and the FCH JU's journey to a greener world will be complete.

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