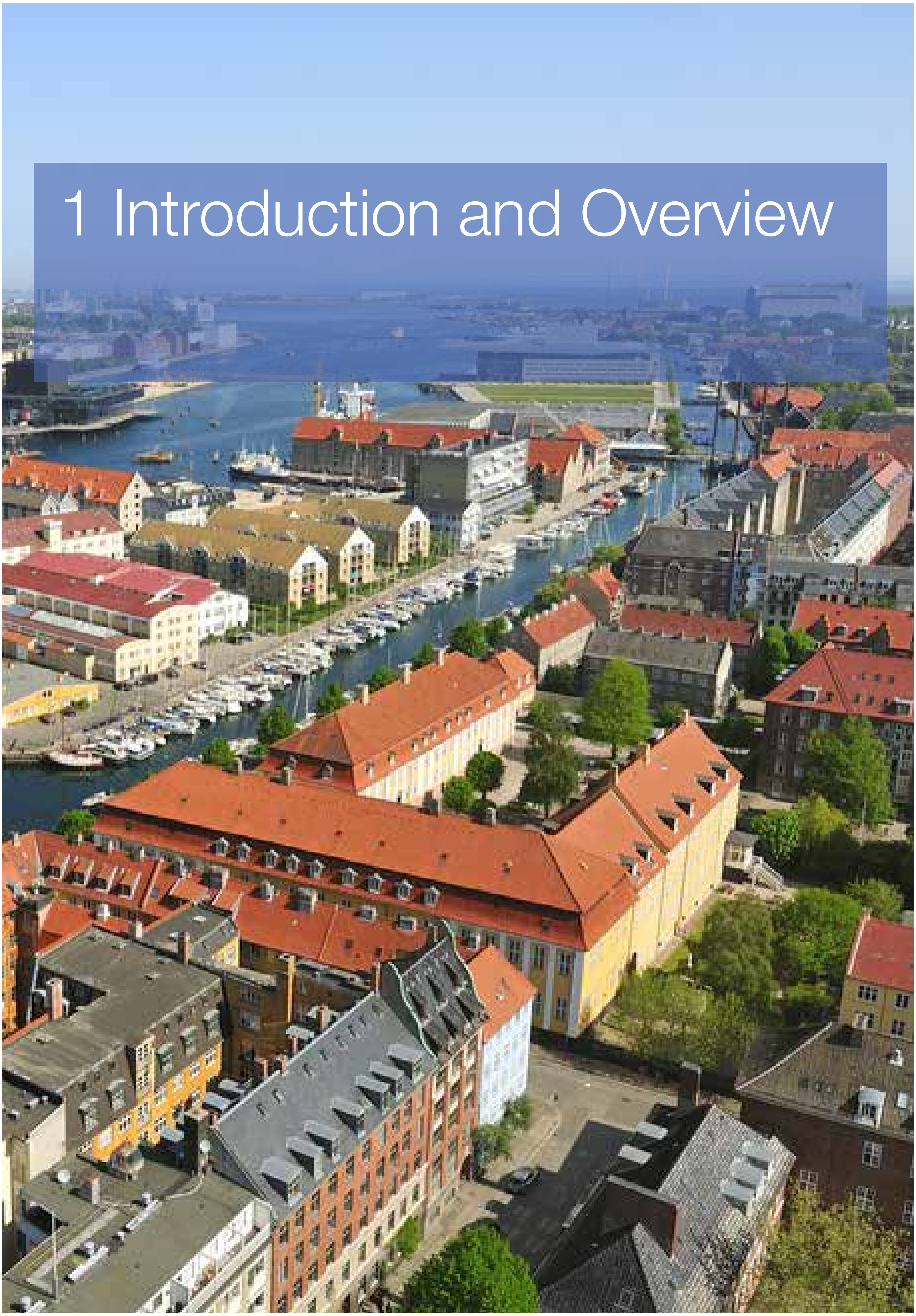
# National Strategies and Plans for Fuel Cells and Infrastructure

## Implementing Agreement for a Programme of Research, Development and Demonstration on Advanced Fuel Cells

This document has been prepared by the National Members and Operating Agents.

# Contents

# 1 Introduction and Overview



Fuel Cells represent a viable and crucial technology for the transformation of the energy system towards drastically less $CO_2$ emissions and high efficiency.

Since there are different resources available and different technologies and policies in place the approaches differ notably for the member countries participating in the Advanced Fuel Cell Technology Collaboration Programme of the IEA (AFC-TCP).

This book aims to compile the strategies, plans, programs and projects of the countries and to provide as complete an overview as possible. It is important to note that activities are not only on a countrywide basis, but very often state, region and even community wide. Moreover, some countries have national plans in place and others do not, yet there may be plans and/or notable activities on one of the other levels. Hence, this book includes such activities. It was the goal to provide the most complete overview of what is going on in the different countries regardless on which level it happens.

I would like to thank the authors and all contributors who furnished the material needed.

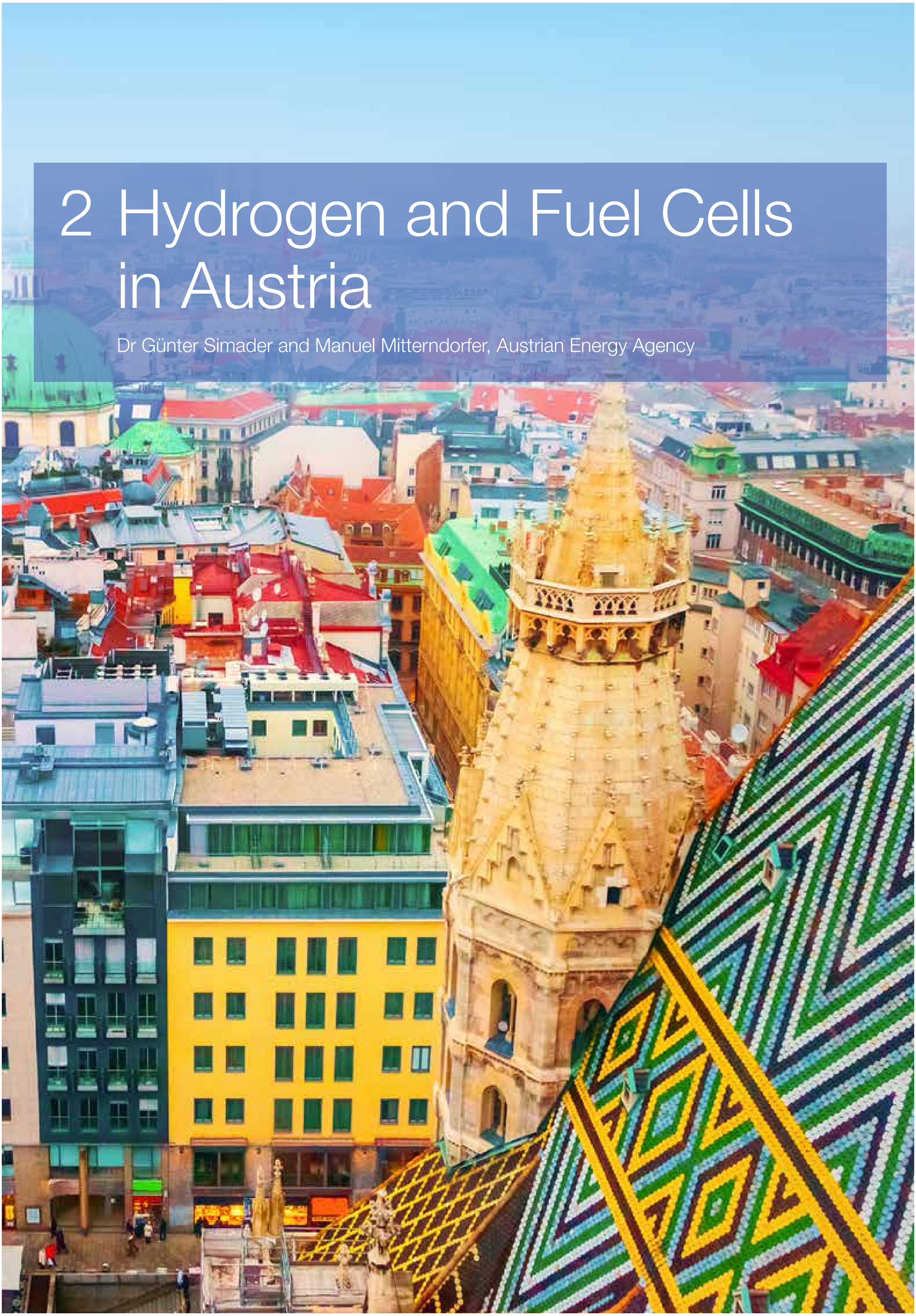
**Prof Dr Detlef Stolten**
**Chairman of the Advanced Fuel Cells Implementing Agreement**

Detlef Stolten took over as Chairman of AFC IA in 2011 after previously serving as Vice Chairman.

Since 1998, Professor Stolten has been the Director of the Institute for Energy and Climate Research – Electrochemical Process Engineering at Research Centre Jülich, Germany. His research focus is the electrochemistry, chemical engineering and systems analysis for the DMFC, HT-PEFC and SOFC technology, particularly the reforming of middle distillates.

# 2 Hydrogen and Fuel Cells in Austria

Dr Günter Simader and Manuel Mitterndorfer, Austrian Energy Agency



## Summary

The major energy policy goals of Austria are to stabilise energy consumption at 1,050PJ by 2020 and to reduce greenhouse gas emissions by 16% (base year: 2005) by 2020. Renewable energy in Austria contributes 32.5% and by 2020 this figure should be 34%. The R&D programmes strategically cover fuel cell topics to support the development of innovative companies in this field. In 2014 EUR[i] 8 million has been spent on national fuel cell and hydrogen projects.

To enhance the competitiveness of the Austrian automotive industry and support new, clean technologies, the Austrian Federal Ministry for Transport, Innovation and Technology developed the Austrian FTI Automotive Strategy in collaboration with the Austrian automotive industry in 2009. Further to this, the National Implementation Plan for Electric Mobility was released in 2012. Both of these plans identified fuel cell and hydrogen technologies as important for clean and efficient transport for the future.

Fuel cell projects in the mobility sector are focused on improving competitiveness, and finding ways of modernising and increasing the efficiency of the transport system. In total, about 500 projects with public funding of EUR 118 million have been supported over the last few years. A new programme called 'Mobility of the Future (2012–2020)' provides an annual budget of approximately EUR 15 million for R&D in the whole transport sector.

**Keywords:** energy policy goals, renewable energy sources, fuel cells, hydrogen, Austria

i European euro

## 2.1 INTRODUCTION

Austria has international expertise in the transport sector. In the past few years, a technological change has taken place, driven by the EU's goal of having transportation that is completely free of fossil fuels, climate-neutral and free of pollutants by 2050. This change has led to a move away from the traditional vehicle drive systems with combustion engines towards an electrically powered drivetrain and entirely new mobility concepts. To keep the Austrian automotive and research industry in a leading position and maintain value creation, it is important that the opportunities provided by these new mobility concepts are exploited promptly so that a common vision of the future and the necessary steps towards it are created.

In the past 20 years, the transport area has fallen short of the emissions reductions required by the EU. Since traffic projections for passengers and goods are estimated to increase, emissions per vehicle must be drastically reduced to meet these targets. Optimised drive systems and energy sources, such as fuel cells, will play a key role in achieving this goal, but they must be fully evaluated to ensure they will deliver the required performance.

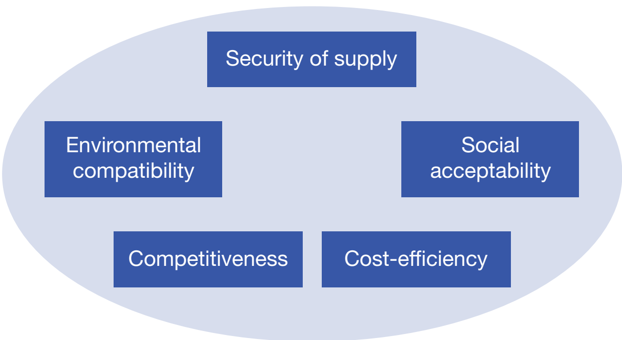
Another key area for fuel cells is providing heat. However, variations in the heat market and other factors, such as low electricity costs and high gas prices, have meant that no follow-up programme has taken place since the last demonstration test carried out in 2008. Interest in fuel cells for this market has increased again due to new building codes and other regulations that have been negotiated recently. A major demonstration programme including between 20 and 30 micro combined heat and power (micro-CHP) systems based on fuel cell technology is being negotiated by Austrian utility companies, manufacturers and ministries.

## 2.2 GENERAL ENERGY GOALS

Austria's major energy policy goals are to stabilise energy consumption at 1,050PJ by 2020 and reduce GHG emissions by 16% by 2020 compared with the 2005 base year. Renewable energy sources in Austria contribute 32.5% of the electricity supply and should achieve up to 34% contribution by 2020.

A goal of the Energy Strategy Austria[1] is the development of a sustainable energy system that provides energy services for private consumers and businesses while fulfilling the EU 20-20-20 targets. Security of supply, environmental compatibility, cost-efficiency, energy efficiency, social acceptability and competitiveness are all part of Energy Strategy Austria (see Figure 2.1).

**Figure 2.1: Framework of Energy Strategy Austria (Source: Austrian Energy Strategy, http://www.energiestrategie.at/, 2010)**




## 2.3 COUNTRY POLICIES

### 2.3.1 Energy Policy

Austria can reach its climate protection goals, drastically reduce its dependence on energy imports, and give its economy and employment a substantial boost by creating an ambitious energy efficiency strategy, conserving energy and committing to the expansion of renewable energy.

Therefore, the energy policy of Austria follows a threefold strategy[1]:

- A consistent improvement in energy efficiency in all fundamental sectors is pivotal for energy and climate policy, and must be attained in the following areas:

> Buildings – reducing space heating and cooling requirements through the improvement of construction standards for the 'Nearly-Zero-Energy Homes'.

> Energy consumption of households and businesses – focusing on electricity consumption and waste heat utilisation supported by energy counselling and energy management systems.

> Efficient mobility (public and private).

> Efficient primary energy input and waste heat utilisation – for energy-intensive businesses in the energy industry, households and businesses.

- The expansion of renewable energy is of great importance to Austria's self-sufficiency and the strengthening of energy security while creating new (highly qualified) jobs through the upcoming 'green' technologies. Strengthening competitiveness is a necessity to attain the goals of energy and climate policies. This will be achieved through:

> Electricity generation – use and expand the potential found in hydropower, wind power, biomass and photovoltaics.

> Space heating – based on regional energy spatial planning and should correspond to the regional strengths, this could either use district heating (waste heat, co-generation and biomass) or individual installations (solar heat, biomass and ambient heat).

> Transport sector – fulfilment of the EU biofuels directive resulting in 10% renewable energy with biofuels and electromobility.

- The economic efficiency of the country is dominated to a very large degree by the long-term security of energy supply for society, the related costs and environmental impact. It is essential to keep energy consumption as low as possible, use local energy resources carefully and further develop them, secure necessary imports through diversification, and provide sufficient infrastructure for transport and storage. This will be addressed through:

> Transmission networks, distribution networks and storage for electric power – the prerequisite for attaining these nationally and internationally influenced goals must also be created in the area of transmission and distribution networks. In the future, the network infrastructure has to be modified to be compatible with an increase in decentralised generation and demand.

> Grid-bound energy sources – due to its geographic location, Austria acts as a hub in the area of grid-bound energy sources. This not only results in responsibility for the European energy supply, but also in economic and environmental opportunities for the Austrian economy.

Table 2.1: Short, medium and long-term roadmap of fuel cell, hydrogen storage and double layer capacitor for fuel cell vehicles (Source: A3PS, 2011)

| Technology | Short-term 2011-2015 | Medium-term 2015-2020 | Long-term 2020-2030 | | | |
|---|---|---|---|---|---|---|
| Fuel cell | Low temperature polymer electrolyte membrane (PEM) fuel cell | Low and medium temperature fuel cell | Solid oxide fuel cell (SOFC) as an auxiliary power unit (APU) | | | |
| Hydrogen storage | Storage at 350 bar | Fuel and refuelling<br>Storage at 700 bar<br>Solid matter storage and ionic liquids | | | | |
| Double layer capacitor | | | | | | |

| Marketability and market penetration | Benefits | Project type |
|---|---|---|
| Full on market | Harmful substances, noises | Materials basic research |
| Technology represented by individual variants on the market | Carbon dioxide and resources | Industrial research |
| Marketable | Added value | Experimental research |
| | Need for R&D | Demonstration |

## 2.3.2 Transportation Policy

Traffic projections for passengers and goods are estimated to increase so, to meet EU requirements, emissions per vehicle must be reduced significantly. Optimised drive systems and energy sources, such as fuel cells, will play a key role in achieving this goal.

Facing these challenges, the Austrian Association for Advanced Propulsion Systems (A3PS) developed a roadmap for implementing alternative drives and propellants in the transportation sector[2]. In Table 2.1, the short, medium and long-term targets for the main components of fuel cell vehicles are highlighted.

In the heavy-duty sector, the use of proton exchange membrane fuel cells (PEFC) in city buses is considered to be at an early commercial stage. Furthermore, in heavy-duty vehicles and buses powered by fuel cells, the use of solid oxide fuel cells (SOFC) as an auxiliary power unit (APU) is expected to achieve marketability soon. In addition to this, the roadmap states that, in the short term, hydrogen storage will reach a pressure 700 bar.

## 2.4 STATE AND REGIONAL POLICIES

Austria is structured as a Federal State consisting of nine provinces. Generally, the provinces follow the state/EU energy policies. However, some provinces have priorities relating to energy autonomy (such as Vorarlberg), climate and environmental protection (such as Salzburg), carbon dioxide ($CO_2$) neutrality (such as Carinthia's master plan), district heating (such as Styria and Vienna) and increasing renewable energy sources by up to 50% by 2020 (in Lower Austria).

Burgenland will be the first region in Europe that will be power autonomous this year. It developed from an electricity importer to an exporter of clean energy based on renewable energy.

However, none of the nine provinces has specific R&D or energy programmes to further increase fuel cells for transportation or stationary applications.

## 2.5 MAJOR COMPANY ACTIVITIES

There are approximately 180 Austrian companies in the automotive industry sector, with 35,000 employees and 2,000 apprentices (more than 360,000 people when taking into account the upstream and downstream industries). Around 90% of its production capacity is exported – with a value of around EUR 12.9 billion. This corresponds to 11% of industrial output and 12.5% of Austria's total exports[2]. In the field of alternative propulsion systems, Austria is oriented towards the major markets of Europe, the USA and Asia.

AVL List GmbH is the world's largest privately owned company for developing, simulating and testing technology for powertrains (hybrid, combustion engines, transmission, electric drive, batteries and software) for passenger cars, trucks and large engines.

In the field of fuel cells, the main objectives of AVL List GmbH are simplification and economy, and durability and reliability of peripheral system components. At a system level, the activities concentrate on control and fuel cell stack diagnosis with a special technique called AVL THDA™ (Total Harmonic Distortion Analysis).

Technology development, manufacturing and sales of high-tech power electronics are the core competence of Fronius International GmbH. About 3,250 Fronius employees worldwide work in three divisions – solar electronics, welding and battery charging systems. The organisation received the Energy Globe Award 2007 for the innovative Hydrogen powered Logistic System (HyLOG) project (hydrogen fuel cells to drive a transport vehicle) and the VDI Innovation Prize for Logistics 2010. A new fleet demonstration project for a logistic service provider in Austria is underway.

MAGNA International Inc is a leading global supplier of technologically advanced automotive components, systems and modules. MAGNA STEYR covers the following product groups:

- Engineering services.
- Vehicle contract manufacturing.
- Innovative fuel and battery systems.
- Roof systems.

MAGNA STEYR offers a wide range of innovative products such as hydrogen components, high-pressure storage systems for mobile or stationary applications and liquid hydrogen tank systems for aviation.

OMV Aktiengesellschaft is Austria's largest listed industrial company. It has Group sales of EUR 43 billion, a workforce of 28,658 employees (2012 year end) and a market capitalisation of approximately EUR 11 billion (31 March 2013). OMV produces large amounts of hydrogen for oil refining and is a signatory to the commitment for hydrogen infrastructure development in Germany. OMV has been involved in several other hydrogen fuel cell projects.

PLANSEE supplies chromium-based interconnections for SOFC fuel cells with high corrosion resistance and mechanical stability. Service intervals of more than 40,000 hours at temperatures of up to 850°C are possible. For next-generation applications, active components in the form of coated metal supported cells (MSC) and lightweight construction interconnectors (special powder metallurgical ferritic (FeCr) alloys) are being developed.

Research conducted by technology company, proionic, is targeted towards the development of a reloadable hydrogen storage system, operating at ambient temperature and pressure, and takes advantage of the properties of ionic liquids. With adequate auxiliary equipment, this storage system could be used as a hydrogen storage system for automotive systems.

## 2.6 LIST OF STAKEHOLDERS

- A3PS.
- Austrian Energy Agency.
- Automotive Cluster Styria.
- Automotive Cluster Upper Austria.
- AIT Austrian Institute of Technology.
- Alset.
- AVL List.
- Bioenergy 2020+.
- Biovest Consulting.
- Department of Sustainable Agricultural Systems at the University of Natural Resources and Life Sciences (BOKU).
- CEST – Competence Centre for Electrochemical Surface Technology.
- Fraunhofer Austria Research.
- FRONIUS International GmbH.
- HyCentA – Hydrogen Centre Austria.
- JOANNEUM RESEARCH.
- KTM Sportmotorcycle.
- MAGNA STEYR.
- Miba Group.
- Montanuniversität Leoben – Chair of Physical Chemistry.
- OMV Aktiengesellschaft.
- Profactor.
- RIC (Regionales Innovations Centrum).
- THIEN eDrives.
- TU Graz – Institute for Internal Combustion Engines and Thermodynamics.
- TU Graz – Institute of Chemical Engineering and Environmental Technology.
- TU Graz – Institute of Electrical Measurement and Measurement Signal Processing.
- TU Vienna – Institute for Powertrains and Automotive Technology.
- TU Vienna – Institute of Chemical Engineering.
- TU Vienna – Institute of Energy Systems and Electric Drives.
- VIRTUAL VEHICLE research centre.

## 2.7 REFERENCES

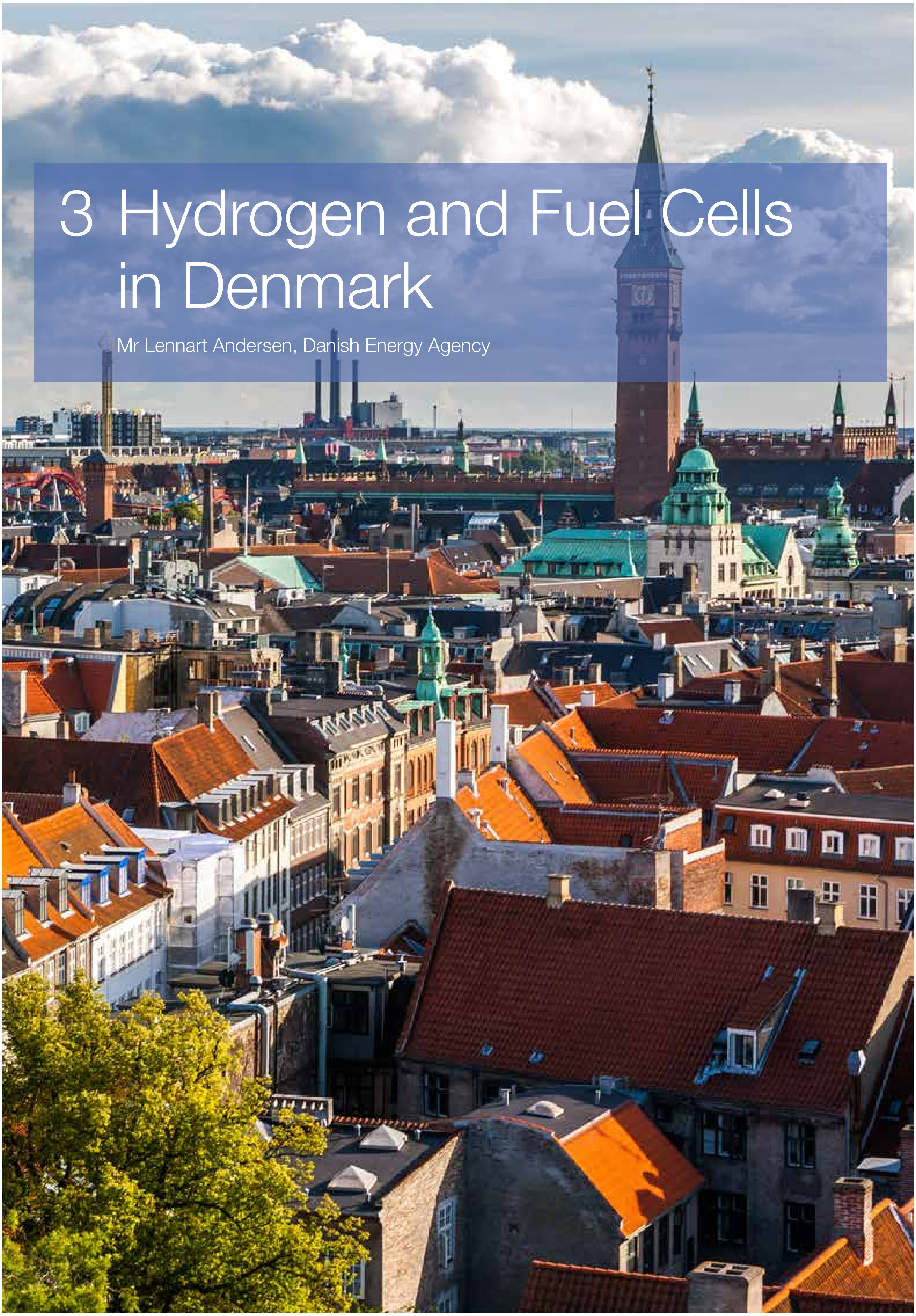

1. Austrian Energy Strategy, http://www.energiestrategie.at/, 2010.
2. A3PS: Eco-Mobility from Austria 2015 plus – A technology roadmap of A3PS to the development and market introduction of alternative propulsion systems and fuels, November 2011.


## 2.8 FURTHER INFORMATION

1. Austrian Energy Agency: http://en.energyagency.at/
2. A3PS: http://www.a3ps.at/site/en
3. Federal Ministry of Science, Research and Economy: http://www.en.bmwfw.gv.at/
4. Federal Ministry for Transport, Innovation and Technology: https://www.bmvit.gv.at/en/index.html

# 3 Hydrogen and Fuel Cells in Denmark

Mr Lennart Andersen, Danish Energy Agency



This report reflects the official energy policy in Denmark in 2014. Please note that a new Danish Government took office in June 2015. The new Government's energy policy differs from previous policy on several points.


### Summary

Denmark must be independent of fossil fuels by the year 2050. This requires significant changes in the Danish energy system in the years to come.

Hydrogen and fuel cell technologies have the potential to be an important part of the future energy system in Denmark. Industry, universities and public authorities all work together in a public-private partnership organisation to speed up the technological development of hydrogen and fuel cell technologies. Strategies and road maps for technological developments in hydrogen and fuel cells are published by the partnership. For a number of years, research and development in hydrogen and fuel cell technologies have been prioritised in the public funding of research for energy technologies.



**Keywords:** Wind turbines, renewable energy sources, fuel cells, hydrogen, Denmark


## 3.1 INTRODUCTION

The entire energy supply in Denmark must come from renewable energy sources by 2050.

The central pillars of Denmark's energy policy are energy efficiency, electrification and renewable energy. There is a need for new technological solutions in all areas to permit integration of fluctuating sources of energy, such as wind turbines, and to reach the energy policy goals efficiently and economically. The Danish Government has identified the need for new solutions in areas such as intelligent regulation of the power grid, energy storage and new renewable energy technologies.

Consequently, in the longer term, hydrogen and fuel cell technologies can be part of the solution to convert and store excess energy and, thereby, contribute to the integration of fluctuating renewable energy into the future Danish energy system.

## 3.2 GENERAL ENERGY GOALS

The long-term goal for Danish energy policy is clear: the entire energy supply – electricity, heating, industry and transport – is to be supplied by renewable energy by 2050.

Only by improving energy efficiency, electrifying energy consumption and expanding supply from renewables will it be possible to phase out fossil fuels completely. The initiatives in Denmark's Energy Agreement for the period 2012–2020 cover these crucial areas (Figure 3.1).

Figure 3.1: Major energy goals from the Danish Energy Agreement of March 2012

| 2020 |
|---|
| 35% renewable energy in final energy consumption |
| Approximately 50% of electricity consumption to be supplied by wind power |
| 7.6% reduction in gross energy consumption in relation to 2010 |
| 34% reduction in greenhouse gas emissions in relation to 1990 |

## 3.3 COUNTRY POLICIES

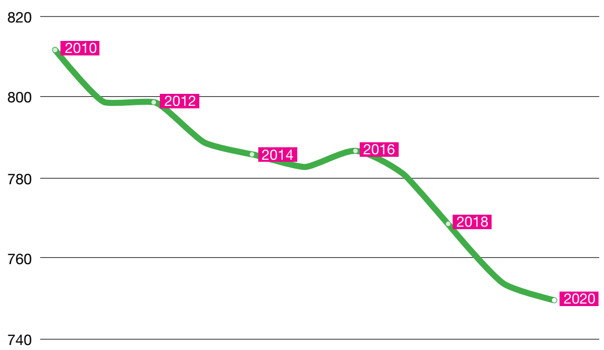
### 3.3.1 National Policies

#### Reduction in Danish gross energy consumption

A crucial element in the transition to 100% renewable energy will be that Denmark uses less energy by switching to more energy efficient technologies. Otherwise, economic growth will push up energy consumption and make it disproportionally expensive to expand the share of renewables in the energy supply. Moreover, investment in more energy efficient technology will often have a quick payback period. It is especially important to invest in retrofitting buildings. Extensive retrofitting is only carried out a few times in the life span of a building.

The goal is to decrease Danish gross energy consumption by 7.6% in 2020 in relation to 2010 (Figure 3.2).

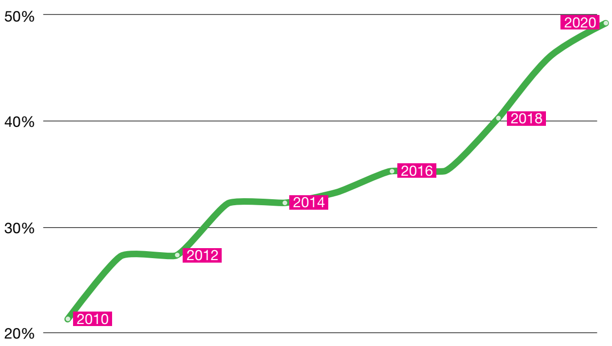
Figure 3.2: Reduction in gross energy consumption 2010–2020




#### Wind power

Denmark has sufficient renewable energy resources to satisfy energy consumption in the long term. The Energy Agreement ensures a substantial expansion of wind power in particular, corresponding to the annual electricity consumption of 1.5 million households. Consequently, approximately 50% of Danish electricity consumption will be covered by wind power in 2020 (Figure 3.3). In comparison, the share was 2% in 1990 and 28% in 2011.

Figure 3.3: Share of wind power in electricity consumption 2010–2020




#### New energy technologies

The parties behind the Energy Agreement stress that efforts to uphold a high level of research, development and demonstration in areas with commercial and growth potential should be maintained. Investing in new green technologies contributes to building Denmark's future prosperity.

In 2014, Denmark spent about DKK[ii] 1 billion in public funding for research, development and demonstration of new energy technologies. In general, the funding is not earmarked for specific energy technologies. The predominant approach is to let companies and universities that perform research in the different green energy technologies compete for the public funding. In recent years, research in hydrogen and fuel cells has been highly prioritised, with about 20% of the public funding granted supporting these areas.

[ii] Danish krone

Strategies and road maps containing specific targets for the technological development of hydrogen and fuel cell technologies in Denmark has been devised by the Danish Partnership for Hydrogen and Fuel Cells and can been seen on the partnership's website (http://www.hydrogennet.dk/326).

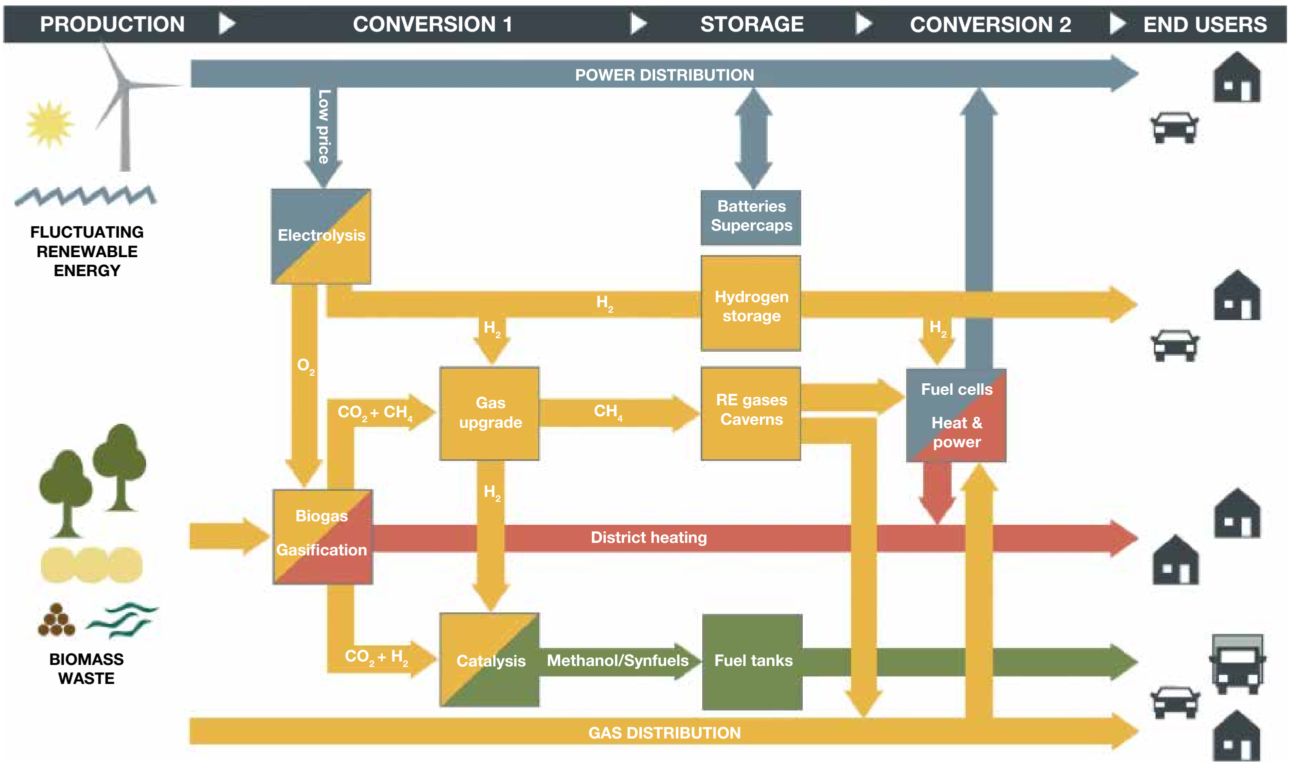
### 3.3.2 The Danish Partnership for Hydrogen and Fuel Cells

The Danish Partnership for Hydrogen and Fuel Cells is an organisation that brings together Danish manufacturers, research institutions, network organisations and public authorities under a common goal – promoting hydrogen and fuel cells in Denmark. The members deal with all aspects of hydrogen and fuel cells. Therefore, they have great interest in getting the technology developed such that hydrogen and fuel cells can compete as an energy technology in the market for alternative energy.

#### The future Danish energy system

The future Danish energy system, as forecast by the Danish Partnership for Hydrogen and Fuel Cells, shows the energy value chain from production to consumption. Figure 3.4 indicates how hydrogen is produced by electrolysis and how fuel cells will be able to balance the future energy system. The integration of electricity, gas and district heating is also shown from production of energy to delivery at the end user. For further details, please see the illustration and explanations below.

Figure 3.4: The future Danish energy system as forecast by the Danish Partnership for Hydrogen and Fuel Cells



### Production

The left side of Figure 3.4 demonstrates how fluctuating renewable electricity supplies (such as wind, solar and wave power) are transmitted to the end user via the electricity grid. In addition, biomass is introduced as a part of the energy system. Yellow and green symbolise agriculture and forestry, blue symbolises biomass from the ocean and finally there is waste from household and industry. Nearly all parties in the Danish Parliament have agreed on the common goal for 2050 – that is, all energy consumed in Denmark shall be based on renewable energy.

### Conversion – step 1

This step of the energy value chain explains how electricity generated from wind, sun and waves is converted into oxygen and storable hydrogen by means of electrolysis. Biomass converted into biogas will be upgraded to methane as a renewable gas (RE gas) or to green synthetic fuels if there is availability of hydrogen from electrolysis.

### Storage and infrastructure

Technically, RE gases (such as hydrogen) can be stored easily at low cost in the Danish gas grid, in caverns or in fuel tanks. Green synthetic fuels can be stored in exactly the same way as those for fossil-based gasoline. Gases and liquid fuels can be stored over long periods. In this way, the electricity grid can be balanced from hours up to days, weeks and even months. This adds an element of seasonal storage for variable renewable generation. Energy can also be stored in large quantities as heat or in small quantities in batteries.

### Conversion – step 2

Hydrogen and RE gases are reconverted into electricity by means of fuel cells or gas turbines. Heat loss from the conversion process can be used for district heating when added to the existing grid.

### End-user consumption

Hydrogen and other fuels (such as methane and green synthetic fuels) are able to deliver environmentally high-quality mobile and stationary energy solutions when applied in fuel cells. In this respect, mobile solutions include 'on-road' and 'off-road' applications whereas stationary solutions include central and decentralised power plants, micro CHP, uninterruptible power supply (UPS) and many other applications in near commercial markets.

## 3.4 STATE AND REGIONAL POLICIES

Denmark is divided into five regions and 98 municipalities. In general, Denmark does not have regional policies that specifically target fuel cells, although some regions and municipalities promote various initiatives in relation to hydrogen and fuel cells.

As an example, the city of Copenhagen is aiming to become the first carbon neutral capital by 2025. One of the major goals for 2025 is that between 20% and 30% of all light vehicles are run on new fuels (such as electricity, hydrogen, biogas or bioethanol). In this context, the city promotes the testing of fuel cell electric vehicles (FCEV) and hydrogen refuelling stations (HRS).

## 3.5 MAJOR COMPANY ACTIVITIES

### 3.5.1 Dantherm Power A/S

Dantherm Power A/S is a subsidiary of Dantherm A/S located in Hobro, Denmark. Since 1958, Dantherm A/S has built a solid reputation as a trustworthy supplier dedicated to constantly setting new standards for customised solutions, support and customer relations.

Dantherm Power A/S focuses on the commercial exploitation of fuel cell technology. From development and production, to sale and support of complete solutions to customers in the telecommunications industry, defence, relief organisations and others who need backup power solutions and mobile power supply equipment.

Dantherm Power A/S also commits major R&D resources to developing new fields in which hydrogen and fuel cell technology is expected to become commercially profitable in a few years (such as micro CHP units aimed at private households).

### 3.5.2 Danish Power Systems

Danish Power Systems (DPS) is a research-based development company founded in 1994. DPS works in the fields of energy and chemistry. Its mission is to promote environmentally sustainable technological developments through research, innovation and consultancy.

DPS's strategy is to provide business partners with competitive, custom-made solutions that are based on state-of-the-art know-how and many years of combined experience. DPS's membrane electrode assemblies (MEA) for high temperature (HT) polymer electrolyte membrane (PEM) fuel cells are based on in-house expertise on polybenzimidazole (PBI) synthesis, and membrane, catalyst and electrode manufacture.

DPS is able to supply MEA for HT-PEM with an area in the range of $10 cm^2$ to $400 cm^2$. The MEA are designed to have an integrated edge sealing for easy implementation.

### 3.5.3 Greenhydrogen.dk ApS

Greenhydrogen.dk ApS was founded in 2007 and is owned by six companies – Hollesen Energy A/S, Dantherm Power A/S, Strandmøllen A/S, Nortec-Optomatic A/S, Innovation Midtvest A/S and EnergiMidt Udvikling A/S.

Greenhydrogen.dk produces electrolysis systems for hydrogen production and has competencies in development and manufacturing of complete systems. Its modular systems ensure optimised plants with high system efficiency, high reliability and simple installation. These are available in a range of capacities from 2 normal $m^3$/hour up to 80 normal $m^3$/hour.

### 3.5.4 H2 Logic

H2 Logic is a leading developer of hydrogen and fuel cell technology that enables sustainable and zero emission electric propulsion of vehicles with the same ease of use as that for fossil-fuelled vehicles. Hydrogen can be refuelled just as fast as gasoline or diesel and enables the same long operating range. Hydrogen is converted to electricity within the fuel cell with a fuel efficiency of more than double that of combustion engines.

H2 Logic supplies hydrogen infrastructure for production and refuelling.

### 3.5.5 IRD Fuel Cells A/S

IRD A/S is a high technology company devoted to research, development and production of fuel cell technology – in favour of the environment. Through strong competencies in electrochemistry, chemistry, materials science, and electronic and mechanical engineering, IRD has transformed ideas and patents – developed over a period of more than 10 years – to commercially viable fuel cell products.

In cooperation with international research groups, strategic partners and customers, efforts made have led to leading technology and products in PEM fuel cell technology and direct methanol fuel cell (DMFC) technology.

## 3.6 LIST OF STAKEHOLDERS

### 3.6.1 Manufacturers of hydrogen and fuel cell technologies

| Company | Website |
|---|---|
| Danish Power Systems | http://daposy.com/ |
| Dantherm Power | http://dantherm-power.com/ |
| Greenhydrogen.dk | http://greenhydrogen.dk/ |
| H2 Logic | http://www.h2logic.com/com/ |
| IRD Fuel Cells | http://www.ird.dk/ |
| LeanEco | http://leaneco.dk/ |
| SerEnergy | http://serenergy.com/ |
| Topsoe | http://www.topsoe.com/ |

### 3.6.2 Network organisations

| Organisation | Website |
|---|---|
| Cemtec | http://cemtec.dk/DK.aspx |
| The Danish Partnership for Hydrogen and Fuel Cells | http://www.hydrogennet.dk/forside0/ |
| LOKE | http://www.loke-holding.dk/ |

### 3.6.3 Universities

| University | Website |
|---|---|
| Technical University of Denmark | http://www.dtu.dk/english |
| Copenhagen University, Nano-Science Centre | http://nano.ku.dk/english/research/nanocatalysis |
| Aalborg University | http://www.en.aau.dk/ |
| Aarhus University, Centre for Energy Technologies | http://auhe.au.dk/en/research/research-centres/centre-for-energy-technologies/ |

## 3.7 FURTHER READING


1. Danish Ministry of Energy, Utilities and Climate, Energy and Building – http://www.kebmin.dk/en http://www.efkm.dk/en
2. Danish Energy Agency – http://www.ens.dk/en
3. Technical University of Denmark – http://www.ecs.dtu.dk/english
4. The Future Use of Gas Infrastructure (in Danish) – http://www.ens.dk/sites/ens.dk/files/undergrund-forsyning/el-naturgas-varmeforsyning/Energianalyser/nyeste/gasinfrastrukturen_-_analyse_2014_web.pdf
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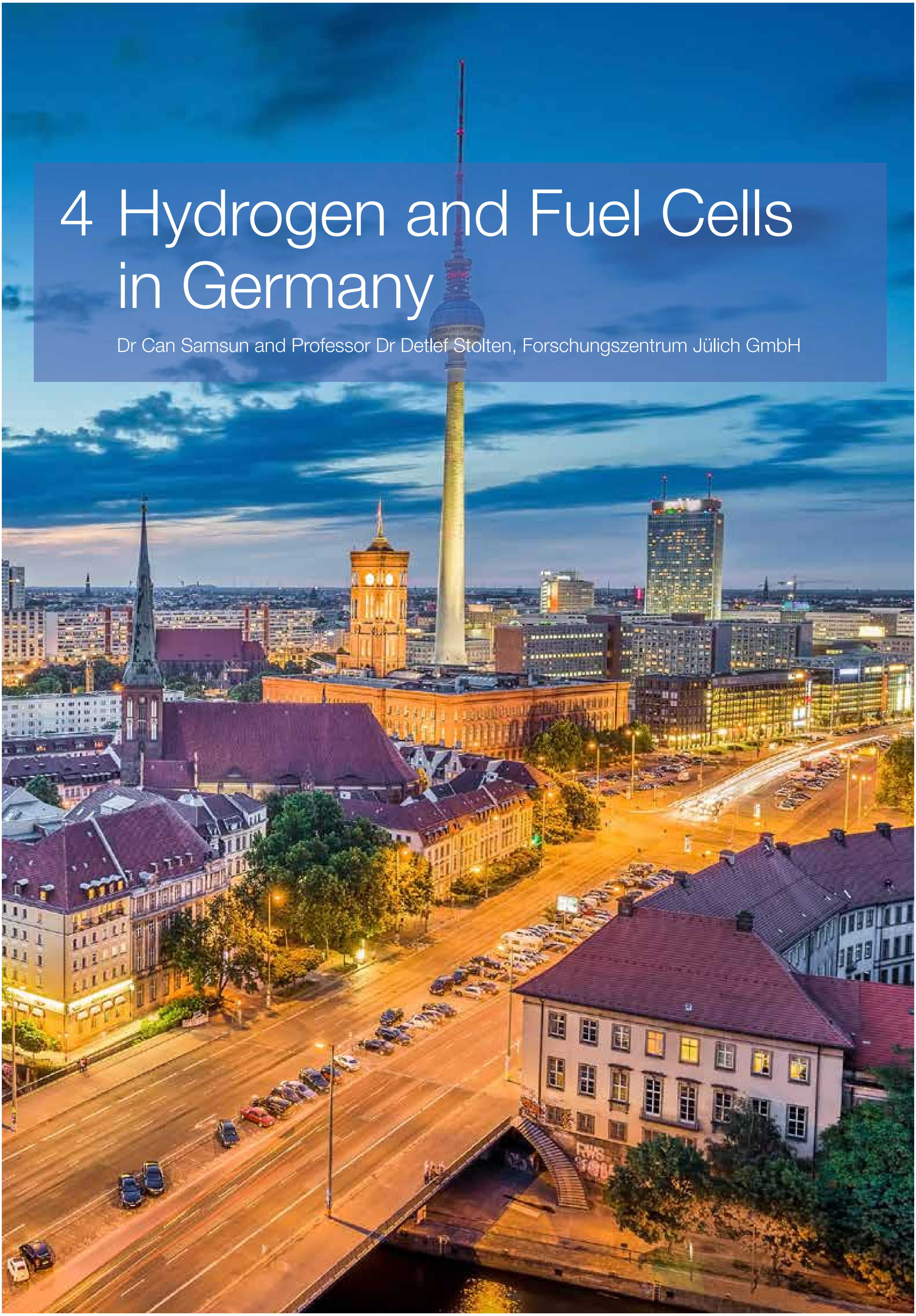
# 4 Hydrogen and Fuel Cells in Germany

Dr Can Samsun and Professor Dr Detlef Stolten, Forschungszentrum Jülich GmbH



## Summary

In 2010, in the Federal Government's Energy Concept, Germany defined a long-term overall strategy for energy for the period up to 2050. According to this strategy, the share of electricity generated from renewable energy sources is to account for 80% by 2050. In its 6th Energy Research Programme, the Federal Government defined the basic tenets and main areas of focus of its funding policy for the coming years. These are:

- Renewable energy.
- Energy efficiency.
- Energy storage technologies and grid technology.
- The integration of renewable energy into the energy supply.
- The interaction of these technologies in the overall system.

The German Government, along with the science and industry sectors, supports the development of fuel cell and hydrogen technologies in Germany in the form of a strategic alliance known as the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP). The NIP's work plan and outline strategic framework for its implementation by 2016 is provided in the National Hydrogen and Fuel Cell Development Plan (NEP). This includes objectives, milestones and outlooks for different areas of application. The NEP can be considered the most important part of the German roadmap for hydrogen and fuel cells.

Details of the NEP are discussed below along with the milestones for further development of the NIP beyond 2025, a brief listing of fuel cells activities from the German states (HIT NIP), major company initiatives and an overview of the stakeholders in Germany.



**Keywords:** energy concept, renewables, fuel cells, hydrogen, Germany


## 4.1 INTRODUCTION

Germany has a structured energy policy with concrete targets. The further development of fuel cell and hydrogen technologies has a well-defined position in this energy policy. Research, development and demonstration projects are organised and coordinated at a national level.

This chapter starts with an overview of general energy goals for Germany. This is followed by the organisation of fuel cell and hydrogen activities, including the main players. Development plans for different application areas including targets, milestones and outlooks are the cornerstones of the German roadmap and will be discussed. Activities at the state level are also briefly highlighted. The chapter concludes with a short discussion of major company initiatives and a list of stakeholders.

## 4.2 GENERAL ENERGY GOALS

The German Federal Government formulated guidelines for an environmentally sound, reliable and affordable energy supply, and defined a roadmap for the age of renewable energy in the Energy Concept of September 2010[1]. The Energy Concept defines a long-term overall strategy for the period up to 2050. Renewable energy sources are to account for the biggest share in this dynamic future energy mix because conventional energy sources are steadily being replaced by renewables. Nuclear technology is considered a bridging technology to facilitate this transition to renewables.

Climate protection targets are an important part of the Energy Concept. Greenhouse gas (GHG) emissions are to be cut by 40% by 2020, and the industrialised nations have further agreed to reduce them by at least 80% by 2050 from the 1990 baseline emissions. To achieve the targeted emission levels, the development path requires a 55% reduction in GHG emissions by 2030, a 70% reduction by 2040 and an 80% to 95% reduction by 2050.

By 2020, renewable energy should account for 18% of the gross final energy consumption in Germany. Subsequent targets for renewables as a proportion of gross final energy consumption have been defined by the German Government as follows:

- 30% by 2030.
- 45% by 2040.
- 60% by 2050.

By 2020, electricity generated from renewable energy sources is to account for 35% of gross electricity consumption. This figure is to increase to 80% by 2050. By 2020, primary energy consumption is to be 20% lower than that in 2008 and 50% lower by 2050. This calls for an annual average gain in energy productivity of 2.1%, based on final energy consumption. Compared with 2008, a cut of 10% is targeted in energy consumption by 2020 and 25% by 2050. The building renovation rate will need to double from the current figure of less than 1% a year to 2% of the total building stock. In the transport sector, final energy consumption is to fall by about 10% by 2020 and by about 40% by 2050 from the baseline energy consumption in 2005.

The Energy Concept was revised following the earthquake and tsunami effecting Japan and the resulting incidents at the country's nuclear facilities. In the cabinet decision of 6 June 2011, the Federal Government decided to accelerate the adoption of renewable energy while ensuring a reliable, economically viable and environmentally sound energy supply for Germany[2]. As a result, eight nuclear power plants were shut down permanently and it was decided to phase out the operation of the remaining nine by 2022.

In its 6th Energy Research Programme 'Research for an environmentally sound, reliable and affordable energy supply', the Federal Government defined the basic tenets and main areas of focus of its funding policy for the coming years[3]. This Programme represents an important step towards implementing Germany's Energy Concept. Its vision is for Germany to become one of the most energy-efficient and environmentally sound economies in the world. Renewable energy, energy efficiency, energy storage technologies and grid technology, the integration of renewable energy into the energy supply and the interaction of these technologies in the overall system are the topics of central importance.

The 6th Energy Research Programme is a joint programme run by the Federal Ministry of Economics and Technology (BMWi); the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU); the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV); and the Federal Ministry of Education and Research (BMBF). It is closely aligned with the research activities of industry, scientific institutes and energy research in the Länder[i]. The Programme's focus incorporates harmonisation with the research activities of the EU and with partner countries in the International Energy Agency (IEA). Under this Programme, the German Federal Government allocated approximately EUR[iii] 3.5 billion to fund the research and development of energy technologies between 2011 and 2014.

[iii] European euro

## 4.3 COUNTRY POLICIES

In 2006, the German Federal Government, along with the industry and science sectors, launched a strategic alliance called the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) to safeguard the further development of fuel cell and hydrogen technologies in Germany. NIP is intended to speed up the process of the market preparation of products based on this future-oriented technology. NIP's total budget, to be invested over a period of 10 years until 2016, is EUR 1.4 billion. The Federal Ministry of Transport and Digital Infrastructure (BMVI) and the BMWi provide half of the funding, while the remainder is funded by participating industries[4]. NIP receives further support from the BMU and the BMBF.

### 4.3.1 National Hydrogen and Fuel Cell Development Plan from 2011

NIP's work plan and outline strategic framework for its implementation by 2016 is provided in the National Hydrogen and Fuel Cell Development Plan (NEP). This includes targets, milestones and outlooks for different areas of application[5]:

- Transport, including hydrogen infrastructure (distribution, storage, refuelling).
- Hydrogen production.
- Household energy supply.
- Industrial applications.
- Special markets for fuel cells.
- Cross-cutting themes.

The NIP includes research and development projects as well as demonstration and market penetration projects. The National Organization Hydrogen and Fuel Cell Technology (NOW GmbH) coordinates and manages the programmes for the market preparation of products and applications in the areas of hydrogen, fuel cell and battery-electric drive technology.

The development plans for the areas of application mentioned above are discussed in detail below and are based on documents from the NEP (from October 2011[5]) and the 6th Energy Research Programme of the Federal Government (from November 2011[3]).

### 4.3.2 Transport

This area includes the development of fuel cell passenger cars and buses, and the required fuelling and storage of hydrogen. Under the auspices of the Clean Energy Partnership (CEP) – a joint initiative of car manufacturers, technology producers and energy companies – significant progress was achieved concerning the service life and power of fuel cell systems for transportation. In this area[3], the following are given priority:

- Fuel cell stacks.
- Peripheral components and electric drive systems.
- Hybridisation of fuel cells and battery storage systems.
- Hydrogen storage for vehicles.
- Full system integration.
- Reforming of energy sources into hydrogen-rich gases.
- Materials with reduced corrosion or hydrogen embrittlement.
- Service stations and infrastructure.

The main targets of the research and development projects are cost reduction, mass and volume reduction, increased lifetime, improved operation conditions and increased efficiency. Demonstration projects aim to validate the technology under everyday operating conditions and prepare the technology for commercialisation, including customer acceptance[5].

Within this sector, the milestone set for 2015 is defined as achieving "competitiveness and customer acceptance compared with conventional technology validated by 2015" and the outlook for 2020 is to have the "competitive position of German industry established in the field of hydrogen and fuel cell technologies".

### 4.3.3 Hydrogen production

The energetic usage of hydrogen is expected to increase for two main reasons[5]. Firstly, the expected increase in the share of renewables in the energy mix in Germany and the EU will lead to a rapid increase in the amount of fluctuating energy from wind and solar power in the electricity supply network. This requires new strategies for flexible regulation of the electricity network, the transport sector and, particularly, the storage of large amounts of energy. At present, chemical storage (for example, using hydrogen) is the most appropriate solution. Secondly, hydrogen is an option as a future fuel for mobility. State-of-the-art fuel cell electric vehicles (FCEV) operating on hydrogen fulfil the comfort expectations of consumers concerning the range and fuelling times. These are difficult to realise with battery electric vehicles (BEV)[5].

Research and development measures include the electrolytic production of hydrogen, hydrogen production from biomass, the recovery of energy from waste material and the use of hydrogen as a by-product in industrial processes. A further area of interest is the storage of larger quantities of hydrogen in the GWh to TWh range. Some specific measures, which will be implemented as a part of future research and development activities, are[3]:

- The development of proton exchange membrane (PEM) electrolysis and alkaline electrolysis for plants in the megawatt (MW) range.
- The development of efficient processes for high-temperature electrolysis.
- The further development of large-scale storage processes (especially caverns and metal hydrides).
- Methanation and hydrogen-based fuel production.
- Distribution and supply paths.

### 4.3.4 Household energy supply

This development plan concerns stationary systems with a power output of up to 5kW. Generating electricity and heat using a single system in domestic households, apartment blocks and business establishments with fuel cell technology allows high overall efficiencies (up to 85%) and can reduce carbon dioxide ($CO_2$) emissions by between 25% and 35% compared to conventional means (such as heat from boilers or electricity from the grid)[5]. By 2015, up to 800 units will be installed and tested as a part of the CALLUX demonstration project, a practical test initiated by partners in the energy and heating systems industries[3]. The objectives of research and development projects are to increase reliability and service life, reduce system complexity and cut costs. The key topics are:

- Cost-effective and durable reformer materials, catalysts, stack materials, reduction of platinum load.
- Increased power output and resistance to impurities.
- Water management of polymer electrolyte fuel cells (PEFC).
- Development of high-temperature PEFC (HT-PEFC).
- Cyclability, new materials and redox resistance of solid oxide fuel cells (SOFC).
- Lifetime (greater than 25,000 hours).
- Degradation mechanisms for stacks.
- System development for high lifetimes and efficiencies.

The objectives of demonstration are technology validation under everyday conditions, supplying industry and customers, and trade acceptance. The key topics are:

- Technology validation.
- Establishing production and supplier chains.
- Electricity grid utilisation and a virtual power plant.
- Consolidating skills in the trade.
- Compatibility with biomethane.

The milestone for 2016 was defined as the installation of 3,000 domestic fuel cell units. Further targets are an increase in electrical system efficiency to more than 33%, total system efficiency of more than 87% and a lifetime of over 25,000 hours for stacks. The 2020 objective is to install 7,200 fuel cell units per year and to achieve cost competitiveness with that of conventional alternatives.

### 4.3.5 Industrial applications

Using fuel cells for the decentralised generation of power and heat in industrial applications will make it possible to achieve primary energy efficiencies of over 90% and over 50% electrical efficiency. Compared with conventional combined heat and power (CHP) systems, using fuel cells for decentralised power generation will reduce carbon monoxide emissions by up to 20% and $CO_2$ emissions by between 30% and 40%. The development plan for industrial applications defines the same objectives for research and development as those for household energy supply. In the current phase, the key topics are:

- Cutting production costs.
- Increasing system size.
- Expanding production capacities.
- Standardising components.

Demonstration projects aim to increase reliability, validate the technology, cut costs, gain acceptance and prepare for commercialisation (a programme was planned to accompany commercialisation). The milestone for 2015 was defined as a stack durability of 40,000 hours. The outlook for 2020 is to achieve competitive systems for the global industrial and energy supply markets[5].

The following key research and development activities are required for different fuel cell technologies for industrial applications[3]:

- Molten carbonate fuel cells (MCFC) technology: improve cell power and efficiency, increase service life, reduce degradation, simplify the entire system, improve balance-of-plant components and use biogenic fuels.
- SOFC technology: develop planar stack technology, scale up to units with electricity outputs of several kW with the option of grouping them together into larger plant, manage and control the entire system, and develop concepts and components for competitive manufacturing technologies for large-scale production.
- PEM technology (conventional and high-temperature): scale up small plants to the 100kW or megawatt output range, optimise entire system and components and introduce hybridisation with micro gas turbines or thermoelectric generators.

### 4.3.6 Special markets

The NEP includes a further section called ‘special markets’. This consists of different applications that cannot be classified under the above-mentioned areas. These are:

- Emergency power supply and/or uninterruptable power supply (UPS) for telecommunications, information technology and traffic engineering.
- Warehouse technology vehicles (such as fork-lift trucks).
- Boats, light vehicles and on-board electric power for the leisure market (such as auxiliary power units (APUs) for caravans).

These applications have a special importance in the development plan, since they enable high sales revenues due to the specialised nature of the market. In this way, the special markets act as a bridge in overcoming economic barriers in energy applications[3].

### 4.3.7 Cross-cutting issues

The NEP also includes cross-cutting issues in the form of activities that are beneficial for all application areas mentioned up to this point. The following key research and development activities are covered under cross-cutting issues[3]:

- Basic research on cell and system components.
- Developing and testing components and systems independently of specific applications.
- Developing methods to predict and improve the service life of cells.
- Developing time-lapse tests.
- Standard test procedures and facilities to compare different systems.
- The use of fuel cells in distributed systems for virtual power stations.

### 4.3.8 Further Development of the National Innovation Programme from 2013

In June 2013, NOW GmbH published a report entitled ‘Hydrogen and fuel cell technologies – key pillars of the energy transition 2.0’. This report states that the everyday suitability and technological marketability was reached in the first stage of NIP for vehicles, and the power and heat supply for buildings. The aim of the second stage is a commercial breakthrough of hydrogen and fuel cell technologies. Representatives from industry, science and the Federal States on the NOW GmbH advisory board recommended the further development of NIP.

The following business areas were defined as important until 2025[6]:

- Fuel cells for electric vehicle drives and hydrogen infrastructure for comprehensive, emission-free mobility.
- Hydrogen generation from renewable energies and integration into the energy system as a link between sustainable mobility and energy supply.
- Fuel cells for stationary energy supply using decentralised co-generation in domestic and other buildings and for industry, and secure power supplies (such as those used for public safety communication systems and telecommunications).

Concrete milestones for the year 2025 were defined for each of the above-mentioned business areas. These milestones are presented in Table 4.1.

**Table 4.1: Milestones for different business areas for the further development of the NIP until 2025[6]**

| | |
|---|---|
| Fuel cell vehicles and hydrogen infrastructure | Over 500 public hydrogen fuelling stations nationally |
| | More than 500,000 fuel cell cars on the road |
| | 2,000 fuel cell buses operating in the public transport system |
| Hydrogen generation from renewables and integration into the energy system | Developing 1,500MW capacity electrolysers for the generation of hydrogen from renewable energy |
| | Definition and implementation of successful business models for power to gas |
| | Development of hydrogen storage mechanisms to store renewable electricity |
| Fuel cells for stationary energy supply | Over 500,000 fuel cell heating appliances in operation |
| | Over 1,000MW of fuel cell CHP capacity in operation |
| | More than 25,000 secure power supply installations in place |

## 4.4 STATE AND REGIONAL POLICIES

Apart from the Federal level, various German states (Länder) also have networking activities for the development of fuel cell and hydrogen technologies. However, at this level, structured programmes such as NIP do not exist. Nevertheless, the state activities are well coordinated and align with the NIP. Overall, activities at the state level provide additional funding sources helping to bring relevant institutions and companies together for the further development, demonstration and market introduction of fuel cell and hydrogen technologies. Table 4.2 gives an overview of the networks created and supported by German states.

Table 4.2: Overview of hydrogen and fuel cell networks and initiatives of German states

| State | Network/Initiative |
|---|---|
| Baden Württemberg | Fuel-Cell and Battery-Alliance Baden-Wuerttemberg |
| Bavaria | Hydrogen Initiative-Bavaria (wiba) |
| Hamburg | Hamburg Initiative for Fuel Cells and Hydrogen Technology |
| Hesse | Wasserstoff- und Brennstoffzellen – Initiative Hessen |
| Lower Saxony | Landesinitiative Brennstoffzelle und Elektromobilität Niedersachsen |
| Mecklenburg-Vorpommern | Wasserstoff, Brennstoffzellen, Elektromobilität in Mecklenburg-Vorpommern |
| North Rhine-Westphalia | Fuel Cell and Hydrogen Network NRW |
| Saxony | Brennstoffzellen Initiative Sachsen |
| Saxony-Anhalt | Brennstoffzellenverband Sachsen-Anhalt |

## 4.5 MAJOR COMPANY ACTIVITIES

The number of institutions and companies working in the field of hydrogen and fuel cells in Germany is one of the highest worldwide. Therefore, it is not possible to mention all of them in this chapter.

At this point, two important developments can be addressed that are relevant for the hydrogen and fuel cell roadmap in Germany. On 8 September 2009, leading original equipment manufacturers (OEM) including Daimler, Ford, GM/Opel, Honda, Hyundai/KIA, Renault/Nissan and Toyota signed a Letter of Understanding on the development and market introduction of fuel cell vehicles. The signing OEMs strongly anticipated that, from 2015 onwards, a significant number of fuel cell vehicles could be commercialised. The target was a few hundred thousand units on a worldwide basis. The signing OEMs also supported the idea of building a hydrogen infrastructure in Europe, with Germany as a starting point, and simultaneously developing similar concepts for the market penetration of hydrogen infrastructure in other regions of the world (the USA, Japan and Korea) as further starting points. On 10 September 2009, representatives of leading industrial companies signed a Memorandum of Understanding, with Germany's Minister for Transport, Building and Urban Affairs in attendance. As part of the initiative, it was decided to review the possibilities of building an infrastructure to supply hydrogen across Germany, with a view to moving forward with the serial production of fuel cell powered vehicles. This became the $H_2$ Mobility initiative, with founding members Daimler, EnBW, Linde, OMV, Shell, Total, Vattenfall and NOW. In September 2013, six partners in the $H_2$ Mobility initiative – the actual partners are Air Liquide, Daimler, Linde, OMV, Shell and Total – set up a specific action plan for the construction of a nationwide hydrogen refuelling network for fuel cell powered electric vehicles.

The target is that, by 2023, the number of hydrogen filling stations on the network in Germany will be increased to about 400. As a first step, it is planned that 100 hydrogen filling stations will be opened in Germany over the next 4 years. A hydrogen supply suitable for everyday use shall be created not only for densely populated areas and main traffic arteries, but also for rural areas. The objective is to offer a hydrogen station at least every 90 kilometres of motorway between densely populated areas. According to this plan, in metropolitan areas, drivers of fuel cell powered vehicles will have at least 10 hydrogen refuelling stations available from 2023. The $H_2$ Mobility initiative predicts a total investment of around EUR 350 million for this future-oriented infrastructure project[7].

## 4.6 LIST OF STAKEHOLDERS

German stakeholders in fuel cells and hydrogen include ministries, research institutions, companies and other organisations.

**Ministries** – at the ministerial level, the Federal Ministry of Transport, Building and Urban Development (BMVBS); BMWi; BMBF; and BMU provide funding for hydrogen and fuel cell projects. NOW GmbH coordinates and manages the programmes for the market preparation of products and applications in the areas of hydrogen, fuel cell and battery-electric drive technology.

**Research institutions** – includes Forschungszentrum Jülich, German Aerospace Center (DLR), Fraunhofer Gesellschafts (including Institutes for Ceramic Technologies and Systems IKTS, for Solar Energy Systems ISE, Institute for Chemical Technology ICT-IMM), Fuel Cell Research Center ZBT, Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW), EWE Research Center NEXT ENERGY and Oel-Waerme Institut (OWI). These are just a few of the many research institutions working on fuel cells and hydrogen.

**Companies** – many companies are involved in fuel cell and hydrogen technologies including Air Liquide Advanced Technologies, Airbus Operations, BalticFuelCells, BASF, Baxi Innotech, Bosch Thermotechnik, Daimler, DBI Gas- und Umwelttechnik, EBZ Fuel Cells and Process Technology, Eisenhuth, Elcore, EnBW Energie Baden-Württemberg, E.ON New Build and Technology, EWE, eZelleron, Flexiva Automation and Robotik, Freudenberg FCCT, FuelCell Energy Solutions, FuelCon, FuMa-Tech, FutureE Fuel Cell Solutions, Helicentris Energysysteme, HIAT, Hüttenberger Produtionstechnik Martin, Linde, MVV Energie, Proton Motor Fuel Cell, Risaer Brennstoffzellentechnik, Schunk Bahn- und Industrietechnik, Sunfire, Truma Gerätetechnik, Ulmer Brennstoffzellen Manufaktur, Vaillant Deutschland, Viessmann Werke GmbH, VNG Verbundnetz Gas, Volkswagen, WS Reformer, and SFC Smart Fuel Cell.

**Further organisations** – includes the German Engineering Federation (VDMA) Fuel Cells Association, which is the industry network for manufacturers of fuel cell systems and components in Germany with more than 60 members. There is also the German Hydrogen and Fuel Cell Association (DWV), which promotes and prepares the general introduction of hydrogen as an energy carrier in the economy.

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# 5 Hydrogen and Fuel Cells in Italy

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## Summary

One of the main weaknesses of the Italian energy sector is the heavy dependence on imports of fossil fuels, mainly natural gas. In 2013, 50% of Italy's energy sector was reliant on gas, with 85% imported from abroad, mostly from Algeria and Russia, two countries with high political instability. This makes the system critically vulnerable and any disruption or shortage could severely affect the Italian economy. The Government, in its efforts to improve the country's energy system and achieve environmental goals, has published the National Energy Strategy (SEN). This chapter outlines how fuel cells and hydrogen technology can benefit from the policies set out in the strategy.

The Italian Government is promoting policies to facilitate research and development (R&D) of clean technologies that work in synergy with European interests. Without this activity, Italy would be unlikely to be able to sustain its energy needs into the future and could lose the benefits of an increased industrial market, increased employment, further revenues and fiscal development.



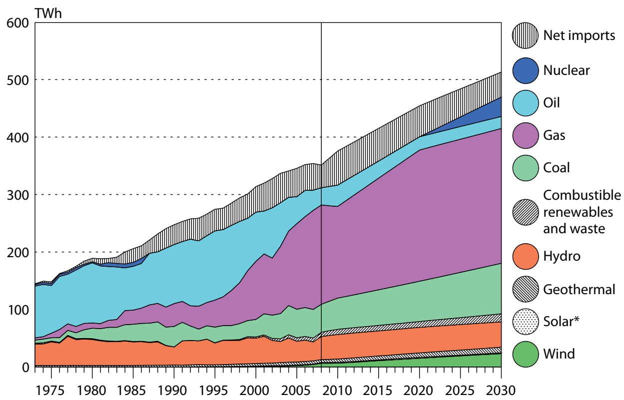
**Keywords:** energy security, fuel cells, Italy


## 5.1 INTRODUCTION

The national and international context of the past few years has turned the spotlight on the dependence of the Italian system on energy imports which, in 2011, reached EUR[iv] 62 billion, with an energy gap of about 84%.

Despite serious indications that the country has a lack of secure supply, such as the blackout of 2003, the Italian energy system continues to be very dependent on external sources. In 2013, the production of electricity was based on 50% natural gas, followed by 30% from renewables, 12% from coal and 8% from oil. As 85% of the gas was imported from Algeria and Russia, Italy was forced to base the energy system on the prices set by this oligopoly and was vulnerable to any developing political instabilities in these countries. This dependence is likely to increase in the future (Figure 5.1[1]). Therefore, it becomes imperative to optimise the energy mix to meet demand peaks and any sudden reductions in imports.

**Figure 5.1: Electricity generation by source for Italy, 1975 to 2030 [1]**



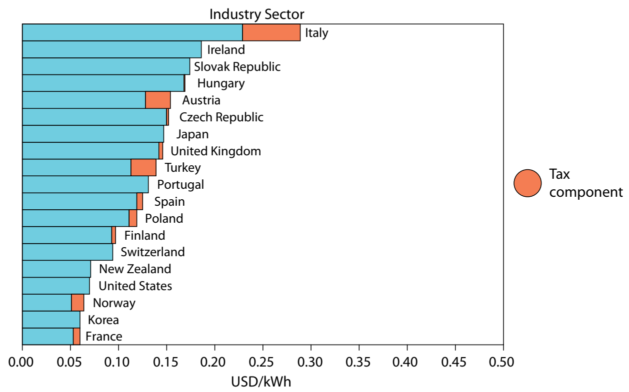

In March 2013, in its efforts to meet the commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol, the Italian Government published its National Energy Strategy (SEN). SEN specifies the objectives that will be promoted in the coming years to achieve significant development of sustainable energy sources, and to ensure energy competitiveness respective to international prices and priorities. This strategy focuses on four main objectives:

1. Reducing the energy cost gap.
2. Achieving environmental objectives.
3. Improving security of supply.
4. Encouraging sustainable growth through development of the energy sector.

[iv] European euro

Accomplishing these goals will allow the country to optimise its production system by lowering electricity prices, which are above the European average (Figure 5.2).

**Figure 5.2: Electricity prices in IEA member countries, 2008[1]**




The Strategy also includes ensuring a close relationship between research and development (R&D) activities and the prioritisation of projects identified by the European Commission's Strategic Energy Technology Plan (SET-Plan). High priorities include research on renewable energy technologies and innovative solutions with low visual impact, smart grids and storage systems, materials and energy efficiency solutions, project development on methods of capture and confinement of carbon dioxide ($CO_2$), and research aimed at the exploitation of deposits of indigenous resources.

With high energy efficiency and a wide variety of fuels available, fuel cells are an attractive technology to consider to reduce greenhouse gas (GHG) emissions and achieve economic growth. The development of fuel cell and hydrogen technology can open a diversity of markets for Italian industry and develop substantial opportunities for job creation.

## 5.2 GENERAL ENERGY GOALS

Given the need to radically transform the energy system and to create a balance between competitiveness and environmental sustainability, Italy has developed four key goals for the coming years:

1. Significantly reduce the gap in energy costs for consumers and businesses, aligning prices and energy costs with Europe by 2020, (savings of EUR 9 billion on gas and electricity bills), without compromising Italian and European competitiveness.
2. Achieve and exceed environmental and decarbonisation objectives. It is proposed to improve environmental standards to play a leading role in the finalisation and adoption of the National Energy Roadmap to 2050, the Italian adoption of the EU's Strategic Energy Plan and Roadmap to 2050:

- A 21% reduction in GHG emissions compared to 2005 levels (EU target: 18%).
- A 24% reduction in primary energy consumption (EU target: 20%).
- A 19% to 20% contribution of renewable energy at the point of final consumption (EU target: 17%).

3. Improve security of supply by reducing dependence on energy imports from foreign countries (from 84% to 67%) resulting in a reduction in costs to around EUR 14 billion per year (compared to the current EUR 62 billion per year). This objective will be accomplished through the replacement of fossil fuels with renewable energy sources, along with the most efficient possible use of resources.
4. Promote sustainable economic growth through the development of the energy sector, taking advantage of the potential growth due to increasing investments (about EUR 170 billion to EUR 180 billion from private investment by 2020). It will be important to ensure that the transition does not damage the Italian and European economy.

## 5.3 COUNTRY POLICIES

The focus of the Italian Government is to boost thematic priority areas such as research on innovative renewables, intelligent networks, storage systems and a special focus on the need to increase efforts in energy efficiency solutions.

Seven flagship priorities will enable the energy goals to be achieved:

1. Promotion of energy efficiency – this is prioritised as it contributes to the achievement of all other objectives. Regarding standards and regulations:

- In the field of high-efficiency cogeneration, further measures will be introduced to complement the regulatory environment and offer incentives to the current scheme.
- In the building and transport industries, rules will be defined for incentives promoting sustainable mobility in urban areas.

2. Competitive gas market and southern European Hub. Italy could become an important crossroads for gas from North African providers. If so, this will create an integrated market, align the Italian gas prices with those in Europe and, consequently, return competitiveness to the installed combined-cycle gas systems. The main interventions in this area would be:

- To eliminate differential prices by increasing the Italian electricity market competitiveness.
- To increase security for the gas supply system.

3. Promotion of renewable energy sources. The objective is to align the incentives to European values while limiting the burden on Italian energy bills:

- Renewable electricity – a reduction of unitary incentives and measures to promote greater integration of different renewable energy technologies in the market and the network.
- Renewable thermal plants – around EUR 15 billion to EUR 20 billion in investments are expected up to 2020:

> For small plants the ‘thermal account’ mechanism will be used as it grants access to the incentive scheme with additional rewards for the most efficient technologies and assigns incentives to hedge a percentage of the initial investment costs.

> For bigger plants, the support mechanism will still be White Certificates.

> For the transport sector, the development of biofuels produced in a more sustainable manner is prioritised. It is mandatory to produce a certain amount of biofuels using renewable sources.

4. Diversification and development of geographical areas of supply and infrastructure of the electricity market. To promote the full integration of a free and efficient electrical market with competitive prices to also include renewable production.
5. Restructuring the refining and fuel distribution network. Modernisation of the network with the goal of reaching a more competitive and technologically advanced system.
6. Sustainable production of national hydrocarbons. Environmental and safety rules in line with the most advanced international standards to use reserves of gas and oil in the safest manner.
7. Modernisation of the system of governance. Ensuring that the decision-making system is more effective and efficient will facilitate the attainment of all the objectives.

This approach suggests that there are favourable conditions for the development of hydrogen and fuel cell technology. Fuel cells are characterised not only by being highly efficient, but also by the variety of fuels that can be employed. These technological improvements would extend the longevity of current energy sources and increase the security and diversification of supply sources.

Becoming a hub for the European natural gas network will be an advantage for the fuel cell industry because of the increasing availability of a fuel (natural gas) that is eminently suitable for fuel cells (especially high-temperature) and has high hydrogen content. This would also facilitate the transition from a fossil hydrocarbon infrastructure to high renewable penetration and hydrogen use, helping the country to achieve the decarbonisation goals and immediately reduce local pollution – a conspicuous problem in the large cities. The use of efficient electrochemical technology allows fuel cells to use a wide variety of fuels and to form a smart infrastructure in combination with wind, solar and other forms of intermittent energy.

Fuel cells can be used as a stationary power supply (for public buildings, hospitals, commercial centres, universities) and many smaller scale applications due to their high efficiency, which is independent of power size. Energy supply diversification and distribution will open markets for fuel cells, fuel cell components and integrated systems. This will lead to opportunities for new jobs associated with R&D, high-tech and innovation; and generate indirect jobs, representing an enormous contribution to the Italian economic system.

## 5.4 STATE AND REGIONAL POLICIES

Italy is organised into 20 regions that have concurrent legislative powers allowing them to enact interventions in the energy sectors of production, transportation and distribution. The Regions promote policies to regulate the functions of local energy agencies and to support research and innovation.

Every region has developed a Regional Energy Plan (PER) which identifies its goals. Examples of innovation at the regional level include the Sicilian PER that contains a series of actions for the use of hydrogen fuel, systems and components for distributed generation and cogeneration based on hydrogen and fuel cell technologies[2]. Some of the projects are:

- High-temperature fuel cells – this provides the possibility of using molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC) with gas turbines'.
- MCFC fuel cell system (1MW) fuelled by natural gas.
- Installation of small and micro-SOFC units for residential zones.
- Medium-sized plants (100kW to 200kW) for domestic applications.
- Average-sized applications of fuel cells.
- Applications in the tertiary sector.
- Fuel cells at low temperature and the introduction of PEM cells in the automotive field.
- Zero-emission home project.

Sardinia's PER aims to develop a programme of industrial research for the production of hydrogen from renewable energy sources to exploit the potential of cleaner fuels[3].

Puglia region has been promoting action plans to develop the scientific and technical research on hydrogen as a fuel for the future since 2005, through the approval of Regional Law number 25/12, article 10 (Promoting sustainable mobility). In 2010, a Declaration of Intent was signed between the region and the H2U Foundation for the testing and implementation of projects related to the use of hydrogen produced from renewable sources. It focuses on the construction and operation of a distribution network of hydrogen, methane-hydrogen mixtures and forms of energy relevant to existing housing stock.

In the region of Lazio, the local government has promoted research and production of smart energy and hydrogen[4], with a particular emphasis on hydrogen systems and renewable energy, including organic photovoltaic cells.

There are also other local projects aimed at the development of hydrogen technologies:

- Civitavecchia Hydrogen Pole is operating a 100kW gasifier for hydrogen production from biowaste and developing a bus fuelled by hydrogen. This is a joint venture by Synergy Lazio Region in two separate projects funded by the 7th Franework Programme, EU[5].
- In 2003, the Venice Industrial Union formed the Hydrogen Park Consortium, based in the industrial area of Porto Marghera. It aims to develop hydrogen as a fuel, demostrating its use in high density industrial and civilian applications. Hydrogen Park members include Enel, Sapio, Vega, Venezia Tecnologie, Vinyls Italia, Confindustria Venezia, Berengo and SAE Impianti e Arkema[6].
- In Lombardy, Zero Regio is a joint initiative between the Lombardy region and the region of Rhein-Main in Germany. The project will develop and demostrate hydrogen infrastructure for zero-emission passenger cars.
- Ingrid Project (High-capacity, hydrogen-based, green-energy storage solutions for grid balancing) is based in the Puglia Region. It has a budget of EUR 23.9 million, of which EUR 3.8 million comes from EU funding and is due to finish in June 2016. The objective is to produce electricity through a fuel cell system fuelled by hydrogen. It will work with a wind power system for hydrogen production through water electrolysis[7].
- Envipark, in the Piedmont region, is a project founded in 1996 by the Comune di Torino (Piemonte) with the support of the EU. It aims to promote the development of applied energy and environmental-related research. This is achieved through participation in projects such as ‘Advanced Energy’ that works on energy production and storage for hydrogen and fuel cell technologies[8].

## 5.5 MAJOR COMPANY ACTIVITIES

### 5.5.1 SOFCpower

SOFCpower is an Italian company based in Trentino that develops and manufactures high-temperature electro-ceramic devices based on SOFC technology. Its first product was the HoTbox, a prototype SOFC-based generator designed for cogeneration fuelled by natural gas. The first commercial product (Engen 2500) was designed for the residential combined heat and power (CHP) market, and there is capacity to produce 1,000 systems per year.

In January 2012, SOFCpower launched ‘Isola Cogenerativa’, the first micro CHP fuel cell plant in Italy to demonstrate the advantages of SOFC CHP. On 28 March 2014, the company opened a scaled-up production plant (2MW/year capacity) in Mezzolombardo, with a total of 60 employees capable of producing up to 100 cogeneration boilers per year.

### 5.5.2 Electro Power Systems

Founded in 2005, Electro Power Systems has headquarters and a manufacturing plant in Italy, and an assembly plant at its partners, VP Energy, in Michigan, USA. Electro Power Systems is a recognised innovator and market leader for fully integrated hydrogen-based fuel cell back-up and energy storage solutions. It has produced and installed more than 500 fuel cell power systems for use in Europe, Asia, Africa, the Middle East and North America. It has recently opened a further manufacturing facility in the USA with VP Energy and VP Energy Manufacturing, and, during 2014, expanded its operations in Australia and Africa.

### 5.5.3 Genport

Founded in 2009, Genport is the Italian spin-off of Politecnico di Milano, with headquarters in Italy and a US subsidiary at the Purdue Research Park in West Lafayette. Genport develops and manufactures portable power solutions to generate and store electrical energy. It combines polymer electrolyte membrane fuel cells (PEMFC) and lithium-ion cells that are fuelled by hydrogen to power any off-grid application.

Genport is involved in several projects in Europe, the USA, Malaysia and Australia, in the fields of agriculture, defence and telecommunications. Two important projects are PEMBeyond and Derry, both 7th Framework Programmes from the EU. PEMBeyond will develop a 5kW PEMFC system operating on crude bioethanol. Derry aims to demonstrate the operation of portable fuel cells at sub-zero temperatures and monitor and control the start-up, operation and shutdown of the portable fuel cell G300 HFC developed by Genport.

### 5.5.4 Dolomitech

Dolomitech was founded in 2010 to develop and commercialise advanced environmentally friendly propulsion systems (such as fuel cell propulsion systems).

In 2012, Dolomitech started the Idrogen Minibus project, which is a 16-seat modified bus that uses a fuel cell in combination with a Li-ion battery system. It is powered by an 80kW alternating current (AC) synchronous electric motor and a 60kW PEMFC.

## 5.6 LIST OF STAKEHOLDERS

Listed below are relevant stakeholders in the fuel cell supply chain in Italy, including companies, and their funders and partners.

### 5.6.1 Technology developers

#### SOLIDpower

**Industrial partners and investors –** ARISTON, Dantherm Power, Gruppo Dolomiti Energia, TRILLARY, ICI Caldaie, Unical, KACST, SAUDI ARAMCO, EBZ Engineering Bausch & Ziege GmbH, Swiss Hydrogen Association HYDROPOLE.

**Academic partners –** École Polytechnique Fédérale de Lausanne, Università degli Studi di Trento, Università degli Studi di Perugia, ENEA, CNR-ITAE Nicola Giordano Institute for Advanced Energy Technologies, CEA French Alternative Energies and Atomic Energy Commission, VTT Technical Research Centre of Finland, EIfER European Institute for Energy Research, IKERLAN Technological Research Centre (Centro de Investigaciones Tecnológicas), FEP Fraunhofer Institutes and Research, FZJ Research Center, Italy Cleantech Network.

### Electro Power Systems (EPS)

**Industrial partners and investors –** McPhy Energy: manufactures equipment that optimises electricity resources, is a provider of hydrogen production and storage solutions at point of consumption, VP Energy: this company works on hydrogen-based fuel cell back up and energy storage solutions, Prima Electro, Prima Industrie, 360 Capital Partners, Ersel Investment Club:

**Academic partners –** LUASA: Lucerne University, JRC-IET: The Joint Research Centre-Institute for Energy and Transport, EC, CNR-ITAE, ENEA, Institute Joseph Stefan, Slovenia, University of Turin, with renowned competence in fuel cell system development and modelling.

### Genport

**Industrial partners and investors –** Politecnico di Milano, Petrone Group.

**Academic partners –** ENEA, CNR-ITAE, Nicola Giordano Institute for Advanced Energy Technologies, CEA French Alternative Energies and Atomic Energy Commission, VTT Technical Research Centre of Finland, Italian Institute of Technology (IIT), Purdue University (Indiana), Battery Innovation Center (Indiana).

### Dolomitech

**Industrial partners –** Wide Automation, Nuvera (develops and manufactures fuel cells), Solvay (develops technologies related to the chemistry of fluorine), Techinsider, Ofira, Linde (supplies industrial gases).

**Academic partners –** CNR Itae, ENEA, Environment Park, Hydrogen Park-Veneto Innovazione.

### 5.6.2 Academic research and development

#### ENEA

Part of the Ministry of Economic Development: its fuel cells and hydrogen development activities date back to 1986[9].

#### CNR

The general entity for scientific research, governed under the Ministry of Education and Research. Its ITAE institute has always been very active in the application of fuel cells and hydrogen technologies[10].

#### Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)

The research entity operating under the Ministry of Environment, Land and Sea. It coordinates regional agencies (ARPA) in their activities enacting environmental policies. As such, it supports projects related to fuel cells and hydrogen, including the project Regio Zero.

### 5.6.3 Industry associations

- **Confindustria** – represents the manufacturing and service companies in Italy. It has demonstrated interest in hydrogen and energy efficiency. It works with the Italian Hydrogen and Fuel Cell Association (H2IT) to create the Italian Platform for hydrogen and fuel cells[11].
- **Association of Producers of Energy from Renewable sources (APER)** – is the largest Italian association of producers of energy from renewable sources[12].
- **Italcogen** – brings together manufacturers and distributors of cogeneration plants, heat recovery and fuel cells at a national level.
- **AssoRinnovabili** – represents producers of renewable electricity and renewable service providers.
- **Assolterm** – the Italian Association of Solar Thermal energy producers that make up about 80 operators (manufacturers and distributors of solar collectors and other plant components, designers, installers, research institutes, etc).
- **Fiper** – the Italian Federation of Producers of Renewable Energy, is an association that brings together the operators of district heating fuelled by woody biomass. Since 2009, it has also included producers of biogas from animal and vegetable origin.

5. **GIFI** – Italian Photovoltaic Industry Association. Established in 1999 within the ANIE Federation – Confindustria, with around 170 associated companies. The main task of this group is preparing proposals for defining the rules of PV system.

### 5.6.4 Technical and scientific associations:

- **ISES Italia** – the International Solar Energy Society promoting the use of renewable sources.
- **Kyoto Club** – a non-profit organisation of enterprises, associations and local authorities committed to achieving the Kyoto protocol.
- **Associazione Italiana degli Economisti dell'Energia (AIEE)** – brings together energy experts and operators to analyse the relevant issues from an economical perspective.

### 5.6.5 Management and administration

- Agencies:

> **Gestore Servizi Energetici (GSE)** – governed by the Ministry of Economy and Finance. It is the main body for the management, mediation, promotion and subsidisation of renewable sources and cogeneration in Italy.

- Ministries:

> Ministry of Economic development (MSE).

> Ministry for the environment, land and sea (MATTM).

> Ministry for Education and Research (MIUR).

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# 6 Hydrogen and Fuel Cells in Japan

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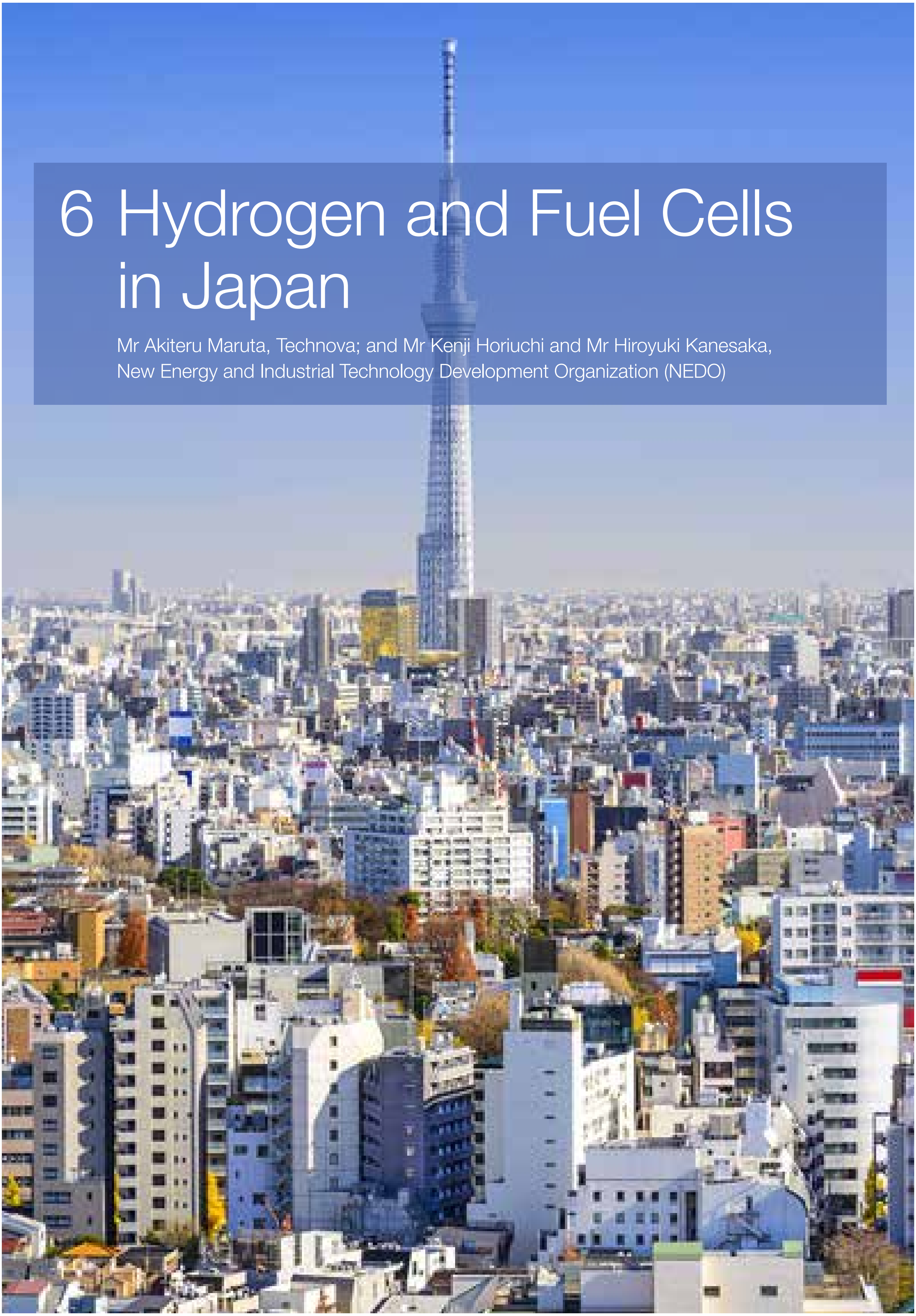


## Summary

Japanese industries and New Energy and Industrial Technology Development Organization (NEDO) have been working together to commercialise fuel cell technologies. In 2009, Japan became the world's first country to commercialise residential fuel cell systems. As of the end of March 2014, 70,000 units were installed in Japan. Vehicle manufacturers have been steadily working towards fuel cell electric vehicle (FCEV) commercialisation and 100 hydrogen stations will be installed in metropolitan areas by 2015.

**Keywords:** energy policy, stationary fuel cells, FCEV, FC buses, FC forklifts, Japan

## 6.1 INTRODUCTION

For Japan, the achievement of the 3Es (Environmental protection, Energy security, Economic growth) is the main motivation for developing innovative energy technologies. It is generally understood that fuel cell and hydrogen technologies can contribute to achieving those goals. With the Government's consistent policy support, industries can commit to long-term research, development and commercialisation activities on fuel cell technologies. Japan's New Energy and Industrial Technology Development Organization (NEDO) works closely with the industrial sector and academia to promote innovative energy technologies.

Japan became the world's first country to commercialise residential fuel cell systems, for which the common brand name 'ENE-FARM' is used by manufacturers and distributors. With dedicated research and development (R&D) efforts in the industry sector and committed support from the Government, Japan achieved the world's first commercial residential fuel cell in 2009. The total number of installed units reached 70,000 by the end of March 2014. In addition, Japanese vehicle manufacturers will start to sell mass-produced fuel cell vehicles by 2015.

Vehicle manufacturers are steadily working towards commercialisation of fuel cell electric vehicles (FCEV) and the Government of Japan has developed a new subsidy programme to install 100 hydrogen stations in metropolitan areas. NEDO and industry are carrying out R&D to develop low cost hydrogen fuel station technology.

This chapter summarises Japan's progress on fuel cell technology – from R&D through to commercialisation.

## 6.2 GENERAL ENERGY GOALS

### 6.2.1 General Goal

For Japan, the achievement of the 3Es (Environmental protection, Energy security, Economic growth) is the main motivation for developing innovative energy technologies. To realise this goal, Japan is focusing on the development of new energy technologies (that are not based on fossil fuels) and energy saving technologies. In addition, technology competitiveness is becoming more important in the global economy. Fuel cell and hydrogen technologies are generally considered to contribute to achieving this goal.

### 6.2.2 Post-Fukushima policy

Following the devastation caused by the Great Tohoku Earthquake in March 2011 and the resulting Fukushima nuclear reactor accident, disaster prevention and preparation for emergencies became a major issue in the policy domain in Japan. Fuel cell and hydrogen technologies are expected to contribute to making Japanese society more resilient in the future.

## 6.3 COUNTRY POLICIES

### 6.3.1 Policy on Fuel Cell and Hydrogen

#### Cool Earth-Innovative Energy Technology Program

In 2008, the Ministry of Economy, Trade and Industry (METI) announced the 'Cool Earth-Innovative Energy Technology Program'. 21 key technologies were identified that may contribute to the G8 agreement on halving of global emissions by 2050 (Figure 6.1). Among these 21 technologies, FCEV, residential fuel cell systems and hydrogen production/storage/transport are highlighted.

Figure 6.1: Innovative energy technologies (Source: METI, 2008)


#### The Strategic Energy Plan of Japan

The Ministry of Economy, Trade and Industry (METI) is the body responsible for developing the national Strategic Energy Plan of Japan, which is regularly updated. The 2010 version was the first to clearly indicate hydrogen and fuel cell technology as an important element for the national energy portfolio. It mentioned the promotion of stationary fuel cells and the development of hydrogen infrastructure in preparation for the launch of FCEVs in 2015.

The 2014 Strategic Energy Plan of Japan also emphasises the importance of hydrogen and fuel cell technologies.

#### Japan Revitalisation Strategy

In June 2013, the Government announced the 'Japan Revitalization Strategy', which is the major policy strategy under the Abe Administration, to help revitalise the Japanese economy. The strategy confirms the importance of the technology for stationary and FCEV.

For stationary fuel cells, the strategy sets a target for 2030 of 5.3 million units installed, which is equivalent to around 10% of all households having stationary fuel cells. For FCEV, the strategy aims to make Japan the world leader in FCEVs by reviewing regulation and supporting hydrogen infrastructure development.

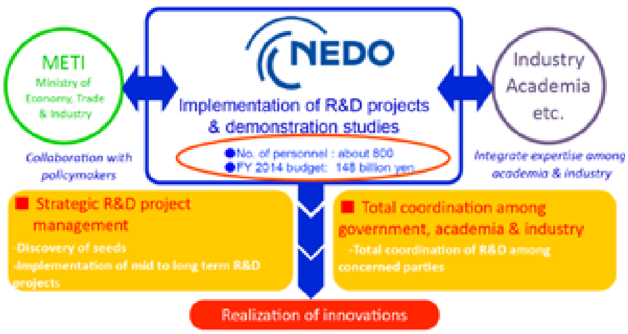
With the Government's consistent policy support, industries will have a long-term commitment to R&D and commercialisation activities on fuel cell technologies.

### 6.3.2 R&D Activities

#### NEDO

NEDO is an R&D and administrative agency under METI. It works closely works with the industry sector and academia to promote innovative energy technologies (Figure 6.2).

Figure 6.2: NEDO's roles and functions



For fuel cell and hydrogen, NEDO has been supporting technology R&D for more than 30 years, starting with phosphoric acid fuel cells (PAFC) and molten carbonate fuel cells (MCFC) (Figure 6.3). One of the remarkable success stories is the commercialisation of a residential polymer electrolyte fuel cell (PEFC) system, for which NEDO started R&D in 1992. In 2005, a large-scale demonstration in a 'real-world' testing environment took place to address system level issues. NEDO is conducting an R&D programme on PEFC and solid oxide fuel cells (SOFC) (Figure 6.4). PEFC programmes focus mainly on FCEV applications, while SOFC programmes focus on stationary applications ranging from residential systems to large-scale power generation (Figure 6.5).

Figure 6.3: Fuel cell and hydrogen technologies – from R&D to market

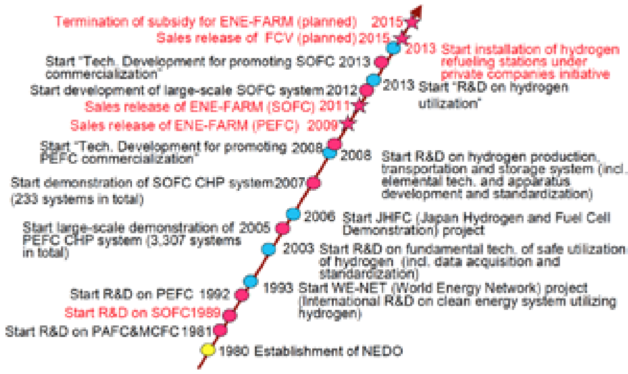



Figure 6.4: NEDO's R&D programmes on fuel cell and hydrogen technologies

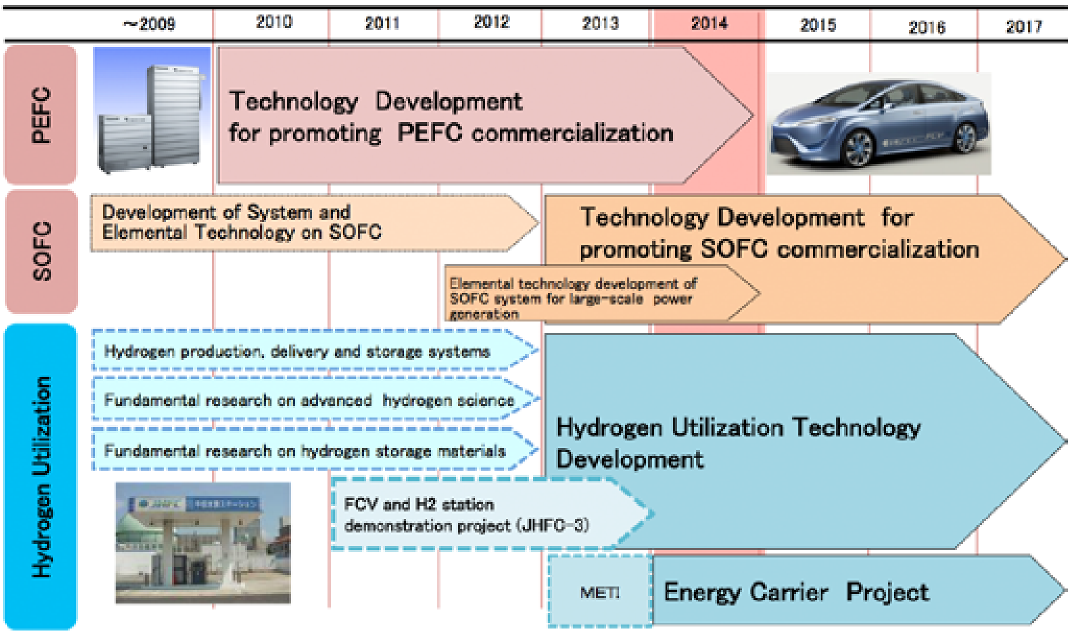


Figure 6.5: NEDO's R&D on SOFC technology

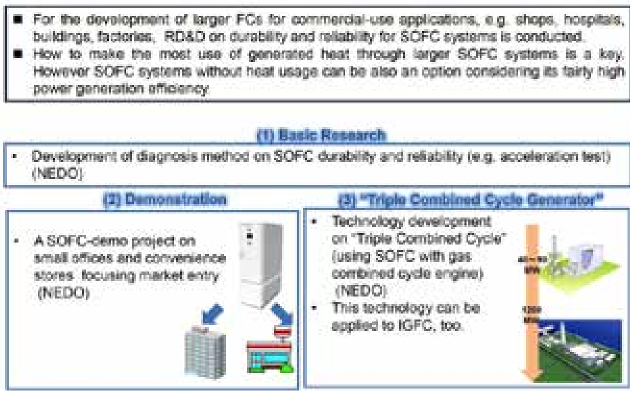



Table 6.1 shows the budgets for NEDO and METI for financial years (FY) 2013 and 2014. NEDO's budget is mainly for R&D and METI's budget is for subsidies to programmes for stationary fuel cells and hydrogen refuelling stations (HRS).

Table 6.1: NEDO's budget for FY2013 and FY 2014

Million JPY

| | | FY 2013 | FY 2014 request |
|---|---|---|---|
| R&D Activities (NEDO) | | | |
| | Development of PEFC technologies | 3,190 | 3,440 |
| | Development of SOFC technologies | 1,240 | 1,500 |
| | Hydrogen Utilization Technology Development | 2,000 | 3,850 |
| | FCV and HRS demonstration project | 750 | --- |
| | R&D for the technologies on H2 storage and H2 transport considering H2 produced by renewable energy source, etc. | 1,130 | 2,200 |
| | Promotion of safety Infrastructure on next generation hydrogen supply system | --- | 270 |
| Installation Support (METI) | | | |
| | Subsidy for HRS | 4,600 | 8,250 |
| | Subsidy for ENE-FARM | 25,050 | 22,400 |

## 6.4 STATE AND REGIONAL POLICIES

Four major metropolitan regions in Japan (Kanto Prefecture, Nagoya Prefecture, Kansai Prefecture and Fukuoka Prefecture) will be the main markets for FCEV sales. These regional governments have organised committees or research groups with industry to make FCEV introduction plans. Additionally, the Fuel Cell Commercialization Conference of Japan (FCCJ), an industry association, has been working with these regional governments to develop initial introduction plans for hydrogen fuel stations.

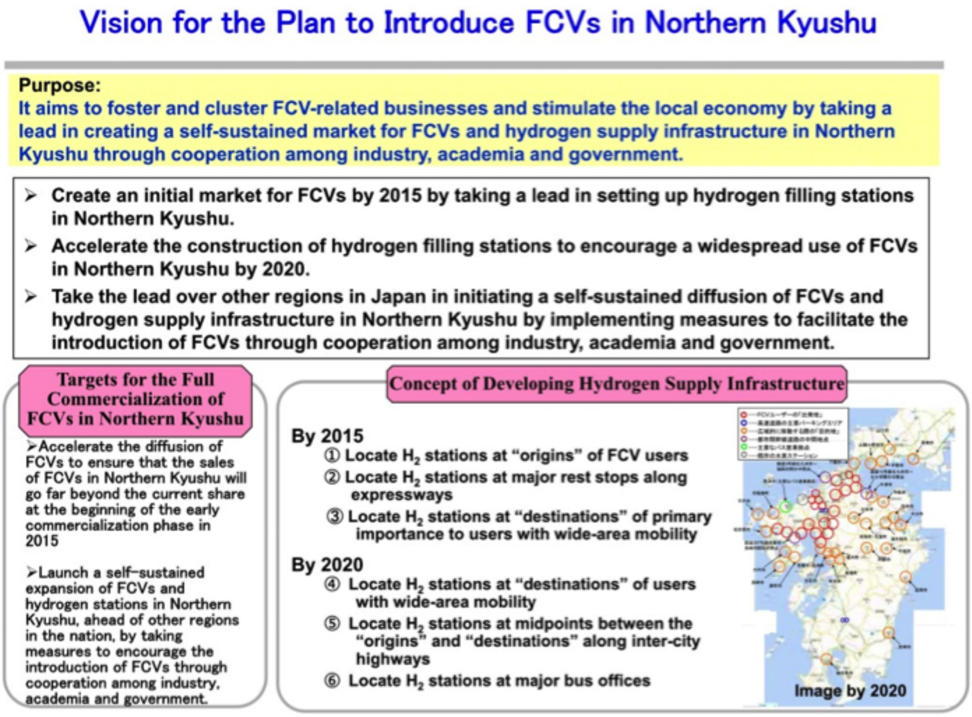
### 6.4.1 Fukuoka Prefecture

Fukuoka Prefecture is the leading region on hydrogen research and fuel cell demonstration projects. Fukuoka Prefecture's regional government established the 'Strategy Conference for Hydrogen Energy', whose main strategy is a project called 'Hy-Life', which consists of five elements (Figure 6.6). The core organisations are Kyushu University and its research centres (Hydrogenius and NEXT-FC), and HyTreC (testing centre for the use of high pressure hydrogen gas).

Fukuoka Prefecture and the neighbouring Saga Prefecture have developed an FCEV and hydrogen fuel station introduction plan for Northern Kyushu region (Figure 6.7), which is the first regional plan announced among the four metropolitan regions.

Figure 6.6: Fukuoka Prefecture's Hy-Life project

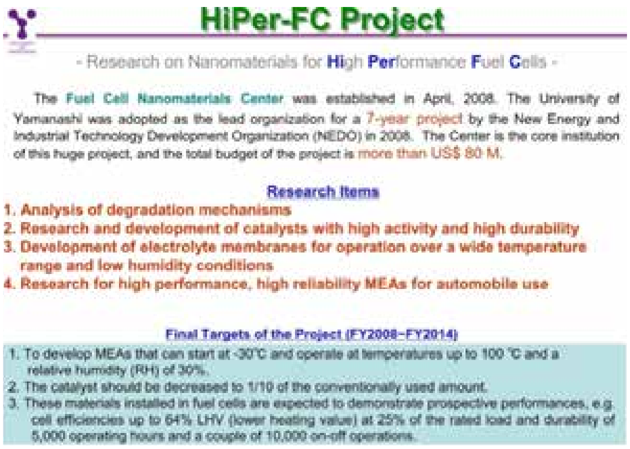

Figure 6.7: Northern Kyushu's FCEV and hydrogen station deployment plan



### 6.4.2 Yamanashi Prefecture

Yamanashi Prefecture is promoting the ‘Yamanashi Valley’ strategy, a fuel cell version of the USA’s ‘Silicon Valley’. The core organisations involved are Yamanashi University and its research centre ‘Fuel Cell Nano-materials Centre’ and HiPer-FC, a basic materials research project for high performance fuel cells (Figure 6.8).

**Figure 6.8: HiPer-FC Project**




## 6.5 MAJOR COMPANY ACTIVITIES

### 6.5.1 Stationary Fuel Cells

Japan is focusing on PEFC and SOFC technologies for residential combined heat and power (CHP) applications, mainly in the 700W to 1,000W range. In 2009, the world’s first PEFC CHP system was commercialised. Today, the common brand name ‘ENE-FARM’ is used by manufacturers and distributors of domestic CHP fuel cells. A SOFC-based residential CHP system called ‘ENE-FARM Type S’ was commercialised in 2011. As of the end of March 2014, there were 70,000 units installed across Japan.

This commercialisation is the direct product of the NEDO-led R&D and field testing, as well as METI’s subsidy programme (Table 4.2). Subsidies for fuel cells started in 2009 with a level of JPY[v] 1.4 million per unit to compensate almost half of the systems’ production cost. Since this is a ‘sunset programme’, the subsidy amount is gradually being reduced and its level in FY 2014 was JPY 0.37 to JPY 0.43 million per unit. By FY 2016, the subsidy is expected to end. At this point, the market has to be self-sustained. It is expected that the cost per unit will be JPY 0.5 to 0.6 million by 2020–2030.

**Figure 6.9: Stationary fuel cell scenario**

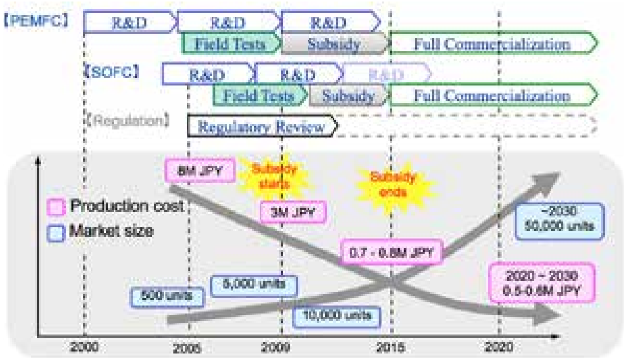


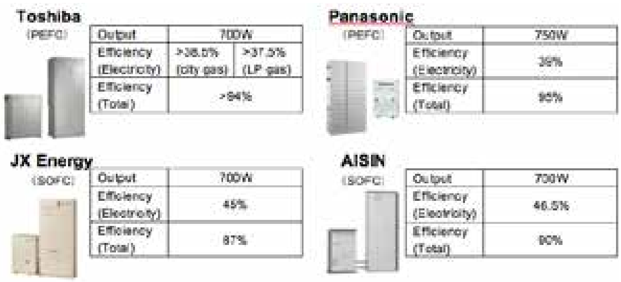

**Table 4.2: METI’s subsidy programme for residential fuel cells**

| | | FY 2009 | FY 2010 | FY 2011 | FY 2012 initial | FY 2012 1st additional | FY 2013 2nd additional | FY 2014 additional |
|---|---|---|---|---|---|---|---|---|
| Budget (Million yen) | total | 8,110 | 6,770 | 17,570 | 9,000 | 1,090 | 25,000 | 20,000 |
| | per unit | 1.40 | 1.30 | 1.05 - 0.85 | 0.70 | 0.50 | 0.45 | 0.37(PEFC) 0.43(SOFC) |
| Inst. number | | 5,030 | 4,985 | 17,995 | 12,300 | 2,177 | 50,000 (max.) | - |
| Accum. number | | 5,030 | 10,015 | 28,010 | 40,310 | 42,487 | 90,000 (max.) | - |

[v] Japanese yen

Four companies are supplying residential units in the 700W or 750W range (Figure 6.10), two of which are supplying PEFC systems while the other two are supplying SOFC systems.

Figure 6.10: ENE-FARM units in the market




For industrial applications (mainly electricity generation), SOFC systems in the range of 5kW to 1.3MW are under development as part of the NEDO programme. There is also a PAFC system with a capacity of 105kW available on the market (Table 6.2).

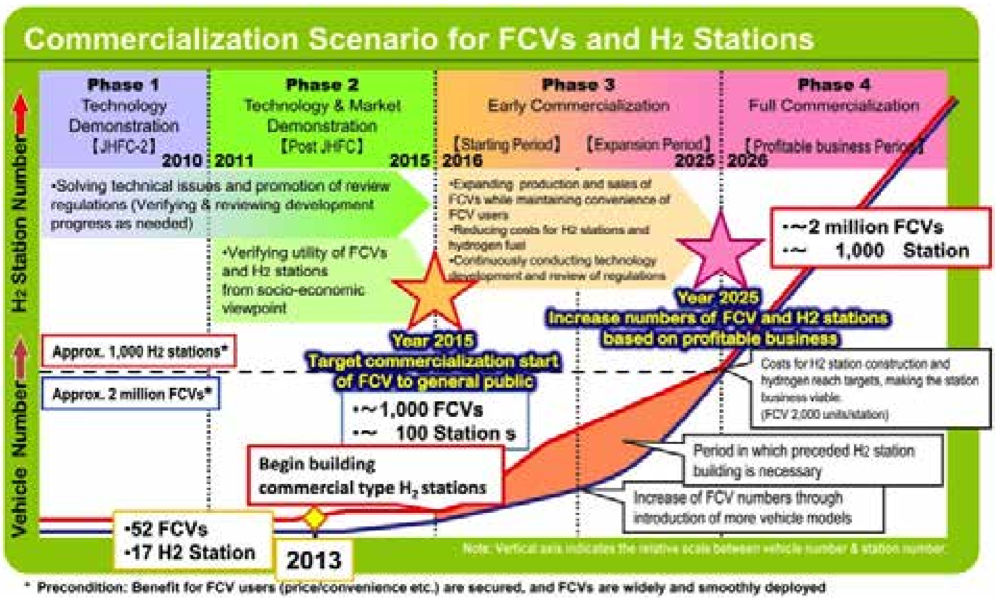
Table 6.3: Fuel cell system for industrial application

| Manufacturer | Miura | Mitsubishi Heavy Industries | | Fuji Electric |
|---|---|---|---|---|
| | FC-5 | 250kW Hybrid | 1MW Hybrid | FP-100i |
| Output (kW) | 5 | 250 | 1,350 | 105 |
| Efficiency (Electricity) | 48% | 55% | 55% | 42% |
| Efficiency (Total) | 90% | 55% | 55% | 42% |
| Size (m) | 0.7 x 1.1 x 1.8 | 12 x 3.2 x 3.2 | 24 x 5 x 3.2 | 2.2 x 5.6 x 3.4 |
| Technology | SOFC | SOFC | SOFC | PAFC |
| Commercialisation | In 2020 | In 2017 | In 2018 | In the market |

## 6.5.2 Fuel Cell Electric Vehicles

In March 2010, the FCCJ, a private-sector organisation to promote fuel cells, created a FCEV commercialisation scenario. It indicates that FCEVs are going to be commercialised from 2015 and the accumulated number of FCEV will be around 2 million by 2025 (Figure 6.11). The deployment of hydrogen fuel stations has to start prior to FCEV commercialisation and the targeted number of installed stations is around 1,000 by 2025, covering most of the cities in Japan.

Figure 6.11: FCV commercialisation scenario



In January 2011, 13 Japanese companies made a joint statement, which confirmed industry's' commitment to FCEV commercialisation in 2015 and on the development of a network of 100 hydrogen stations in major metropolitan cities.

Vehicle manufacturers are also steadily working toward commercialising FCEV. In November 2013, Toyota and Honda announced their new fuel cell concept models (Figure 6.12).

#### Figure 6.12: New design concept models

Toyota's FCV Concept    Honda's FCV Concept

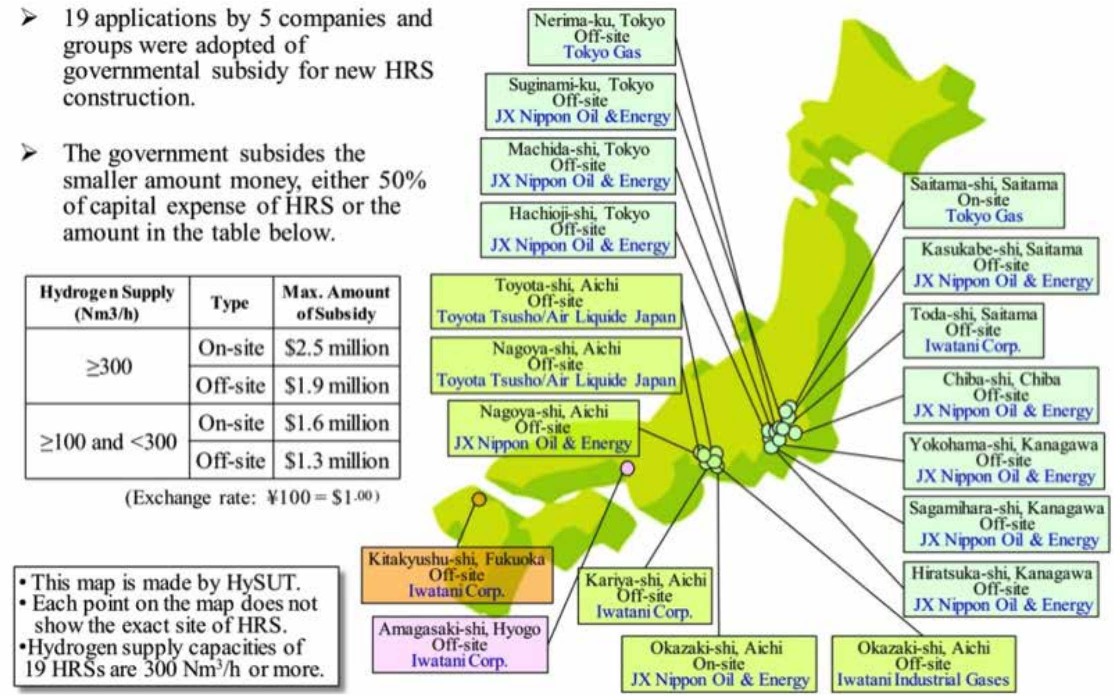
Furthermore, Japanese vehicle manufacturers are becoming the core of a global alliance for FCEV development and deployment (Figure 6.13). These alliances will offer benefits to consumers through technology development and cost reduction through volume production.

#### Figure 6.13: Global alliances for FCEV development and deployment


To support the hydrogen fuel station network development, METI developed a subsidy programme to build hydrogen fuel stations. For FY 2013, JPY 4.6 billion was allocated for this programme and 19 applications were adopted to be subsidised for hydrogen station construction (Figure 6.14). These stations are commercial-ready stations, with a hydrogen supply capacity of 300 normal $m^3$/hour, or 27kg hydrogen/hour.

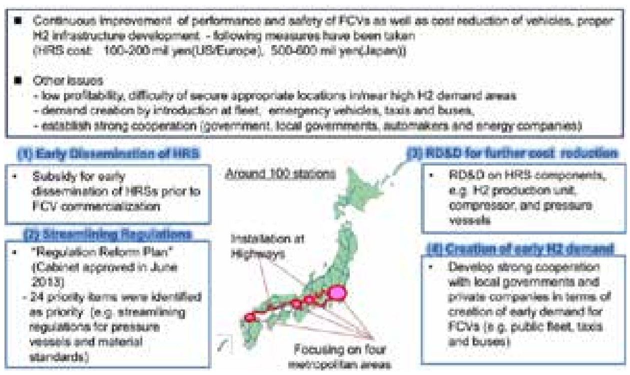
The Government is continuing this programme and the FY 2014 budget for it was JPY 7.2 billion.

Figure 6.14: 19 hydrogen stations adopted in 2013 FY subsidy programme




There are several technical and non-technical issues affecting hydrogen station deployment (Figure 6.15). One of the major issues is the cost of hydrogen stations in Japan, which is 2 to 3 times higher than similar stations in the USA and Europe. To support cost reduction, NEDO and industry are conducting R&D to develop low-cost station technology. However, the non-technical issues, such as regulation and profitability analysis, are becoming a serious difficulty for deployment. To resolve this, it is necessary that all stakeholders, including public sector and private sector work together to solve these issues.

Figure 6.15: Current issues for hydrogen station deployment



An important transportation application for fuel cells is buses. Toyota and its group company, Hino, developed several fuel cell buses in 2004 for the Aichi Expo. Some of these buses are still in operation as public transport at an airport (Figure 6.16). The current technology uses compressed hydrogen at 35MPa.

Toyota and Hino are planning to commercialise a new FC bus in 2016. This new bus will be based on Toyota's FCEV technology so that it adopts 70MPa technology.

Figure 6.16: FC bus


Since FCEV and fuel cell buses are equipped with fuel cell stacks, the electricity generating component, these vehicles can be used as a backup power supply system in case of emergency. According to Toyota, one fully fuelled fuel cell bus contains the equivalent of 455kWh of electricity compared with a fully fuelled FCEV which only has the equivalent of 120kWh of electricity. This means that, in an emergency, two fuel cell buses can be used to supply enough electricity for a typical hospital with a minimum electrical demand of 963kWh/day.

For the same purpose, Honda has started a demonstration of V2H (vehicles to home) by connecting its FCEV to the demonstration house in Kita-Kyushu Hydrogen Town (Figure 6.17). The backup power supply capability of fuel cells has clear advantages over battery electric vehicles, which usually have 24kWh of electricity when fully charged.

Figure 6.17: Honda's V2H demonstration

### 6.5.3 Other Applications

Another promising application for fuel cell technology is fuel cell forklifts, which are widely used in North America. In Japan, Toyota Industries Corporation is manufacturing a fuel cell forklift (Figure 6.18) using its fuel cell stack technology. At present, the unit is being tested at the Kita-Kyushu Hydrogen Town.

Figure 6.18: Fuel cell forklift

## 6.6 LIST OF STAKEHOLDERS

Table 6.4 to Table 6.7 indicate the major stakeholders of fuel cell and hydrogen technologies and commercialisation activities.

### Table 6.4 Governmental organisations

| Name | Description |
|---|---|
| Ministry of Economy, Trade and Industry (METI) | Ministry responsible for industrial policy and related regulations |
| Ministry of Land, Infrastructure and Transport (MLIT) | Ministry responsible for transportation policy and related regulations |
| New Energy and Industrial Technology Development Organization (NEDO) | Funding organisation on new energy-related R&D, under METI |

### Table 6.5 Industry associations

| Name | Description |
|---|---|
| Fuel Cell Commercialisation Conference of Japan (FCCJ) | Industry association to promote FC and hydrogen technologies |
| Japan Petroleum Energy Center (J-PEC) | R&D organisation for petroleum study as well as hydrogen stations |
| Japan Automotive Research Association (JARI) | R&D organisation on automotive study as well as FCEV |
| Japan Automobile Manufacturers Association (JAMA) | Industry association organised by automakers |

### Table 6.6: Research organisations

| Name | Description |
|---|---|
| Advanced industrial Science and Technology (AIST) | National institute for advanced research |
| FC-Cubic | R&D organisation formed by private companies, focusing on advanced FC technologies |
| Research Association of Hydrogen Supply/Utilisation Technology (HySUT) | R&D organisation formed by private companies, focusing on advanced FC technologies |
| Kyushu University | Focusing on hydrogen study<br>• NEXT-FC (SOFC R&D)<br>• Hydrogenius (hydrogen R&D) |
| Yamanashi University | Focusing on FC study<br>• Fuel Cell Nanomaterials Center (advanced FC R&D) |

### Table 6.7: Other organisations

| Name | Description |
|---|---|
| Hydrogen Energy System Society, Japan (HESS) | Academic organisation with wide variety of members including industries |
| FC Development Information Center (FCDIC) | Organisation to disseminate FC/ hydrogen-related information |
| Hydrogen Energy Test and Research Center (HyTreC) | Testing centre for equipment and devices used for high pressure hydrogen gas applications |

## 6.7 FURTHER READING


1. Cool Earth-Innovative Energy Technology Program http://www.meti.go.jp/english/newtopics/data/pdf/031320CoolEarth.pdf
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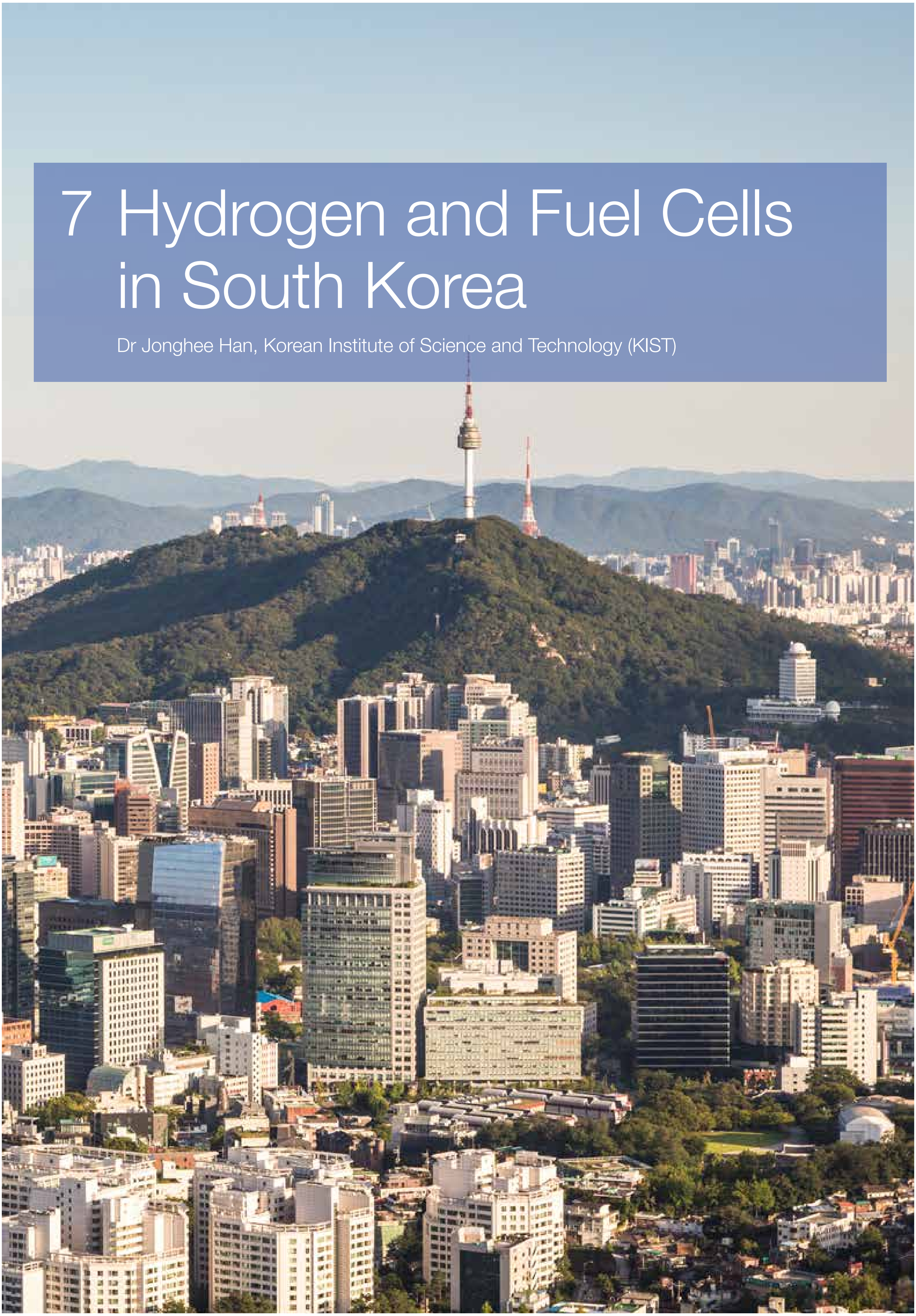
3. Japan Revitalization Strategy, 2013 http://www.kantei.go.jp/jp/singi/keizaisaisei/pdf/en_saikou_jpn_hon.pdf
4. Profile of NEDO (April 2012 - March 2013) http://www.nedo.go.jp/content/100755419.pdf
5. Fukuoka Hy-Life Project http://www.iphe.net/docs/Meetings/SC22/Workshop/IPHE%20Workshop%20Smart%20Cities%20Presentations/3_2%20Yamada_Fukuoka_Hy-life_project.pdf

# 7 Hydrogen and Fuel Cells in South Korea

Dr Jonghee Han, Korean Institute of Science and Technology (KIST)



## Summary

South Korea imports most of its energy and is a large emitter of carbon dioxide. The South Korean Government focuses on deploying new and renewable energy (NRE) to secure the energy supply and to help solve the climate change issue. In 2014, the South Korean Government announced the 4th Basic Plan for NRE Technology and Development and Usage/Distribution. This initiative was intended to promote NRE and to increase the share of NRE in total energy supply to 11% by 2035. To reach this goal, the South Korean Government is pursuing a number of policies such as subsidies and the renewable portfolio standard (RPS). These policies are creating a market for fuel cell industries and, as a result, many companies, including POSCO Energy and Hyundai Motors, are focusing their activities on fuel cell development.

**Keywords:** new and renewable energy, subsidy, renewable portfolio standard, South Korea.

## 7.1 INTRODUCTION

Due to rapid economic growth, South Korea's energy consumption has increased sharply since the 1970s. Its total primary energy consumption in 2011 was 275.7 million tonnes of oil equivalent (TOE), ranking South Korea as the 10th largest energy consuming country in the world. With poor indigenous energy resources, Korea imports 96.4% of its energy from abroad. In 2011, the cost for this imported energy was USD[i] 172 billion. In addition, South Korea's total greenhouse gas emissions (GHG) in 2013 amounted to 620 million tonnes of carbon dioxide equivalent ($CO_2e$), ranking South Korea as the 7th largest $CO_2$ emitting country in the world.

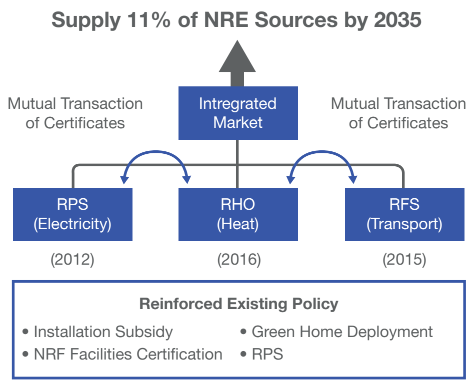
To tackle issues related to climate change and energy security, new and renewable energy (NRE) plays a very important role in South Korea.

The South Korean Government has defined 10 NRE resources including fuel cells, solar energy, wind power and biomass energy. In 2014, Korea established the 4th Basic Plan for NRE Technology and Development and Usage/Distribution. This initiative was intended to promote NRE as a key component of South Korea's future industrial development and increase the share of NRE in total energy supply to 11% by 2035. To reach this goal, the South Korean Government is pursuing a number of policies such as the Renewable Portfolio Standard (RPS), Renewable Heat Obligation (RHO) and Renewable Fuel Standards.

## 7.2 GOALS FOR NEW AND RENEWABLE ENERGY IN SOUTH KOREA

The 4th Basic Plan for NRE Technology and Development and Usage/Distribution was launched in 2014 with the aim of enabling the NRE industry to innovate and boost the South Korean economy. NRE deployment targets are set to increase the NRE proportion of the primary energy mix to 11% by 2035. The fundamental objectives of the plan are to develop market competitiveness in the industry, nurture the social acceptance of sustainable energy sources, enhance technology development for business creation and expand infrastructure to improve consumer convenience.

Figure 7.1: The goal of NRE deployment in South Korea (Source: Annual Report of KEMCO, 2013)




[i] USD is the U.S. dollar

## 7.3 NATIONAL POLICIES FOR NEW AND RENEWABLE ENERGY DEPLOYMENT IN SOUTH KOREA

### 7.3.1 General Installation Subsidy

The South Korean Government provides subsidies to accelerate NRE deployment. These aim to create the initial market for new technologies and systems developed domestically. Also, they facilitate the establishment and accelerate the deployment of infrastructure for commercialised technologies and equipment. These subsidies can be classified into two categories: demonstration project subsidies and general business subsidies.

The demonstration project subsidy has been designed to help technologies and systems to penetrate the initial market and strengthen their competitiveness through these projects. Those who wish to install NRE systems could receive subsidies of up to 80% of the installation costs through a review process.

The general business subsidy seeks to stimulate the market for NRE systems that have already been commercialised. The Government provides a subsidy of up to 50% of the installation costs for these commercialised systems.

### 7.3.2 Home Subsidy

To encourage NRE deployment, the South Korean Government has launched programmes to provide subsidies for the installation of NRE systems in the residential sector. After the successful completion of overall feasibility studies, the Home Subsidy was launched in 2004.

The basic plan for the Home Subsidy focuses on installing NRE facilities in houses and fostering the NRE industry in the long term. The Government provides support for a certain portion of the installation costs. Until 2009, the main target was houses equipped with photovoltaic (PV) technology. However, since 2010, the Home Subsidy has focused on a variety of sources, such as fuel cells, PV, solar thermal and geothermal systems.

### 7.3.3 Renewable Portfolio Standard

The RPS is a system that requires power producers to supply a certain amount of power from NRE sources.

A total of 13 companies, including the Korea Water Resources Corporation, Korea District Heating Corporation and electricity generators with a capacity of more than 500MW (NRE power plants excluded), are required to follow the RPS. Companies required to comply with the RPS must implement the scheme by installing renewable energy power plants or purchasing a Renewable Energy Certificate (REC) from renewable energy producers.

Table 7.1: Obligatory power supply rate by NRE

| Year | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|---|---|---|
| Target (%) | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 |

### 7.3.4 Others

In addition to subsidies and RPS, the South Korean Government is pursuing various policies to promote NRE deployment. These policies include mandatory use for public buildings, 1 million green homes programme and 'H-Town'. The mandatory use for public buildings policy forced new, renovated and expanded public buildings larger than 1,000 square metres to use NRE for more than 5% of their total energy load. In the 1 million green homes programme, which aims to disseminate 1 million green homes by 2020, the Government provides subsides to install fuel cell systems and PV for private residential homes, multi-family homes and public rental homes. The Government also carries out the 'H-Town' project, building a town that uses hydrogen fuel cells for electricity, heating and transportation. In this project, hydrogen produced from biogas and by-product hydrogen generated in liquefied natural gas (LNG) reforming, sewage treatment systems, livestock farms and power plants, is used for hydrogen fuel cells. The first pilot projects of 'H-Town' were conducted in Ulsan, and will be rolled out across other cities in South Korea.

## 7.4 MAJOR COMPANY ACTIVITIES

### 7.4.1 POSCO Energy

POSCO Energy started to develop molten carbonate fuel cells (MCFC) during the early 2000s and, in collaboration with KEPCO, developed a 125kW external reforming-type MCFC system in 2010. Additionally, since 2007, POSCO Energy has had a strategic license agreement with FuelCell Energy in the USA to manufacture and distribute MCFC. POSCO Energy now produces MCFC systems at its manufacturing facility in Pohang. Its annual production capacity is 50MW. Up to the time of writing, POSCO Energy has provided more than 113MW of MCFC systems to Gyeonggi, Geonra, Gyeongsang and Chungchung provinces including the world's largest fuel cell power plant of 59MW in Hwaseong which provides electrical power and district heating to the city. POSCO Energy is aiming to expand its market to other areas such as Japan and Southeast Asia based on the experience and technology obtained from the domestic market.

Figure 7.2: The world's largest MCFC power plant located in Hwaseong City (Source: POSCO Energy)

### 7.4.2 Hyundai Motor Company

Hyundai Motor Company started developing fuel cells for the automotive sector in 1998. The company has successfully developed a proprietary world-class stack and a hydrogen fuel cell engine that performed comparably with internal combustion engines. In 2013, after creating modules for critical components and developing low-cost materials, Hyundai Motor Company succeeded in producing the ix35 Fuel Cell vehicle – the world's first mass produced hydrogen fuel cell vehicle. This vehicle was showcased in Europe from 2012 and was chosen to participate in a European Union pilot project in March 2013. It will be sold in the USA and South Korea from 2014 with the aim of introducing customers to the world of hydrogen fuel cell vehicles.

Figure 7.3: Hyundai's ix35 fuel cell vehicle
(Source: Hyundai Motors)


### 7.4.3 Others

Several other companies are developing and selling fuel cell systems in South Korea. These include Doosan and LG. Also, many companies such as Kolon, Dongjin, Hanwha, and AutoEn are developing and selling materials and components for fuel cell systems.

## 7.5 FURTHER READING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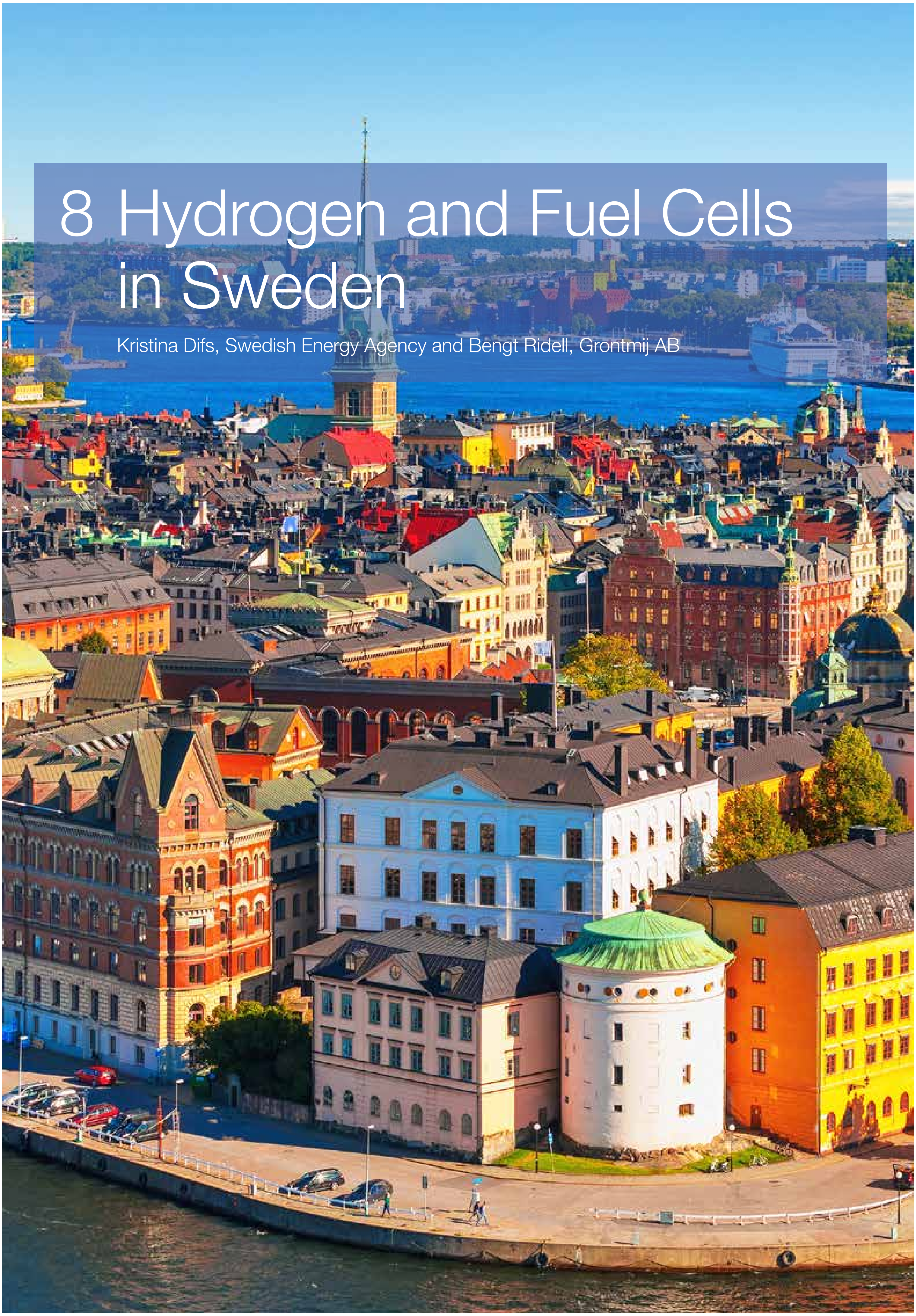
2. Overview of New and Renewable Energy, Korea Energy Management Corporation. (www.energy.or.kr)
3. Annual Report 2013, Korea Energy Management Corporation (www.energy.or.kr).
4. http://www.investkorea.org

# 8 Hydrogen and Fuel Cells in Sweden

Kristina Difs, Swedish Energy Agency and Bengt Ridell, Grontmij AB



## Summary

Sweden has set ambitious energy goals to combat climate change, increase energy security and strengthen competitiveness. The production of electricity and heat is, to a large extent, free from fossil fuels and greenhouse gas (GHG) emissions. The major potential for Sweden to reduce GHG emissions on a national scale is in the transport sector. As a step towards zero net GHG emissions by 2050, a target has been set for the vehicle fleet to be independent of fossil fuels by 2030. To reach these goals, research and development into clean energy technologies must be prioritised. Fuel cells have the potential to make a contribution to these targets. Sweden has well-established automotive companies and these companies have started a technology change from conventional drive system with combustion engines towards electrification of the drivetrain. For example, there is ongoing research and demonstration into using fuel cells for auxiliary power units (APU) in heavy trucks and range extenders for battery electric vehicles. There are a number of Government-funded research and demonstration programmes where research is conducted on hydrogen and fuel cells. Annually, the Government spends around EUR[v1] 2 million on fuel cell and hydrogen projects in Sweden.

There are no national strategies and roadmaps for technological development in hydrogen and fuel cells. However, national stakeholders have been developing a plan for hydrogen infrastructure development in Sweden for 2014-2020 in the EU-financed project Hydrogen Infrastructure for Transport, National Implementation Plan Sweden (HIT NIP-SE)[1].



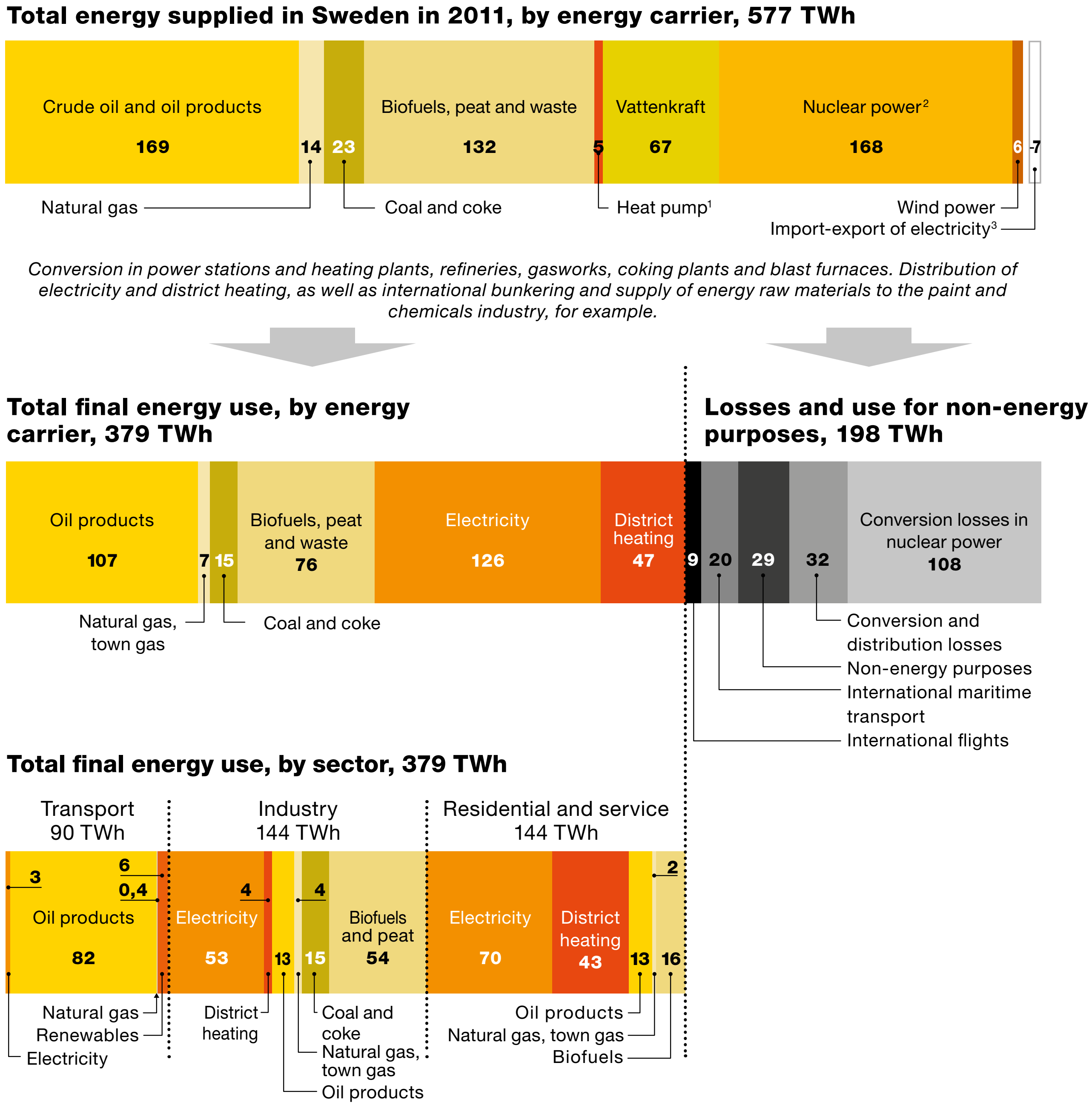
**Keywords:** renewable energy, sustainable energy system, transport sector, fuel cell, hydrogen, Sweden


## 8.1 INTRODUCTION

The Swedish energy system is characterised by a high share of renewable energy. Electricity is mainly supplied from hydropower and nuclear power, which makes the electricity supply almost carbon-free. Hydropower also has the advantage that it can be used as regulation power, which reduces the need for gas power plants as regulation power. See Figure 8.1 for the total energy supply and final use in Sweden in 2011.

[vi] European euro

Figure 8.1: Total energy supply and final use in Sweden in 2011[2]



Due to the high share of hydropower and nuclear power, electricity prices have been relatively low in Sweden compared to those in other European countries. This has resulted in a high share of electrical heating in the residential and service sectors. Additionally, district heating is one of the most common heating options for the residential and service sectors[2].

Considering that electricity prices are relatively low, the lack of gas distribution network in large parts of Sweden and the high share of electrical and district heating, the number of stationary fuel cells connected to the main power grid is low in the Swedish energy sector.

The most interesting possible future applications for stationary fuel cells in Sweden are as backup power or remote power as a replacement for lead-acid battery systems. Fuel cells for backup power have been tested by the telecommunications industry and for high-voltage switches in the main power grid. An interesting use of backup power is in data centres, a fast growing industry in Sweden, which have a high energy demand.

Another possible use of stationary fuel cells in Sweden is in connection with biogas production. Using anaerobic digestion to produce biogas at wastewater treatment plants and with agriculture waste is a growing and promising industry in Sweden. The main use of upgraded biogas today is as transport fuel, but this market is not yet mature and does not yet have a long-term framework regarding taxation and subsidies – and that makes the future uncertain. Fuel cells can be an efficient way to use biogas to produce electricity and heat.

Fuel cells could also be an interesting option for the transport sector. Sweden has well-established automotive companies in the form of Volvo Group, Scania CV AB and Volvo Car Corporation. Driven by the EU emission reduction targets for new vehicles, these companies have started a technology change from conventional drive systems with combustion engines towards electrification of the drivetrain. There is ongoing research and demonstration into using fuel cells for auxiliary power units (APU) in heavy trucks and as range extenders. These activities are mostly performed by universities and automotive suppliers.

## 8.2 GENERAL ENERGY GOALS

In 2009, Sweden adopted new energy goals under the ‘integrated climate and energy policy’ framework[3]. The overall energy goals aim to combat climate change, increase the energy security and strengthen the competitiveness of Sweden. By 2020, Sweden shall have:

- A share of at least 50% renewable energy in gross final consumption and 10% renewable energy in the transport sector.
- 20 % more efficient use of energy.
- A reduction of GHG emissions by 40%.

The base year for these targets is 2008. As a step towards achieving zero net greenhouse gas (GHG) emissions by 2050, a target has been set to achieve a vehicle fleet that is independent of fossil fuels by 2030.

## 8.3 COUNTRY POLICIES

Sweden has no national roadmap for hydrogen and fuel cells, but a number of Government-funded research and demonstration programmes exist to help achieve the national energy goals. For hydrogen production, the Energy Gas Technology programme includes research and demonstration of production, distribution and storage of energy gases such as methane, hydrogen and dimethyl ether (DME). As part of the Materials Technology for Thermal Energy Processes programme, research in the area of materials technology is being undertaken to enable renewable fuels (biogas, liquid biofuels and hydrogen) to be used efficiently for heat and electricity production. Research is also being carried out on hydrogen production from photosynthesising bacteria and artificial photosynthesis.

There is one main research programme relating to fuel cells – FFI (Fordonstrategisk Forskning och Innovation – Strategic Vehicle Research and Innovation). FFI is a major partnership between the Swedish Government and the automotive industry, which includes joint funding of research, innovation and development. FFI concentrates on climate, environment and safety issues in the industry. The FFI roadmap for 2025 includes developing electric vehicles that can travel longer distances – some of these vehicles are equipped with fuel cells. In a Competence Centre (collaboration between national industry and universities), research in the field of high-temperature corrosion is being performed. In this Centre, research aims to develop new materials and processes for more efficient energy conversion technologies such as fuel cells.

Overall, the Government spends around EUR 2 million a year on fuel cell and hydrogen projects in Sweden.

### 8.3.1 Transport policy

Sweden has an ambitious target of having a vehicle fleet that, by 2030, is independent of fossil fuels. In 2012, renewable energy accounted for 12.6% of the transport sector's energy use. This comprised 65% biodiesel, 25% ethanol and 10% biogas[4]. In 2012, the Government commissioned research to explore alternative courses of action and identify measures to reduce the GHG emissions from the transportation sector and its dependence on fossil fuels. One of the conclusions from the research is that there are uncertainties as to how fast the development of different types of electric and fuel cells vehicles will be. Therefore, the authors recommended that the Swedish Government review the incentives and needs for investments in different types of infrastructure on a regular basis[5].

The market and technology development of hydrogen-fuelled fuel cell vehicles is not yet a major priority among the vehicle manufacturers in Sweden. Different alternatives for a hydrogen infrastructure suitable for use in Sweden are studied mainly through different EU projects.

## 8.4 STATE AND REGIONAL POLICIES

Sweden is divided into 21 regions and 290 municipalities. Generally speaking, Sweden does not have regional policies that specifically target fuel cells. However, some regions support various initiatives in relation to hydrogen and fuel cells. For example, four regions in Sweden (Skåne, Halland, Västra Götaland and Värmland) are members of the European Association for Hydrogen and fuel cells and Electro-mobility in European Regions (HyER). The aim of HyER is the development of electric transportation – battery electric vehicles and fuel cell electric vehicles (FCEV). HyER represents over 30 regions and cities in Europe.

The H2Skåne network is another initiative which aims to increase the growth of environmental technology in the Skåne region. It has been supported by the European Regional Development Fund to focus on the cooperation between regional actors dealing with hydrogen. The region of Skåne is also participating in the EU-funded project Next Move. This project facilitates cross-border cooperation to meet strategic challenges like purchasing and service for the regions and municipalities that want to become early users of emission-free vehicles. The Next Move project brings early users together to build up knowledge and experience about fuel cell vehicles.

## 8.5 MAJOR COMPANY ACTIVITIES

### 8.5.1 Sweco

Sweco has managed the HIT NIP SE project[1], which is a part of the EU Trans-European Transport Network (TEN-T) HIT project. The Swedish part is funded by the Innovation and Networks Executive Agency (INEA). The purpose of the project is to develop an evidence-based knowledge base for hydrogen as a vehicle fuel, and to propose a plan for infrastructure development in Sweden between 2014 and 2020. The HIT NIP-SE project is led by Hydrogen Sweden and involves 25 other organisations. Sweco will manage the Swedish part of the new project 'HIT-2' where hydrogen fuel stations will be established in Stockholm and Gothenburg in 2015.

### 8.5.2 PowerCell AB

PowerCell is a developer and manufacturer of polymer electrolyte fuel cells (PEFC), diesel reformers and fuel cells systems. It delivers single stacks and complete power packs fuelled by hydrogen or other fuels.

### 8.5.3 myFC

myFC is a manufacturer and developer of commercial portable fuel cells. The main product, Powertrekk, is suitable for mobile phones and laptops, and it is available on the market.

### 8.5.4 Impact Coatings AB

Impact Coatings supplies physical vapour deposition (PVD) equipment to the component manufacturing industry for industrial surface treatment. The company has developed a special surface protection suitable for metallic bipolar plates. Impact Coating has received a substantial contract from the fuel cell vehicles industry.

### 8.5.5 Sandvik Materials Technology

Sandvik Materials Technology is a developer and producer of special metals. One of its products that is suitable for use in fuel cells is a pre-coated strip steel for the production of bipolar plates and interconnectors for different types of fuel cells (such as PEFC and solid oxide fuel cells (SOFC)).

### 8.5.6 Hydrogen Sweden (Vätgas Sverige)

Hydrogen Sweden is a public private partnership with members and financiers from industry and non-governmental organisations (NGOs); and local, regional and national government.

## 8.6 LIST OF STAKEHOLDERS

Below is a selected list of stakeholders in the fuel cell area in Sweden:

- **Hydrogen Sweden –** a non-profit public/private partnership among business, government and academia to promote the use of hydrogen.
- **PowerCell AB –** Developer and manufacture of PEFC fuel cells reformers and fuel cells systems.
- **myFC AB –** developer and manufacturer of commercial portable fuel cells.
- **Cellkraft AB –** developer of robust fuel PEFC fuel cells.
- **Impact Coatings AB –** coating of metallic bipolar plates.
- **Sandvik MT AB –** metallic bipolar plates and interconnectors.
- **Höganäs AB –** the world's largest manufacturer of metal powders. Developer of interconnector material for SOFC.
- **Catator –** developer of catalytic process design including fuel cells systems.
- **Sweco –** consultant hydrogen infrastructure, market and technology issues.
- **ÅF –** consultant in fuel cells and hydrogen infrastructure, market and technology issues.
- **SP –** technical research institute.
- **Metacon –** developer and manufacturer of small-scale methane reformers.
- **The Swedish Gas Association –** a member-funded, industry association dedicated to promoting a greater use of energy gases.
- **Air Liquide –** managing the production and distribution of hydrogen as well as the production of power via fuel cells.
- **SHC –** the Swedish Hybrid Vehicle Centre.
- **KTH –** The Royal Institute of Technology in Stockholm research in PEFC and MCFC cells and stacks and also MCFC electrolysers.
- **LTH –** Lund institute of Technology at the University of Lund, research on SOFC cells and stacks and fluid mechanics.
- **CTH –** Chalmers Institute of technology, research into materials for fuel cells (SOFC and PEFC).
- **Region Skåne and the City of Malmö –** owner of three fuel cell vehicles and one hydrogen filling station.
- **Grontmij –** consultant specialist in fuel cells, hydrogen systems, and market and technology issues.
- **Swedish Energy Agency –** a Government agency for national energy policy issues. The Swedish Energy Agency works for the use of renewable energy, improved technologies, a smarter end-use of energy and mitigation of climate change.

## 8.7 REFERENCES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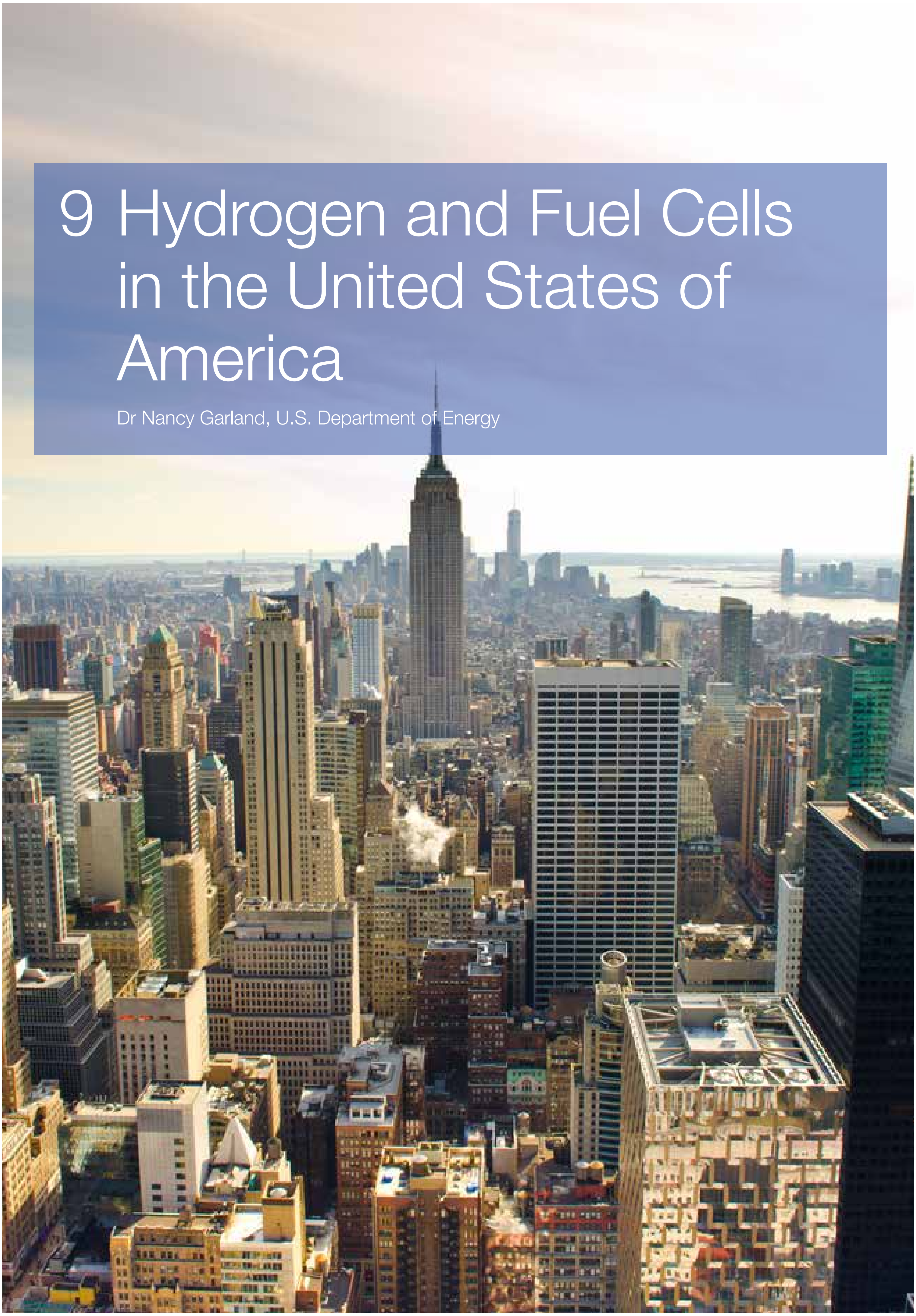
## 8.8 FURTHER READING

Compiled documentation from the Swedish Fuel Programme research, technology status reports, etc (Swedish and some in English) – http://www.elforsk.se/Programomraden/El--Varme/Bransleceller

Information about activities and projects in Sweden regarding hydrogen as an energy carrier compiled by Hydrogen Sweden – http://www.vatgas.se/in-english

# 9 Hydrogen and Fuel Cells in the United States of America

Dr Nancy Garland, U.S. Department of Energy



## Summary

This chapter provides an overview of national and state strategies to introduce hydrogen and fuel cell technologies to stakeholders in the United States. As in other countries around the world, efforts to introduce clean and efficient hydrogen and fuel cell technologies in the United States are driven by legislation and by national, state, and regional policies. In 2014, sales of hydrogen and fuel cell systems increased, and major vehicle manufacturers started to lease fuel cell vehicles to the public and made plans to sell fuel cell vehicles commercially in 2015. Driving the efforts leading to the commercial introduction of these technologies, the U.S. Department of Energy (DOE) supports hydrogen and fuel cell technology research and development, demonstration and deployment. A list of DOE's stakeholders is included in this document.

**Keywords:** hydrogen, fuel cell vehicles, U.S.

## 9.1 INTRODUCTION

The U.S. Department of Energy’s DOE's goals for hydrogen and fuel cells are driven by the following legislation:

- Energy Policy Act of 2005 (EPAct 2005), Public Law 109-58, Section 801 et seq.
- Energy Independence and Security Act (EISA) of 2007, Public Law 110-140.

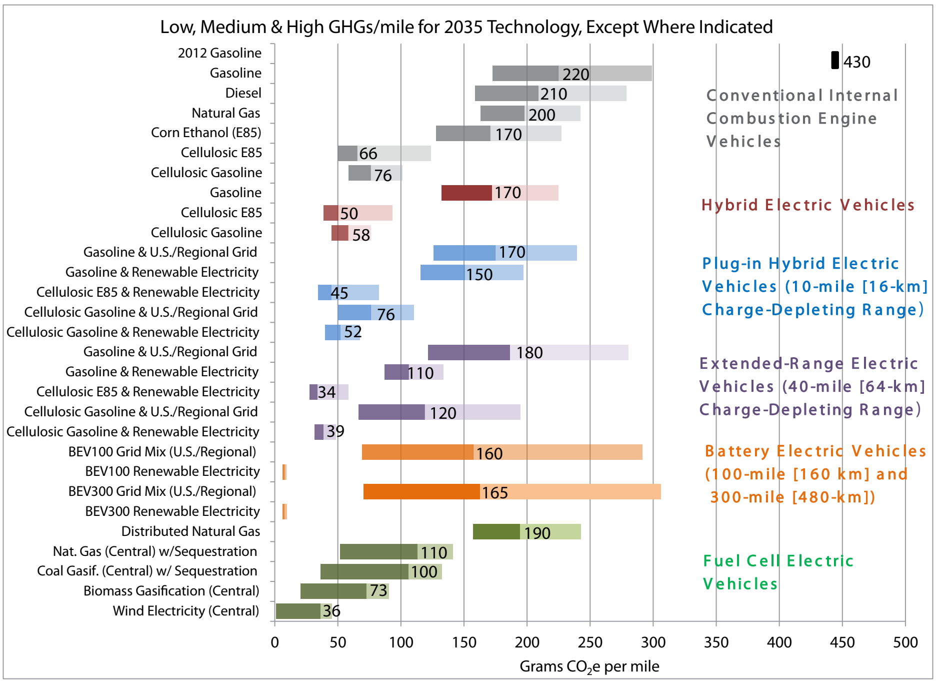
Section 805. Activities, of EPAct 2005 states ‘The Secretary of Energy, in partnership with the private sector, shall conduct programs to address … 6) Development of safe, durable, affordable, and efficient fuel cells, including fuel-flexible fuel cell power systems, improved manufacturing processes, high-temperature membranes, cost-effective fuel processing for natural gas, fuel cell stack and system reliability, low temperature operation, and cold start capability.’

Section 805, Program Goals, of EPAct 2005 states ‘3) FUEL CELLS – The goals for fuel cells and their portable, stationary and transportation applications are to enable:

- Safe, economical and environmentally sound hydrogen fuel cells.
- Fuel cells for light duty and other vehicles.
- Other technologies consistent with the Department’s plan[1].’

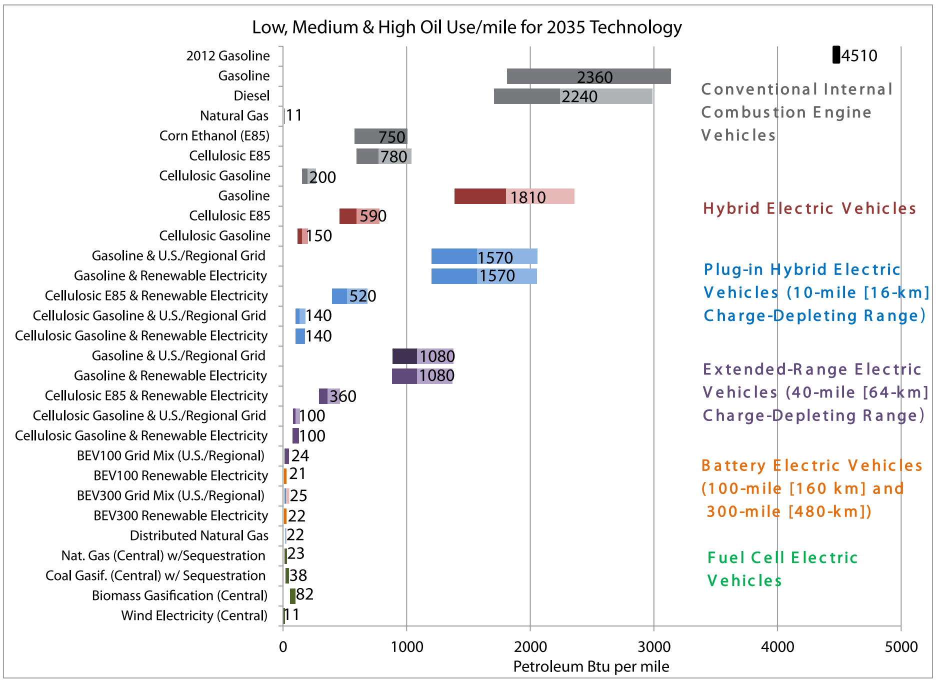
The mission of the DOE’s Fuel Cell Technologies Office is to enable the widespread commercialisation of a portfolio of hydrogen and fuel cell technologies through basic and applied research, technology development and demonstration, and diverse efforts to overcome institutional and market challenges[1]. Fuel cells provide clean, efficient power to the commercial, residential, industrial and transportation sectors. Fuel cells can be used in a wide range of applications including prime and backup power, lift trucks, combined heat and power (CHP) systems, and light-duty vehicles. Additionally, fuel cells can be powered by diverse fuels. Well-to-wheels studies of greenhouse gas (GHG) emissions and petroleum use for light-duty vehicles with various fuels are illustrated in Figure 9.1 and Figure 9.2 respectively. The benefits provided by fuel cells can be seen in the figures.

## Figure 9.1: Well-to-wheels greenhouse gases emissions for 2035, mid-size car




(Source: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf)

## Figure 9.2: Well-to-wheels petroleum energy use for 2035, mid-size car




(Source: http://www.hydrogen.energy.gov/pdfs/13005_well_to_wheels_ghg_oil_ldvs.pdf#page=4)

## 9.2 GENERAL ENERGY GOALS

The United States generates over 6 billion metric tonnes of carbon emissions annually[2]. In 2009, President Obama pledged that, by 2020, the United States would reduce its GHG emissions by around 17% compared with 2005 levels if other major countries agreed to limit their emissions as well[3]. In 2011, President Obama set a goal to reduce oil imports by a third by 2020[4]. In 2012, he further raised the goal to reduce imports by half by 2020. To achieve this goal, the United States must:

- Increase domestic production of oil.
- Develop substitutes for oil (for example, by almost doubling the production of biofuels since 2007).
- Improve energy efficiency to reduce the use of oil.

In 2012, the Obama Administration increased the fuel economy standards for light-duty vehicles to 54.5 miles per gallon (19.3 km/litre) by 2025, which will reduce carbon emissions by 6 billion tonnes. Efficiency standards for appliances and federal buildings, set between 2008 and 2013, will reduce carbon emissions by approximately 3 billion tonnes cumulatively by 2030. DOE's Better Buildings Challenge focuses on improving the energy efficiency of commercial and industrial buildings by at least 20% by 2020[5].

## 9.3 COUNTRY POLICIES

The Emergency Economic Stabilization Act, authorised by Congress in 2008, includes tax incentives to reduce the cost of fuel cell systems. Applicants could receive an investment tax credit of 30% for qualified fuel cell property or USD [vii] 3,000/kW of the fuel cell nameplate capacity (that is, rated power), whichever is less. The equipment must be installed by 31 December 2016. The Act also includes a credit of 10% for CHP systems[6].

## 9.4 STATE AND REGIONAL POLICIES

States offer financial incentives for fuel cell installations as well. The State of California has a Self-Generation Incentive Program. Under this, applicants who install CHP/Co-generation systems will receive a state rebate, which for fuel cells (CHP or electric only) is USD 1.83/W. The incentive payment is capped at 3MW[7]. California continues to lead the United States with policies and funding programmes that advance fuel cells and hydrogen infrastructure. In February 2013, California issued the 2013 Zero Emission Vehicles (ZEV) Action Plan that includes actions for state agencies to meet a goal of 1.5 million ZEV by 2025. In September 2013, the Governor of California signed Assembly Bill 8 (AB8) into law[8]. AB8 provides funding for at least 100 hydrogen stations with a commitment of USD 20 million per year. In May 2014, the California Energy Commission approved almost USD 50 million to add 28 new hydrogen refuelling stations to the nine existing stations and 17 stations under development[9]. The companies receiving funding include Air Liquide, First Element, HyGen, IGT, ITM, Linde, Hydrogen Technology & Energy Corporation and Ontario CNG Station Inc.

The governors of California, Connecticut, Massachusetts, Maryland, New York, Oregon, Rhode Island and Vermont signed a Memorandum of Understanding to coordinate efforts to support their ZEV programmes that support battery and fuel cell electric vehicles. The states agreed to a target of at least 3.3 million ZEV collectively in their states by 2025. The states also agreed to cooperate in the development of a hydrogen refuelling infrastructure[10].

Several states, including Connecticut and Ohio, have initiated efforts to develop hydrogen and fuel cell supply chains. The Connecticut Hydrogen and Fuel Cell Deployment Plan, published in 2012, states that, ‘potentially 938,000MWh of electricity could be generated each year through the development of between 119MW

[vii] USD is the U.S. dollar

and 158MW of fuel cell generating capacity, and there are approximately 600 companies in the state that are involved in the hydrogen and fuel cell supply chain'.
These companies are estimated to have generated circa USD 500 million in revenue and investment, more than USD 20 million in state and local tax revenue, and over USD 260 million in gross state product. Eight of these companies are original equipment manufacturers (OEM) of hydrogen and/or fuel cell systems and responsible for creating 1,074 direct jobs and generating USD 254 million in direct revenue and investment in 2010. Connecticut is developing its supply chain and the Connecticut Center for Advanced Technology (CCAT) has published an online, searchable database of hydrogen and fuel cell companies[11] for the North East Electrochemical Energy Cluster (Connecticut, New York, New Jersey, and Maine). CCAT helps companies access local supply chains and helps suppliers meet their needs, including 'speed-dating' events, during which hydrogen and fuel cell OEM and suppliers meet face to face briefly to network and increase the number of contacts[12].

Ohio is served by the Ohio Fuel Cell Coalition (OFCC) that works to strengthen Ohio's fuel cell industry and to transform the region into a global leader in fuel cell technology. The OFCC works to:

- Integrate the fuel cell infrastructure with supply chains.
- Inform the public of the benefits of fuel cells as clean and efficient energy conversion devices.
- Strengthen partnerships and increase economic opportunities in Ohio.

The OFCC has an online searchable map that illustrates Ohio's supply chain and it has held supply chain networking events at conferences[13].

## 9.5 MAJOR COMPANY ACTIVITIES

In 2014, Hyundai began leasing fuel cell vehicles in Los Angeles. Customers only have to pay a securing deposit of USD 2,999 and then pay USD 299/month for the lease, which includes fuel and maintenance. The revenue from FuelCell Energy, Inc. (a global power company that develops and operates fuel cell power systems) grew by USD 67 million, reaching almost USD 190 million during the 2013 financial year (year ending October 31). Product sales, service agreements and licence revenues increased by USD 60 million to over USD 170 million, primarily due to a Bridgeport (Connecticut) fuel cell park project of approximately USD 55 million, licence and royalty income of USD 4 million and service revenue related to a new agreement with POSCO Energy (South Korea). Plug Power's revenue grew by USD 0.5 million to more than USD 26 million, with approximately USD 25 million in product and service revenue and USD 1.5 million in R&D funding. In 2013, three customers (Mercedes-Benz, Procter & Gamble and Lowe's) supplied one-third of Plug Power's total revenue[14].

## 9.6 LIST OF STAKEHOLDERS

**A**ddison Bain, Advanced Technology International, Air Products and Chemicals, Inc., Altergy Systems, Ameresco, Inc., AOC, LLC, Applied Nanotech, Inc., Argonne National Laboratory, Arizona State University, Arkema Inc, Automotive Fuel Cell Cooperation,

**B**allard Fuel Cells, Battelle, Becht Engineering, Ben C. Gerwick Inc., Bio2Electric, LLC, Black & Veatch Corporation, Boeing Research and Technology, Brookhaven National Laboratory, Brown University, Bucknell University, Burns & McDonnell Engineering Co., Inc.,

**C**alifornia Air Resources Board, California Fuel Cell Partnership, California Institute of Technology, California State University, Los Angeles, Carnegie Mellon University, Case Western Reserve University, CellEra, Inc., Center for Transportation and the Environment, Ceramatec, Inc., City of Santa Fe Springs, Clemson University, Colorado School of Mines, Columbia University, Compressed Gas Association, Composite Technology Development, Inc., Concepts NREC,

**D**alhousie University, Davidson Code Concepts, Delaware State University, Delphi Automotive Systems, LLC, Dynalene Inc.,

**E**aton Corporation, Electricore, Inc., Electrosynthesis Co. Inc., Engineering, Procurement & Construction, Entegris, Inc., Ericsson Services, Inc.,

**F**edEx Express, Firexplo, Fluer, Inc. Ford Motor Company, Fuel Cell and Hydrogen Energy Association, FuelCell Energy, Inc.,

**G**as Technology Institute, General Motors Company, George Washington University, Georgetown University, Georgia Institute of Technology, Giner, Inc., Global Engineering and Technology, Graftech International Holdings Inc., Greenway Energy, LLC, GWS Solutions of Tolland, LLC,

**H**2 Technology Consulting LLC, H2Pump LLC, Hanford Fire Department, Hawaii Hydrogen Carriers, LLC, Hawaii Natural Energy Institute, Hazardous Materials Management and Emergency Response Training and Eduction Center, HD Systems, Hexagon Lincoln, HRL Laboratories, LLC, Hydrogenics Corporation, HyGen Industries,

**I**BIS Associates, Inc., IdaTech, LLC, Illinois Institute of Technology, Indiana University Purdue University, InnovaTek, Ion Power Inc., IRD Fuel Cells, LLC,

**J**. Craig Venter Institute, Jet Propulsion Laboratory, Johns Hopkins University, Johnson Matthey Fuel Cells,

**K**elvin Hecht, Kettering University,

**L**awrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Lehigh University, Linde LLC, Los Alamos National Laboratory,

**M**assachusetts Institute of Technology, MegaStir Technologies, Michigan State University, Michigan Technological University, Midwest Optoelectronics, LLC, Mitsubishi Heavy Industries, Ltd., Mohawk Innovative Technologies, Inc., MVSystems, Incorporated,

**N**ational Fire Protection Association, National Institute of Standards and Technology, National Renewable Energy Laboratory, Nissan Technical Center, Northeastern University, Nuvera Fuel Cells, Inc.,

**O**ak Ridge National Laboratory, Ohio State University, Oorja Protonics, Inc., Oregon State University, Orion Enterprises, Inc.,

**P**ACCAR, Inc., Pacific Northwest National Laboratory, Pajarito Powder, Parker Hannifin Ltd domnick hunter Division, Pennsylvania State University, Plug Power Inc., Powdermet Inc., Proton OnSite, Protonex Inc., Protonex Technology Corporation,

**Q**uantum Fuel Systems Technologies Worldwide, Inc., Queen's University,

**R**CF Economic and Financial Consulting, Inc., ReliOn, Inc., Rensselaer Polytechnic Institute, Rochester Institute of Technology, Rutgers University,

**S**AE International, Sandia National Laboratories, Savannah River National Laboratory, Science Applications International Corporation, SFC Energy, Spectrum Automation, Sprint Nextel, Stanford University, State University of New York, Albany, Stony Brook University, Strategic Analysis, Inc., SunHydro LLC, Sustainable Innovations, LLC,

**T**DA Research, Inc., Tech-Etch, Technical University Berlin, Tetramer Technologies, LLC, Texas A&M University, Thermochemical Engineering Solutions, Toray Composites America, TreadStone Technologies, Inc., Tufts University,

**U**nited Technologies Research Center, Université de Lorraine, Université du Québec à Trois-Rivières, University of Alabama, University of Arkansas at Little Rock, University of California, Berkeley, University of California, Irvine, University of California, Santa Barbara, University of Chicago, University of Colorado, University of Connecticut, University of Delaware, University of Hawaii, University of Michigan, University of New Mexico, University of Oregon, University of Pennsylvania, University of Pittsburgh , University of Rochester, University of South Carolina, University of Southern California, University of Tennessee, University of Texas, University of Toledo, University of Waterloo, University of Wisconsin, University of Wyoming,

**V**irginia Polytechnic Institute and State University, Virginia Tech,

**W**.L. Gore & Associates, Inc., William C. Fort,

**X**unlight Corporation,

**Y**onsei University, and

**Z**ero Carbon Energy[15].

**3**M Company,

## 9.7 OTHER

H2USA, a public-private partnership focused on advancing the hydrogen infrastructure in the USA, was launched at the end of 2013 and has 25 members[16].

## 9.8 REFERENCES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15. http://www.hydrogen.energy.gov/annual_progress14.html
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## 9.9 FURTHER READING

http://www.netl.doe.gov/research/coal/energy-systems/fuel-cells

http://energy.gov/eere/fuelcells/fuel-cell-technologies-office