FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

FCH JU – SUCCESS STORIES

A PARTNERSHIP DEDICATED TO CLEAN ENERGY AND TRANSPORT IN EUROPE

www.fch.europa.eu
@fch_ju

ISBN 978-92-9246-329-8 EG-03-18-411-EN-C

Publications Office

FCH JU – SUCCESS STORIES

A PARTNERSHIP DEDICATED TO CLEAN ENERGY AND TRANSPORT IN EUROPE

FUEL CELLS AND HYDROGEN
JOINT UNDERTAKING

CONTENTS

INTRODUCTION

SECTION 1
Development and deployment

SECTION 2
New generation products

SECTION 3
Opening markets

SECTION 4
Fuelling growth

FOREWORD

Dear reader,

You hold in your hands an account of the Fuel Cells and Hydrogen Joint Undertaking's success stories. Preparing these success stories for publication gave us a chance to look back and see what we have achieved together over the past ten years.
It is amazing to see the enormous progress that fuel cell and hydrogen technology has made. None of this is possible without the many dedicated men and women who work countless hours to make their projects a success. Each of these stories show how collaboration between research, industry and policy makers in a European partnership delivers the best innovations and accelerates the transition to a greener world.
I hope you will enjoy reading these stories and helping us to spread the word about the latest developments in fuel cell and hydrogen technology. It is important that European citizens learn more about these successes, and the many ensuing benefits for all. The hydrogen economy is just at the beginning of a long journey and I am sure that we will see many more success stories in future. Thanks to all the people who contributed to make this brochure a reality.

Bart Biebuyck
Executive director of the **FCH JU**

ON THE ROAD TO A LOW-CARBON FUTURE

As 2018 marks the ten-year anniversary of the Fuel Cells and Hydrogen Joint Undertaking (**FCH JU**), it is inspiring to look back over the many accomplishments of the past decade. The projects described in these pages illustrate the approach of continuous learning exemplified by the **FCH JU**'s projects, from creating low-carbon and sustainable solutions, enabling market entry for new products, developing 'next generation' products based on previous research, to opening new markets for European expertise in fuel cell and hydrogen (FCH) technology.

The **FCH JU**'s achievements are due, in part, to its multi-stakeholder structure: a public-private partnership between industry, research and the European Commission. Industry-led research has pioneered new developments in FCH technology and brought many of them to the cusp of commercialisation. Market uptake from public authorities, major companies and citizens alike has boosted confidence in these clean technologies, establishing hydrogen as a cornerstone of Europe's energy transition.

DEVELOPING SOLUTIONS FOR A GREENER WORLD

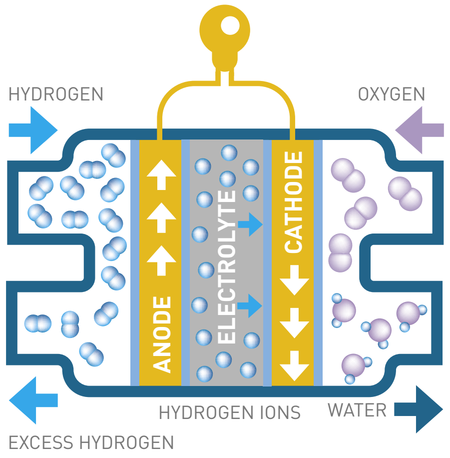
Citizens are at the heart of Europe's Energy Union, a strategy aimed at providing clean, secure and affordable energy for all. For some years now, and as a signatory to the Paris Agreement in 2015, the EU has been actively targeting reductions in carbon dioxide (CO_2) emissions.

AGREED IN JUNE 2018, THE MOST RECENT EU CLIMATE AND ENERGY TARGETS FOR 2030 ARE:

In support of these and other policy commitments, over the last ten years the **FCH JU** has been developing and deploying new low-carbon solutions. In transport, a challenging sector to decarbonise, the **FCH JU** has funded a series of flagship bus, car and refuelling infrastructure projects to demonstrate the hydrogen fuel cell technology's reliability and financial viability, bringing down costs and building the investor confidence needed to upscale FCH use across the transport sector.

Hydrogen fuel cells enable the production of electricity with improved efficiency when compared to internal combustion engines (ICEs). They emit only water, and produce no CO_2 emissions, which are largely responsible for global warming, nor other atmospheric pollutants (such as NO_x, SO_x or particulate matter). The reduced emissions and higher efficiency of the fuel cells relative to ICEs mean that increased deployment of fuel cell electric vehicles is aligned with European policy goals for transport and air pollution.

DEPLOYMENT OF FUEL CELL ELECTRIC VEHICLES IS ALIGNED WITH EUROPEAN POLICY GOALS FOR TRANSPORT AND AIR POLLUTION.



With more renewable energy comes an increase in demand for energy storage. The role of hydrogen in clean energy storage has become increasingly important for the **FCH JU**, and significant research progress has been made since 2011. An excess of hydrogen produced by electrolysis – the splitting of water into hydrogen and oxygen – led to the realisation of its potential as backup power: harnessing the intermittent power of renewables and enabling higher penetration of renewable energy across other sectors. The **FCH JU** has allocated considerable resources to the refinement of the electrolysis process, with the result that Europe is now a world leader in the key technology, the proton exchange membrane (PEM). Now green hydrogen production sites are setting up all over Europe, from Scotland's remote Orkney Islands to the industrial heartlands of Austria.

Most buildings in Europe are heated using individual gas boilers, which maintains dependency on fossil fuel imports and causes local air pollution. The **FCH JU** has been instrumental in the development and commercialisation of fuel cell micro Combined Heat and Power (µCHP) units – in essence, mini-power plants - that allow householders and businesses to produce much of their own electricity, heat and hot water.

A PARTIAL SOLUTION FOR DECARBONISING EUROPE'S ENERGY MARKETS AND DELIVERING CLEAN HEAT AND POWER FOR HOMES AND SMALL BUSINESS.

This cutting-edge technology offers very high fuel-to-energy conversion efficiencies – allowing for the potential achievement of overall CO_2 emissions reduction of between 30% and 80%. Furthermore, as fuel cells do not rely on combustion they have zero or negligible impact on local air emissions. Fuel cell µCHP demonstrates a partial solution for decarbonising Europe's energy markets and delivering clean heat and power for homes and small business.

HYDROGEN TERRITORIES

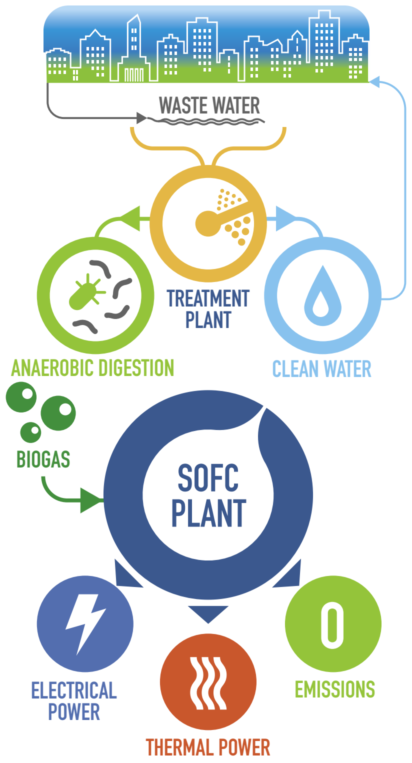
These multiple applications of fuel cell and hydrogen technology have opened up the prospect of 'hydrogen territories', regions that implement a fully integrated model of hydrogen production, storage, transportation, and utilisation for heat, power, and mobility. Locally produced (or 'decentralized') hydrogen can contribute to a region's energy independence, and boost local skills, jobs and economic growth. Other societal benefits include reduced noise pollution and cleaner air, improving citizens' quality of life.

ONE EXAMPLE, THE FCH JU-FUNDED **BIG HIT PROJECT**, WILL CONVERT EXCESS ELECTRICITY GENERATED BY RENEWABLE SOURCES ON THE ORKNEY ISLANDS INTO HYDROGEN, TO BE COMPRESSED AND STORED IN HIGH-PRESSURE CYLINDERS FOR TRANSPORT BY ROAD AND SEA.

It can then be used as fuel in other applications such as heating buildings and fuelling vehicles. The potential for replication in other island communities is significant.

These projects are based on circular economy principles: minimising the use of critical raw materials and recovering energy. The circular economy principle is exemplified by the DEMOSOFC project, which has brought into operation the largest biogas-fed fuel cell plant in Europe. The system works by recovering the biogas from the anaerobic digestion of the sludge produced by Turin's wastewater treatment process and using it to generate zero-emission energy. The replication potential of this, and of other innovative projects is huge and supports Europe's commitment to growing a sustainable and circular economy.

New possibilities are being opened up thanks to green hydrogen. The increasing power of PEM electrolysers is making green hydrogen production suitable for a growing range of applications, and attracting a broader base of end users, including heavy industry. In Linz, Austria, the H2FUTURE consortium will produce green hydrogen onsite, with the ultimate aim of producing emissions-free steel. Meanwhile the Refhyne project is testing the electrolyser use on a large industrial scale in the area of refining. By channelling renewable electricity into the industry, transport and building sectors, green hydrogen is advancing the practice of sector coupling and sectoral integration.



SUSTAINING GROWTH

The FCH JU's unique public-private partnership has proven to be an effective platform for strategic cooperation between public authorities, industry and research; the level of cooperation that is necessary for development and subsequent large-scale deployment of fuel cell and hydrogen technology. In particular, the FCH JU network nurtures European SMEs and start-ups, whose productivity and competitiveness benefit all.

The FCH JU community is diverse and inclusive: industry grouping Hydrogen Europe gathers SMEs alongside major industry players, universities and research organisations are convened in Hydrogen Europe Research, and many stakeholders are involved with the FCH JU on the path to commercialisation, including NGOs, utilities, heating operators, transport operators, energy service companies, energy and mobility associations, municipalities, regional authorities, and Member States.

As part of the global community, the FCH JU works internationally, cooperating with partners from China, the U.S. and Japan in the shared quest for a greener and sustainable world. The cooperation and cross-fertilization evident across the FCH JU community and beyond borders has enabled technology breakthroughs in key areas, establishing European world-leading expertise.

OVER €1 BILLION FROM THE FCH JU, MATCHED BY THE PRIVATE SECTOR, SPENT ON 203 PROJECTS IN THE LAST TEN YEARS HAS LAID THE GROUND FOR A CLEAN ENERGY REVOLUTION.

Now, to drive wider uptake, a stable regulatory environment must complement the investment already made. To stay at the cutting edge of FCH technological developments, and create an industrial renaissance in Europe, the EU needs to build on the FCH JU's success to date, and help us continue our journey to a low-carbon future.

SECTION 1: DEVELOPMENT AND DEPLOYMENT

THE FCH JU HAS PLAYED A PIVOTAL ROLE IN THE COMMERCIALISATION OF HYDROGEN-FUELLED BUSES IN EUROPE BY FUNDING DEMONSTRATION PROJECTS AND BRINGING TOGETHER KEY STAKEHOLDERS ON THE SUPPLY AND DEMAND SIDE.

The result: fuel efficiency has increased three-fold and refuelling time has halved. What's more, the buses are appreciated by city dwellers and passengers as a clean, green, quiet urban transport solution.

HIGH PERFORMANCE CROWD-PLEASERS

The public reaction to trialling of hydrogen buses in large urban centres has been very positive. They are good for the environment and public health, with no carbon or particulate emissions and reduced reliance on fossil fuels when green hydrogen is used. **Hydrogen fuel cell buses have a long range (300 – 400 km) and are quick to refuel.** Their popularity with drivers and passengers is also due to the lack of vibrations and noise. Urban residents appreciate the improvement in air quality and reduced noise pollution, with the knock-on positive effects on their health. Altogether, hydrogen buses represent a strategic choice for city councils striving to improve the quality of life for citizens.

The technology's performance is constantly improving: fuel efficiency has increased three-fold in 15 years and refuelling time has more than halved. As enough fuel is carried onboard for a full shift, no route infrastructure is required, only a refuelling station at the bus depot. Furthermore, there is an opportunity to create employment and economic development by becoming a world leader in the technology. This opens up the prospect of new jobs and skillsets, business opportunities both within Europe and for export markets, boosting economic growth.

SPREADING THE WORD: BUSES IN ACTION

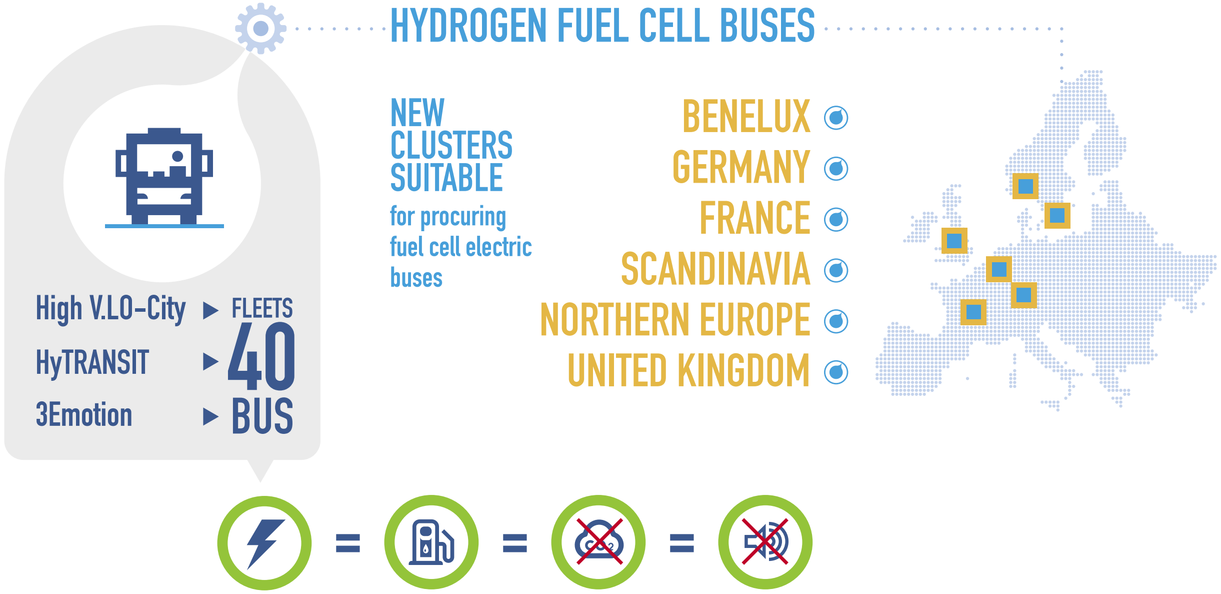
Small-scale demonstration trials have been taking place in commercial fleets around the world thanks to **FCH JU** funding. There are currently more than **40 FCH JU**-supported buses on the road (of an estimated 65) fuel cell buses in operation around Europe. The most recent projects, **JIVE** and **JIVE2**, will bring the number of **hydrogen buses close to 400**, with fleets as large as **40 in some cities**.

SPREADING THE WORD: BUSES IN ACTION

Fuel efficiency has increased three-fold in 15 years and refuelling time has more than halved.

Clean Hydrogen in European Cities (CHIC), the **FCH JU** co-financed flagship project, was launched in 2010 to deploy 56 fuel cell electric buses (of which 26 are funded by the **FCH JU**) along with the refuelling infrastructure across Europe and in Canada. CHIC 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.

Other **FCH JU** projects followed, such as High V.LO-City, HyTRANSIT and 3Emotion, which trialled bigger fleets (of around 20 buses) in cities throughout Europe. They identified, initiated and coordinated a series of new clusters suitable for procuring fuel cell electric buses in 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. Moreover, they bring the added value of zero noise or particle pollution.



ENABLING COMMERCIAL UPTAKE

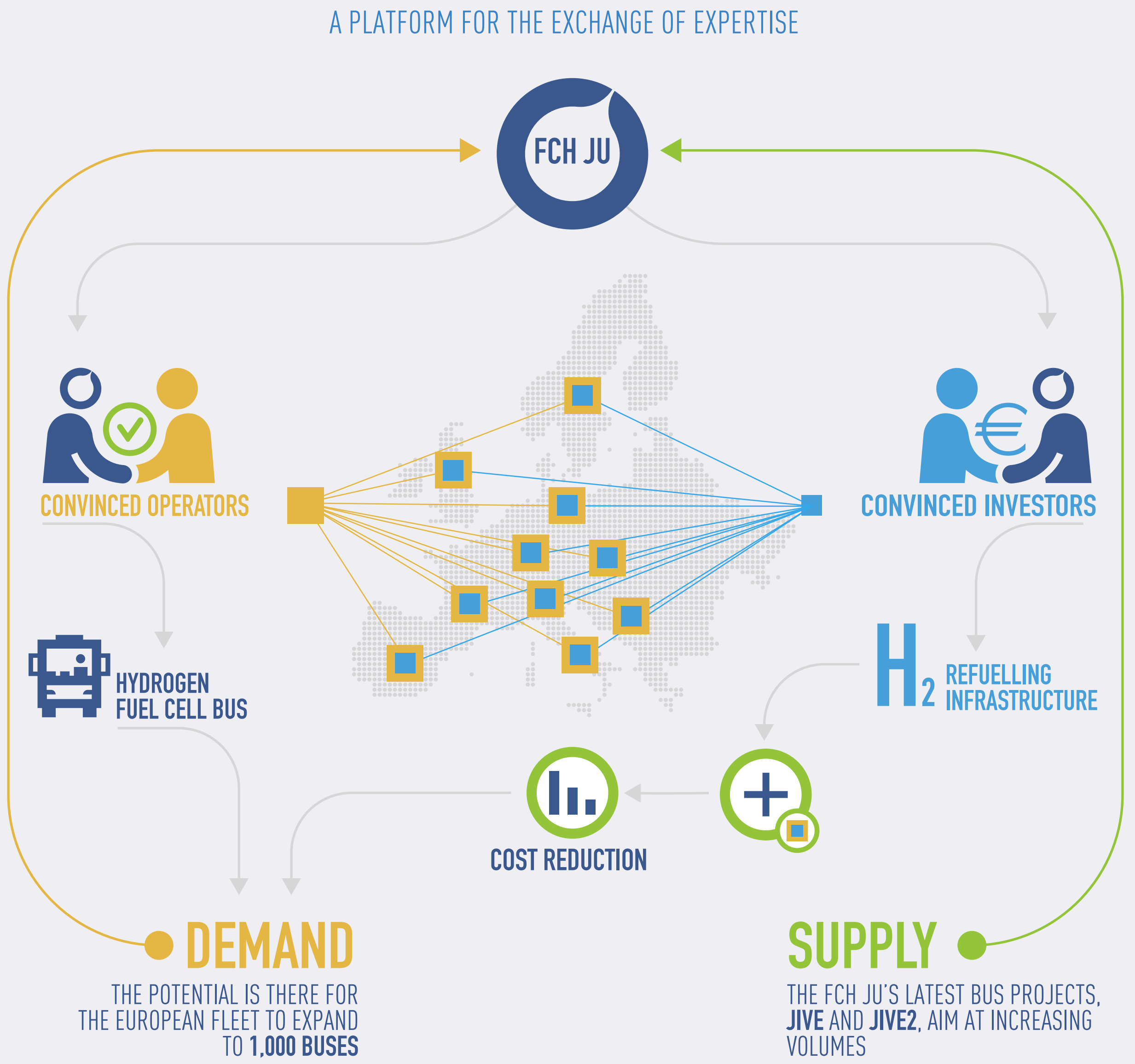
The first step by the **FCH JU** was to gather the supply and demand side. Acting as a platform allowed for the exchange of expertise, building further insight into what would make a fuel cell fleet viable.

Due to limited experience in applying hydrogen fuel cell technology to public transport, there was a pressing need for evidence that fuel cell powered buses were reliable and cost effective to convince operators, manufacturers and authorities to invest in the technology. Another potential barrier was the need for a refuelling infrastructure. However, without demand for access to a reliable, local and convenient source of hydrogen, there is no incentive to invest in the infrastructure.

Operators have to know that the infrastructure is there, and investors need the confidence in demand to invest in the infrastructure. Economies of scale are also needed to bring down costs sufficiently to enable wider scale deployment.

To address cost reduction and open the gate to market deployment, the **FCH JU**'s latest bus projects, JIVE and JIVE2, aim at increasing volumes. Through the largest ever deployment of fuel cell buses in Europe, they will contribute to commercialisation. The potential is there for the European fleet to expand to 1,000 buses, which would bring down costs to a level competitive with hybrid vehicles.

The **FCH JU** has also helped to increase the level of commitment from the supply and the demand sides by organising signature ceremonies for manufacturers and operators to pledge their commitment to fuel cell bus expansion.
Supporting the development of fuel cell buses, from making a business case to proving commercial viability, is an ongoing journey for the **FCH JU**.



The FCH JU is committed to the rollout across Europe of hydrogen fuel cell electric vehicles (FCEVs). This is an exciting prospect, as FCEVs have the potential to replace the internal combustion engine and reduce air pollution, CO_2 emissions and fossil fuel use.

In Paris, the FCEV taxi fleet is set for exponential growth, and hydrogen refuelling infrastructure is expanding across Europe to enable wider uptake of this low-carbon mobility solution.

A GREEN ALTERNATIVE

Despite numerous incentives to reduce car use, the number of polluting vehicles on our roads continues to grow. Even with manufacturers increasing engine efficiency, 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.
In response, a range of alternatively powered cars is being developed, including battery and hybrid models.

Cars powered by hydrogen fuel cells offer an ideal solution. They emit no pollutants; the only byproduct is water.
The generation of the fuel can also be emissions-free when it is produced through water-based electrolysis powered by renewable energy. At the same time, the cars can cover comparable distances per tank, with a refuelling time equivalent to that of conventional petrol or diesel cars, currently around five minutes. In addition, the energy efficiency of a fuel cell is typically between **40%** and **60%**, compared with **25%** for a petrol engine.
Next to battery-powered electric vehicles, FCEVs have two main advantages: an extended range, and no lengthy recharging time.

THE WAY FORWARD: FUEL CELL HYDROGEN CARS

THE FCH JU IS COMMITTED TO THE ROLLOUT ACROSS EUROPE OF HYDROGEN FUEL CELL ELECTRIC VEHICLES (FCEVS).

BARRIERS TO OVERCOME: COST AND REFUELLING INFRASTRUCTURE

The technology for fuel cell cars is already well established: they are quiet, responsive, and perform as well as any modern vehicle. Paris already operates a fleet of 100 fuel cell electric taxis, the largest such fleet in the world. The initial deployment has been a success: by the end of 2018, the Parisian fleet will number 200, and by the end of 2020, there will be 600 FCEV taxis in the capital.
These early market adoptions support car manufacturers, who are beginning to make fuel cell vehicles available to consumers.

However, with the cars currently being built only in small numbers, the prices remain high. The sparse refuelling infrastructure is the other main barrier for hydrogen-powered cars. Dedicated service stations are needed, and the refuelling infrastructure must reach a critical density in order to build consumer trust.

SOLUTIONS: PILOT PROJECTS

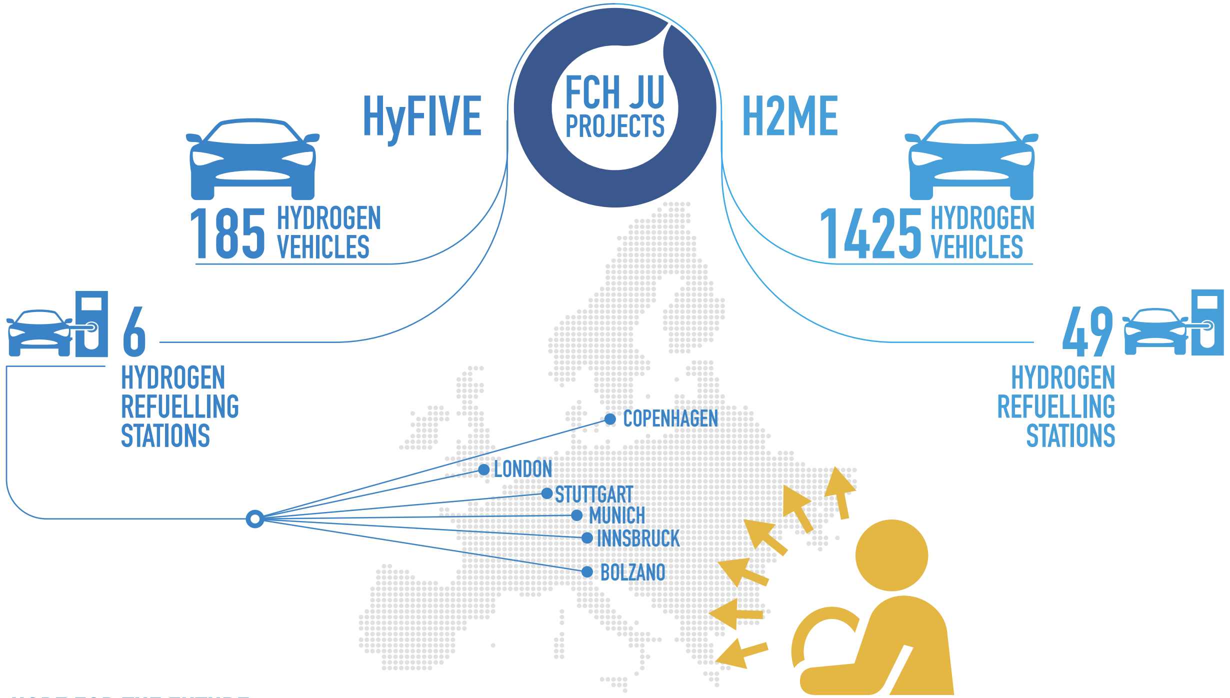
The **FCH JU** has sought ways to overcome the challenges to the uptake of FCEVs. The basic prerequisite is for car manufacturers and infrastructure providers to work hand in hand — one will not become established without the other. At the same time, the **FCH JU** also focuses on improving consumer confidence by encouraging the adoption of existing standards for refuelling stations.

To address these challenges, the **FCH JU** has co-funded a series of projects. The largest FCEV demonstration projects of the **FCH JU** are HyFIVE and H2ME. HyFIVE put 185 hydrogen vehicles into operation, along with six hydrogen refuelling stations across 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, which bring together Europe's leading initiatives in hydrogen mobility — in France, Germany the UK and Scandinavia — helping to significantly expand the number of Europe's hydrogen vehicles and its station network.

H2ME is the biggest FCEV car demonstration project to date. The first project began in 2015, aiming at deploying 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. Once complete, these projects will allow an FCEV driver to travel across the continent along several routes.

These projects demonstrate the potential of hydrogen-fuelled road transport as a pan-European solution to the need for viable and competitive alternatives to fossil fuels. By supporting vehicle deployment and building the infrastructure required to take FCEVs from demonstration to market initiation phase, the **FCH JU** is tackling the remaining pre-commercial barriers.



HOPE FOR THE FUTURE

As the technology continues to improve, and prices come down, FCEVs are well positioned to underpin zero-emissions transport in Europe. This depends upon the average car owner being able to make the switch easily to hydrogen fuel cell technology. It is this issue of accessibility that needs to be further developed to gain the momentum crucial for mass deployment. Meanwhile, uptake will also be driven by regulatory factors such as the introduction of increased restrictions on the use of polluting combustion-engine vehicles, especially in urban environments.

The early deployment of FCEVs and refuelling infrastructure has boosted the public's confidence in the technology. Thus, the **FCH JU** support has created the foundation for wider market uptake of FCEVs – and cleaner air for Europe's citizens.

USING GREEN HYDROGEN FOR ENERGY STORAGE AND SECTOR COUPLING

GREEN HYDROGEN – WHY AND HOW?

Electrolysis can use excess electricity to split water molecules into oxygen and hydrogen. Making 'green' hydrogen through electrolysis powered by electricity from renewable energy sources avoids all emissions, unlike the process currently producing most hydrogen: steam methane reforming. To replace this hydrogen with green hydrogen would supply industry with a completely clean fuel. When used to power transport, it could decarbonise that sector also. Thus, the radical potential is there to vastly reduce emissions from the industry and transport sectors while also tackling fossil fuel dependence.

Green hydrogen can also be fed to fuel cells to generate electricity for the grid. In this way it can play a balancing role during periods of high demand: it captures the surplus of electricity produced at times by wind and solar sources and acts as an energy carrier– harnessing the excess power generated and releasing it as needed.

The technology behind electrolysis has existed for a hundred years but it needed to be improved to become flexible enough to be coupled to renewables. The challenge was to develop the technology while reducing costs, but also provide electricity grid services at the same time. It was important to show that production methods were technically feasible, adapted to real world conditions, and financially viable. The point is now being reached where electrolysis is being used more widely and taken up by companies as a clean energy storage solution and to produce transport fuel.

THE FCH JU IS PLAYING AN IMPORTANT ROLE IN ESTABLISHING GREEN HYDROGEN AS A VIABLE APPROACH TO ENERGY STORAGE AND CLEAN FUEL. THE DEVELOPMENT OF MORE SOPHISTICATED ELECTROLYSIS TECHNIQUES IS HELPING TO OPTIMISE THE INTEGRATION OF RENEWABLE ENERGY, AND THE DEMONSTRATION OF APPLICATIONS IN THE TRANSPORT AND INDUSTRY SECTORS IS OPENING UP NEW MARKETS AND ADVANCING SECTORAL INTEGRATION.

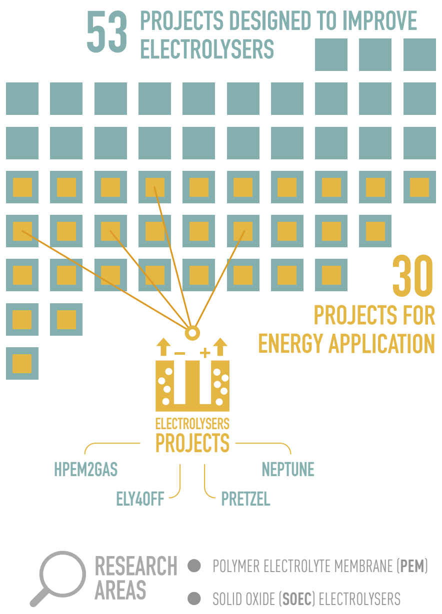
TWO-FOLD APPROACH

There are two distinct strands supported by the **FCH JU**. One encourages the development of more powerful and more efficient electrolysers. The other supports field demonstrations of technologies in transport and industrial applications to open up new markets.

To drive the first strand, the **FCH JU** supported a series of projects designed to improve electrolysers. 30 out of the 53 projects related to hydrogen production support the development of electrolysis for energy application. Among these are HPEM2GAS, ELY4OFF, PRETZEL and NEPTUNE. Important areas of research include delivering advances in the initial alkaline electrolysers as well as in other types, including polymer electrolyte membrane (PEM) and solid oxide (SOEC) electrolysers.

The second strand relates to FCH JU energy projects that have demonstrated the increasing power of electrolysers. This has risen from 100 kW, with project Don Quichote in 2011, to 6 MW in the 2016 H2FUTURE project.

The increasing power will make electrolysers suitable for a growing range of applications, which is attracting a broader base of end users, including heavy industry. The H2FUTURE project, for example, is injecting green hydrogen into steel production, thereby eliminating greenhouse gas emissions that would normally ensue. Demonstrating that even energy-dependent sectors can rely on this technology will make for increasingly green industrial production.



Ambitious renewable energy targets could result in a ten-fold increase in demand for energy storage. This in turn would enable the creation of the green hydrogen needed to decarbonise industry and transport. The improved electrolysers will play a key role by harnessing surplus electricity generated through wind and solar power and releasing it back onto the grid as needed. So, the development of hydrogen storage properties is also a key area, as explored in the HyUnder project.

Even with increasing access to spare generating capacity, green hydrogen from electrolysis remains relatively expensive. However, a growing number of cities and regions are eager to demonstrate their commitment to clean technologies. Through a current study, the **FCH JU** is taking the lead in creating green hydrogen market certificates to satisfy this demand.

In the ten years since its inception, the **FCH JU** has put in place many of the building blocks to smooth the transition to renewable energy sources through clean hydrogen. Its support has increased sectoral interest and boosted confidence in the technology. Equally its unique public–private partnership structure is driving the uptake of this technology. It allows suppliers and end users to work together in a way that would not happen spontaneously, while enabling a long-term, strategic perspective on the sector.

HEAT AND POWER YOUR HOME WITH FUEL CELLS

Those concerned about reducing their carbon footprint know that the first place to start is at home. One new solution is on offer in the form of decentralised electricity production through fuel cell micro Combined Heat and Power (µCHP) units, which allow users to produce much of their own electricity, heat and hot water. The **FCH JU** has been instrumental in the development and commercialisation of this cutting-edge technology: a clean, distributed energy solution that can deliver efficiencies as high as **90%**.

POWER TO THE PEOPLE

Though new-generation modern homes are increasingly energy-efficient, most are heated by gas boilers. Fuel cell µCHP units offer an alternative: efficient, clean, distributed energy solutions for heat and power generation near the point of consumption. These units are usually installed in residential or small commercial buildings and provide heating and hot water in buildings. At the same time, they can generate electricity to replace or complement that supplied by the grid. **The technology offers very high fuel-to-energy conversion efficiencies – electrical efficiencies of up to 60% and overall heat and power combined efficiencies as high as 90% and even more**.

As the fuel cell produces the electricity more efficiently and affordably, with minimal environment impact, the consumer does not have to buy electricity from the grid. In fact, consumers are thus transformed into 'prosumers', who can sell excess electricity back to the grid. While the units cannot fully replace the need for external power, the increased efficiency sharply reduces both the need for electricity supply from the grid and primary energy needs. Overall CO_2 emission reductions of between 30% and 80% can be achieved. What's more, as the fuel cells are not powered by combustion, they do not contribute to air pollution.

EXPANDING THE APPLICATION OF FUEL CELL µCHP TECHNOLOGY

Until recently, the existing fuel cell technology had a number of limitations. The fuel cells were large, expensive to manufacture, and required regular maintenance. However, the **FCH JU** realised that the development of fuel cell µCHP units was critical as they could transform natural gas into the hydrogen needed to power the fuel cells, making them suitable for any home connected to the gas network.

In order to show that fuel cell µCHPs are ideal for the domestic environment, the **FCH JU** needed to trial the technology on a wider scale than previously attempted. The intention was not only to demonstrate benefits to consumers, but the size of the market opportunities to potential manufacturers.

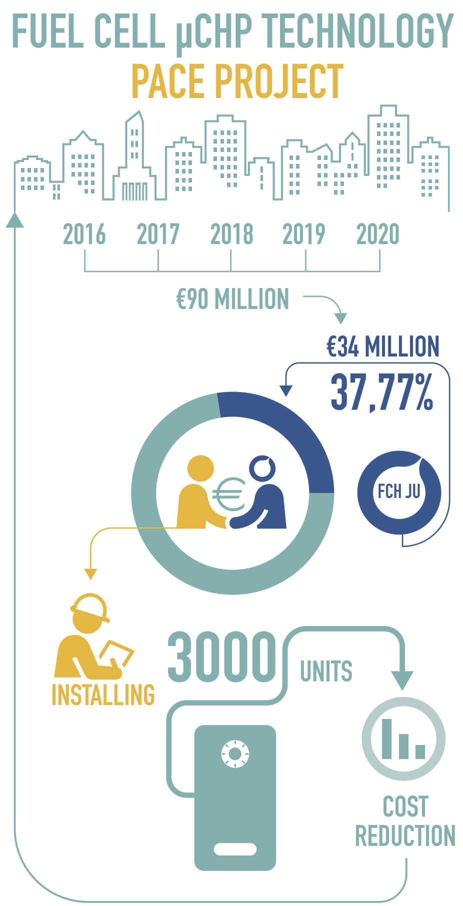
In 2012 the launch of an **FCH JU** co-funded project, ene.field, supported the installation of over 1,000 residential fuel cell µCHPs in ten EU countries over five years. The project results have allowed the participating manufacturers to refine their technologies and business models, and to develop a track record of installations. Consumer confidence in the technology has also grown.

KEEPING PACE – RAMPING UP PRODUCTION

Since early 2016 the decarbonisation of heating provision in the building sector has become one of the priorities of EU energy policy – first with the launch of the inaugural EU Heating and Cooling Strategy, then later with the Clean Energy Package legislative proposals. A number of the ene.field manufacturers joined forces with other partners in PACE – a five-year project launched in June 2016 to bring fuel cell µCHP technology closer to mass commercialisation. Backed by the **FCH JU** (€34 million out of €90 million), it aims at installing close to 3,000 units with real customers. It will allow manufacturers to scale up production (thereby reducing production costs by at least 30%) and improve the durability of the fuel cells at the core of the units.

The domestic deployment of fuel cell 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 **FCH JU** public–private partnership model is key to this success. It allows the SMEs involved to engage with important future partners: utilities, energy services companies, house builders, and local governments. This is an important factor alongside providing support for the investment required for the early development of the technology.

Financial incentives will also dictate the rate of future uptake; these were central to the technology's success in Japan where units are installed in the order of hundreds of thousands. Measures were put in place in Germany in 2016 to this end, and the UK has a feed-in tariff in place for microgeneration technologies including fuel cells. These schemes contribute to generating confidence in the market, and additional private investment in the sector is starting to pick up. New business models are emerging and beginning to be implemented, offering end consumers innovative propositions. This building momentum, accelerated by renewed European policy commitment to ambitious climate and energy targets, means that manufacturers can expect to see steadily growing demand.



ON THE MOVE: AUTOMOTIVE FUEL CELL STACKS

A CORE AMBITION OF THE FCH JU HAS BEEN TO ENCOURAGE THE DEVELOPMENT OF HYDROGEN FUEL CELLS FOR TRANSPORT APPLICATIONS, WITH A VIEW TO DEVELOPING THIS INDUSTRY WITHIN THE EU. PROGRESSING FROM HAND MANUFACTURING TO AUTOMATED ASSEMBLY OF HIGH QUALITY, HIGH PERFORMANCE STACK, IS A PREREQUISITE FOR INDUSTRIALISING PRODUCTION OF FUEL CELLS FOR CARS. THANKS TO FCH JU SUPPORT, THE TECHNOLOGY IS NOW IN A PRE-COMMERCIAL PHASE.

BRINGING EUROPE UP TO SPEED IN AUTOMOTIVE FUEL CELL STACK

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 polluting 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 applications. Vehicles on European roads using fuel cells were reliant on technology from Japan or North America. Developing the technology to produce fuel cell stacks was therefore an early priority for the FCH JU, in order to develop this industry within the EU.

In 2009, the FCH JU established the AUTO-STACK project as a cluster initiative for automotive fuel cell stack in Europe. This was followed by STACKTEST, which was a three-year project that developed and validated industry-wide harmonised test procedures for fuel cell stacks.

The most recent project, AUTO-STACK CORE, established a platform for developing best-of-its-class automotive stack hardware with superior power density and performance while meeting commercial target cost of particular importance in maintaining the manufacturing base within the EU. The project combined the collective expertise of automotive original equipment manufacturers (OEMs), component suppliers, system integrators and research institutes. The collaboration between these stakeholders, previously disconnected, is central to the success of the FCH JU approach. Over half of the funding for this project came from the FCH JU.

AUTO-STACK CORE ONWARDS

While room for improvement remains, this collaboration brought European fuel cell stacks even closer to being ready for the market. AUTO-STACK CORE set out to address some of the most critical challenges of fuel cell commercialisation. It acted as a platform to substantially improve economies of scale and reduce investment cost for individual OEMs by sharing the same stack hardware for different vehicles and vehicle categories. The project saw the weight and size of stacks fall while power increased.

Successive generations of stacks were also developed through the project. The last version achieved high performance results and high-power density at lower costs, in response to the demanding expectations of car OEMs. The success of these developments was recognised in the community, which led to car OEMs capitalising on the results and starting a limited production of stack. **FCH JU** initiatives have therefore helped to create a supply chain allowing for the standardisation process of stack production and impacting cost reduction. This was fundamental to enabling the first stage of the commercialisation process.

Based on these successes, in July 2017 a German 'Autostack industry' project was launched as a natural follow-up to the **FCH JU** projects. This national initiative is the next step toward mass fuel cell manufacturing. Over three years, this joint initiative of the German automotive and supply industries aims to provide the technical, economic and technological basis for the commercial introduction of fuel cell vehicles in Germany and Europe by 2020.

The project will enable the transition from hand manufacturing to automated assembly of high quality, high performance stack, which is a prerequisite for a broad market launch of fuel cell vehicles. The key challenge now is to further boost fuel cells' performance, service life and reliability while cutting costs.

With this new project, all the jigsaw pieces will fall into place to industrialise the production of fuel cells for automobiles. The **FCH JU** is proud to have been instrumental in contributing to this outcome. The competitive production of automotive fuel cell stack in Europe is close to becoming a reality. This highlights how European projects can act to inspire and support national initiatives when industry collaborates with research, harnessing the best of European skills and innovation.

LOWERING COSTS OF HYDROGEN STORAGE TANKS

THE COPERNIC PROJECT SUCCESSFULLY DEMONSTRATED THAT TANKS OF HYDROGEN VEHICLES CAN BE MANUFACTURED AT MUCH LOWER COSTS, ACHIEVING A REDUCTION OF 80% IN JUST THREE YEARS. COMMERCIALISATION AND FURTHER IMPROVEMENT OF THE NEWLY DEVELOPED MATERIALS AND TECHNIQUES ARE THE NEXT STEPS, AS THE SMES INVOLVED LOOK TO OFFERING PROTOTYPES TO VEHICLE MANUFACTURERS.

HIGH COST BARRIERS TO OVERCOME

Hydrogen vehicles could present an ideal alternative to the fossil fuel-reliant combustion engine. They produce no carbon emissions, have a better range and quicker refuelling time than battery-powered vehicles. However, the expense of production up to this point has meant that there was no hope of mass deployment. This was the challenge that the COPERNIC project, supported by the **FCH JU**, set out to address.
The aim was to bring down the costs of hydrogen cars and make them more viable commercially. This was to be achieved also by improving the overall design and manufacturing process for hydrogen storage tanks, as well as the quality of the materials used.

COPERNIC PROJECT
HYDROGEN FUEL TANK PRICE
-80%
in **3** YEARS
from **15,000 €** to **3,000 €**

OPTIMISING MATERIAL, AUTOMATING THE PROCESS

A major achievement of the project was to bring down the price of a hydrogen fuel tank from €15,000 to €3,000 over a three-year period, so that COPERNIC's tanks now cost five times less than other tanks available today.

The COPERNIC team first set about developing a material to be used in the production of the hydrogen tank: they tested and selected several carbon fibres to achieve the best performance for the price. The next step was to optimise the structure of the composite needed for high-pressure vessels, effectively reducing the mass of the composite by 20%.

Even with this improvement, the hydrogen tanks were still costly. The team therefore focused on increasing the productivity of the manufacturing process. 'We needed to reduce the time it takes to manufacture one tank. We also wanted this to be a repeatable and reliable process,' explained project coordinator Stephane Villalonga of CEA in France. The solution was a robot to replace the traditional classic filament winding process.
The automatisation meant an improvement in the quality and reliability of the composite, leading to the duration of the winding process being halved.

CHEAPER, BIGGER, SAFER

The project also demonstrated that it is cheaper to manufacture a bigger tank than to manufacture and use several smaller ones. The hydrogen storage is, however, more than a tank. It also includes pressure safety valves and protective equipment against fire.
To reduce the number of components in the system, the COPERNIC project tested and certified an on-tank valve that connects the hydrogen tank to the car fuel cell.
The valve simplifies the system and reduces the price of managing the pressure – tank manufacturers have already expressed an interest.

COPERNIC engineers didn't stop there, however. They also developed a way to monitor the health of the tank in real time during manufacturing and over its lifecycle. By placing optical fibres and sensors into the tank at the start of the manufacturing process, they helped to optimise the safety of the tank and enabled the car calculator to receive feedback on the safety of the vessel.

WHAT NEXT?

Since completion of the COPERNIC project in November 2016, the project's partner companies, mostly SMEs, have been active in bringing this potentially game-changing technology closer to commercialisation. Some of the consortium members are now in a position to propose prototype tanks to vehicle manufacturers.

The EU-funded HIPHONE (HIgh Pressure tank for HydrOgeN storage) project aims at developing and certifying the hydrogen tank based on COPERNIC results. Also, a new joint venture, HYCE, which grew out of the COPERNIC consortium, is manufacturing and commercialising the first European tank of 64 litres at 700 bar for on-board hydrogen storage in 2018. This will mean an even higher driving range, ultimately contributing to greater interest in the technology.

The **FCH JU** has been instrumental in supporting these developments and forging synergies amongst innovative SMEs, increasing job opportunities in the field. Thanks to the rapid progress made on this front, more hydrogen cars could appear on the market sooner than expected.

STACK CHP – BUILDING FOR ENERGY EFFICIENCY

A NEW HIGH-PERFORMANCE SOLID OXIDE FUEL CELL (SOFC) STACK, DESIGNED FOR MASS PRODUCTION, HAS BEEN DEVELOPED BY ONE OF THE FCH JU-FUNDED PROJECTS.
NELLHI HAS IMPROVED THE MANUFACTURING AND PERFORMANCE OF A 1KW STACK, WHICH BROKE THE WORLD RECORD FOR ELECTRICAL EFFICIENCY AT THAT RANGE.
APPLICATIONS RANGE FROM HOME HEAT AND POWER TO DECARBONISING ENERGY-INTENSIVE INDUSTRY.

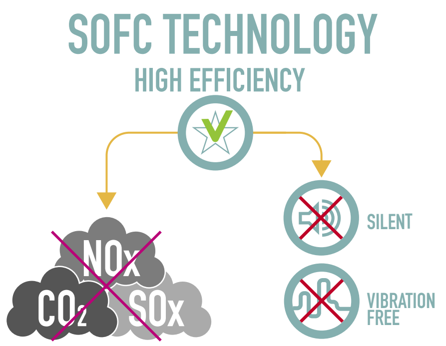
SOFC TECHNOLOGY AT THE CUTTING EDGE

SOFC technology has a crucial part to play in this consumer empowerment, which is why the collaborative NELLHI project concentrated on exploiting its potential for producing electrical power and heat.

This cutting-edge technology converts the chemical energy in hydrocarbon fuels, of both fossil and renewable origin, directly to electrical power and heat, avoiding the inefficient and polluting stage of combustion. The SOFC stack is the most efficient device available for power generation: **60%** net electrical efficiency for a small 1 kW system fed with natural gas has already been achieved, and **70%** is within reach, which is double the efficiency of the most efficient combustion engines of the same size and with less than a tenth of the harmful emissions produced by burning any fuel.

If the fuel is obtained from renewable sources, such as biogas, the operation of the SOFC is effectively carbon-neutral.
The SOFC can be also reversed to work as an electrical power storage system, capturing renewable electricity in the form of chemical energy.
The overall advantages of SOFC technology over combustion engines are:

- high efficiency, including at a small scale
- insignificant NO_x, SO_x and particulate emissions; reduced CO_2 emissions
- silent, vibration-free operation



A STACK FOR SELF-SUFFICIENCY

The NELLHI project brought together specialised industries, each focusing on a specific key component or aspect of the finalised stack. Among the steps taken to produce the high-performing cells was: the development of an optimal microstructure to decrease the operational temperature, the reduction of the final cell price and an increase in the manufacturing rate. A new, ultra-high compressibility seal was also developed.

The applications of these stacks vary depending on how many of them are combined for what purpose. One application is stationary small-scale power plants (1-5 kW) or µCHP, residential-scale combined heat and power. This concept is known as distributed, or decentralised, generation. Each end-user becomes a producer as well, able to sell electricity when supply exceeds the household's demand. Considerable amounts of primary energy input can be saved by producing power on the spot and using the excess heat for heating purposes, rather than relying on centralised production of power and separate heat generation.

As they can run on biogas, and other residual fuels, SOFC modules put together to power scales of around 50-100 kW can also be used effectively for the recuperation of energy from waste streams in the food and agriculture industry and making municipal waste-water treatment cleaner and more efficient. In Europe alone, waste-water treatment plants serving 20,000 people have huge potential, with **2.5 – 7 billion m^3 per year** of biogas that could generate 1–2.5 GW of power using SOFC.
This can largely be used on-site, with significant savings for the plant on its electricity bill.

The end-product developed between 2014 and 2017 was a stack ready for integration in any clean power-generating system and implementation in the energy market.
The partners in the NELLHI project have consolidated their positions as key component manufacturers in the European arena of SOFC technology. Their focused activity has allowed bottlenecks in design and production processes to surface and be dealt with.
This constructive collaboration has been acknowledged and rewarded through the follow-up projects that build on the knowledge base of NELLHI's achievements:

INNOSOFC: Adoption of **NELLHI** stack development for integration in a **50 kWe** combined heat and power system
qSOFC: Mass-manufacturing and quality assurance of **NELLHI** stack components

MEMBRANE ELECTRODE ASSEMBLY

AT THE HEART OF EVERY FUEL CELL IS THE MEMBRANE ELECTRODE ASSEMBLY (MEA). A KEY MISSION FOR THE FCH JU IS TO IMPROVE ITS PERFORMANCE WHILE BRINGING DOWN THE PRODUCTION COSTS, WHICH IS OF PARTICULAR VALUE TO THE EUROPEAN AUTOMOBILE INDUSTRY.

Many precious materials are used in the production of MEAs and new, innovative solutions can conserve their use. Thanks to the industry and research base established in Europe with support from the **FCH JU**, there is potential for building a strong European manufacturing base to supply a global market.

REDUCING PLATINUM CONTENT IN CATALYSTS

The MEA is a vital component of every fuel cell, forming its core and determining the performance and longevity of the device. This is why the **FCH JU** funds research into improving MEAs. In particular, it has focused on the MEAs used in polymer electrolyte membrane (PEM) electrolysers and fuel cells. These MEAs are made up of PEM, catalyst layers and gas diffusion layers – elements arranged in series to form a fuel cell 'stack'.
The research has concentrated especially on catalysts. Currently, the catalysts for most fuel cells are platinum-based. The usage of precious metals in the fuel cell manufacturing processes has an important impact on production costs. One of the **FCH JU** main objectives is reducing the use of platinum group metals in PEM fuel cells without decreasing overall performance.

Effective cooperation between the scientific community and industry has been key to the success of research activities on catalysts. An especially fruitful collaboration has been that between the CNRS (Centre National de Recherche Scientifique) and Johnson Matthey Fuel Cells in a series of **FCH JU** projects aimed at 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 targeted reduction of the platinum load in PEM fuel cathodes. Its goal was pursued through the development of innovative catalytic materials and optimal catalytic layer design.

The IMPACT project (2012–2016) examined how to increase the lifespan of fuel cells with ultralow platinum, followed by 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.

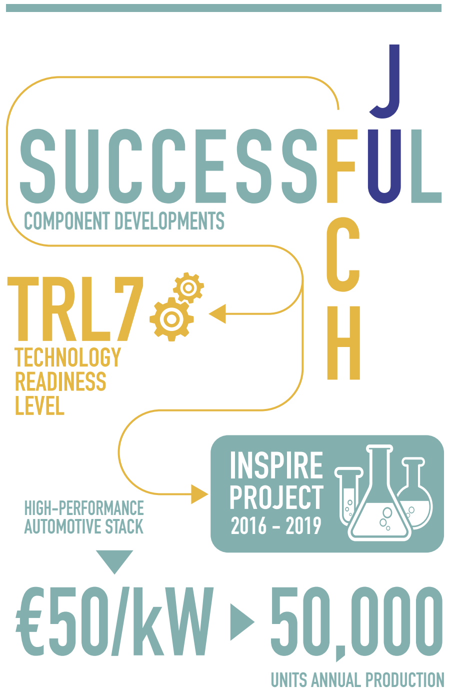
TRANSPORT APPLICATIONS

A long-term objective is to establish a European stack-manufacturing capability for transport applications. This started in the AUTO-STACK CORE project in which stacks were developed that are comparable in performance with commercially available ones from Toyota, Nissan or Honda, with an estimated cost for mass production of 37 €/kW. IMPACT and IMMEDIATE projects, BMW became part of subsequent projects with an interest in adopting the products developed for their automotive stacks. The 'Autostack Industry' national initiative is the next step toward mass fuel cell manufacturing. Over three years this €60 million joint initiative of the German automotive and supply industries aims to provide the technical, economic and technological basis for the commercial introduction of fuel cell vehicles in Germany and Europe by 2020.

FCH JU projects with higher TRL levels followed, focused on 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.
The stack and components are based on automotive PEM fuel cell technology which is presently TRL5 for component manufacturing approach and concepts.
The project will deliver a TRL7 stack and component design, at TRL7 manufacturing maturity, a consistent stack power of 90 kW, and demonstrated cost reduction.

Successful component developments from other **FCH JU** projects (MAESTRO, IMPACT and STAMPEM) are also being incorporated and taken to TRL7. The prospects for achieving this strategic manufacturing objective are very promising. Meanwhile, another **FCH JU**-funded project, INSPIRE (2016–2019), is seeking to develop and integrate the most advanced critical stack components into a high-performance automotive 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. While PEM fuel cells are finding applications in both stationary and transport application, they are proving particularly interesting to the automotive industry as it moves to develop fuel cell-powered vehicles.



SAFETY FIRST

SAFETY GOES HAND IN HAND WITH THE ADVANCEMENT OF HYDROGEN FUEL CELL TECHNOLOGY, AND THE FCH JU IS DEDICATED TO FUNDING THIS AREA, AS WELL AS THAT OF EDUCATION AND COMMUNICATION AROUND THE TECHNOLOGY.

Successes include contributing to the development of regulations and standards, establishing the European Hydrogen Safety Panel (EHSP) and putting together emergency response training programs. Winning public trust in the safety of FCH technology is essential to building the confidence needed for widespread take-up.

RESEARCH

The first main activity line is known as pre-normative research whose results are used to develop regulations and standards. Among the FCH 2 JU-funded projects in this area are HySEA and PRESLHY. HySEA (2015–2018) aims to improve hydrogen safety by studying vented deflagrations in enclosures and containers for hydrogen energy applications. Its ambition is to facilitate the safe and successful introduction of hydrogen energy systems by introducing harmonised standard vent sizing requirements.

PRESLHY, up and running since early 2018, will be performing pre-normative research for the safe use of cryogenic liquid hydrogen with a consortium consisting of European key organisations from the International Association for Hydrogen Safety, HySafe.
Its work programme is to be aligned with other international activities also dedicated to safety issues relating to liquid hydrogen.

The results will help to improve the knowledge base, which will be reflected in appropriate recommendations for development or revision of specific international standards. So, the main objectives of PRESLHY are to identify critical knowledge gaps and to close these by developing and validating new appropriate models. These will allow for cost-efficient safer design and internationally harmonised, performance-based standards and regulations. The objectives are fully aligned with European scientific-technological interests and strategies and are very important to further the safe introduction and scale-up of hydrogen as an energy carrier.

On top of these projects, further initiatives are being undertaken such as the implementation of the Regulations, Codes and Standards Strategy Coordination Group (RCS SCG) trying to identify the gaps and needs for additional pre-normative research or RCS in the field.
As a final dimension of this concern about safety, FCH JU has recently launched the European Hydrogen Safety Panel (EHSP).
The EHSP is composed of a multidisciplinary pool of safety experts whose mission is to assist the FCH JU in assuring that hydrogen safety is adequately managed, and to promote and disseminate hydrogen safety culture within and outside of the FCH JU programme.

EDUCATION

The other main line of activity funded by the **FCH JU** in this area is that of education and training. Among the highlights are: HyResponse – a training programme for first responders; KnowHY – a training offer for technicians and workers in hydrogen fuel cell technology), and NET-Tools – digital education for various target groups: schools, universities and professionals.

HyResponse (2013–2016) was a 'Coordination and Support Action ' project aimed at establishing the world's first comprehensive emergency response training programme, i.e. a European Hydrogen Safety Training Platform, to facilitate safer deployment of FCH systems and infrastructure. The developed core training programme is threefold: educational training, including the state-of-the-art knowledge in hydrogen safety; operational training on mock-up real scale hydrogen and fuel cell installations, and innovative virtual reality training.

The KnowHY consortium consisted of partners from many European countries, combining expertise in FCH technologies as well as training and education. They developed customised courses and modules for technicians, workers and professionals in general with a practical knowledge in installation, maintenance and operation of hydrogen and fuel cell applications. The end result of the 42-month project, completed in 2018, has been effective first training, covering an understanding of the technology, its safety and regulatory aspects in the practical as well as the theoretical domain. Around 800 fire fighters have been trained.

NET-Tools (2017–2020) is setting out to provide novel education and training tools based on digital applications related to hydrogen and fuel cell technology. NET-Tools will constitute a technology platform, developing an e-infrastructure and providing digital tools and an information service to deliver education and training about FCH technologies. Education and training for the FCH technology sector is critical for the current and future workforce as well as for the further implementation of a promising technology within Europe.

The **FCH JU** is committed to maximising the safety of fuel cell hydrogen technology and conveying the relevant information about this aspect of it to all concerned, whether on the inside as a worker or researcher, or from an external perspective as a member of the general public. This helps to broaden the support base for FCH technologies as a cornerstone of the energy transition.

BIG HIT: OVERCOMING GRID CONSTRAINTS FOR RENEWABLE ENERGY PROVISION

ON SCOTLAND'S REMOTE ORKNEY ISLANDS, WIND, WAVE AND TIDAL INSTALLATIONS ARE PRODUCING MORE ELECTRICITY THAN THE ISLAND NEEDS. THE FCH JU PROJECT 'BIG HIT' IS CONVERTING THE EXCESS RENEWABLE ELECTRICITY INTO GREEN HYDROGEN AND DEMONSTRATING THE ADVANTAGES OF AN ENERGY-INDEPENDENT, LOW-CARBON 'HYDROGEN TERRITORY', THAT CAN BE REPLICATED ELSEWHERE.

SAVING LOST RENEWABLE ENERGY

Scotland's Orkney Islands have one of Europe's highest levels of renewable energy use, with over 1,000 wind, wave and tidal energy installations serving 10,000 households. Nonetheless, additional renewable generation is limited by the capacity of the electricity network.

More electricity is generated from renewable sources in Orkney than the population uses, and the surplus is usually transferred to the UK's national grid network. However, it often happens that surplus energy is available but the cables transferring it are at full capacity. On such occasions, turbines are switched off or 'curtailed' and the energy is lost, with the wind turbines on the islands of Shapinsay and Eday losing over 30 % of annual output.

The **FCH JU**-funded BIG HIT project aims to convert this lost energy into hydrogen, which will then be compressed and stored in high-pressure cylinders for transport by road and sea. This will then be used as' fuel in other applications such as heating buildings and fuelling vehicles.

GREEN HYDROGEN CLOSE TO HOME

Some of the hydrogen will heat Shapinsay Island's school and community building via a catalytic system that eliminates all harmful emissions. It will also supply fuel to a charging station for a fleet of five range-extended fuel cell vans to be used by the Orkney Islands council. In addition, the harbour buildings will be powered by the hydrogen as well as a marina in Orkney's capital Kirkwall and three ferries, when docked.

The aim of the project is to create a replicable hydrogen territory. Producing low-carbon heat, power and transport through the implementation of a fully integrated model of hydrogen production, storage, transportation and utilisation will be a world first. The challenges to overcome are both logistical and regulatory.

The project builds on the achievements of Orkney's Surf 'n' Turf initiative which established the production of hydrogen on Eday Island using wave and tidal energy, as well as the island's wind turbine. Together with the installation on Shapinsay Island, the Eday Island turbine provides the energy used to generate the hydrogen for BIG HIT.

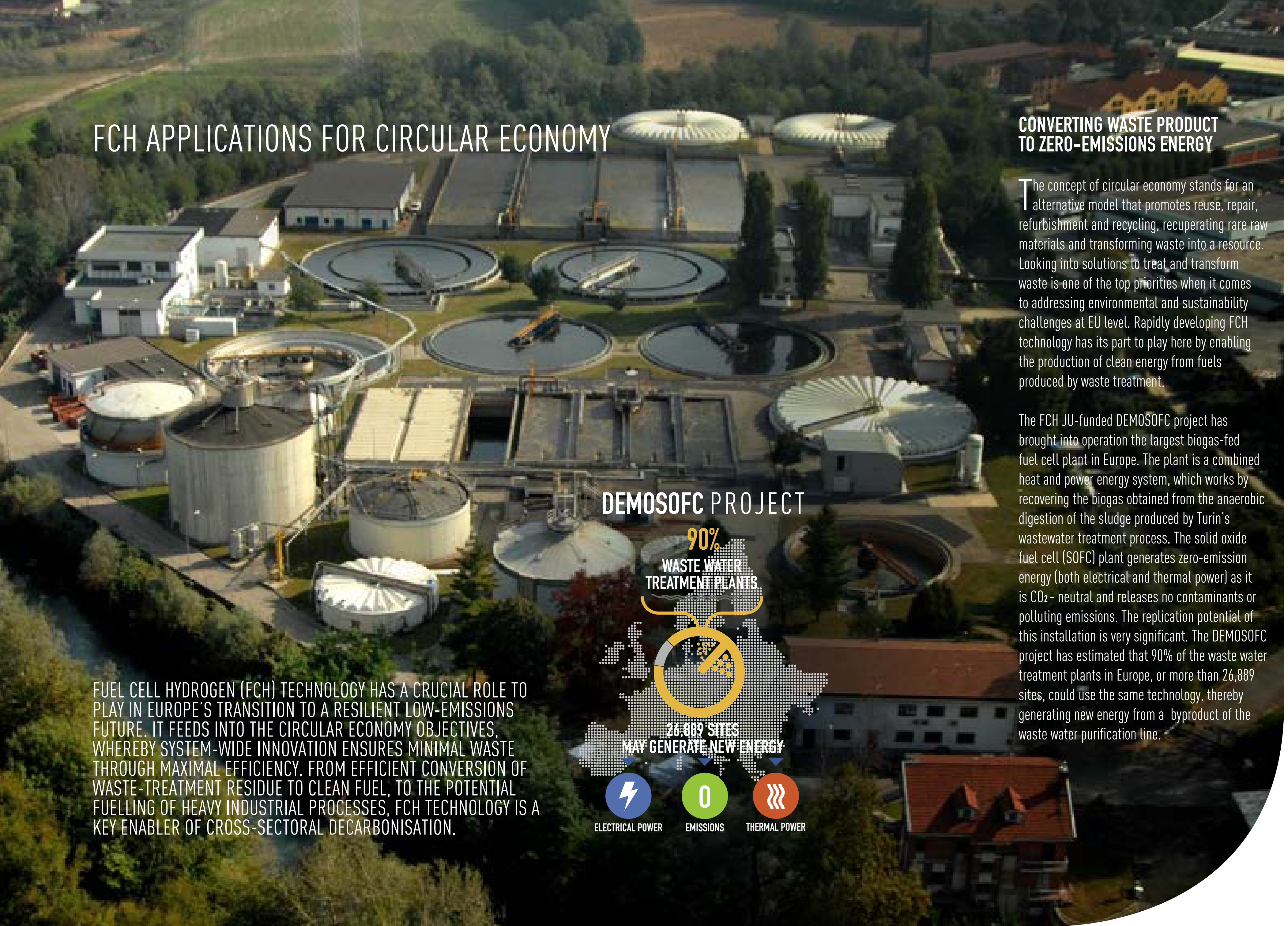
Curtailed capacity from the turbines powers a 1-megawatt electrolyser on Shapinsay Island installed under the project. This passes an electric current through water to break it down into its basic components, thereby producing low-carbon hydrogen. The hydrogen is then taken to the project's fuel cell in Kirkwall where it is turned into heat and power. Designed to marine standards, the Kirkwall fuel cell will also be used by Orkney College in training future mariners in the skills needed for safe operation of hydrogen-powered ferries.

A BEACON OF HOPE

TWELVE PARTNERS ARE PARTICIPATING IN THE COLLABORATIVE PROJECT – FROM DENMARK, FRANCE, ITALY, MALTA, SPAIN AND THE UK. MALTA IS DESIGNATED AS A 'FOLLOWER TERRITORY', WHICH CAN LEARN FROM THE RESULTS IN ORDER TO APPLY THEM IN ITS JURISDICTION.

The replication potential of the model for isolated territories is key, and dissemination of the knowledge will be achieved through a 'remote territories platform'. In this way the project can be studied far beyond Orkney itself. Social and economic impacts will be analysed in the course of the project. BIG HIT's results will be made available to all interested regions and community groups so that they can identify the potential for adopting such an approach in their own territory.

Although it remains at a small scale, this **FCH JU** project highlights the potential of hydrogen to make better use of renewable electricity. The use of the hydrogen produced in both stationary applications for residential or public buildings, and in the transport sector in a small fleet of vans, shows the interconnectivity that this energy vector brings into these previously separated sectors. The production, logistics, usage and managing model being developed in BIG HIT for a small archipelago community will serve to showcase and scale up the use of this solution for bigger territories. This visionary project demonstrates the feasibility of the path towards decarbonisation and realistic alternatives to fossil fuel power.



FCH APPLICATIONS FOR CIRCULAR ECONOMY

FUEL CELL HYDROGEN (FCH) TECHNOLOGY HAS A CRUCIAL ROLE TO PLAY IN EUROPE'S TRANSITION TO A RESILIENT LOW-EMISSIONS FUTURE. IT FEEDS INTO THE CIRCULAR ECONOMY OBJECTIVES, WHEREBY SYSTEM-WIDE INNOVATION ENSURES MINIMAL WASTE THROUGH MAXIMAL EFFICIENCY. FROM EFFICIENT CONVERSION OF WASTE-TREATMENT RESIDUE TO CLEAN FUEL, TO THE POTENTIAL FUELLING OF HEAVY INDUSTRIAL PROCESSES, FCH TECHNOLOGY IS A KEY ENABLER OF CROSS-SECTORAL DECARBONISATION.

CONVERTING WASTE PRODUCT TO ZERO-EMISSIONS ENERGY

The concept of circular economy stands for an alternative model that promotes reuse, repair, refurbishment and recycling, recuperating rare raw materials and transforming waste into a resource. Looking into solutions to treat and transform waste is one of the top priorities when it comes to addressing environmental and sustainability challenges at EU level. Rapidly developing FCH technology has its part to play here by enabling the production of clean energy from fuels produced by waste treatment.

The FCH JU-funded DEMOSOFC project has brought into operation the largest biogas-fed fuel cell plant in Europe. The plant is a combined heat and power energy system, which works by recovering the biogas obtained from the anaerobic digestion of the sludge produced by Turin's wastewater treatment process. The solid oxide fuel cell (SOFC) plant generates zero-emission energy (both electrical and thermal power) as it is CO_2- neutral and releases no contaminants or polluting emissions. The replication potential of this installation is very significant. The DEMOSOFC project has estimated that 90% of the waste water treatment plants in Europe, or more than 26,889 sites, could use the same technology, thereby generating new energy from a byproduct of the waste water purification line.

GREENING INDUSTRY – NEW SECTORS

Zero emissions is also the name of the game when it comes to green hydrogen – obtained by electrolysis powered by electricity from renewable sources. The increasing power of electrolysers is making green hydrogen production suitable for a growing range of applications, which is attracting a broader base of end users, including heavy industry. This fuel presents enormous potential for use as an industrial process gas, as well as for energy storage. The emphasis is on increasing capacity, efficiency, dynamic operation capabilities and reducing costs of novel electrolysers.

The H2FUTURE project, which began in early 2017, is an important step towards coupling the energy and industry sectors. Green hydrogen for industrial use and for balancing the power reserve market will be produced in one of the largest and most modern electrolysers (6MW capacity) using proton exchange membrane (PEM) technology. The green hydrogen generated at the steel plant in Austria will be fed directly into the internal gas network, allowing the testing of the use of hydrogen in various process stages of steel production, in a bid to phase out the use of coal in the longer term. The pilot plant, with funding of €12 million from the **FCH JU**, is designed to be a technological milestone on the pathway to energy transition, and thus to the gradual decarbonisation of the steel industry.

A subsequent **FCH JU**-funded project, Refhyne, launched in January 2018, is on course to build the largest hydrogen electrolysis plant of its kind in the world, with a capacity of 10MW, at the Rhineland refinery in Germany. The high-pressure electrolyser will provide bulk quantities of hydrogen to the refinery's hydrogen pipeline system (displacing 1% of the current supply by two steam methane reformers). This project will assist in testing the polymer electrolyte membrane technology on a large industrial scale, making it feasible for introduction in other industry plants, as well as potentially being a step towards the future of refining. 1,300 tonnes of hydrogen will be produced per year, which can be fully integrated into the refinery processes, such as for the desulphurisation of conventional fuels.

The **FCH JU** considers that there is a window of opportunity for these new generation electrolysers to prove themselves in heavy industries like refineries, and the scaling-up of PEM electrolysers is seen as a vital advance towards decarbonising the industrial sector. Thanks to green hydrogen, renewables can expect to achieve increased penetration, and progress will be made towards overall EU emissions reduction targets. Green hydrogen allows the channelling of renewable electricity into industry, transport and building sectors, contributing to the EU climate and energy goals.

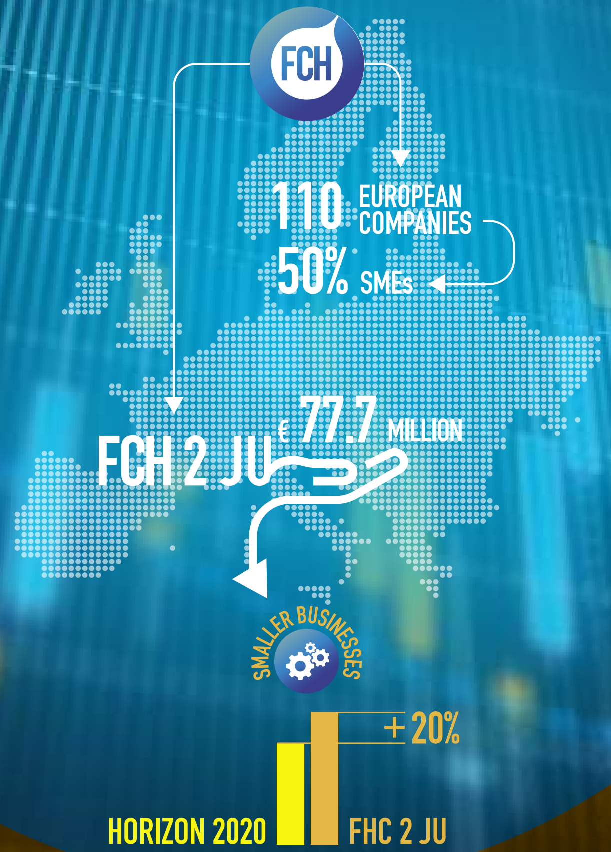
BOOSTING INVESTMENT IN EUROPEAN SMES

FROM THE OUTSET, SMALL AND MEDIUM-SIZED ENTERPRISES (SMES) HAVE BEEN CENTRAL IN THE FCH JU COMMUNITY. RECOGNISING SMES AS A KEY COMPONENT OF THE INDUSTRIAL SECTOR, THE FCH JU HAS HELPED SMES INVOLVED IN FUEL CELL AND HYDROGEN TECHNOLOGY TO EXPAND AND DEVELOP CUTTING EDGE TECHNOLOGIES THROUGH THEIR COLLABORATION WITH POLICY MAKERS, MAJOR INTERNATIONAL COMPANIES, RESEARCH PARTNERS AND OTHERS.

HYDROGEN EUROPE: SUPPORTING BUSINESSES

Hydrogen Europe is the grouping of **FCH JU** industry members, which comprises 110 companies representing the European industry, national associations and research centres active in the sector. Membership has grown from just 60 companies in 2008, and half of the Hydrogen Europe members are SMEs – reflecting the infancy of this technology. 27% (€ 77.7 million) of the **FCH 2 JU** financial programme is dedicated to smaller businesses, exceeding the Horizon 2020 target of ensuring at least 20% of its funding is allocated to SMEs. 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.

SECTION 4: FUELLING GROWTH



BUILDING BRIDGES BETWEEN TECHNOLOGY AND DEPLOYMENT

The public-private partnership model has not only given SMEs access to investment that they might otherwise not have found, but it has allowed them to engage with critical future partners such as utilities, energy service companies, and local government. Working alongside larger companies in the same field has also meant that the SMEs can tap into the expertise, distribution networks, support and potential customers of those organisations. Continued investment and industry confidence have been underpinned by this pooling of resources, both within the industrial sector, and between research, industry and the European Commission, and the community's joint roadmap has enabled the acceleration of technological development to the point where real-world fuel cell hydrogen solutions are on the verge of market deployment.

RECIPES FOR SUCCESS

The following examples demonstrate the achievements of some of these SMEs. H2 Logic, set up in 2003, is a Danish SME that anticipated the need for low-cost, reliable and user-friendly hydrogen refuelling stations (HRS). Having field tested its products with the help of **FCH JU** finance, it went on to participate successfully in several **FCH JU**-funded projects and grew from its initial three co-founders to a team of 77 people. In 2015 H2 Logic was sold on 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 HRS a year, enough to fuel 200,000 hydrogen vehicles.

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. 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. The **FCH JU** enabled Elcogen to finance R&D work with leading European institutes. The support meant that Elcogen could develop products and production processes with top technology companies, and 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 game-changing technology. The young company, a spin-off from the research institute CEA — one of the main research bodies in the **FCH JU** programme – is building on ten years of R&D by the CEA and has received €40 million in investment. With operational support from CEA, the spin-off is setting up the first reversible solid oxide cell stack manufacturing line, and will become fully operational in 2018, with plans to increase its staff from seven to 20 by then.

SMEs are central to Europe's economy. In the last five years, SMEs have created around 85% of new jobs and provided two-thirds of the total private sector employment in the EU. The **FCH JU** continues to deliver on one of its top strategic priorities: to ensure that Europe's SMEs are key player in hydrogen and fuel cell development. The **FCH JU**'s unique public–private partnership structure has made it possible to develop a network of partners to nurture SMEs, whose productivity and competitiveness will benefit everyone.

INTERNATIONAL COOPERATION

FUEL CELLS AND HYDROGEN TECHNOLOGY IS A WORLDWIDE EFFORT, AND KEY FCH JU STAKEHOLDERS ARE INVOLVED IN THESE DEVELOPMENTS. THAT'S WHY ESTABLISHING AND MAINTAINING LINKS WITH OTHER MAJOR FCH-RELATED PROGRAMMES GLOBALLY IS A NECESSARY PART OF THE FCH JU'S WORK.

THIS ALSO FITS WITH THE WIDER EU POLICY CONTEXT: THE IMPORTANCE OF INTERNATIONAL COOPERATION IN SCIENCE AND TECHNOLOGY IS EXPLICITLY RECOGNIZED IN THE INNOVATION UNION, A FLAGSHIP INITIATIVE OF THE EUROPE 2020 STRATEGY FOR SMART, SUSTAINABLE AND INCLUSIVE GROWTH, AND IN THE HORIZON 2020 PROGRAMME.

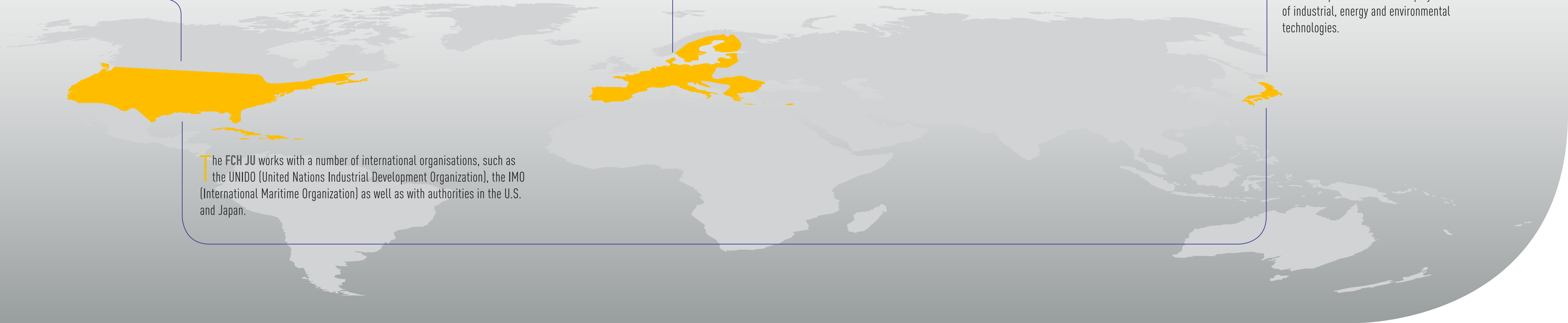
Close cooperation takes place between the **FCH JU** and the U.S. Department of Energy (DoE). The DoE's Hydrogen and Fuel Cells Program conducts research and development in hydrogen production, delivery, storage, and fuel cells, as well as activities in technology validation, manufacturing, systems analysis and integration, safety, codes and standards, and education.

Cooperation includes discussion of the **FCH JU**'s annual work programme, and identification of suitable topics for international collaboration. This is particularly valid in areas of cross cutting nature such as regulatory and policy frameworks, socio-economic and environmental assessments, codes, standards, safety or harmonised methodologies for monitoring of activities (for example hydrogen purity, hydrogen cooling and hydrogen dispensing measurement). These areas play a very important role in early market activation and where intellectual property rights are less of an issue. In addition, the **FCH JU** assists the DoE with their annual program review, and the DoE provides experts to help evaluate proposals in **FCH JU** calls.

A GLOBAL COMMUNITY

The **FCH JU** coordinates work with the European Commission's inhouse science research service, the Joint Research Centre (JRC), in particular with the JRC representatives on the steering committee of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE). Established in 2003, the IPHE is an international inter-governmental partnership currently consisting of eighteen member countries and the European Commission. Its objective is to facilitate and accelerate the transition to clean and efficient energy and mobility systems using hydrogen and fuel cell technologies across applications and sectors.

The **FCH JU** also has a longstanding cooperation with the New Energy and Industrial Technology Development Organization (NEDO), Japan's largest public management organisation promoting research and development as well as deployment of industrial, energy and environmental technologies.



The **FCH JU** works with a number of international organisations, such as the UNIDO (United Nations Industrial Development Organization), the IMO (International Maritime Organization) as well as with authorities in the U.S. and Japan.

NATIONAL COOPERATION AND PROJECTS

In Europe, the **FCH JU** works with NOW GmbH (National Organisation Hydrogen and Fuel Cell Technology), responsible for the coordination and management of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP) and the Electromobility Model Regions programme of Germany's Federal Ministry of Transport and Digital Infrastructure (BMVI). After Japan, Germany has the highest number (56) of hydrogen refuelling stations installed and is the most advanced European market for fuel cell micro-cogeneration with more than 1500 units installed.

These achievements are largely due to the involvement of national partners in **FCH JU**-funded projects. Many **FCH JU**-funded projects include national-level partners or contributors from outside the EU. In line with international cooperation at the programme level, these collaborations are usually in the fields where there is no competition, such as safety or pre-normative research (PNR). For safety and PNR, **FCH JU**-funded projects are enabling knowledge exchange with the global fuel cells and hydrogen community. The HySEA project is conducting pre-normative research on vented deflagrations in enclosures and containers for hydrogen energy applications, with the goal of facilitating the safe and successful introduction of hydrogen energy systems by introducing harmonized standard vent sizing requirements. Participants in the HySEA consortium include two Chinese partners, the University of Science and Technology of China and the Hefei University of Technology.

The HyCORA project, focused on developing a strategy to lower the cost of hydrogen fuel quality assurance, is underway in collaboration with the Los Alamos and Sandia laboratories in the USA. The HyResponse project establishes the world's first comprehensive training programme for first responders, and as such, trains firefighters of different nationalities outside EU. In addition, the development of virtual reality training material has established a number of U.S.-based collaborations.

In the H2Sense project, European scientists worked together with colleagues from the National Renewable Energy Laboratory (NREL) in Colorado, U.S.A., in order to pool their knowledge of developments in hydrogen sensor technology as well as deployment and commercialization. As well as supporting international cooperation through these projects and programmes, the **FCH JU** continuously tries to identify priority areas, at policy and technology level, where coordinated and collaborative international activities are of interest.

EUROPEAN EXPERTISE OPENING NEW MARKETS FOR GREENING CHINESE INDUSTRY

The aim of the DEMCOPEM-2MW (DEMonstration, COmbined heat and power [or cogeneration], PEM fuel cells and 2 Mega Watt electrical power) project is to demonstrate the feasibility, reliability, and availability of PEM fuel cells in a large-scale stationary application of at least 2 MWe in China.

In the autumn of 2016, the 2 MWe PEM fuel cell generator was put into operation at the Ynnovate Sanzheng Fine Chemicals chlor-alkali plant in Yingkou, Liaoning province, China. Hydrogen produced onsite as a of the chemical factory can be directly fed into the cogeneration unit, generating electricity, heat and water for use in the chlor-alkali production process and lowering overall electricity consumption by 20%.
And with the key polymer electrolyte membrane (PEM) technology coming from the European experts involved, the project is a clear win-win in international collaboration.

European project partners MTSA (system integrator) and Nedstack (stack supplier) have assisted Ynnovate with the operation of the system on a regular basis: both remotely and by means of local visits. At the same time, Ynnovate have gained considerable understanding of the system functioning. In combination with the implemented technical optimisations, system reliability was improved and requests for advice and assistance by MTSA and Nedstack decreased to a low level.

China was selected as the demonstration site for this project, in part because the local high electricity prices and periodic shortages in supply, along with the availability for hydrogen as a byproduct, all constitute favourable conditions for the business case. Moreover, China is home to 50% of the chlor-alkali world production, and with the Chinese government intent on greening the industry, the project promoters forecast that 20-50 PEM power plant units of at least 2 MWe in the coming 5-8 years seems a realistic option in the Chinese market, with a clear upside potential up to 600 MWe installed capacity worldwide in the years after.

p. 2

© Copyright of Istock / Vagabondatheart
H2 bus in Antwerp © HighVLOcity

p.3

Cell Stack production in qSOFC project © Elcogen, 2018
© Copyright of Shutterstock / Mikhail Berkut
© Copyright of Istock / MicroStockHub

p.4 Hydrogen nozzle © Sven Ehlers, 2016

p.6 © Copyright of Istock / Vagabondatheart

p.9 © Copyright of Pomilio Blumm

p.11 © Copyright of Pomilio Blumm

p.12-13 © Copyright of Shutterstock / Mikhail Berkut

p.15 © Copyright of Istock / Azman Jaka

p.16-17 H2 bus in Antwerp ©HighVLOcity

p.18 Oslo H2bus © VH CHIC

p.20 Refuelling a H2 car © WaterstofNet VZW, 2018

p.22-23 H2 Taxi in Paris © Air Liquide, J. Melin

p.27 Green H2 production and storage © WaterstofNet VZW, 2018

p.29 © Copyright of Istock / deliormanli

p.30-31 Fuel cell micro Combined Heat and Power (µCHP) units © Viessmann Group, 2017

p.33 Exhibition of Fuel Cell micro-CHP units - ene.field and PACE projects © COGEN Europe, 2017

p.34-35 Cell Stack production in qSOFC project © Elcogen, 2018

p.36 NELLHI stack © Elcogen, 2018

p.38-39 Production of the hydrogen tank © COPERNIC

p.41 High-performance solid oxide fuel cell (sofc) stack, © Elring Klinger, 2018

p.42 Elcogen factory - Project qSOFC3, © Elcogen, 2018

p.43 NELLHI stack © Elcogen, 2018

p.44 Automatic Stack Assembly Line © VOLUMETRIQ, 2018

p.47 © Copyright of Shutterstock / Grzegorz Czapski

p.48 © Copyright of Shutterstock / Voraorn Ratanakorn

p.50-51 Hydrogen economy in Orkney Islands, Scotland © BIG HIT (Colin Keldie), 2018

p.53 © Copyright of Pomilio Blumm

p.54-55 SMAT Waste Water Treament Plant (Collegno, IT) © DEMOSOFC

p.56-57 © Copyright of Istock / MicroStockHub

p.58-59 © Copyright of Shutterstock / Rawpixel.com

p.60-61 © Copyright of Pomilio Blumm

p.62-63 © Copyright of Shutterstock / Chesky

www.fch-ju.eu
More information on the European Union is available on the Internet (http://europa.eu).
Design: Pomilio Blumm - Pescara
Printed by Imprimerie Bietlot in Belgium
Luxembourg: Publications Office of the European Union, 2018

Print	ISBN 978-92-9246-329-8	doi:10.2843/698702	EG-03-18-411-EN-C
PDF	ISBN 978-92-9246-330-4	doi:10.2843/883948	EG-05-18-411-EN-N