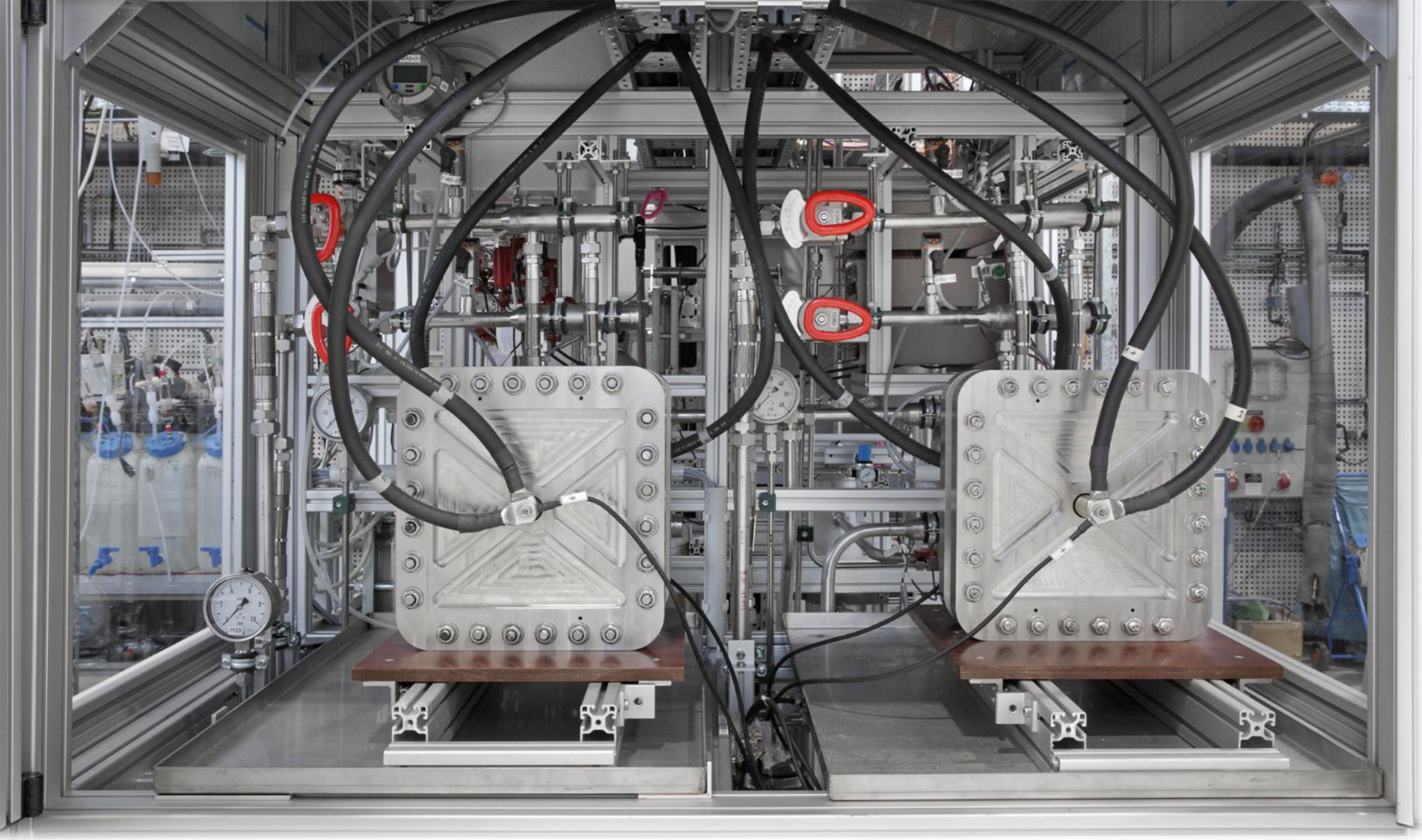

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Annual Report 2018 / 2019

Advanced Fuel Cells

Technology Collaboration Programme

The AFC TCP, the Technology Collaboration Programme on Advanced Fuel Cells is a Programme of Research, Development and Demonstration on Advanced Fuel Cells, and functions within a framework created by the International Energy Agency (IEA). Views, findings and publications of the AFC TCP do not necessarily represent the views or policies of the IEA Secretariat or of all its individual member countries.

This Annual Report has been prepared by the National Members, Operating Agents and the Secretariat of the Executive Committee, who also acted as editor.

Copies can be obtained from the programme's web site at www.ieafuelcell.com or from:

Michael Rex

EE ENERGY ENGINEERS GmbH

Secretary, IEA Advanced Fuel Cells Executive Committee

Roßstraße 92

40476 Düsseldorf

Germany

secretariat@ieafuelcell.com

NAME	ORGANIZATION	COUNTRY
DR GÜNTER SIMADER	Austrian Energy Agency (E.V.A.)	Austria
STEFAN REUTER	Austrian Energy Agency (E.V.A.)	Austria
ZHENG YALI	Society of Automotive Engineers of China (SAE China)	China
HUILAI (STEVEN) ZHANG	Society of Automotive Engineers of China (SAE China)	China
DR ANKICA KOVAC	University of Zagreb	Croatia
ANNIKA FISCHER	Danish Energy Agency	Denmark
DR JARI KIVIAHO	VITO Technical Research (VTT)	Finland
THIERRY PRIEM	Alternative Energies and Atomic Energy Commission (CEA)	France
PROFESSOR DR DETLEF STOLTEN	Forschungszentrum Jülich	Germany
DR R CAN SAMSUN	Forschungszentrum Jülich	Germany
DR GIDEON FRIEDMANN	Ministry of Energy	Israel
DR VIVIANA CIGOLOTTI	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	Italy
DR FABIO MATERA	Istituto di Technologie Avanzate per l'Energia (ITAE),Italy	Italy
EIJI OHIRA	New Energy and Industrial Technology Development Organization	Japan
DR JONGHEE HAN	Korea Institute of Science and Technology	Korea
CARLOS FUNEZ	Centro Nacional del Hidrógeno (CNH2)	Spain
DR HANNAH SUNDQUIST	Swedish Energy Agency	Sweden
DR STEFAN OBERHOLZER	Swiss Federal Office of Energy	Switzerland
DR DI-JIA LIU	Argonne National Laboratory	USA
DR RAJESH AHLUWALIA	Argonne National Laboratory	USA
DR NANCY GARLAND	Department of Energy	USA

Table 1: Contributing authors

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1. Chairman's Welcome

I am pleased to present the Annual Report of the Technology Collaboration Programme on Advanced Fuel Cells (AFC TCP), a branch of the International Energy Agency (IEA).

Energy storage and conversion is still a very important link between the steps of energy production and energy consumption. Environmental circumstances require a change to step away from fossil fuels to rather store and utilize green and renewable energies. Hydrogen, a clean energy carrier, and fuel cells which are known as an effective electrochemical converter without involving any moving mechanical part are playing a major role in implementing those targets.

Many cities, regions and countries have started or are planning to focus their energy policy on hydrogen and fuel cells. For example, Japan has already started its hydrogen strategy in 2017 to realize a hydrogen society in 2050; Germany aims for "world number one" spot in green hydrogen and Austria aims to become the world´s number one hydrogen nation.

In our report on mobile fuel cell applications, where we track the market trends each year, we see a worldwide positive increase of fuel cell electric vehicles from the year 2018 to the year 2019 by 69 %. For the next years, this number (25,212 fuel cell electric vehicles as of end of 2019) will increase rapidly. Also, we found out that more than half of the total hydrogen refueling stations (public and private) worldwide are operated by Japan, Germany and the U.S. This might change in the next year as more and more countries see the high potential of this technology and are implementing their hydrogen and fuel cell programs in the mobile sector.

Our eight fuel cell annexes, which recently have been expanded to 2024, are dedicated to fostering the research and development of fuel cells for transportation, as well as for both stationary and portable applications.

Any company or institution of an IEA member country is invited to join our Annex, under the guide of which technical work to develop and better understand fuel cells is being performed. Interested companies or institutions from non-member states are also welcome to contact us to consider membership. Moreover, we are happy to welcome companies and organizations to Executive Committee meetings on a sponsorship basis, providing direct access to the most current international technical discussions on fuel cells and the opportunity to expand an international network.

For further information, please see our website at www.ieafuelcell.com or contact us directly via email: **secretariat@ieafuelcell.com.**

Professor Stolten is Director of the Institute of Techno-economical Systems Analysis, IEK-3 at Research Center Julich, Germany. His research focus is on electrochemistry, chemical engineering and systems analysis for DMFC, HT-PEFC and SOFC technology.

Chairman of the Technology Collaboration Programme on Advanced Fuel Cells

2. INTRODUCTION

The aim of the Technology Collaboration Programme on Advanced Fuel Cells is to contribute to the research, development and demonstration (RD&D) of fuel cell technologies. It also disseminates information on fuel cell technologies to all its member countries and organizations.

The international collaboration that we create in the AFC TCP aids RD&D efforts by directly sharing information and new developments, focusing on the key areas important to member countries, companies and research institutions. The collaboration between countries facilitates the creation of demonstration programmes,and identifies the barriers for the market introduction of fuel cell applications and works to lower them.

The AFC TCP is in a unique position to provide an overview of the status of fuel cell technology and deployment in its member countries, and the opportunities and barriers they face. Our focus is to work together to improve and advance fuel cell technology.

Key messages – facts

- Power to Gas – with electrolyzer as an enabling component – is an economical option for increasing the flexibility of the electric grid
- But focus has shifted towards using H2 for energy storage. To promote the establishment of water electrolyzers for energy storage applications the system efficiency needs to increase and the system costs need to be reduced. Long term stability for the newly developed components needs to be demonstrated. A big challenge is the test of newly developed systems for 50.000 hours and more
- The number of SOFC in sizes up to 5 kW_e has increased extensively. Large fuel cells from 100 kW_e up to MW-class is a success in several regions. The large fuel cells are getting significantly larger but they still depend heavily on subsidies and on large investors
- Fuel cells as back up or power in remote areas is an increasing market world-wide in telecom and data centers
- The number of fuel cell electric vehicles (FCEV) has increased from 2018 to 2019 to 25.212. This is an increase of 69% to 2018

KEY MESSAGES – OBSERVATIONS

- SOFC is good for distributed combined heat and power production
    - +50% electrical efficiency at system level have been reached at 1,5 kW_e and 20 kW_e class
    - 70 000 hours runtime for SOFC stack proved

  Key barriers are stack's limited lifetime and/or too high manufacturing costs
- Commercialization of fuel cells has commenced in all major transportation sectors including light-duty vehicles (LDVs), passenger buses, and forklifts for material

handling. A new focus lies in heavy-duty transport applications
- Portable fuel cells, which offer higher power density, longer operating range and shorter refueling time compared to battery operation, cover a wide range of applications: from hand-held devices to APU (caravan, marine, camping units), back-up and UPS units, off-grid generators for homes, electric forklifts, light traction (light electric vehicles, golf carts), transportable units for telecom or road signalling, and also drones
- New directives from EU and other regions can facilitate the market expansion of stationary fuel cells

2.1. The International Energy Agency

The IEA is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all.

The IEA was created in 1974 to help co-ordinate a collective response to major disruptions in the supply of oil. While oil security this remains a key aspect of our work, the IEA has evolved and expanded significantly since its foundation.

IEA analysis is built upon a foundation of activities and focus areas including data and statistics, training, innovation and international cooperation.

Taking an all-fuels, all-technology approach, the IEA advocates policies that enhance the reliability, affordability and sustainability of energy. It examines the full spectrum issues including renewables, oil, gas and coal supply and demand, energy efficiency, clean energy technologies, electricity systems and markets, access to energy, demand-side management, and much more.

Since 2015, the IEA has opened its doors to major emerging countries to expand its global impact, and deepen cooperation in energy security, data and statistics, energy policy analysis, energy efficiency, and the growing use of clean energy technologies.

The IEA is governed by the IEA Governing Board, which is supported through several specialized standing groups and committees.

One of this specialized standing groups is the Committee on Energy Research and Technology (CERT), which consists of senior experts from IEA member governments, considers effective energy technology and policies to improve energy security, encourage environmental protection, and maintain economic growth. Four specialized Working Parties support the CERT:

- Working Party on Energy End-use Technologies (EUWP): technologies and processes to improve efficiency in the buildings, electricity, industry, and transport sectors;
- Working Party on Fossil Fuels (WPFF): cleaner use of coal, improvements in gas/oil exploration, and carbon capture and storage;
- Fusion Power Coordinating Committee (FPCC): fusion devices, technologies, materials,

and physics phenomena; and

- Working Party on Renewable Energy Technology (REWP): technologies, socioeconomic issues, and deployment policies.

Each Working Party coordinates the research activities of relevant IEA Technology Collaboration Programmes (TCPs). The CERT directly oversees TCPs of a cross-cutting nature.

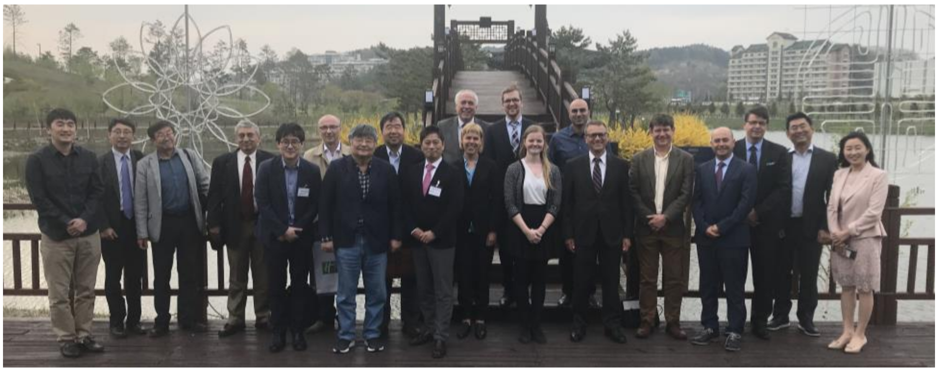
2.2. TECHNOLOGY COLLABORATION PROGRAMME

The Technology Collaboration Programme (TCP), a multilateral mechanism established by the International Energy Agency (IEA) 45 years ago, was created with a belief that the future of energy security and sustainability starts with global collaboration. The programme is made up of thousands of experts across government, academia and industry in 55 countries dedicated to advancing common research and the application of specific energy technologies. Currently, 40 individual technology collaborations are working across several technologies or sector categories: energy efficiency end-use technologies (buildings, transport, industry and electricity), renewable energy and hydrogen, fossil energies, fusion power, and cross-cutting issues. These technology collaborations are a critical, member-driven part of the IEA family, but they are functionally and legally autonomous from the IEA Secretariat. The breadth of the analytical expertise in the Technology Collaboration Programme is a unique asset in the global transition to a cleaner energy future.

The Technology Collaboration Programme on Advanced Fuel Cells (AFC TCP) is a Programme of Research, Development and Demonstration on Advanced Fuel Cells, designed to advance the state of understanding of all Contracting Parties in the field of advanced fuel cells. It achieves this through a coordinated programme of information exchange on the research and technology development underway internationally, as well as performing systems analysis. The focus is the technologies most likely to achieve widespread deployment – molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and polymer electrolyte fuel cells (PEFC) and applications of fuel cells, specifically stationary power generation, portable power and transport. There is a strong emphasis on information exchange through Annex meetings, workshops and reports. The work is undertaken on a task-sharing basis with each participating country providing an agreed level of effort throughout the Annexes.

The current period of the AFC TCP was extended from March 2019 to February 2024.

This report gives an overview of the status, progress and plans of the programme, summarizing the activities and decisions of the Executive Committee, as well as of each of the Annexes during 2018 and 2019.



Group picture of 58th ExCo meeting in Pyeongchang, Korea

2.3. NATIONAL OVERVIEWS

2.3.1. AUSTRIA

The Austrian government is determined to reach carbon neutrality by the year 2040. An intermediate target along this path is to cover 100% of the domestic electricity consumption from renewable energy sources by 2030 and cut the greenhouse gas emissions by 36 % compared to 2005. Hydrogen technologies and fuel cells are seen as a key element in achieving these goals by enabling sector integration and sector coupling. Thus, a national hydrogen strategy will be developed by 2020.

In order to position Austria as an innovation leader, research and technology development in the field of fuel cells and hydrogen will be accelerated especially in areas that are difficult to decarbonize, such as industry and transport. The public R&D expenditures in hydrogen and fuel cell technologies amounted to EUR 9.4 million in 2019 and EUR 8 million in 2018. The Austrian Climate and Energy Fund plays a key role in funding the R&D activities, as 61.7 % of the public expenditures were provided by this fund in 2019.

With the Austrian Hydrogen Initiative Flagship Region Power & Gas a project was implemented that aims to demonstrate the conversion of the Austrian economy to a largely carbon neutral system by producing and using renewable hydrogen as an important core component in the fields of energy, industry and mobility. This will generate investments of EUR 125 million for different projects in the fields of green hydrogen, green industry and green mobility in the upcoming years.

Whereas in previous years mainly smaller R&D projects were conducted in Austria, an increased focus is now on large-scale demonstration projects. At the site of the steelmaking company voestalpine in Linz, a six MW PEM electrolyser is in operation since 11/2019, producing 1,200 m³ green hydrogen per hour for the integration into the steelmaking process and providing grid services.

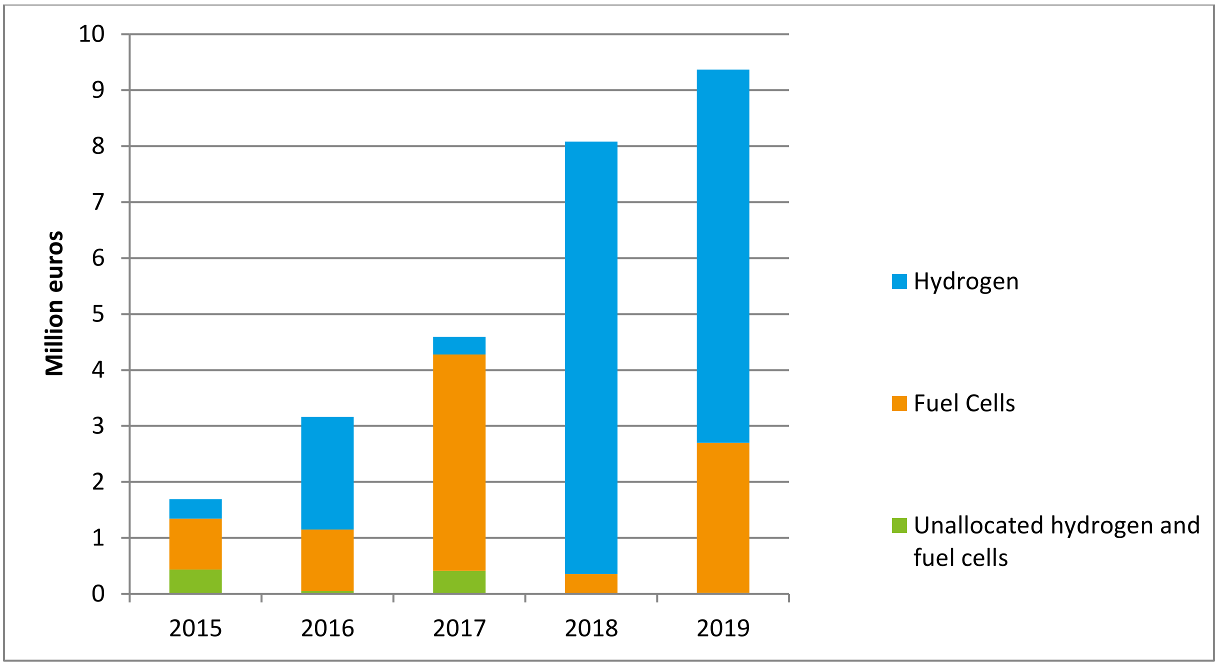


Figure 1: Public R&D expenditures on hydrogen and fuel cells. Source: Indinger, A.; Katzenschlager, M. (2020): Energieforschungserhebung 2019 – Ausgaben der öffentlichen Hand in Österreich.

Figure 2: Six MW electrolyser at the voestalpine site in Linz. Copyright: voestalpine

In the mobility sector, the most potential is seen with fuel cell applications for heavy and special vehicles. The cities of Vienna and Graz have planned the demonstration operation of a bus line with fuel cell busses in the next years. In Tyrol, a 32 km narrow gauge train line will be operated with five fuel cell trains starting in 2023. The needed hydrogen will be produced by two 1.5 MW electrolyzers using local hydropower.

Subsidies for the purchase of fuel cell vehicles and hydrogen refuelling stations are available for private households, companies and organizations. The condition for the subsidy is a guarantee by the recipient to use 100 % green hydrogen. Additionally, FCEVs are exempt from the registration tax for new vehicles and the annual ownership tax.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF DOMESTIC STATIONARY UNITS	50-60	Up to 30 systems (m-chp) implemented within the enefield demonstration project. Involved companies are vaillant, viessmann, elcore and bosch. Presently, 17 systems implemented within pace project. Involved companies are solidpower and viessmann.
NUMBER OF OTHER STATIONARY UNITS (LARGE SCALE)	1	150 kW reversible SOC (Sunfire HyLink 40) implemented at Mellach CCGT plant within HOTFLEX project
INSTALLED ELECTROLYSER (LARGE SCALE)	6 MW PEM	In operation since 11/2019 at the production site of voestalpine (steel manufacturer)
NUMBER OF OPERATIONAL FUEL CELL VEHICLES	41 1	Passenger cars Bus
HYDROGEN REFUELLING STATIONS	7	Five stations publicly available, one semi-public, one closed for internal use only

Table 2: Summary of Austrian fuel cell information

2.3.2. CHINA

China attaches great importance to fuel cell technological and industrial development and has issued a series of strategic plans and policies in recent two years, regarding the hydrogen and fuel cell technology as the innovative tasks and key support areas.

DATE	DEPARTMENT	DOCUMENT	MAIN CONENT
DEC 2018	National Bureau of Statistics	Strategic Emerging Industry Classification (2018)	Hydrogen refueling and storage facilities are listed
DEC 2018	The Ministry of Science and Technology	Notice on Soliciting Opinions for 9 Key Special Projects, including the National Key R&D Program High-tech Field "Renewable Energy and Hydrogen Energy Technology"	Focusing on hydrogen refueling station safety and key technology research and development
JAN 2019	The Ministry of Ecology and Environment	Pollution Control of Diesel Trucks Action Plan (Environmental Ring [2018] No. 179)	Encouraging localities to organize demonstration operations of fuel cell trucks and build several hydrogen refueling demonstration stations.
MAR 2019	The Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology and National Development and Reform Commission	Notice on Further Improving the Financial Subsidy Policy for the Promotion and Application of New Energy Vehicles	Supporting local governments in the construction of charging (hydrogenation) infrastructure
MAR 2019	The State Council	Government Work Report	Promoting the construction of charging, hydrogenation and other facilities
MAR 2019	The State Council	Opinions of the State Council on Implementing	Supporting the construction of charging, hydrogenation

		the Division of Labor of Key Departments in the "Government Work Report"	and other facilities, and clarifying relevant management departments
MAR 2019	The Ministry of Ecology and Environment, Ministry of Housing and Urban-Rural Development, Ministry of Industry and Information Technology, Ministry of Natural Resources, National Development and Reform Commission, National Energy Administration, People's Bank of China	Guiding Catalogue for the Green Industry (2019)	Hydrogenation facility manufacturing, fuel cell equipment manufacturing, hydrogen energy utilization facility construction and operation are listed.
JUN 2019	National Development and Reform Commission and the Ministry of Commerce	The Catalogue of Industries for Encouraged Foreign Investment (2019)	Encouraging the construction and operation of hydrogen refueling stations
NOV 2019	National Development and Reform Commission	Guidance Catalogue for Industrial Structure Adjustment (2019)	Encouraging efficient hydrogen production, hydrogen transportation and hydrogen storage technologies
DEC 2019	The Ministry of Industry and Information Technology	New Energy Vehicle Industry Development Plan (2021-2035)	Completion of infrastructure construction: Charging and hydrogen fuel supply infrastructure

Table 3: Summary of policies

On February 11, 2018, the National Alliance of Hydrogen and Full Cell was established to comprehensively promote the market maturity and international competitiveness of China's hydrogen energy and fuel cell technology.

In 2019, a total of 2,737 hydrogen fuel cell vehicles were sold nationwide, a year-on-year increase of 79%. The number of hydrogen fuel cell vehicles in China exceeded 6,000. It has reached the goal in "Energy-saving and New Energy Vehicle Technology Roadmap" that 5,000 hydrogen fuel cells by 2020 have been achieved.

Hydrogen fuel cell vehicles have been commercialized in 17 provinces, of which Guangdong and Shanghai have accumulated more than one thousand. At present, the vehicles on sale are mainly medium-sized trucks and large-sized and medium-sized buses. Hydrogen fuel cell heavy trucks are still in the R&D and verification stage but have achieved phased results, including Shaanxi Automobile, Sinotruk, Hongyan, Dayun, Jiangling and other enterprises.

Regarding the construction of hydrogen refueling stations, the current shortage of hydrogen refueling stations still affects the development of the hydrogen energy industry. However, China’s hydrogen energy supporting facilities related management standards are being improved. Foshan, Wuhan, Jining, Shanghai and other places have formulated or issued clear hydrogen refueling station management measure. According to incomplete statistics, as of the end of 2019, there are more than 130 hydrogen refueling stations under construction and completion across the country, of which 61 have been completed, and 52 are in operation in 36 cities including Guangzhou, Foshan, Shanghai, and Beijing.

2.3.3. Croatia

Croatia joined the AFC TCP in Spring 2018. Fuel Cells are not yet playing a major role in Croatia, but the topic is getting more and more attention. Since 2006, the University of Zagreb established a course with the title „Hydrogen and Fuel Cells“ to elaborate and communicate the subject. In May 2019, the first Croatian hydrogen refueling station (HRS) was installed, which can provide up to 30 bar and was added on the EU hydrogen map. This HRS serves to refuel Croatian first hydrogen-powered bicycle which was presented to the public in June 2016. This bicycle is powered by a PEM fuel cell of 300 W.

In September 2019, an educational workshop with the title „Hydrogen and Fuel Cells“ was organized for representatives of industry to raise awareness of the importance of this technology. Key speakers were Ankica Kovač, Frano Brabir, and Mihajlo Firak. Also this month, a Croatia-Mirai challenge from Zagreb to Brussels was organized in collaboration of UNIZAG FSB (Ankica Kovač) and Toyota Croatia d.o.o.. This was the first time that an FCEV drove on Croatian roads. The objective was to demonstrate both clean transport and the lack of HRS infrastructure in this part of Europe because the nearest HRS to Croatia is located in Graz (Austria).

One month later, in October 2019, a business meeting 'Hydrogen in Croatia in INA d.d.` was organized where, among others, the Croatian Minister of Energy and Environmental Protection, Tomislav Ćorić, and Executive Director of FCH JU, Bart Biebuyck, took part in.

Regarding to Croatian Energy Strategy the transition to alternative fuel in transport is particularly intense after 2030 with 2050. The strategy plan is to install 25 HRSs for the first decade, 50 for the second, and 75 HRSs by 2050.

2.3.4. Denmark

The Danish Government’s long-term goal for the country’s energy policy is to be independent of fossil fuels by the year 2050. Most recently, the political parties in the Danish Parliament formulated a target to reduce Denmark's greenhouse gas emissions by 70% in 2030 compared with 1990 (A et al., 2019).

The green transition of the energy system has accelerated over the past years and the share of fluctuating renewable energy mainly from wind energy in the Danish energy system has increased significantly. In 2019 the wind power production corresponded to 46 % of the total electricity consumption in Denmark. Furthermore the Finance Act agreement has established a green future fund of DKK 25 billion. And initiated a study regarding the possibilities of building energy islands using/converting large amounts of offshore wind. The goal is to be able to convert electricity into electric fuels for use in industry as well as in aircraft, ships and trucks (Power2X).

The Danish Government has not define any roadmaps regarding the development and implementation of fuel cells. Nevertheless hydrogen and fuel cell technologies are foreseen to be a part of the future green energy system with a high proportion of fluctuating renewable energy. Thus the Danish programmes for research and development within new energy technology still has a high interest in supporting the development of new balancing hydrogen and fuel cell technologies as well as other applications and the programmes administrates a comprehensive portfolio of projects within this area.

In 2018/2019 the Danish programmes granted public support for 4 research, development and demonstration projects in the field of fuel cells technologies. The projects cover applications as SOEC, MFC, and fueling infrastructure for fuel cell vehicles. Also research related to reusing materials from fuel cells was supported.

The total support for the supported projects amounted to app. EUR 8 million.

The Danish Partnership for Hydrogen and Fuel Cells https://brintbranchen.dk/english/ is a national driver in supporting the development of hydrogen and fuel cell technologies. The Partnership comprises all the leading Danish stakeholders within industry, academia and organizations.

2.3.5. Finland

The Finnish Fuel Cell Programme aims to speed the development and application of innovative fuel cell and hydrogen technologies for growing global markets. The programme has facilitated more than 70 successful projects, with more than 60 companies involved. Finnish organisations are also actively participating in EU-projects, especially on FCH-JU funded projects with more than 40 projects and a total value of EUR 160 million. Finnish industry is now starting to invest in fuel cell applications, especially in marine applications, combined heat and power, working machines, and back-up applications. Short descriptions of those company activities are the following:

Convion (http://convion.fi) Convion Ltd was established in 2012 and in January 2013, the company took over Wärtsilä's fuel cell program and continued development and commercialization of products based on solid oxide fuel cell technology as an independent company. Despite its young age, Convion has a significant background in the development of highly efficient SOFC systems. Since the year 2000 Convion team has developed and operated several generations of 20 kW and 50 kW SOFC power units fuelled by natural gas and biogas.

Convion develops fuel cell systems based on Solid Oxide Fuel Cell (SOFC) technology for distributed power generation and industrial self-generation purposes. Convion's SOFC products are designed for electrical power output in the range of 50-300 kW and to make possible clean and highly efficient way to generate power. Convion systems are well suited to combined heat and power generation. Convion designs SOFC systems for power security, the competitiveness of life cycle costs, grid and fuel flexibility and minimal emissions.

Convion will provide a complete power generation solution based on SOFC technology. Products will be distributed to global markets in cooperation with key partners and customers. Main figures of Convion fuel cell unit are shown in the table below:

Performance	**Targets**
Net power output	58kW (3x400-440V AC 50/60Hz)
Energy efficiency (LHV)	
Electrical (net , AC)	> 53 %
Total (exhaust 40°C)	> 80 %
Heat recover	
Exhaust gas flow	650 kg/h
Exhaust gas temperature	222 °C
Emissions	
NOx	< 2 ppm
Particulates(PM10)	< 0.09 mg/kWh
CO_2 (NG, nominal load)	354 kg/MWh
CO_2 (with heat recovery)	234 kg/MWh
Fuels	Natural gas, City gas, Biogas
Dimensions (L x W x H)	
power unit	3,5 x 1,9 x 2,3 m
aux. equipment	2,4 x 0,6 x 2,2 m
Noise level	< 70 dB(A) at 1 m
Installation	Indoor / outdoor
Temperature	-20 – +40°C

Source: http://convion.fi/wp/wp-content/uploads/2015/11/perf_table.png

Each Convion C50 module is a fully integrated and autonomously operable power unit. Installations of multiple parallel modules can form an on-site power plant of the power output of several hundreds of kilowatts, securing critical loads and providing continuous power and heat generation as a back-bone generator of a local microgrid. Yet, each module can be shut down for maintenance individually, making maintenance easy and minimally interfering with other functions.

Convion has started operating a biogas fuelled C50 SOFC system in Italy. The start-up marks the launch of a demonstration of Convion's fuel-flexible C50 SOFC co-generation unit at an industrial biogas installation and an important milestone along the path of commercialization of the product. After a successful trial operation of the module in Finland and completion of site installation at Collegno wastewater treatment plant of SMAT, the unit started producing power and heat for the plant's consumption. The installation is the largest solid oxide fuel cell plant in the world fueled by biogas directly. The installation is part of a European project called DEMOSOFC (http://www.demosofc.eu/).

Elcogen (https://elcogen.com) is the world's most advanced manufacturer of ceramic anode-supported solid oxide cells and stacks. Their proprietary cells and stacks deliver market-leading electrical efficiency and are positioned to achieve market-enabling lifetime and cost levels. To date, they have commercialized two product generations and have sold our technology to 60+ industry-leading customers globally. Elcogen's 18 years of SOC R&D are protected by several patent families, which cover the design and manufacturing of their cells and stacks.

Their stack's low operating temperature of 650°C enables longer lifetimes and the use of low-cost materials at the cell, stack and system level.

Elcogen, an European manufacturer of the world's most efficient SOFC cells, is pleased to announce LOI agreement with E&KOA – Korean SOFC stack manufacturer and P&P Energytech – Korean SOFC system integrator. The purpose of the agreement is to cooperate in the best effort towards the commercialization of SOFC system to the mass market.

Elcogen, and European manufacturer of the world's most efficient SOFC fuel cells, is pleased to announce LOI commercialization agreement with Magnex CO., LTD., a Japanese SOFC stack and SOFC system developer. The purpose of the agreement is to cooperate in the best effort towards the commercialization of SOFC products to the mass market.

LEMENE: Lempäälän Energia and leading fuel cell system developer Convion have signed an agreement regarding delivery of two Convion C50 fuel cell systems to Marjamäki district. (http://www.lempaalanenergia.fi/content/en/1/10005/Frontpage.html). It has been chosen as one of eleven key projects concerning renewable energy and new technology in 2017. As a key project, LEMEE has been granted an investment aid from The Ministry of Economic Affairs and Employment (MEAE). The key projects focus on future energy solutions so that Finland can achieve its national targets and those laid down at EU level for 2030.

The project objective is to create an energy self-sufficient business district. It is located in Marjamäki industry area in the municipality of Lempäälä. The energy is going to be produced using renewable energy sources, such as solar power and biogas. There will be a 4 MW solar power plant (2 MW + 2 MW), gas engine capacity of 8,1 MW, and fuel cell solutions providing a total of 130 kW.

This key project serves as an exceptional opportunity to explore how a larger scale smart grid acts and functions in the current electricity market. Also, the energy self-sufficient district offers a fruitful and interesting environment for research and development for businesses and learning institutions.

THT Control (http://www.thtcontrol.com/) is a provider of industrial automation and control systems and related services. More recently THT Control has started looking into small-scale energy production market with a focus on off-grid electricity production and storage. They are currently building up their know-how and capabilities towards becoming a company capable of offering fuel cell based power generation solutions. In 2019 they joined the EU H2020 (FCH JU) funded consortium Everywh2ere (http://www.everywh2ere.eu/) which aims at building several 25…100 kWe power class fuel cell gensets. THT Controls role is related to system integration of these gensets. They are also part of the EU H2020 (FCH JU) project Empower, which started in 2020 and aims at demonstrating novel HTPEM fuel cell CHP systems.

ABB is a leading global technology corporation. ABB Finland has roughly 5´400 employees and is working with several technology sectors, one of them being Marine & Ports. In this segment, they are developing fuel cell solutions for modular power supply system in marine use (https://new.abb.com/marine/systems-and-solutions/electric-solutions/fuel-cell).

ABB Finland is currently part of two FCH 2 JU funded project where fuel cell solutions are developed for marine and inland waterway applications. In MARANDA project (https://projectsites.vtt.fi/sites/maranda/), emission-free hydrogen-fuelled PEMFC based hybrid powertrain system is developed for marine applications and validated on board the research vessel Aranda. In the project, ABB has the role of designing and delivering power electronics.

ABB Finland is also taking part in FLAGSHIPS project (https://flagships.eu/). In this project, ABB Finland will provide a power and propulsion solution for a newbuilt zero-emission hydrogen & fuel cell powered push boat operating along the Rhône River in Lyon, France.

Also, in 2018, ABB and Ballard Power Systems have signed a Memorandum of Understanding (MoU) on developing the next-generation fuel cell power system for marine applications. The target of this co-operation is to create a megawatt-scale solution for powering larger ships. To supplement this, in 2020, ABB signed a MoU with Hydrogène de France with the intent to jointly manufacture megawatt-scale fuel cell systems.

2.3.6. France

New Initiatives, Programs, and Policies on Hydrogen and Fuel Cells

- **French National Hydrogen Plan** (June 2018). Development of regional ecosystems of hydrogen mobility for zero-emission solutions for road, rail, river, etc. transport with the deployment of:
- By 2023:
- ✓ 5,000 light commercial vehicles and 200 heavy vehicles (buses, trucks, regional trains, boats)
- ✓ 100 hydrogen stations to refuel vehicles with locally produced hydrogen.

- By 2028:
- ✓ 20,000 to 50,000 light commercial vehicles and 800 to 2,000 heavy vehicles
- ✓ 400 to 1,000 hydrogen stations.

In 2019, 100 million euros have been earmarked for the deployment of clean hydrogen. ADEME (French environmental and energy management agency) supports this deployment.

- Hydrogen Mobility France.

More than 400 hydrogen vehicles are on the road in France and more than 80 Fuel Cell buses are in the process of being deployed (17 FC buses deployed as of April 2020).

The main French FC vehicles are the Hydrogen Taxis "Hype Project". The hype is the world's first fleet of hydrogen taxis. Launched on 7 December 2015 during COP 21, by STEP ("Société du Taxi Electrique Parisien"), with 5 first vehicles. Today, the fleet has 110 vehicles, with a target of 600 in 2021. On February 2019, Air Liquide, Idex, STEP and Toyota created the company HysetCo for Hydrogen mobility deployment.

- **Ministers Bruno Le Maire and Elisabeth Borne met the Hydrogen Council in Paris**. For its third Annual Meeting, the Hydrogen Council met in Versailles on 20th of January on the sidelines of the "Choose France Summit" organized by President Macron.

The Minister of Economy and Finance, Bruno Le Maire, and the Minister of Ecology and Inclusive Transition, Elisabeth Borne, addressed the Hydrogen Council members engaged in scaling up hydrogen solutions. "France believes in hydrogen. This technology is strategic if we want to achieve a zero-carbon economy. I, therefore, proposed to Emmanuel Macron that the hydrogen sector be chosen, within the framework of the "Productive Pact", among those whose development must be accelerated," said Bruno Le Maire.

- **Launch by the French Government two new Calls for Expressions of Interest on Hydrogen**. With a budget of €22M, a first AMI «Aid for the emergence of hydrogen mobility in the rail sector» addresses the regional rail transport authorities and aims to support the emergence of hydrogen mobility in the rail sector via bi-mode trains (electric/hydrogen).

A second AMI "Large-scale projects on the design, production and use of hydrogen systems" launched in January with mid-term closures mid-April (160 proposals) and end of June, to identify the structuring projects for the hydrogen sector and to accelerate the large-scale development of innovative technological levels on industrial and infrastructure projects.

The Ministry states that "The most effective structuring projects to develop the industrial clean hydrogen production can be supported in calls for projects launched in April 2020 or be supported at European level, for example in the framework of major projects of European Projects of Common European Interest (IPCEI)".

- **Recovery plan for the automotive sector**: On 26th of May, President Macron presented the stimulus package for the automotive sector, which he described as historic and focuses on clean cars. Thus, the bonus for electric vehicles (including those running on hydrogen) is increased to €7,000 for individuals and €5,000 for businesses. Also, an aid of € 5,000 will be granted for the purchase of an electric vehicle as part of the conversion premium (which will be accessible to three-quarters of the French). It will be valid for the first 200,000 vehicles.

- **Recovery plan for the aeronautic sector: Green aircraft: €1.5 billion by the end of 2022** (8 June). In addition to its immediate support for the aerospace sector, the government's recovery plan also aims to intensify R&D on "environmental disruption": accelerate the work on the green or sustainable aircraft. For this, no less than €1.5B will be released by the end of 2022 with the objective "to develop a regional aircraft with hybrid propulsion for commissioning at the end of the decade", stresses Elisabeth Borne, Minister of Ecological Transition. For the successor to the Airbus A320, the timetable is also tight since it is a question of developing a first demonstrator between 2026 and 2028 with an entry into operation between 2033 and 2035. With two areas of work: "energy efficiency thanks to a 30% decrease in fuel consumption and a 100% biofuel capacity" and "the switch to hydrogen as primary energy".

Demonstration, Deployments, and Workforce Developments Update

- **Symbio, a Faurecia Michelin Hydrogen Company** (Nov 2019): Equally owned by Faurecia and Michelin, the joint venture will invest €140M now, notably in a new factory in the region of Lyon. Symbio aims at becoming a world leader in hydrogen mobility by developing, producing, and marketing hydrogen fuel cell systems for light vehicles, commercial vehicles, buses and trucks, as well as for other areas of electromobility. Chaired by Fabio Ferrari, the founder of Symbio, it aims to hold 25% of the hydrogen market with a turnover of €1.5B by 2030.
- **Safra and Michelin/Symbio: working together for a 100% French hydrogen-powered bus**. The launch of the first-ever SAFRA bus, fitted with a Michelin/Symbio hydrogen system, demonstrates the capacities of French industry and technique for this type of vehicle. The development of hydrogen-powered mass transit has become a major environmental and economic issue, so this collaboration between two French companies is a major coup.
- **Alstom a major player in hydrogen trains**: After 18 months of testing, the two trains, which were put into service in September 2018, travelled 180,000 km. With this pilot operation, Alstom demonstrated that it is possible to use fuel cell technology for the daily transport of passengers. This success makes Alstom a major player in the market for green and sustainable mobility solutions for rail transport». Alstom is to build hydrogen trains for Italy (a five-year agreement signed with SNAM), to deliver 41 Coradia iLint trains to the German states of Lower Saxony and Hesse in 2022 and has tested for ten days at night, without a passenger, in the north of the Netherlands.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF DOMESTIC STATIONARY UNITS (*AS OF JUNE 2020)*	112	Baxi, Panasonic, Viessmann European (Ene.field 35, PACE 66) and national (ADEME & GRDF) funded projects for residential and small tertiary 1 system r-SOC in demonstration

NUMBER OF OTHER STATIONARY UNITS (LARGE SCALE)	1 (200kW): hydrogen and fuel cell system coupled with a PV plant for peak shaving on the electric grid	Myrte Project (Corsica) led by AREVA SE
	4 units	GRDF (Epilog project), Powidian&Mahytec (mountain refuge)

Table 4 Summary of France fuel cell information

2.3.7. Germany

The share of renewable energy in gross electricity consumption increased from 6.3% to 42.1% between 2000 and 2019 in Germany. The share of renewables in gross final energy consumption increased from 6.2% in 2004 to 17.1% in 2019. The 35% target for 2020 for gross electricity consumption was already achieved in 2017; the 18% target for 2020 for gross final energy consumption can also be possibly achieved in 2020 based on the present trend. Yet, the 2030 target of 40% reduction in gross final energy consumption will require considerable additional efforts, especially in the heating and transport sectors, according to the German Environmental Agency. Meanwhile, emissions of greenhouse gases declined by around 36% from 1990 to 2019. Germany, however, aims to reduce greenhouse gas emissions by 40% by 2020 and at least 55% by 2030. The ultimate target is to achieve greenhouse neutrality to a high degree by 2050. Massive and rapid efforts are required to achieve the set targets. [1]

Hydrogen and fuel cell technologies offer the potential to face the challenging requirements of the future energy mix and realize the Energy Transition (*Energiewende*) in Germany. Highly efficient and zero-emission fuel cell electric vehicles for transportation, fuel cell micro combined heat and power systems for households, large scale fuel cell systems for industrial applications and the possibility to store excess electricity produced from renewables as hydrogen via electrolysis provide solutions to achieve the energy goals.

Through the interministerial National Innovation Programme Hydrogen and Fuel Cells Technology (NIP) in its second phase covering 2016 – 2026, the German government continues its strong support in research and development on one hand and the market activation in terms of bringing first products into series on the other hand. The Federal Ministry of Transport and Digital Infrastructure (BMVI) supports the technology with 480 million Euros for the initial period between 2016 – 2022. Accompanied by two funding guidelines, the BMVI funding aims to support those products which are technically ready but not yet competitive during the market ramp-up. The Federal Ministry for Economic Affairs and Energy (BMWi) supports applied research and development for hydrogen and fuel cells with an annual budget of 25 million Euros within the 7th Energy Research Programme. Since 2016, BMWi also supports private households in purchasing a fuel cell heating device. In the reporting period covering the two years (2018 – 2019), the BMVI funding support to hydrogen and fuel cell technologies exceeded 303 million Euros, whereas the BMWi funding support exceeded 61 million Euros. Further ministries involved in the NIP are the Federal Ministry for the Environment (BMU) and the Federal Ministry for Education and Research (BMBF). NOW GmbH coordinates and manages the National Innovation Programme (NIP). [2]

With 81 public hydrogen refueling stations as of end of 2019, Germany is the country with the second-highest number of public refueling stations worldwide after Japan. At this time, further 9 stations were in planning, 6 in approval, 3 in execution and 6 in the trial operation phase. The roadmap aims to reach 100 stations in 2020 to achieve basic coverage for Germany independent of the number of vehicles. Further targets include 400 stations until 2025 to support the market rollout being dependent on the number of vehicles on the road [3].

VDMA Fuel Cells Survey 2019 showed that the revenues in the German fuel cell industry were around 60 million Euros in 2018 and 120 million Euros in 2019 based on survey results and additional estimation of VDMA. The companies expect further strong growth with revenues in the range of 700 million Euros for 2024. The employees for stationary and early markets in Germany are estimated with 1400 in 2018 and 1500 in 2019. It is expected that the number increases to 2700 in 2024. The annual number of fuel cell systems produced in Germany was estimated as 8000 units in 2018 and 11,000 units in 2019. The industry expects high growth rates in the next years, reaching 93,000 systems produced in 2024 in Germany. [4]

In September 2018, Alstom’s hydrogen fuel cell train entered passenger service in Lower Saxony on a nearly 100 km line, offering 1000 km autonomy with one tank and whole day operation [5]. The new plug-in hybrid fuel cell vehicle of Daimler, the GLC F-CELL, is offered in the form of a full-service rental basis at 799 Euro/month [6]. StreetScooter GmbH announced that they would introduce a fuel cell model increasing the range of their base battery model (Work L) from 167 km to 500-700 km with a fuel cell range extender [7]. 500 vehicles will be introduced in the fleet of Deutsche Post and further 300 units will be purchased by Westnetz until 2023 [8, 9]. Van Hool (Belgium) received an order to build 40 hydrogen fuel cell buses for the cities of Cologne and Wuppertal. The buses can operate 350 km (full day’s schedule) with 38.2 kg hydrogen tank capacity [10]. Further highlights from the Germany country update in 2018 included:

FFZ70 project team creating a plug-and-play solution for tugger trains and fuel cells to enable easy retrofitting from batteries to fuel cells. (BMW Group, Linde, Günsel, Fronius, TUM, supported by BMVI and coordinated by NOW GmbH)

DLR combining concentrated solar energy (heat) with high-temperature electrolyzer (SOE) and achieving stable steam production at 700 °C.

Fluorine-free membrane electrode assemblies for PEFCs and water electrolysis developed in the PSUMEA-3 project. (MPI for Solid State Research, ZSW, Hahn-Schickard-Institut, Fumatech, Bosch, Siemens, supported by BMBF)

Metal microstructure plates and related production equipment from Graebener Maschinentechnik.

The extension of the product portfolio of Siemens with Silyzer 300 electrolyzer with 75% HHV system efficiency and 17.5 MW power consumption based on 24 modules.

In July 2019 the Federal Ministry for Economic Affairs and Energy (BMWi) announced that they would provide 100 Mio Euro funding per year for “Real laboratories of the energy transition”. In 20 real laboratories nationwide, selected out of 90 applications, companies will be testing above all new hydrogen technologies on an industrial scale and in a real environment. In this context, the Federal Minister stated that hydrogen technologies offer a huge potential for the energy transition, climate protection as well as new jobs. [11]

Two fuel cell trains being already in regular passenger operation in Lower Saxony in 2019 and a previous order of 14 trains to start operation from 2021, it was announced in 2019 that Alstom will deliver 27 additional fuel cell trains until the timetable change in 2022/2023. These trains will replace diesel trains in four regional railway lines in the Taunus mountain range (north of Frankfurt) [12].

Further highlights from the Germany country update 2019 included:

Self-assembling and self-healing catalyst films for alkaline water electrolysis from Ruhr-University Bochum, Analytical Chemistry – Center for Electrochemical Sciences,

HT-PEM with immobilized ionic liquids developed by Transfer centre Sustainable Electrochemistry of Saarland University and KIST Europe,

400 kW PEM electrolysis stack, PEFCs for operation temperatures up to 120 °C, efficient operation strategies for DMFC, quick start for fuel processing for diesel-based APU and reversible SOC system from Forschungszentrum Jülich,

X-EMU project for the development and validation of a high-performance fuel cell propulsion system for hybrid EMU railcars by IEM, ISEA, vka (RWTH Aachen University) and Siemens,

Fuel cell system simulation focusing on membrane water management by Institute for Combustion Engines (vka) of RWTH Aachen University,

Large fuel cell system for the use with diesel or methane (SchIBZ™ project) by ThyssenKrupp Marine Systems, OWI, ZBT, Sunfire, Hülsenbusch Apparatebau, Rosswag Engineering, Tec4Fuels, DNVGL, Leibniz Universität Hannover,

Fuel cell system testing at FEV Europe GmbH, and

Production technology for metal microstructures for fuel cells and electrolysis from Graebener.

As of June 2020, the National Hydrogen Strategy was announced by the Federal Government as an important milestone in Germany’s strategy to achieve the goals of the Energy transition. However, since the current AFC TCP report period is limited to 2018-2019, the National Hydrogen Strategy will be explained in detail in the upcoming 2020 report.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF STATIONARY APPLICATIONS	at least 6600	Number of residential systems which received subsidies with KfW 433 Programme since 2016
NUMBER OF DOMESTIC STATIONARY UNITS	6600	see above
PORTABLE UNITS	approx. 300 units for telecom back-up power	clean power net

Table 5: Summary of German fuel cell information

Sources

[1] German Environmental Agency

[2] NOW GmbH Annual Report 2019

[3] H2 Mobility

[4] VDMA Fuel Cells

[5] Joint press release of Alstom, Ministry of Economy and Transport of Lower Saxony, LNVG and EVB from 09/2018, Bremervörde

[6] ADAC, 2/11/2018,

[7] A. Kampker, 17. Jahrestreffen des Netzwerks Brennstoffzelle und Wasserstoff, Elektromobilität NRW, November 30, 2017, Düsseldorf

[8] Reuters, 29/09/2018,

[9] Innogy press release 6/7/2018, Essen

[10] Van Hool press release 28/2/2018, Koningshooikt

[11] Federal Ministry for Economic Affairs and Energy

[12] Rhein-Main-Verkehrsverbund

2.3.8. Israel

In 2016, the Israeli government decided on a series of steps designed to ensure that Israel meets its target of 17% Renewable Energy (RE) electricity production (in energy terms), and 17% reduction in electricity use by 2030, compared to business as usual. The RE target includes interim targets of 10% in 2020, 13% in 2025 and 17% in 2030.

During 2019, total RE capacity in Israel has dramatically increased by 45% from 1,501 MW to 2,326 MW (Figure 3:Development of Renewable Energy capacity in Israel through 2019.); Out of the total installed capacity only about 70 MW are not solar (and over 2,000 MW are PV). Overall, in 2019 Israel has reached a level of ~6% RE electricity generation potential (calculated from the end of year capacity).

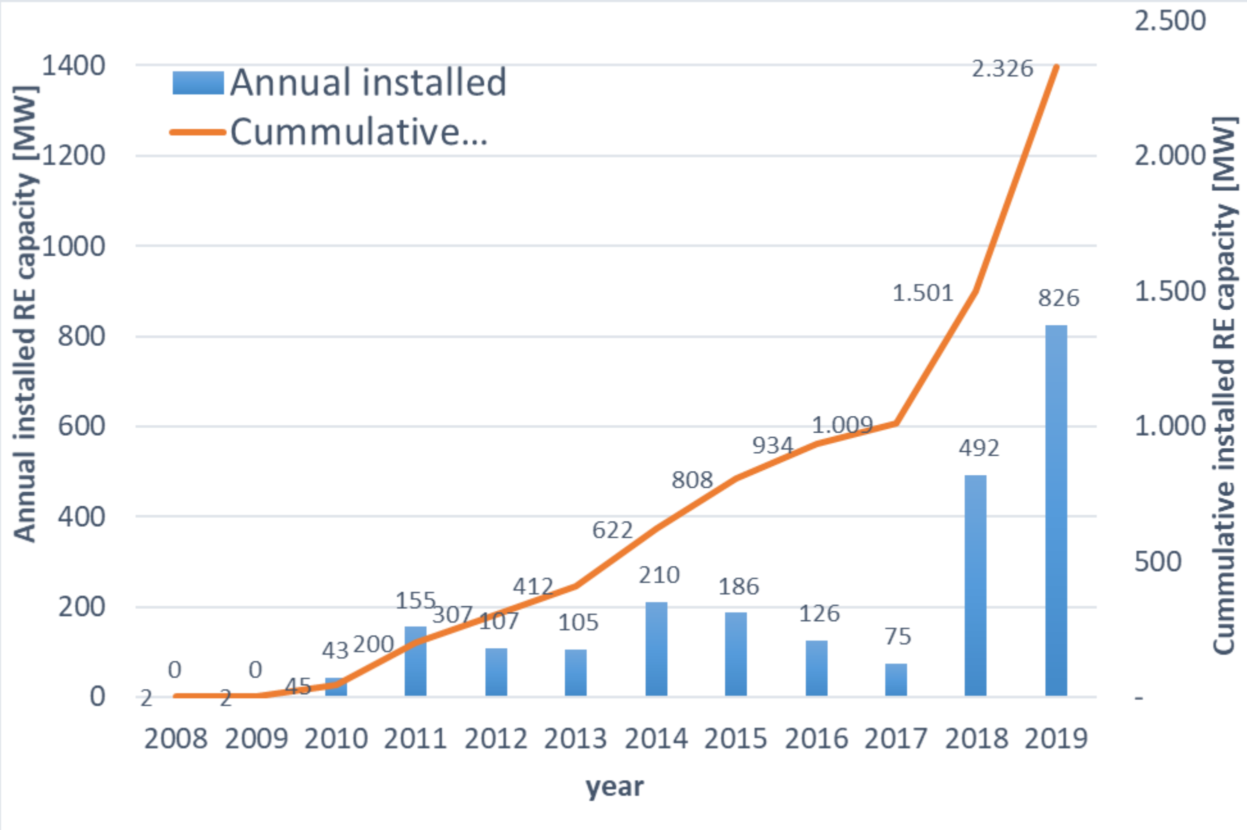


Figure 3:Development of Renewable Energy capacity in Israel through 2019.

The development of fuel cells and hydrogen technologies in Israel is driven by private companies, academic research and the Government, individually and in collaboration. Starting in 2010, the government is conducting a national program to find transportation fuel alternatives for fossil fuels. Originally centered on Natural Gas derivatives, it is centered today on electric transportation, including battery storage, hydrogen and fuel cells.

Academic Research

Most of the fuel cells' research in the Israeli academia is conducted by the Israeli Fuel Cell Consortium (IFCC) which is composed of 12 research labs from all major universities in Israel. Their main focus is on fuel cells for electromobility, and as such, the IFCC has put most of its effort on the development of proton exchange membrane fuel cells (PEMFC). Researchers in the IFCC have been working to reduce the price of this technology by either lowering the platinum group metal (PGM) catalysts' loadings or completely replacing them with PGM-free catalysts, while maintaining the overall performance. They have also been working on the development of advanced corrosion-resistant supports, flow fields and gas diffusion layers in order to increase the system durability. In addition, the IFCC has been working on alkaline exchange membrane fuel cells (AEMFCs) to support the pioneering Israeli industry in the field. The IFCC has made significant progress, making this technology close to that of PEMFCs in terms of power outputs, and now focuses on AEMFC durability. Members of the IFCC collaborate closely with Israeli industry, researchers and companies from outside Israel.

Industrial Research and Development

Several companies are active in areas related to fuel cells. PO Celltech and Gencell are developing alkaline fuel cells. Gencell is already selling its products. It is also developing an Ammonia based alkaline fuel cell.

A new startup – H2Pro was founded in 2019 to develop a low cost, very efficient, and safe eletrolyzer technology. The academic research on which the technology is based was funded by the Ministry of Energy.

Market Implementation

The Ministry of Energy is currently supporting the construction of the first Hydrogen refueling station in Israel, which will be built by Sonol. Hydrogen for transportation standards are being adopted.

Elbit Systems is developing a drone based on a PEM fuel cell made by Ballard. Other Israeli niche drone companies are currently developing their proprietary fuel cells-based drones.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF DOMESTIC STATIONARY UNITS	3 X 5KW (with option to provide peaks up to 300KVA)	**Gencell as life saving infinite backup in operating rooms**

Table 6: Summary of Israel's fuel cell information

2.3.9. ITALY

The first important milestone has been accomplished in 2016 when Italy with the legislative decree 16 December 2016, n. 257 committed to build the infrastructure for alternative fuels, of which hydrogen is also a part, following the development perspective of the National Strategic Plan on Hydrogen Mobility included in Annex III "National Strategic Framework, Section b, Supply of Hydrogen for road transport" developed with the support of the Italian Hydrogen and Fuel Cells Association (H2IT) with 40 members to date.

The National Plan for Hydrogen Mobility has been integrated by the Ministry of Economic Development into the National Strategic Framework for alternative fuels, in view of Italy's required Plan for Alternative Fuels Infrastructure, following EU Directive 2014/94/EU. The Plan suggests Italy deploy an adequate number of refuelling stations to allow the circulation of fuel cell powered vehicles on the territory by December 31, 2025. The Plan includes a series of scenarios related to the number of cars and refuelling stations, and relative quantities of hydrogen to produce, estimating costs, and incentives.

H2IT updated the scenarios of the National Plan for Hydrogen Mobility in 2019, and the final report is publicly available. https://www.h2it.it/wp-content/uploads/2019/12/Piano-Nazionale_Mobilita-Idrogeno_integrale_2019_FINALE.pdf.

Article 5 of Legislative Decree 16 December 2016, n. 257 ordered the update of the technical regulation of fire prevention issued in 2006 (technologically outdated, but still applicable at the time). Intensive work between the Ministry of the Interior, the Central Directorate for Prevention and Technical Safety of the Fire Department, and the Hydrogen Working Group of 'Assogastecnici' led to the publication of the Decree 23 October 2018 "Technical regulation of fire prevention for the design, construction and operation of hydrogen refuelling stations for mobility".

This technical regulation will facilitate:

- allowing the delivery of hydrogen at a pressure of 700 bar as required by the technical characteristics of the cars currently on the market;
- allowing the use of the engineering approach for the assessment of the installations on a case by case basis, guaranteeing the safety of the work and the refueling activity of the station;
- aligning Italy to other European countries, allowing the application of internationally recognized technical standards;
- allowing to partially overcome the economic and social limits deriving from the regulations in force up till then.

The Italian Government published the National Energy and Climate Plan in January 2020 (NECP) and sent the final text to the European Commission according to the Governance of the Energy Union and Climate Action. The Plan sets out measures to ensure the creation of a secure, sustainable and competitive energy system to achieve sustainable growth promote fundamental role of research and innovation in the cleantech sector and reach the 2030 environmental targets at European level. The targets for RES are very significant and assume to cover more than 55% of the demand in the electricity field, 33% of the demand in the thermal sector and more than 21% in the transport sector, for an overall target of 30% of the gross energy consumption.

The NECP recognizes the strategic role of hydrogen in reducing CO2 emissions and improving the energy system flexibility. In the mobility sector, hydrogen is expected to contribute around 1% of the 2030 RES-Transport target, through direct use or the introduction of methane in the network also for transport use. Development of power-to-gas long-term storage systems, enabling the large-scale integration of the electricity produced from renewable energy (PV, wind) into the energy system is also expected in the next decade.

One of the five dimensions of the NECP proposal is represented by the research, innovation and competitiveness's pillar. The dimension includes and refers to the national participation to Mission Innovation which is committed to double public funds for R&D for clean energy from 222 Million Euro in 2013 to 444 Million Euro in 2021. Italy has joined the MI IC#8 on Hydrogen and took part actively to the Mission innovation "Hydrogen Valleys" workshop organized in Antwerp on March 2019 presenting its national "Hydrogen Valley" located in Bolzano, South Tyrol.

Italy has also joined the Hydrogen Initiative, launched by the European Commission in September 2018 in Linz, Austria, to maximise the great potentials of sustainable hydrogen technology for the decarbonisation of multiple sectors, the energy system and for the long-term energy security of the EU.

In June 2019, the Italian Ministry of Economic Development set up The Hydrogen Table gathering the main national industrial players in the value chain to encourage the development of hydrogen-related projects. 35 companies and research bodies participated in the first meeting. Subsequently, three subgroups were created to examine specific technical needs. A total of 53 companies and research bodies participated at this stage. The three working groups were organized on 3 main thematics: "Production, storage and power to gas", "Transport" and "Regulation". This initiative aims to define the priorities, the guidelines and to make a competitiveness assessment on the Italian hydrogen sector and to promote the development of hydrogen-related projects that can have positive impacts from the technological, economic and social point of views. In 2020 other important companies requested direct involvement and numerous projects were presented.

Hydrogen R&D activities are currently funded at national level under the Fund for Research on the electrical system financed by a component of the electricity tariff.

Significant research is being carried out in Italy, mainly through mobilising European funds from the FCH 2 JU (€98M funding per year from the FCH JU supporting over 140 projects and 100 beneficiaries in 13 years spanning the two framework programmes). National programmes are currently funding 5 projects worth €8.5M. Also, there is a lot of internal R&D taking place in universities, ranging from innovative materials to new fuel cell architectures to monitoring and diagnostic algorithms and system integration.

Among the most notable demonstration projects are the following:

- The Bolzano refuelling station is an example of excellence at European level: hydrogen is produced by electrolysis completely from renewable sources. To date, 5 hydrogen buses, 10 Hyundai ix35 Fuel Cell cars, 10 Hyundai Nexo, added to the car park in 2020, and some Toyota Mirai are operating. Another 12 buses have been ordered and will circulate in the area soon.
- 3 FC Buses and H2 refuelling station deployed in Sanremo at the end of 2018
- SNAM (Italian gas Transmission System Operator) initiates first hydrogen injection in the gas grid (5%-10% Blending)
- Ongoing demonstration of a 174 kWe SOFC plant running on biogas from waste-water treatment near Turin

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF DOMESTIC STATIONARY UNITS	100	http://www.pace-energy.eu/ http://enefield.eu/category/field-trials/
NUMBER OF OTHER STATIONARY UNITS	50kW+50kW	REMOTE has the objective to **demonstrate the technical and economic feasibility of two fuel cells-based H2 energy storage solutions** (one integrated P2P system, one nonintegrated P2G+G2P system). **4 DEMOs** supplied by renewable electricity will installed in either isolated micro-grids or off-grid remote areas, 2 demos in Italy: **Ginostra – (South of Italy)**: off-grid configuration (island); RES based on PV generators; residential loads available on-site; almost complete substitution of fossil fuels. End-user: ENEL Green Power (EGP), utility. **Ambornetti – (North of Italy)**: off-grid configuration (remote Alps); RES based on hybrid system with PV-biomass CHP generators; residential loads available on-site; complete substitution of fossil fuels. End-user: IRIS srl (IRIS), stakeholder of the hamlet.

Table 7: Summary of Italian fuel cell information

2.3.10. JAPAN

Japan is the leading country in the field of commercialized fuel cells for residential applications and passenger cars. Currently, the Japanese government shows strong leadership to realized "Hydrogen Based Society."

Japanese Government compiled "The Basic Hydrogen Strategy" on December 26, 2017. The strategy shows future visions that Japan should achieve with an eye on 2050 and also serves as an action plan to accomplish the visions by 2030.

To achieve this common goal, Ministry of Economy, Trade and Industry (METI) revised its "The Strategic Road Map for Hydrogen and Fuel Cells on March 12, 2019. The renewed roadmap defines (i) new targets on the specification of basic technologies and the breakdown of costs, and necessary measures for achieving these goals, and (ii) that Japan will convene a working group consisting of experts to review the status of implementation in each area stipulated by the roadmap.

Japan's current target by 2030 are as follow:

RESIDENCIAL FUEL	Instruction number	5.3 million (in 2030)

CELL	Payback period (price)	5 years (in 2030)
MOBILITY	Number of Passenger Vehicles Number of Fuel Cell Bus	800 k (in 2030) 1.2k (in 2030)
HYDROGEN REFUELING STATIONS	Number of Stations Installation cost (in JPY) Operation cost (in JPY)	900 (in 2030) 200 million (in 2025) 15 million (in 2025)

Commercialization of the ENE-FARM micro-CHP residential fuel cell products has been particularly successful. The first of these products was launched in early 2009, and the total number of installed systems was over 350,000 by the end of March 2020. Since the price of ENE-FARM has been decreasing, METI) terminated the subsidy for PEFC type ENE-FARM in 2019. METI has continued to provide subsidy for SOFC type ENE-FARM, but it is low level (USD 100-400 / unit, up to the size of the Unit). About 60 Fuel Cell Buses (Toyota "SORA") are operated regularly, most of them by the Bureau of Transportation, Tokyo Metropolitan Government.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF STATIONARY APPLICATIONS	Over 350,000 units	Ene-Farm as end of March 2020

Table 8: Summary of Japans fuel cell information

2.3.11. KOREA

The Korean government has strong willing to move toward hydrogen economy and it adopts various policies and programs to activate hydrogen economy. In 2019, the government announced “Hydrogen Economy Roadmap 2040”, the strategical roadmap including Korea’s dissemination targets of fuel cells and hydrogen. In the roadmap, Korea setup a goal to be a leader in the hydrogen economy by 2040. The roadmap also includes the 2040 target of Korea’s dissemination of fuel cell systems and the target numbers is 2.9 million FCVs and 8GW stationary fuel cells disseminated by 2040. The government tries to reach the goals and it subsides fuel cell vehicles, fuel cell systems for power generation hydrogen refueling stations to facilitate dissemination with various programs. As results of these policies and programs 4.167 fuel cell vehicles were sold in 2019 and 396MW of fuel cell power generation system are in operation in Korea by 2019. Also, 54 hydrogen refueling stations were installed by 2019.

			2018	2022	2040
Goal	FCEVs		1.8K	81K	6.2M
	FC power generation	Com. & Utility	307MW	1.5GW	15GW
		Res. & Building	7MW	50MW	2.1GW
	H2 supply (ton/year)		130K	470K	5.26M
	H2 price (KRW/kg)			6,000	3,000

Table 9: Korea´s target of hydrogen and fuel cells dissemination in "Hydrogen Economy Roadmap 2040"

The government also published “Hydrogen Technology Roadmap” as an action plan for technology development in 2019. The technology roadmap includes the strategies of R&D on several core technologies of hydrogen production, storage & transportation of hydrogen, FCVs and fuel cells for stationary applications. The government keeps increasing its investment on R&D for hydrogen and total government R&D fund on hydrogen and fuel cells reaches about 100 million USD in 2019.

Doosan Fuel Cell, a manufacturer of PAFC and PEFC produces stationary fuel cell systems for power for drones, residential, building and distributed power generation applications. Doosan produces and sells 400kW PAFC systems for distributed power generation 200 MW systems are installed in Korea by 2019. Doosan produces small PEFC for power of drones. Doosan’s drones successfully flew more than 2hour.

Hyundai Motors produces FCVs (NEXO) and it sold 4.167 NEXO in 2019. Hyundai also develops 200kW fuel cell stack for heavy duty vehicles. Hyundai also participates in many demonstration programs of local governments which aims to facilitate dissemination of buses and taxies in different places in Korea. By 2019, 15 buses and 10 taxies were provided to participate in the demonstration programs.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF STATIONARY APPLICATIONS	Over 350,000 units	MCFC: 100KW/300kW/1.2MW/2.4MW POSCO Energy Products PAFC: 400kW Doosan(ClearEdge) Products PEFC: 1kW/5kW/10kW Doosan(Fuel Cell Power), S-Fuel Cell Products
NUMBER OF OTHER STATIONARY UNITS (LARGE SCALE)	MCFC: 27 sites PAFC: 25 sites	

Table 10: Summary of Korea´s fuel cell information

2.3.12. Spain

The Spanish electricity generation park is increasingly renewable. During 2019 the non-polluting installed power has experienced a growth of 10% with the entry into operation of nearly 5,000 MW new "green". In this way, clean energies now represent 49.3% of the generation capacity in Spain, which has more than 108,000 MW, according to information estimated by "Red Electrica de España" at the end of 2019. Photovoltaic solar energy, which closes 2019 with more than 7,800 MW of installed power, has been this year the technology that has most increased its presence in the generation park, with an increase of 66% compared to 2018. Wind power, which has added more than 1,600 MW new to its generation park, ended the year with more than 25,200 MW installed. This year, 2019, has also seen the Spanish debut in offshore wind power, with the entry into service of Spain's first offshore wind turbine, on the island of Gran Canarias, with a generation capacity of 5 MW, which is counted as part of the wind power industry. Decarbonization in Spain has also advanced not only due to the installation of new renewable power, but also due to the closure of the Anllares coal power plant in Leon, with 347 MW of installed polluting generation capacity has been reduced In 2019, Spain produced 261,020 GWh of electricity, of which 36.8% was generated from renewable technologies. In addition, 58.6% of the electricity produced during the year in Spain has come from technologies that do not emit CO2 into the atmosphere [1].

Hydrogen and fuel cell technologies offer the potential to face the challenging requirements of the future energy mix and realize the Energy Transition in Spain. Highly efficient and zero emission fuel cell electric vehicles for transportation, fuel cell micro combined heat and power systems for households, large scale fuel cell systems for industry applications and the possibility to store excess electricity produced from renewables as hydrogen via electrolysis provide solutions to achieve the energy goals. Spain have a very high potential in order to produce green hydrogen due their very nice renewable sources.

With 4 hydrogen refueling stations as of end of 2019, Spain is of the European countries that have a smaller number of refueling stations. At this time, according with the Spanish Government planification "Estrategia de Impulso del vehículo con energías alternativas (VEA) (2014-2020)", Spain will have up to 20 hydrogen refueling stations at the end of 2020. Regarding the vehicles, Spain have some demonstration hydrogen vehicles and 4 commercial light duty vehicles at the end of 2019 and the goal ad the end of 2020 is have up to 500 hydrogen vehicles. [2].

As of August 2020, the National Hydrogen Roadmap [3] draft was published by the government as an important milestone in Spain strategy to achieve the goals of the Energy transition. Also, the Hydrogen Spanish Association will be developed the hydrogen sectorial agenda. Both documents will be the key documents in order to define the hydrogen strategy at national level. However, since the current AFC TCP report period is limited to 2018-2019, the National Hydrogen Roadmap and the Sectorial Agenda will be explained in detail in the upcoming 2020 report.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF DOMESTIC STATIONARY UNITS	2 (feb.-2019 , oct.-2019)	2 x PEMFC mCHP units of 0,75 kWe

Sources

[1] Red electrica de España https://www.ree.es/es/sala-de-prensa/actualidad/notas-de-prensa/2019/12/espana-cierra-2019-con-un-10-mas-de-potencia-instalada-de-generacion-renovable

[2] Estrategia de Impulso del vehículo con energías alternativas (VEA) (2014-2020) http://anavam.com/wp-content/uploads/2017/02/4-MT-ANAVAM-Jos%C3%A9-Rodriguez-Herrer%C3%ADas.pdf

[3] Hoja de Ruta del Hidrógeno: una apuesta por el hidrógeno renovable. Junio 2020. https://energia.gob.es/es-es/Participacion/Paginas/DetalleParticipacionPublica.aspx?k=337

2.3.13. Sweden

To combat climate change, Sweden has set up several ambitious climate and energy goals

- By 2030, the use of energy is to be 50 %more efficient, compared with 2005. (target according to the Swedish Energy Agreement)
- By 2030, the emissions from transports are to be 70 % less than in 2010
  - (target from the Paris agreement in 2015)
- The target by 2040 is 100 % renewable electricity production. This is a target, not a deadline for banning nuclear power, nor does it mean closing nuclear power plants through political decisions
  - (target according to the Swedish Energy Agreement)

- By 2045, Sweden is to have zero net emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions.

To reach these goals, research and development in clean energy technologies must be prioritised. Fuel cells can contribute to reaching these goals.

The hydrogen and fuel cell activities in Sweden are driven from the bottom-up, by industry, academic research and experts. The Swedish Government aims to observe the market and to support industry and universities with national activities. The Swedish Government initiated in 2009 a vehicle research programme called FFI (Fordonstrategisk Forskning och Innovation - Strategic Vehicle Research and Innovation). FFI is a major partnership between the Swedish government and automotive industry which includes joint funding of research, innovation and development concentrating on climate & environment and safety in the automotive industry. The fuel cell research activities in FFI have focused on PEFC and SOFC (about EUR 600,000 per year). The Swedish Energy Agency also finance participation in fuel cells and hydrogen-related IEA and EU activities (about EUR 80,000 per year) and at the beginning of 2014, they also launched a project to cover the international business development for fuel cell transport applications (about 100,000 per year). Overall, the government invests in several fuel cell and hydrogen projects in Sweden each year. Some recent examples are:

Scania is developing a fuel cell refuse truck together with Renova, a waste handling company in western Sweden. The truck will feature a fully electrified powertrain as well as an electrified compactor.

- SSAB, LKAB and Vattenfall have joined forces to create HYBRIT – a joint venture project that endeavours to revolutionize steel-making. HYBRIT aims to replace coking coal, traditionally needed for ore-based steel making, with hydrogen. The result will be unique: the world’s first fossil-free steel-making technology, with virtually no carbon footprint. The goal is to have a solution for fossil-free steel by 2026. A successful HYBRIT means that together we can reduce Sweden’s CO2 emissions by 10 % and Finland’s by 7 %.
- Swedish Electromobility Centre is a national Centre of Excellence for e-mobility that unite Sweden’s expertise and are a node for interaction between academia, industry and society. The centre was founded by the Swedish Energy Agency in partnership with Swedish automotive industry and academia. Energy storage including fuel cells is one out of five research themes of the centre.

NUMBER OF UNITS		DETAILS / COMMENTS / COMPANIES INVOLVED
NUMBER OF STATIONARY APPLICATIONS	Less than 1MW	A small number of back-up power units are or have been installed for test or demonstrations
NUMBER OF DOMESTIC STATIONARY UNITS	Less than 10	A few PEFC units running but not really as residential fuel cells

PORTABEL UNITS		myFC, a Swedish company has commercialised the Powertrekk unit for battery charging. However, the company has stopped the production and now it focuses on the integration of its fuel cell technology in other products, such as cars

2.3.14. SWITZERLAND

General Framework

The Swiss energy policy [1] describes how Switzerland can withdraw from nuclear power (36% of total power production [2]) on a step-by-step basis and gradually restructure the Swiss energy system by 2050. These moves are to take place without endangering Switzerland's currently high level of supply security and its affordable energy supply. The strategy calls for a significant increase in energy efficiency, the increased use of renewable energy and the reduction of energy-related CO2 emissions. The corresponding energy legislation was accepted in a popular referendum in May 2017 and entered into force in January 2018. In the climate sector and with reference to the reduction of use of fossil energy the focus is now on the next stage of the Swiss climate policy which is currently being debated in Parliament and which involves national implementation of the Paris Convention by 2030. In summer 2019, the Swiss government also decided that the net greenhouse gas emissions shall be reduced to zero by 2050. Simultaneously the administration was asked to draft a corresponding long-term climate strategy for 2050.

National Research Programme on Hydrogen and Fuel Cells

The Swiss Federal Office of Energy (SFOE) runs a RTD programme on hydrogen and fuel cells technology that involves a broad range of stakeholders. The programme is part of the long-standing coordinative activities by the SFOE to support research and development of energy technologies in Switzerland, where funds deployed in a subsidiary manner aim to fill gaps in Switzerland's funding landscape. Grants are given to private entities, the domain of the Swiss Federal Institutes of Technology (ETH), universities of applied sciences and universities.

Current research priorities of the SFOE programme are PEFC for mobile applications using hydrogen as the energy source (research in the materials sector, system development, and demonstration and testing of pilot projects) and solid oxide fuel cells (SOFC) for use in co-generation plants and operation with natural gas/biogas. Topics are increasing life time and reliability of fuel cell systems, modelling and experimental validation of electrochemical processes, development of cheaper and more reliable materials (membranes, inter-connectors, catalyser materials), and integration of fuel cells in overall systems (balance of system).

On average, 28 million Euro are available as public funding for fuel cells and hydrogen research in Switzerland, thereof about 58% as base funding within the federal research institutions (ETH Zurich, Paul Scherrer Institute, Empa, ETH Lausanne) and 42% as competitive funds (SFOE and EU projects, projects funded by the Swiss Innovation Agency and the Swiss National Science

Foundation). An overview on projects with Swiss partners is here https://h2fc.ch/projects.

H2 mobility in Switzerland

Hydrogen mobility in Switzerland is being driven forward on private initiative. In 2018 the Association pro H2 mobility Switzerland was founded with the aim of establishing a nationwide hydrogen filling station infrastructure by 2023 on the basis of renewably produced ("green") hydrogen. Members are major Swiss players from the transport and mobility industry and various filling station operators. As far as vehicles are concerned, the focus will initially be on trucks. Their annual hydrogen consumption is a factor of 30–50 higher in comparison with a passenger car, thus ensuring the profitability of service stations. To this end, the Swiss company H2 Energy AG has launched the joint venture "Hyundai Hydrogen Mobility" with the Korean manufacturer Hyundai, in order to introduce around 1000 fuel cell trucks in the 34-tonne class (Xcient Fuel Cell) in Switzerland. The "Hydrospider" joint venture of H2 Energy, Alpiq and the gas company Linde ensures the production of "green" hydrogen, which is supplied to hydrogen filling stations in Switzerland. Incentives for the use of fuel cell trucks in Switzerland are provided by the exemption from performance-related heavy vehicle tax LSVA and exemption from the mineral oil tax for hydrogen as a fuel.

The Swiss Federal Office of Energy SFOE helped to trigger H2 mobility in Switzerland with stakeholder dialogues and an intensive demonstration phase 2016 to 2020. The chain "Production of green hydrogen with run-of-river power", "Public hydrogen filling station" and "Use of a fuel cell truck" was demonstrated on a pilot scale as part of several projects funded by the Swiss Federal Office of Energy SFOE. Guidelines were also drawn up in connection with the construction of the first publicly accessible hydrogen filling station in 2016.

References

[1] http://www.energystrategy2050.ch

[2] In 2019, there were four nuclear power plants with five reactors in operation. Thereof, a first reactor (355 MW) was closed in December 2019 and is now being prepared for nuclear decommissioning

Fuel cell application in Switzerland:

Application	totale power (kW)	Number	Description
Fuel cell trucks	2'280	12	Hyundai plus 1 Esoro/SwissHydrogen
Fuel cell passenger cars	5'580	93	Hyundai, Toyota, Diverse
Micro-CHP	30	20	
Combined Heat and Power (CHP)	250	1	MCFC installation 2010
Fuel cell UPS (telecom)	12	6	Swisscom, Polycom
Power-Production	200	1	PSI
Autonomous energy supply	8	2	Diverse pilots
Total	8'360		

Table 11: Fuel Cell Information of Switzerland (status 09/2020)

2.3.15. USA

The mission of the Fuel Cell Technologies Office is to enable the widespread commercialization 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. The appropriation for FY18 was USD 115,000,000 and for FY19 was USD 120,000,000.

Key targets:

Fuel cells

- Develop a 65% peak-efficient, direct hydrogen fuel cell power system for transportation that can achieve 5,000-hour durability (ultimate 8,000 hours) and be mass produced at a cost of $40/kW by 2020 (ultimate $30/kW).
- Develop distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas that achieve 45% electrical efficiency and 60,000-hour durability at an equipment cost of $1,500/kW by 2020.
- Develop medium-scale CHP systems (100 kW–3 MW) by 2020 that achieve 50% electrical efficiency, 90% CHP efficiency and 80,000-hour durability at a cost of $1,500/kW for operation on natural gas and $2,100/kW when configured for operation on biogas.

Hydrogen storage

- By 2020, develop and verify onboard automotive hydrogen storage systems achieving 1.8 kWh/kg system (5.5 wt.% hydrogen) and 1.3 kWh/L system (0.040 kg hydrogen/L) at a cost of $10/kWh ($333/kg H_2 stored).
- Enable an ultimate full-fleet target of 2.5 kWh/kg system (7.5 wt% hydrogen) and 2.3 kWh/litre (0.070 kg hydrogen/litre) at a cost of USD 8/kWh (USD 266/kg hydrogen stored) for onboard automotive hydrogen storage.

Hydrogen production

- By 2020, reduce the cost of distributed production of hydrogen from biomass-derived renewable liquids to <$2.30/gge (≤$4.00 delivered and dispensed).
- By 2020, reduce the cost of distributed production of hydrogen from water electrolysis to <$2.30/gge (≤$4.00 delivered and dispensed).

Key accomplishments

A number of key accomplishments are found at https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office-accomplishments-and-progress:

Vehicles – buses

California's Clean Transit Regulation requires that 25% of buses procured from 2023 should be zero emission, and targets 100% by 2040.[1]

Fuel cell power plants in buses have surpassed the DOE/DOT ultimate target of 25,000 hours; the top fuel cell power plant accumulated >32,000 hours of operation.[2]

Stationary fuel cells

In September 2019, Cummins, Inc. increased its fuel cell capabilities and added hydrogen production capabilities following acquisition of Hydrogenics, a Canadian company.[3]

DOE deployed 1,600 early market fuel cell forklifts and backup power units enabling more than 23,000 systems to be deployed or on order by industry without DOE funding.[4]

Vehicles – trucks

In 2018, FedEx demonstrated the world's first fuel cell airport ground support equipment fleet. The fleet of zero-emission, hydrogen-powered airport cargo tractors was demonstrated at the Memphis, Tennessee airport.[5]

Vehicles - cars

DOE validated the durability of light duty fuel cell vehicles of 4,100 hours.[6]

DOE established the Fuel Cell Consortium for Performance and Durability (FC-PAD) to explore and optimize component properties, behavior, and phenomena. In 2019, FC-PAD increased focus on heavy-duty applications, especially increasing MEA durability towards ultimate target of(preliminary) 25,000 h.[7]

DOE established the ElectroCatalysis Consortium to develop PGM-free catalysts and electrode structures for next-generation fuel cells. The Consortium synthesized an atomically dispersed Fe-N-C catalyst and demonstrated performance in H_2/air of 113 mA/cm^2 at 0.8 V, nearly 2.5x the 2018 project baseline.[7]

References and Notes

1. https://ww2.arb.ca.gov/resources/fact-sheets/innovative-clean-transit-ict-regulation-fact-sheet

2. https://www.hydrogen.energy.gov/pdfs/review20/ta013_eudy_2020_o.pdf

3. https://www.hydrogenics.com/2019/09/19/cummins-closes-on-its-acquisition-of-hydrogenics/

4. DOE Hydrogen and Fuel Cell Program Records #17003 and #17004

5. https://www.hydrogen.energy.gov/pdfs/review18/mt011_pitts_2018_p.pdf

6. https://www.hydrogen.energy.gov/pdfs/16019_fuel_cell_stack_durability_2016.pdf

7. https://www.hydrogen.energy.gov/pdfs/review19/plenary_fuel_cell_papageorgopoulos_2019.pdf

2.4. TRACKING MARKET TRENDS: REPORT ON FUEL CELL ELECTRIC VEHICLES AS OF END 2019

At the beginning of 2020, AFC TCP started a survey to monitor the number of fuel cell vehicles on the road as of end of 2019. This is the third AFC TCP survey on this topic, followed by the ones, which reported the status at the end of 2017 and 2018.

All reports with more detailed information are available on the website of the AFC TCP: www.ieafuelcell.com/publications.

This latest report gives a brief overview of the status of the numbers of fuel cell vehicles and hydrogen refueling stations worldwide as of end 2019. According to AFC TCP data collection results, the number of fuel cell vehicles including passenger cars, buses, light- and medium-duty trucks and heavy-duty trucks amounted to 25,212. Moreover, 470 hydrogen refueling stations were in operation at the end of 2019. More than half of the vehicles are operated in Asia. Passenger cars dominate the total number with a share of 75%. From that, 46% of the vehicles are registered in Asia. A focus on the Chinese market showed a strong increase in the number of buses on the road from 421 in 2018 to 4297 in 2019. Similarly, the number of light- and medium-duty trucks (commercial vehicles) increased from 412 to 1807. With these numbers, China strongly dominated both markets worldwide. The numbers for the passenger cars and hydrogen refueling stations showed an increase of 69% and respectively 23% in 2019, both numbers representing a stronger increase rate than 2018. The total number of vehicles showed a much stronger increase of 95%.

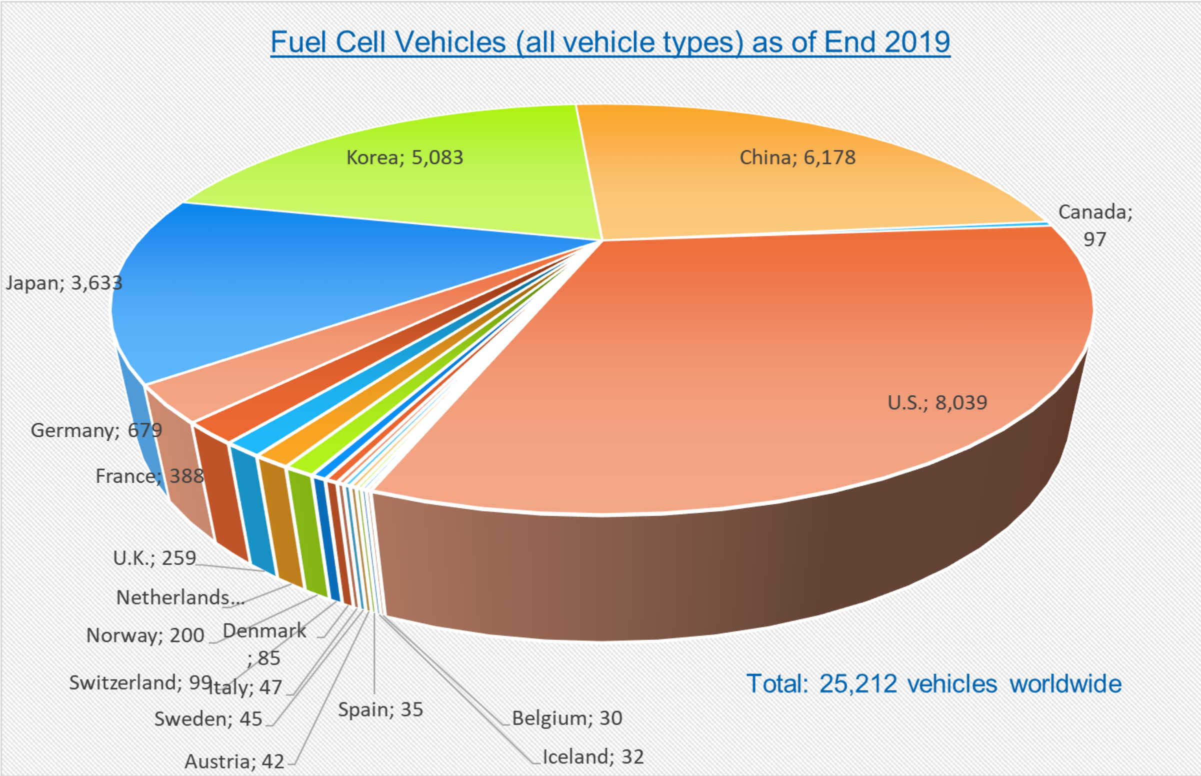


Figure 4: DISTRIBUTION OF FUEL CELL VEHICLES ON THE ROAD AS OF END 2019.

The three countries with the highest numbers of publicly available hydrogen refueling stations have not changed and Japan (113), Germany (81) and the U.S. (48) are still the top three countries in this category. With these numbers, the publicly available HRS in these three countries (242) represent more than half of the total HRS (public and private) worldwide.

The total number of HRS worldwide showed an increase of 23% in the last year. Thus, the increase is stronger than the 15% observed in the year before. A combined analysis of the number of vehicles and stations for the top 6 countries having the highest number of hydrogen refueling stations showed that in Korea, the U.S. and China the number of cars per station is more than 100, whereas this number is lower than 35 for Japan, France and Germany. Korea and Germany show both extremes in this analysis, with 149.5 cars per station in Korea and 8.4 in Germany.

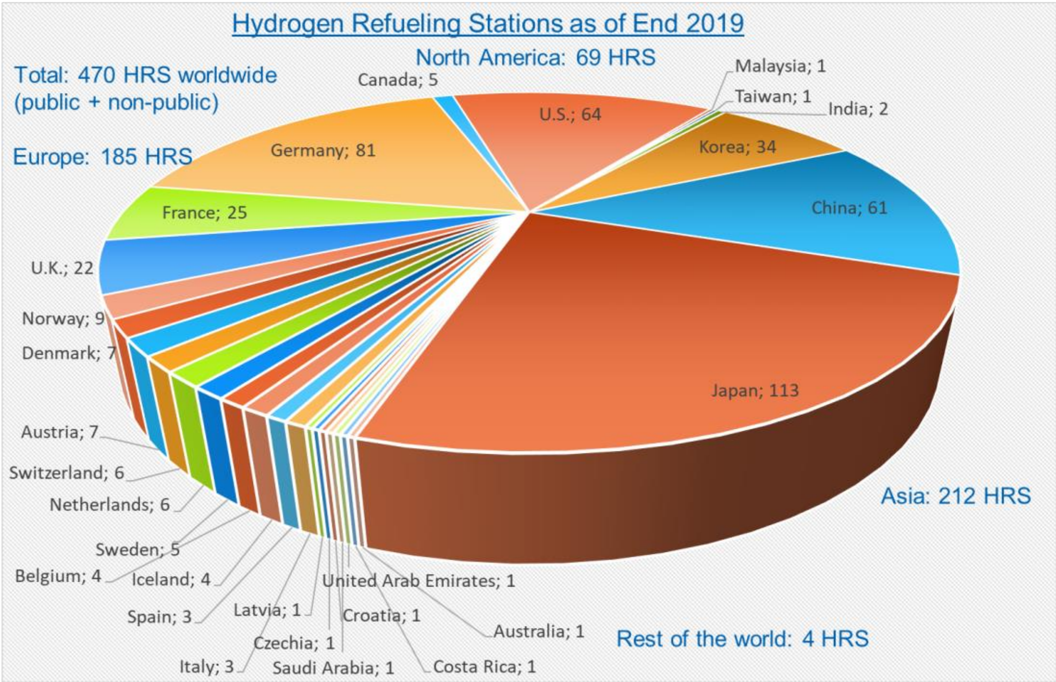


Figure 5: OVERVIEW OF PUBLIC AND NON-PUBLIC HYDROGEN REFUELING STATIONS (HRS) WORLDWIDE AS OF END 2019.

The report also showed big differences between the available national and regional incentives for purchasing a fuel cell vehicle. In many countries, the same incentives apply for battery electric vehicles and fuel cell electric vehicles. The available exemptions in Switzerland enable significant savings for heavy-duty transportation with fuel cells. Switzerland will be one of the countries in focus for the next years since a fleet of 1,600 heavy-duty trucks is planned until 2025 here. Analyzing the announced roadmaps, targets and visions for Korea, Japan, China, Europe, California and the worldwide vision of Hydrogen Council for 2050, we can conclude that hydrogen and fuel cells have a strong potential to play a critical role for sustainable mobility.

3. Executive Committee Report

3.1. Activities

Two Executive Committee (ExCo) meetings were held in 2018 and 2019.

MEETINGS	DATE AND PLACE
ExCo 56	Feb 27 – March 01, 2018; Tokyo, Japan
EXCO 57	Nov 06 – Nov 08, 2018; Linz, Austria
EXCO 58	May 07 – May 09, 2019; Pyeongchang, Korea
EXCO 59	Sep 25 – Sep 27, 2019; Rugao, China

Table 12: Executive Committee Meetings 2018 and 2019

Within all four ExCo meetings, Outreach Events with key-groups in the respective countries were organized and members of the Executive Committee or Annexes presented and discussed fuel cell related topics:

Tokyo: In cooperation with the 6th FC International Meeting, Operating Agents from the AFC TCP gave short activity reports of their respective annexes and invited Japanese companies to join their annexes.

Linz: The Austrian Energy Agency and the AFC TCP organized an Outreach Event in cooperation with the HyLaw national workshop with the title: Market Readiness of Fuel Cells addressing Austrian stakeholders. A highlight was the presentation of H2Energy, who presented the status quo of fuel cell heavy-duty transport at Hyundai and Coop in Switzerland in the Outreach Event as well as in the ExCo meeting. In this meeting, the ExCo decided to focus on heavy-duty vehicle applications in the future.

Pyeongchang: In PyeongChang, the AFC TCP took part in the International Hydrogen Forum 2019 with the Title: Green Hydrogen Economy. Chairman Detlef Stolten gave a presentation to more than 500 people including domestic and foreign experts on hydrogen and fuel cell. During the ExCo meeting, AFC TCP and the Korean Institute of Science and Technology also organized an internal outreach meeting with Hyundai, S Fuelcell, Doosan, Kogas, Elchemtech, KIST, KIER and a representative from the South Korean Government to share details of the current work status of fuel cells and to discuss business opportunities for fuel cell systems beyond automotive.

Rugao: The 59th ExCo meeting took place during the 4th International Hydrogen Fuel Cell Vehicle Congress in Rugao, China. Here, the AFC TCP was a Co-organizer of the Forum B: H2 Stations & infrastructure as well as the organizer of the Outreach Meeting “Fuel Cell Progress of AFC TCP member countries”

The AFC TCP continues to produce two newsletters a year, sharing the work and news of the group with a wide audience. They are available through the website and are sent by email directly to the people on our distribution list.

The AFC TCP supported the publication "initial approaches in benchmarking and round-robin testing for proton exchange membrane water electrolyzers" to the International Journal of Hydrogen Energy in April 2019 as well as published a position paper on solid oxide cells in October 2019. Furthermore, it published the first survey on fuel cell electric vehicles in 2018 and the second survey in 2019. The third survey started in 2019 and was finished in the first half of 2020.

The website of the AFC TCP was re-designed and a new logo was introduced to convey a new visual identity of the AFC TCP to optimize the AFC TCP image concerning digital platforms. But most of all, to represent the subject of fuel cells.

In 2018, the AFC TCP voted to take forward the request of extension of a new term 2019-2024 of the AFC TCP, which was successfully accepted in February 2019 by the Committee on Energy Research and Technology of the International Energy Agency.

3.2. Membership

In the beginning of 2018, AFC TCP welcomed Croatia as a new member of the AFC TCP.

In 2019, AFC TCP also welcomed Spain as a full member of the AFC TCP. Since 2016, the Centro Nacional Del Hidrógeno (CNH2) was a sponsor organization and due to the country membership withdraw its sponsorship in the beginning of the same year.

The AFC TCP has now 15 participating countries and one organizational member (sponsor).

There were a few changes of ExCo-Representatives in 2018 and 2019. The current list of ExCo representatives can be found on the website of the AFC TCP:

http://www.ieafuelcell.com/index.php?id=9.

3.3. Financing and procedures

All activities under the Annexes of the Implementing Agreement are task shared. The only cost-shared activity is the Common Fund, which provides funding for the Executive Committee Secretariat. The new funding arrangements were introduced in 2011, whereby there are three tiers of Common Fund contributions; the level of payment is led by a country´s level of GDP.

Since 2015 two types of membership are offered:

- Contracting Parties: the national government of a country can join the Technology Collaboration Programme on Advanced Fuel Cells as a Contracting Party.
- Sponsors: research organizations, industry, and business partners may join the Technology Collaboration Programme on Advanced Fuel Cells as Sponsors.

3.4. Key Decisions in 2018 / 2019

- It was unanimously decided to update the website and the logo to convey new digital visibility and to simplify service and maintenance. The new website is online since early 2019.
- Unanimous decision to continue to collect the number of fuel cell electric vehicles and number of hydrogen station and to communicate those numbers as an output of the AFC TCP beyond 2018.
- Integration of a new subsite “hydrogen as a fuel for fuel cells” into the new website in 2019.
- The duration of al annexes has been adapted to the new term of the AFC TCP: March 1, 2019 – February 29, 2024
- A subtask heavy-duty vehicles application will be set up and led by SAE-China.

3.5. Future Plans

Information exchange with other Technology Collaboration Programmes continues to be encouraged, building on links already in place with the Hydrogen and Hybrid Electric Vehicle Technology Collaboration Programmes. The AFC TCP will also continue to work closely with the IEA and their working groups, as well as attend and contribute to respective meetings.

Two Executive Committee meetings will be held in 2020. Due to the COVID-19 pandemic, both meetings will be held as digital meetings.

4. ANNEX REPORTS

4.1. ANNEX 30: ELECTROLYSIS

KEY MESSAGES ANNEX 30 – FACTS

- Germany, Italy, France, Japan, Korea, together with the European Union and many others have well recognized the relevance of Hydrogen via water electrolyzers as the only available route to store renewable energy. Several hydrogen programs are being deployed, a rapid increase of demonstration projects together with industry can be found.
- The community recognizes alkaline and PEM water electrolyzers as the only commercially available technologies, not only for today´s market demand but also towards any necessary scaling-up step to reach in a few years the demand of energy storage using renewables.
- Solid oxide and AEM electrolyzers are clearly behind from a market deployment perspective, but indeed possess a strong potential to increase efficiency and reach significant cost reduction.
- Significant R&D still needs to be pursued to transform state-of-the-art into next-generation water electrolyzers with higher efficiency, lower cost, and long-term durability.

KEY MESSAGES ANNEX 30 – OBSERVATIONS

- The main technical challenges and development goals facing water electrolysis are improved stack performance (efficiency) and durability, scaling up current 1 MW platforms into 10, 100, 1000 megawatt size range; well-aligned to grid integration and high-pressure operation.
- There is a clear need to identify degradation mechanisms for next-generation devices, anticipating long-term characteristics of stacks before testing them for periods over 20.000 hours. In other words, the group has identified the importance to develop accelerated stress tests (ASTs).
- It is also of key interest to determine the economics of scale for water electrolyzers. Current 1-5 MW systems are still far from what can be envisioned for energy storage applications (> 1 GW). How can automation and advanced manufacturing technologies assist in cost reduction?
- Harmonization of baseline performance, testing hardware, operating protocols for performance evaluation and durability tests in of key interest to both academy and industry members of the annex 30.

The objective of the Electrolysis Annex is to provide a platform for international information sharing and learning between experts with knowledge and experience of electrolyzer technologies. It seeks to understand how these can best be deployed in energy systems in order to accelerate the development and eventual commercialization of the following technologies:

- PEM water electrolysis
- Alkaline electrolysis,
- Anion Exchange Membrane (AEM) electrolysis

Four breakout groups were created within the annex, to improve both communications within meetings and combine expertise. As of 2020, we have:

- Membranes – Leader: Prof. Hanke-Rauschenbach/Dr. Boris Bensmann LUH Hannover, Germany
- Catalysts – Leader: Dr. Guido Bender NREL, USA
- PLT and Bipolar Plates: Leader Dr. Aldo Gago, DLR, Germany
- Alkaline Cells: Prof. Jens Oluf Jensen, DTU, Dänemark

The work of the Annex 30 focuses on low temperature water electrolysis technologies. In addition to information exchange, the standardization of definitions (completed in 2018), harmonization of test procedures/protocols is the focus of the current activity.

This Annex is active since 2014, having been set up in response to increasing interest in utilizing renewable energy across Europe – especially stranded energy and that generated when grid output exceeds demand. The Operating Agent is Marcelo Carmo, head of the Institute of Energy and Climate Research Institute (IEK-14) at the Forschungszentrum Jülich GmbH in Germany, and a list of participating organizations can be found below.

4.1.1. Activities

The goal has been to host two workshops per year, with location following the order: Europe → America → Europe → Asia, and then back with the same rule. Here a list of the workshops that have been organized so far:

YEAR	SEASON	LOCATION
2014	Fall	Forschungszentrum Jülich, Jülich, Germany
2015	Spring	Herten Hydrogen Center of Excellence, Herten, Germany
2015	Fall	National Renewable Energy Laboratory, Golden, USA
2016	Spring	New Energy and Industrial Technology Development (NEDO), Tokyo, Japan
2016	Fall	Institute for Energy Technology, Instituttveien 18, Kjeller, Norway
2017	Spring	Fraunhofer ISE, Freiburg, Germany
2017	Fall	3M, St. Paul, USA
2018	Spring	Paris Süd University, Paris, France

2018	Fall	National Renewable Energy Laboratory, Golden, USA
2019	Spring	Leibniz University Hannover, Hannover, Germany
2019	Fall	China Society of Automotive Engineers, Rugao, China
2020	Spring	Denmark Technical University DTU, Copenhagen, Denmark (Post-poned to Spring 2021)
2020	Fall	NEL Hydrogen, Wallingford, USA (Postponed to Fall 2021)

The workshop has received high interest and therefore a high number of attendees. The group has decided in the spring of 2018 to limit the number of attendees to 50, excluding those coming from the host institution. The invitation is sent to all past three workshops attendees, and are listed on the first-come basis. It was also decided to fix the duration of the workshops into two days, with an extra day that can be added for "site visit" if necessary. The workshop program runs as follows:

30 % of its time for presentations which:

- 2 plenaries talks by the host
- 3-5 Keynotes via invitation, with topics related to the workshop (annex 30)
- 4-8 short presentations for new members

50% of its time for breakout group sections

- Membrane and Catalysts groups running in parallel for roughly 3-4 hours
- Catalysts and PTLs groups running in parallel for roughly 3-4 hours

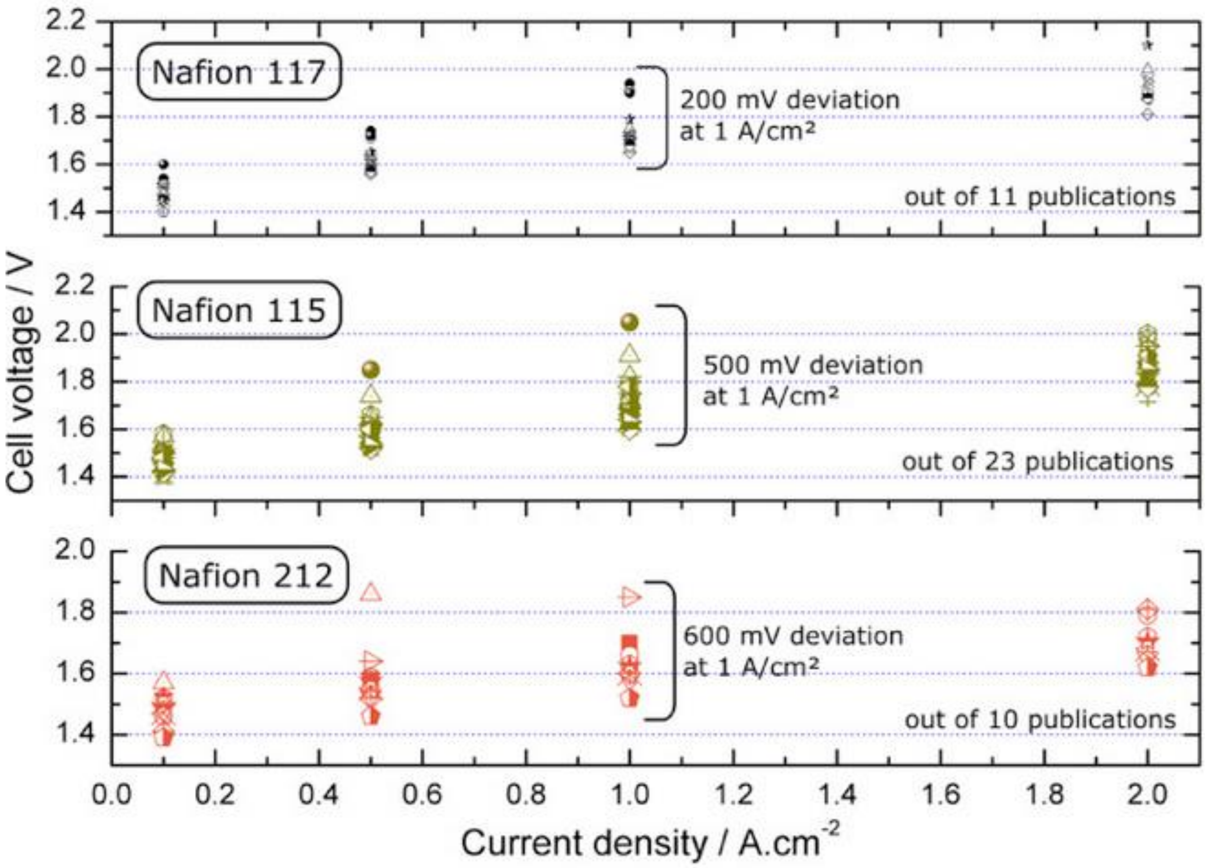
10% of its time for Harmonization activities focused on PEM Electrolysis

- Phase 1 – 1st Published at International Journal of Hydrogen Energy (https://doi.org/10.1016/j.ijhydene.2019.02.074)
- Phase 2 – 2nd Manuscript under preparation (finish 2020)
- Phase 3 – Under Discussion…. (delayed by COVID)

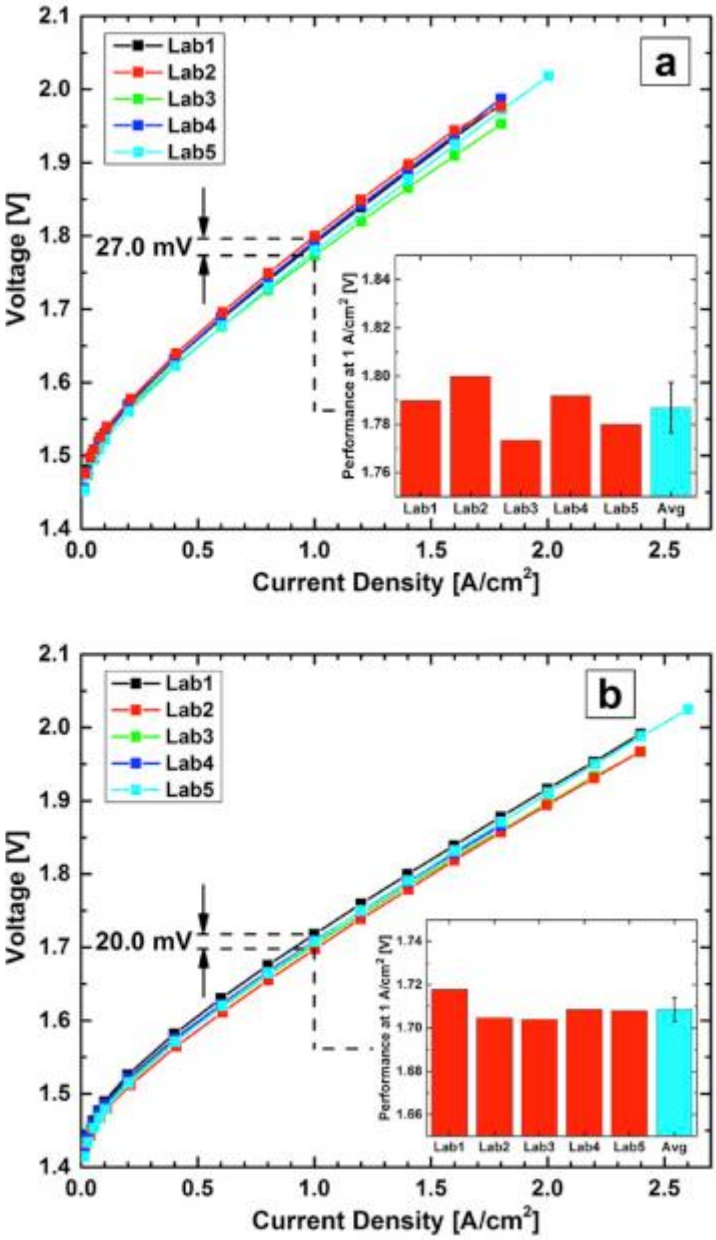
10% of its time for a site visit

4.1.2. Technical development

As ever-increasing amounts of renewable electricity enter the energy supply mix on a regional, national and international basis, greater emphasis is being placed on energy conversion and storage technologies to deal with the oscillations, excess and lack of electricity. Hydrogen generation via proton exchange membrane water electrolysis (PEMWE) is one technology that offers a pathway to store large amounts of electricity in the form of hydrogen. The challenges to widespread adoption of PEM water electrolyzers lie in their high capital and operating costs, which both need to be reduced through R&D. Evaluation of reported PEMWE performance data in the literature reveals that there are excessive variations of in situ performance results that make it difficult to conclude the pathway forward to performance optimization and future R&D directions (See Figure Below).



To enable the meaningful comparison of in situ performance evaluation across laboratories there is an obvious need for standardization of materials and testing protocols. Herein, we address this need by reporting the results of a round-robin test effort conducted at the laboratories of five contributors to the IEA Electrolysis Annex 30. For this effort, a method and equipment framework was first developed and then verified concerning its feasibility for measuring water electrolysis performance accurately across the various laboratories. The effort utilized identical sets of test articles, materials, and test cells, and employed a set of shared test protocols. It further defined a minimum skeleton of requirements for the test station equipment. The maximum observed deviation between laboratories at 1 A cm−2 at cell temperatures of 60 °C (Figure A below) and 80 °C (Figure B below) was 27 and 20 mV, respectively.



The deviation of the results from the laboratory to the laboratory was 2–3 times higher than the lowest deviation observed at one single lab and test station. However, the highest deviations observed were one-tenth of those extracted by a literature survey on similar material sets.

The Annex 30 group endorses the urgent need to identify one or more reference sets of materials in addition to the method and equipment framework introduced here, to enable accurate comparison of results across the entire community. The results further imply that cell temperature control appears to be the most significant source of deviation between results and that care must be taken concerning break-in conditions and cell electrical connections for meaningful performance data.

The publication of this activity can be found at:

https://doi.org/10.1016/j.ijhydene.2019.02.074

4.1.3. Work plan

1. Finalize Phase 2 of Round-Robin-Test (Harmonization Activity), with manuscript submission into a peer-reviewed journal by the end of 2020.
2. Start phase 3, targeting the development of first Accelerated Stress Tests (ASTs). Here we have the Joint Research Center (JRC) of the Hydrogen Joint Undertaking from the EU participating, the Department of Energy (DOE) in the United States. NEDO in Japan has also demonstrated interest and should join the effort.
3. Membrane group: Compile a review manuscript related to ASTs for membranes within PEM electrolyzers
4. Catalyst group: Intensify Webinar discussion that is happening once a month with several experts across the world. The Webinar has been used to seed joint publications, projects, collaboration at the international level, exchange of IP-free information, and development of ASTs for catalysts and catalyst layers.
5. Membrane group: Write a review manuscript on Alkaline Water Electrolyzers. The chapters have been already distributed, outline is finished, and coordination is set. The aim is to finish the manuscript by the end of 2021.

Workflow has been disrupted by the current COVID-19 situation and should be resumed and adjusted in 2021. The group is reluctant to organize the workshop via the web, since the meetings were always very productive due to intense one-to-one exchange at the workshop. Webinars are and were already happening within the breakout groups, and therefore, meetings for 2020 were requested to be shifted into 2021. If the lockdown situation remains, the group is planning a webinar for summer 2021.

COUNTRY	COMPANY / INSTITUTION
AUSTRALIA	AquaHydrex
AUSTRIA	Salzgitter AG
BELGIUM	Agfa
BELGIUM	Chemours
BELGIUM	European Commission
BELGIUM	Fuel Cells and Hydrogen Joint Undertaking
BELGIUM	Hydrogenics
BELGIUM	JRC
BELGIUM	The Chemours Company
BELGIUM	VITO
BRAZIL	USP
CANADA	GreenHydrogen
CHINA	China Society of Automotive Engineers

CHINA	Cockerilll Jingli Hydrogen
CHINA	DICP
CHINA	Nanjing University
CHINA	Shanghai Zhizhen New Energy Equipment Co., Ltd.
CHINA	Wuhan University of Technology
CZECH REPUBLIC	Uni Prag
DENMARK	DTU Dänemark
DENMARK	EWII
FRANCE	CEA
FRANCE	Engie Lab CRIGEN
FRANCE	Université Montpellier
FRANCE	University Paris Sud
GERMANY	Carbotech Gas Systems GmbH
GERMANY	Clausthal University of Technology
GERMANY	DLR
GERMANY	EFZN
GERMANY	EIFER
GERMANY	Energieagentur NRW
GERMANY	Evonik
GERMANY	Forschungszentrum Jülich
GERMANY	Fraunhofer IFAM
GERMANY	Fraunhofer IMWS
GERMANY	Fraunhofer ISE
GERMANY	Freundenberg
GERMANY	Fumatech
GERMANY	Greenerity GmbH
GERMANY	H-TEC
GERMANY	HYREF GmbH
GERMANY	Kumatec
GERMANY	Leibniz Universität Hannover
GERMANY	Ludwig-Bölkow-Systemtechnik

GERMANY	Max Planck Institute
GERMANY	Now GmbH
GERMANY	Siemens AG
GERMANY	sunfire GmbH
GERMANY	ThyssenKrupp
GERMANY	TU Clausthal
GERMANY	Uni Freiburg
GERMANY	Uni Hannover
GERMANY	ZBT GmbH
GERMANY/FRANCE	Air Liquide
GERMANY/FRANCE	AREVA H2Gen
HOLLAND	TNO
ITALY	Enapter
ITALY	CNRC-NRC
ITALY	ITAE
ITALY	McPhy
ITALY	Polimi
ITALY	University Palermo
JAPAN	AIST
JAPAN	Asahi Kasei Corporation
JAPAN	Daikin Chemical
JAPAN	Hitachi Zosen
JAPAN	Kobelco
JAPAN	NEDO
JAPAN	Tanaka
JAPAN	Technova Inc
JAPAN	Toray
JAPAN	Toshiba
JAPAN	University of Tokyo
JAPAN	Yokohoma National University
NORWAY	ISFH

NORWAY	SINTEF
SOUTH AFRICA	HySA
SOUTH KOREA	KIER
SOUTH KOREA	KIST
SOUTH KOREA	Korea Institute of Energy Research
SPAIN	Instituto Nacional de Electricidad y Energías Limpias
SWITZERLAND	E4Tech
SWITZERLAND	PSI - Paul Scherrer Institut
UK	ITM Power GmbH
USA	3M
USA	Colorado School of Mines
USA	Dioxide Materials
USA	DOE
USA	Giner Inc.
USA	LANL
USA	LBL
USA	LLNL
USA	Nelhydrogen
USA	NREL
USA	ORNL
USA	Teledyness
USA	Universtiy of South Carolina
USA/JAPAN/ITALY	De Nora

Figure 6: List of participating organizations in Annex 30

4.2. ANNEX 31: POLYMER ELECTROLYTE FUEL CELLS (PEFC)

KEY MESSAGES ANNEX 31 – FACTS
▪ Research on PEM fuel cell and fuel cell components at the US starts to shift to mid and heavy-duty vehicle applications, of which long-term stability represents a key challenge

- Alkaline membrane development has experienced some significant break-throughs, opens up the new possibility of AEM based fuel cell and electrolyzer
- Significant progress has been made in PGM-free ORR catalyst for fuel cell through ElectroCat consortium sponsored by DOE. The catalyst stability under fuel cell operating condition remains to be a major challenge

KEY MESSAGES ANNEX 31 – OBSERVATIONS

- The focus on fuel cell technology application is very much dependent on the region of the world, requiring a tailored approach in organizing Annex activities
- Reducing cost and improving durability still remain the top priorities in fuel cell material and system R&D. Major technology breakthroughs, such as high-temperature membranes and durable catalysts, are important to light duty as well as heavy-duty fuel cell vehicle
- Transferring the laboratory technology to practical application in real-world should be accelerated

The objective of the Polymer Electrolyte Fuel Cells Annex is to contribute to the identification and development of techniques and materials which can reduce the cost and improve the performance and durability of polymer electrolyte fuel cells (PEFC or, equivalently, PEMFC), direct fuel polymer electrolyte fuel cells (DF-PEFC) and corresponding fuel cell systems.

During this reporting period, Annex 31 held two meetings. The 17th meeting was held on October 6, 2017, at Washington DC. Eleven representatives from 8 organizations in 7 countries participated in the meeting. The 18th meeting was held on May 2, 2019, at Washington DC. Seven participants from 4 organizations in 4 countries attended the meeting.

4.2.1. Activities

The R&D activities in Annex 31 cover all aspects of proton exchange membrane fuel cell (PEMFC), direct fuel polymer electrolyte fuel cell (DF-PEFC) and alkaline fuel cell (AFC), from individual component materials to whole stacks and systems. These activities are divided into three major subtasks:

1) New stack materials

Research in the new stack materials aims to develop improved, durable, lower-cost polymer electrolyte membranes, electrode catalysts and structures, catalyst supports, membrane-electrode assemblies, bipolar plates, and other stack materials and designs for PEFC.

2) System, component, and balance-of-plant issues in PEFC systems

This subtask includes systems analysis, stack/system hardware designs and prototypes, and modelling and engineering. This subtask also engages in testing, characterization, and standardization of test procedures related to end-user aspects, such as the effects of contaminants on durability, water and heat management, operating environments and duty cycles, and freeze-thaw cycles. The development of fuel processors for PEFC for CHP and APU applications is also addressed in this subtask.

3) DF-PEFC technology

The third subtask focuses on the research and development of DF-PEFC technology, including systems using direct methanol fuel cells, direct ethanol fuel cell, and direct borohydride fuel cells. It involves the development of the cell materials, investigation of the relationship between cell performance and operating conditions, stack and system design and analysis, and investigation of fuel-specific issues for these direct-fuel polymer electrolyte fuel cell systems.

4) Alkaline fuel cell

The fourth subtask focuses on research and development of alkaline membrane fuel cell, including catalyst (PGM and non-PGM anode and cathode catalysts, low precious metal loadings) and membrane (alkaline membrane material, alkaline ionomer material, alkaline MEA).

4.2.2. TECHNICAL DEVELOPMENTS

Professor Viktor Hacker's team (TUG –Austria) has recently developed a polyaniline coated carbon substrate as a protective layer, which improved catalyst stability, activity, durability compared to commercial Pt/C. A ternary PdxNiyBiz anode catalyst developed by his team also demonstrated promising performance for as the anode catalyst for the alkaline direct ethanol fuel cell.

Danish Power System focuses on design, synthesis, and production of polybenzimidazole (PBI)-based membranes (Dapozol®) for fuel cells operating at temperatures as high as 160°C. DPS is currently working on the reduction of the Pt loading requirement for high-temperature fuel cell applications.

Professor Christophe Coutanceau team (Université de Poitiers, France) developed a new synthesis method by grafting ionomer directly with Pt/C particle through S-S chain scission reaction over a low-cost, hydrocarbon-based polymer. They demonstrated that such method could stabilize the catalyst by reducing the agglomeration and improve mass/charge transfer with better triple-phase boundaries.

Korean Institute of Energy Research (KIER) (Korea) has been working on a metal-ordered mesoporous porphyrinic carbon as ORR catalysts and tested the catalytic performance at both RDE and fuel cell levels. They used silica spheres as a template and found that the catalysts synthesized using porphyrinic precursor provided a higher mesopore concentration and improved mass transport.

ICT Fraunhofer (Germany) developed a new high throughput synthesis process to produce synthesize metal-organic framework as the precursor for PGM-free catalyst. Argonne National Lab team collaborated with ICT by evaluating their catalyst performance using ANL's post-treatment and testing procedure. A presentation entitled "Low-cost ZIF-8 metal-organic frameworks as a precursor for Fe/N/C oxygen reduction catalysts" was given by Dr. Cremers of ICT at 2019 Electrolysis & Fuel Cell Discussions, "Towards Catalysts Free of Critical Raw Material for Fuel Cells & Electrolysers" 15-18 September 2019, La Grande Motte, France.

Jülich team (Germany) developed a fuel cell stack system modeling tool including fuel and water management. They are working on the complexed coupling mechanism of electrochemical reactions/heat and mass transport processes in fuel cell in an attempt to provide the prediction with better precision between these key factors.

Israel Fuel Cell Consortium (Israel) studied the possible failure mechanism of the precious metal-free cathode for fuel cells under alkaline conditions based on an accelerated stress test that mimics realistic operating conditions. They suggested that new catalyst systems should be studied by case-specific ASTs

VTT team (Finland) is currently investigating the negative impact of fuel cell impurities, specifically formaldehyde and formic acid produced during the electrocatalytic process, on the performance and lifetime of PEM fuel cells. They found that a very small voltage drop in 4 hours due to ~1.6 ppm formic acid.

Argonne National Lab (USA) recently developed an ultralow loading Pt catalyst through synergistic catalysis between Pt and PGM-free active site. The new catalyst demonstrated the potential of substantial reduction of platinum metal usage.

4.2.3. WORK PLAN

The fuel cell development is becoming regional dependent with each continent focusing on a different aspect of technology implementations from a passenger vehicle to mid- and heavy-duty truck and marine applications. The Annex 31 activities need to address these needs and find common ground for all participating members. In 2020, Annex 31 will try to reorganize the workshop planned at France with the engagement of local FC researchers, if the situation permits. The workshop will include an alkaline fuel cell theme-based meeting. Annex 31 will also continue to attract new members from participating countries.

COUNTRY	COMPANY / INSTITUTION
AUSTRIA	Graz University of Technology
CANADA	Simon Fraser University
CHINA	Dalian Institute of Chemical Physics (DICP)
CHINA	Shanghai Jiao Tong University
DENMARK	Danish Power Systems
FINLAND	VTT
FRANCE	Institut de Chimie des Matériaux et des Milieux de Poitiers
GERMANY	Forschungszentrum Jülich
GERMANY	Technische Universität Darmstadt
GERMANY	ICT Fraunhofer

ISRAEL	Israel Fuel Cells Consortium (IFCC)
ITALY	CNR-ITAE
JAPAN	Yamanashi University
SOUTH KOREA	Korea Institute of Energy Research (KIER)
SOUTH KOREA	Korea Advanced Institute of Science and Technology (KAIST)
SWEDEN	KTH – Royal Institute of Technology (x3)
USA	Argonne National Laboratory

Figure 7: List of participating organizations in Annex 31

4.3. ANNEX 32: SOLID OXIDE FUEL CELLS

KEY MESSAGES ANNEX 32 – FACTS

- Solid oxide cells (SOCs) enable flexible storage of renewable electricity and provide the best available efficiency for decentralized production of heat from one kW up to several MW.
- The key advantages of the SOC technology have been established as (i) high conversion efficiency, (ii) flexibility regarding fuel, (iii) low-cost materials and (iv) possibility to produce/utilize heat, (v) real technical ability of reversible operation.
- Some critical current KPIs for SOFC installations of 100-250kWe are the following:
  - Capex > 4000 €/kW_e
  - Maintenance costs > 2,5 € Ct/kwh
  - Lifetime > 10 years (operating hours > 8500/year)
  - Thermo-cycling > 100
  - Efficiency > 85% (Electrical efficiency > 55 % & Thermal efficiency > 30%)

KEY MESSAGES ANNEX 32 – OBSERVATIONS

- SOC technology is becoming a significant solution for a variety of applications:
  - SOFC offer fuel flexibility, e.g. at biogas plants, and/or where the added efficiency is worth the extra investment, i.e. where fuel is expensive.
  - SOE technology has the potential to be a major pathway for affordable, green hydrogen and thus becoming a cornerstone of the future hydrogen economies.
- Effort should be put into reducing system cost through mass production of components and systems.
- The SOE technology is still at a pre-commercial stage and efforts need to be targeted to large-scale demonstrations that are integrated with renewable power sources and where waste heat is utilized.

The Annex 32 intends to employ to reach following overall objectives:

- The continuation and intensification of the open information exchange to focus and accelerate the development of SOC towards commercialization.
- To organize a series of annual workshops where representatives from the participating countries present the status of SOFC research, development and demonstration in their respective countries, in addition to discussing a selected topic.
- Where possible, these workshops will be linked to other relevant conferences, to maximize scientific impact and minimize travelling costs. The workshops lead to open discussions relating to common problems and will be organized to have realizable and achievable aims.

4.3.1. Activities

The annual meeting in 2018 was held on July 2nd in conjunction with the European Fuel Cell Forum in Switzerland. Thirteen attendees from ten countries actively participated in the meeting.
The annual meeting in 2019 was held in conjunction with the 16th International Symposium on Solid Oxide Fuel Cells (SOFC XVI) in Kyoto on September 8th. Eighteen attendees from thirteen countries actively participated in the meeting.

"POSITION PAPER ON SOLID OXIDE CELLS (SOCs)" has been prepared and published in October 2019.

During 2019 and 2020 work has been carried out to update the SOFC Yellow Pages document. The new version of Yellow pages will probably be published at the beginning of 2021.

4.3.2. Technical Development

For SOFC technology, effort should be put into reducing system cost through mass production of components and systems. Lot technical work has to be done to reach following KPIs for SOFC installations (100 to 250kWe) which are critical for successful commercialization:

- Capex < 1500 €/kW_e
- Maintenance costs < 2,5 € Ct/kWh
- Lifetime > 15 years (operating hours > 8500/year)
- Thermo-cycling > 300
- Efficiency > 90% (Electrical efficiency > 60% & Thermal efficiency > 30%)

To achieve cost targets by 2040 a minimum manufacturing volume of 250MW/year is required per manufacturer.

The SOE technology is still at a pre-commercial stage and efforts need to be targeted to large-scale demonstrations that are integrated with renewable power sources and where waste heat is utilized

4.3.3. Work plan

The overall objective is the continuation and intensification of the open information exchanges to accelerate the development of SOC towards commercialization and the general the focus areas are the following:

- Costs structures of SOC stacks and the whole SOC systems.
- Degradation mechanisms and accelerated lifetime testing
- Durability and lifetime issues
- Identification of possible opportunities for collaboration
- High-temperature electrolyzers

The aim of arranging the next annual meeting in conjunction with European Fuel Cell Forum in Lucerne (Switzerland) in October 2020 will be failed because of corona incident. Possibility to arrange a remote meeting later in the year 2020 is under consideration. Also, the purpose is to arrange physical annex meeting at least in the year 2021.

The new version of Yellow pages will be updated in 2020 and it will be published at the beginning of 2021.

COUNTRY	COMPANY / INSTITUTION
DENMARK	Risø DTU National Laboratory for Sustainable Energy
FINLAND	VTT
FRANCE	Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
GERMANY	Forschungszentrum Jülich GmbH
GERMANY	Fraunhofer IKTS
ITALY	ENEA Centro Ricerche Casaccia
JAPAN	Japan Institute of Advanced Industrial Science and Technology (AIST)
JAPAN	Technova
KOREA	Korea Institute of Energy Research (KIER)
NETHERLANDS	Delft University of Technology
POLAND	Department of High Temperature Electrochemical Processes (HiTEP)
SWEDEN	Department of Energy Sciences
SWITZERLAND	SOLIDpower SpA (HTceramix)
USA	Pacific Northwest National Laboratory
USA	National Energy Technology Laboratory (US DOE)
USA	OxEon Energy LLC

Figure 8: List of participating organizations in Annex 32

4.4. Annex 33: Fuel cells for stationary applications

KEY MESSAGES ANNEX 33– FACTS

- The total installed capacity is forecasted to grow from 220 MW to 612 MW, and the market will be lad by US in North America and Japan (and China in the near future) in Asia. For the micro CHP market, Japan and Europe are leading the market and the R&D activities, thanks to ad-hoc subsides and programmes.
- Japan results to be the main leader in CHP installations thanks to the ENEFARM programme with more than 314 000 fuel cells installed, where the price per sale has been decreased to US$7,000/unit for PEM and US$8,800/unit for SOFC.
- Europe is keeping pace with Japan, with 4100 of CHP units installed, thanks to three main actions (Callux, PACE and ene.field).
- For larger stationary applications, USA is leading the pictures, with a cumulated installed capacity of 500 MW.
- Fuel cells as back up or power in remote areas is an increasing market world-wide in telecom

KEY MESSAGES ANNEX 33 – OBSERVATIONS

- The main sectors where stationary fuel cells have been employed are (a) micro-CHP, (b) large stationary applications, (c) UPS and IPS.
- The developers of fuel cells from Japan has a great advantage with huge amounts of installations and experience from operation and production. These experiences are essential for a commercial breakthrough globally.
- The European market is increasing but still behind North America and Asia.
- Most of the big players are located in Europe, Japan and USA. Depending on the size applications, the market is dominant in different countries. Japan and Europe have lower installations of large-scale fuel cell stationary installations, while in South Korea PAFC and MCFC are the most installed technologies.
- For the residential micro-CHP applications, Europe and Japan are leading the market, thanks to ad hoc aimed subsides and programmes.

Annex 33 is an application-type annex with the objective to better understand how stationary fuel cell systems may be deployed successfully in energy systems. The work focuses on the market requirements for fuel cells in stationary applications; both opportunities and obstacles are investigated and discussed. Market development is followed closely with a special focus on fuels, environment and competitiveness. All kinds of stationary applications are addressed, both grid-connected and stand-alone. Opportunities in niche and broader markets are investigated, where fuel cells have advantages over existing, competing technologies. Obstacles to be overcome are discussed as well as recommendations for new regulations. All fuel cell technologies and sizes under development are considered for analysis in Annex 33.

The market for small stationary fuel cells for residential use has increased significantly, but very locally. A **first** major **task** in the new annex is to investigate untapped markets for residential stationary fuel cells, where there is a viable economic and environmental case, analyzing how the market varies between countries, including energy prices and the framework for the use and production of electricity and heat.

A **second task** is to investigate the implications for stationary fuel cells caused by the introduction of new Directives or relevant legal regulations and standards. Effects on the increase of fuel cell competitiveness will be discussed to provide IEA-qualified input to the ongoing regulatory processes, elaborating recommendations and justifications as needed.

A **third task** is to investigate technology and market development of large fuel cell plants. These are often used in parallel with the grid in sensitive applications, such as hospitals, banks, offices, warehouses and supermarkets. The state of the art will be studied by analyzing user cases in the different IEA Member countries and beyond.

A **fourth** essential **task** is to predict how fuel cells will be applied in future energy systems, and in particular the opportunities concerning the use of renewable fuels and hydrogen, applications for H2 mobility, smart grids, power to gas, and other applications where FCs can play a pioneering role.

4.4.1. Activities

Annex 33 has been organized with one or two meetings each year during the last working period. Annex 33 holds a series of annual workshops where representatives from the participating countries present the status of research, development and demonstration in their respective countries, in addition to discussing a selected topic. Where possible, these workshops will be linked to other relevant conferences.

In 2018, a meeting was held in Augsburg, Germany, 24th-25th October 2018, hosted by Erdgas Schwaben. The participants came from Sweden, Austria, Denmark, Japan, Switzerland, USA and Germany.

In 2019, a meeting took place in Naples, Italy in December 2019, during the next European Fuel Cell Conference, Naples 9th -11th December 2019, and was hosted by ENEA. The participants came from Austria, Italy, Germany, Japan, USA, Switzerland and Spain.

4.4.2. Technical Developments

This Annex has been focused mainly on information sharing and learning between experts with knowledge and experience on fuel cells technologies for stationary applications. In particular, the technical developments in this Annex are described as follows:

Subtask 1 Small stationary fuel cells. This subtask handles markets for residential stationary fuel cells, where there is a viable economic and environmental case, analysing how the market varies between countries, including energy prices and the framework for the use and production of electricity and heat. In this subtask the mission is to investigate market possibilities and viability for small residential stationary fuel cells as well as residential fuel cells for larger buildings. The work in the Subtask includes comparison between different technologies ICE engines, Stirling engines, PEFC and SOFC.

A detailed analysis on Japan has been analysed, where the market activities for small stationary fuel cells for residential use have increased significantly on several places. The outstanding region is Japan with now more than 314 000 fuel cells installed within the Ene-Farm program, where of 162 000 Panasonic's PEFC. The actual selling price is 8800 $/unit for SOFC and 7000 $/unit for PEFC. For PEFC Ene-Farm,there are no subsidy programs at the moment, but for SOFC Ene-Farm, subisidy is still adapted. Japan is very active also in the transport sector, where 108 HRS have been opened with 3300 FCV running. Panasonic is one of the three suppliers of microCHP systems in the ENE-Farm program. A new model has been introduced in 2017 and it have already reached 90 000 hr of operations. Panasonic presented the new model using hydrogen as a fuel for cogeneration and monogeneration which will be ready for 2021, having a power generation efficiency of 56%.

In Italy, SOLID POWER is a developer and manufacture of complete SOFC system. SOLID POWER has acquired the German part of CFCL, Ceramic Fuel Cell including the BlueGen and the manufacturing facilities in Germany. In 2019 Solid Power has opened a new production plant in Italy with 50 MW/y planned. Solid Power has installed 1500 units in 12 countries. The main product today from SOLID POWER is a 1,5 kWe unit called BluGen BG15. The electric efficiency is high about 60 % AC for the complete system. SOLID POWER is participating in several EU projects including PACE project, where the objective is to install 10 000 units in 2020. The next step for SOLID POWER is to develop larger units from 6 kWe based on the existing in house technologies.

Subtask 2 The implementation New Directives and Regulations. This subtask handles the implications for stationary fuel cells caused by the introduction of new Directives or relevant legal regulations and standards. Effects on the increase of fuel cell competitiveness has been discussed to provide IEA-qualified input to the ongoing regulatory processes, elaborating recommendations and justifications as needed. There are several new directives regarding energy issues that will influence the future market for fuel cells. The Subtask focuses on Europe but also other region will be dealt with. In particular, the upcoming EU regulations and directives strongly influence the market uptake of fuel cell systems. The aim of this Subtask is to identify upcoming opportunities or threats from the implementation of the EU directives and regulations in the various countries, as Energy Efficiency (EE) Directive, Ecodesign and Labelling Directive, Building Directive (EPBD), RES renewable Energy Systems Directive.

Subtask 3 Large scale fuel cell applications. This subtask handles the analysis of technology and market development of large fuel cell plants. These are often used in parallel with the grid in sensitive applications, such as hospitals, banks, offices, warehouses and supermarkets.

Subtask 4 Fuel cells in the future energy systems. This subtask handles the new application for fuel cells in the near future energy systems, and in particular the opportunities concerning the use of renewable fuels and hydrogen, applications for H2 mobility, smart grids, power to gas, and other applications where FCs can play a pioneering role. Two main FCH JU funded project has been presented: CH2P and SWITCH. The purpose of the CH2P project is to realize a new technology at high efficiency and limited impact on carbon emissions, able to generate hydrogen and power for use in refuelling stations of the next future impacting the sustainability of the transport sector. In the project SOFC is used in a new flexible and variable way, including reversible mode in next future; it combines hot and cold components with capacity to reach high efficiency, low costs and highly pure hydrogen production. Using one single technology, it can realize the distribution of all the alternative fuels of the EU – compliant with the DAFI directive. SWITCH project is the next step, with the production of green hydrogen in a flexible and reversible way.

Moreover, Annex 33 has been involved from IEA in the data collection for technical and economic information and market deployment of stationary fuel cells applications, and a report has been prepared (under revision).

4.4.3. WORK PLAN

The work and the meeting schedule will continue as planned in the next years.

Annex 33 intends to expand and to conduct activities to attract new members, above all from international countries as US and Canada.

Because of the covid-19 emergency, it is not possible at this moment to schedule the next meeting.

COUNTRY	COMPANY / INSTITUTION
AUSTRIA	Austrian Energy Agency
FINLAND	VTT, Convion
FRANCE	Engie
GERMANY	Sunfire
ISRAEL	GenCell
ITALY	ENEA (Operating Agent), SolidPower
JAPAN	Technova, Toshiba, Panasonic, AISIN Seiki
KOREA	KIST, Doosan

SWEDEN	Sweco, PowerCell
SWITZERLAND	Beratung Renz Consulting
SPAIN	CNH2
USA	DoE, Gaia Energy Research Institute

Table 13: List of participating organizations in Annex 33

4.5. ANNEX 34: FUEL CELLS FOR TRANSPORTATION

KEY MESSAGES ANNEX 34– FACTS

- Commercial fuel cell vehicles from Honda, Hyundai and Toyota are available for purchase or lease. These refuel in minutes, have up to 360 mi range, and offer 66-mpgge or comparable fuel economy.
- A fuel cell electric bus (FCEB) in the United States DOE-DOT project has exceeded the 2016 durability target of 25,000 h in June 2017.
- Industry's first heavy-duty fuel cell truck has been placed in service at Los Angeles Port Authority. Fuel cell electric delivery and parcel trucks have been delivered to UPS and FedEx. Over 15,000 fuel cell forklifts have been deployed or are on order.
- World's 1st 4-seater fuel cell plane took off at a German airport in Stuttgart. 1st fuel cell cargo tow trucks have been deployed at an U.S. airport.
- World's 1st hydrogen fuel cell train has been launched in Germany. Two trains built by the French company Alstom are operating on a 62-mile stretch in northern Germany.

KEY MESSAGES ANNEX 34 – OBSERVATIONS

- FCS cost status: $50/kW for 100,000 systems/year, $45/kW for 500,000 systems/year
- FCS Goal for LDVs: $30/kW and 8,000 hours of durability
- Examples of Early Stage R&D Needed to Meet the FCS Goals
- Low-PGM and PGM-free catalysts
- Durability and performance of membranes, bipolar plates, electrodes, etc.
- Pt loading improvement
- H2 Production, Delivery & Dispensing: $16/kg - $13/kg status at low production volume and limited market penetration, $10/kg - $5/kg status at high production volume and competitive market penetration, <$4/kg ultimate target

- On-board Storage Cost of 700-bar Compressed System: $24/kWh status at low production volume, $17/kWh projected status at 100K/year, $15/kWh projected status at 500K/year; $8/kWh ultimate target

The objective of Annex 34 is to develop an understanding of fuel cells for transportation with their particular properties, applications, and fuel requirements. Vehicles addressed include fork-lift trucks, passenger cars, auxiliary power units (APU), buses, light duty vehicles and aviation power. Annex 34 consists of the following four subtasks.

Subtask A: Advanced Fuel Cell Systems for Transportation

- Fuel cell system and hydrogen storage technology
- Current issues and areas of research

Subtask B: Fuel Infrastructure

- Distributed and central hydrogen production technologies
- WTW studies

Subtask C: Technology Validation

- Light duty vehicles and buses
- Hydrogen production

Subtask D: Economics

- Automotive fuel cell systems and on-board hydrogen storage
- Hydrogen production and delivery infrastructure

This Annex has been in operation since February 2009 and will run until February 2024. The Operating Agent for this Annex is Dr Rajesh Ahluwalia from the United States Department of Energy's Argonne National Laboratory (ANL) in Illinois.

4.5.1. Activities

To date, the Annex has held ten workshops. The workshops consist of technical presentations and discussions with particular emphasis on PEFC membrane electrode assemblies and stacks, hydrogen infrastructure, technology validation, and economics. Representatives from the member countries participate in the workshops.

4.5.2. TECHNICAL DEVELOPMENTS

Cost and durability are regarded as crucial issues in fuel cells for transportation. The cost issues are related to the use of noble metals in electrocatalysts and their current low production volumes. The durability issues arise because of the added stresses placed on the cells due to load (cell potential) cycling and rapidly varying operating conditions of fuel and air flow rates, pressures, temperatures, and relative humidity.

Subtask A: Advanced Fuel Cell Systems for Transportation

Whereas catalysts and MEAs do not meet the durability targets on standard accelerated stress tests (ASTs), engineering solutions are available to extend the stack lifetime by controlling the operating conditions. Figure 9 shows some controls that can be implemented to limit the cell voltage during stack idling, to avoid the formation of H_2-air front during start-up by depleting oxygen during stack shutdown, and to prevent icing during sub-freeze start by maximizing in-stack heat production.

Recent studies indicate that 80-kW$_e$ stacks with state-of-the-art (SOA) alloy catalysts can reach 1180 ± 55 mW/cm^2 gross power density, exceeding the target of 1000 mW/cm^2 at low Pt loadings (0.125 mg-Pt/cm^2 total). The projected FCS cost is 46.0 ± 0.7 \$/kW$_e$ at 2.5 atm stack inlet pressure and 95°C stack coolant outlet temperature for high volume manufacturing (500,000 units/year).

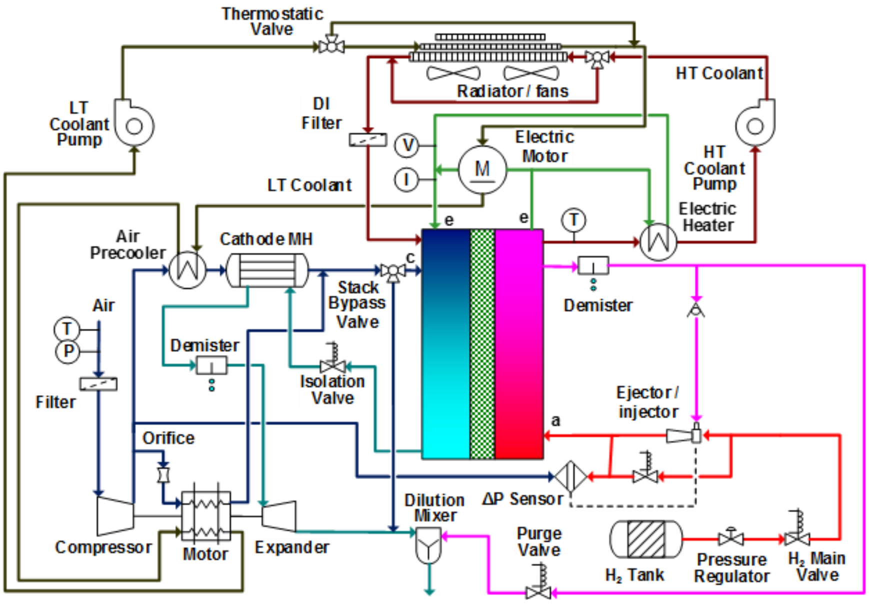


Figure 9: FCS Configuration with Controls. Ref.: R.K Ahluwalia, X. Wang, and J-K Peng, "Fuel Cell System Modeling and Analysis," US DOE Hydrogen and Fuel Cells Program, 2018 Annual Merit Review and Peer Evaluation Meeting, Washington D.C., June 13-15, 2018.

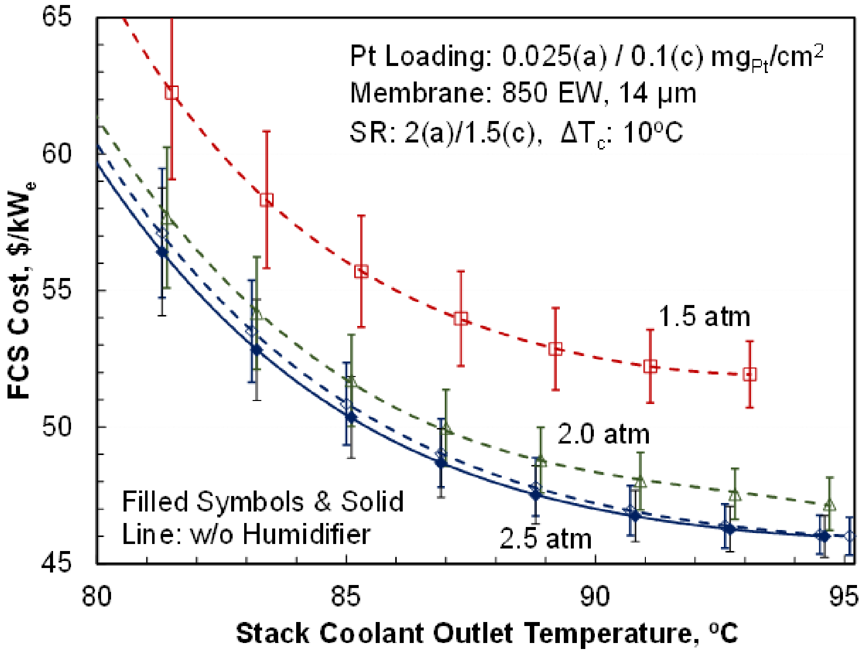


Figure 10: Performance of Automotive FCS with SOA d-PtCo/C Cathode Catalyst. Ref.: R.K Ahluwalia, X. Wang, and J-K Peng, "Fuel Cell System Modeling and Analysis," US DOE Hydrogen and Fuel Cells Program, 2018 Annual Merit Review and Peer Evaluation Meeting, Washington D.C., June 13-15, 2018

Improved understanding of electrode microstructure and catalyst-ionomer interfaces is required to optimize the kinetics of oxygen reduction reaction in cathodes and to facilitate water transport. A method has been developed to reconstruct electrode microstructure at 1-nm resolution by supplementing nano-computed tomography with data from multiple techniques including transmission electron microscopy, ultra-small angle X-ray scattering and porosimetry. The method provides unique insights into transport phenomena that limit cell performance at high current densities. Figure 11 shows a representative ionomer size distribution in which the larger sizes (15-30 nm) correspond to ionomer agglomerates whereas film sizes are in the 5-10 nm range.

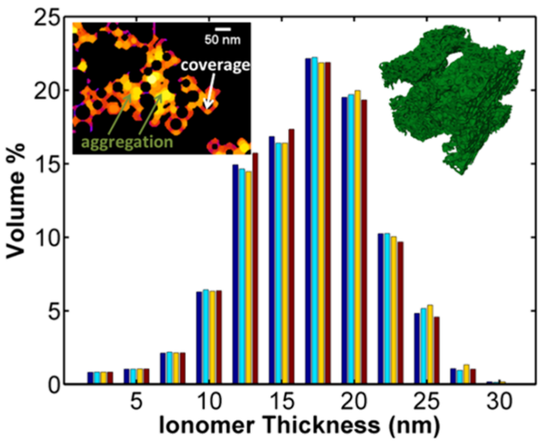


Figure 11: Electrode microstructure reconstruction

Meeting the ultimate FCS cost target of $30/kW for LDVs may require PGM-free catalysts. High-throughput synthesis and characterization methods are being used to screen precursors, solvents and heat treatment protocols for enhanced activity of PGM-free (Zn_xFe_{1-x})ZIF-F-derived catalysts for oxygen reduction reaction. Figure 12 shows highest activities for iron nitrate and sulfate precursors, with pyrolysis temperatures of 900°C and 1000°C and intermediate iron to zinc atomic ratio (2.5/97.5, 5/95). The next step is to scale up the promising compositions and test their performance in an MEA.

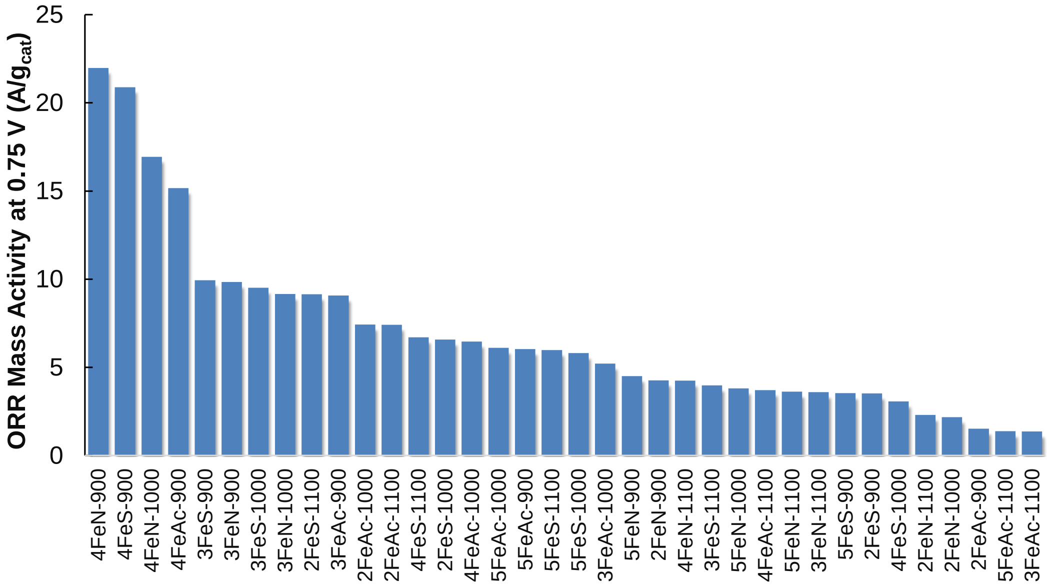


Figure 12: High-throughput synthesis and characterization. ORR activities determined using m-CFDE cell. Ref. D. Myers and P. Zelanay, ElectroCat (Electrocatalysis Consortium), 2018 Hydrogen and Fuel Cell Annual Merit Review

Subtask B: Fuel Infrastructure

Different countries are pursuing customized strategies and plans to develop the hydrogen infrastructure. Figure 13 is a snapshot in time depicting the 2018 planned and operating, public and private, refueling stations in France and the size of FCV fleet to be served.

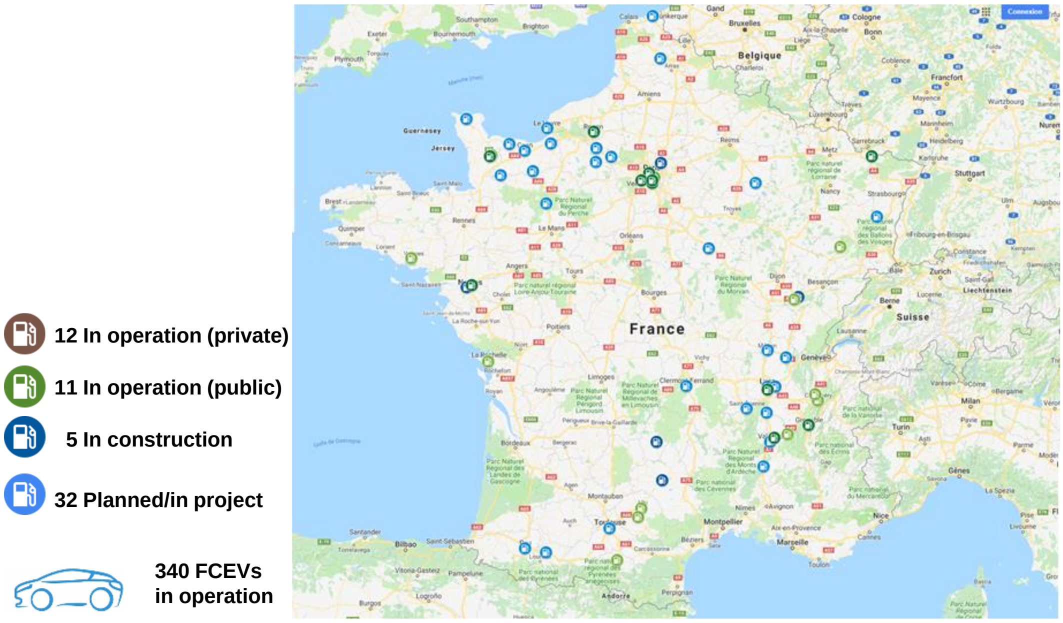


Figure 13: Development of Hydrogen Infrastructure in France. Source: Mobilite Hydrogen France

Subtask C: Technology Validation

As shown in Figure 14, a fuel cell powerplant (FCPP) in NREL FCEB Evaluation has exceeded 30,000-h lifetime, six FCPPs have surpassed the DOE/DOT ultimate target of 25,000 h, and twelve FCPPs have operated for more than 20,000 h.

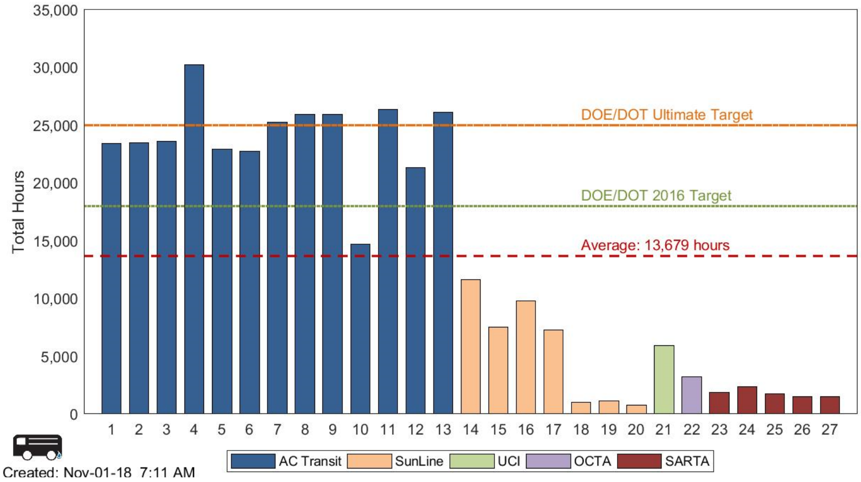


Figure 14: Total hours accumulated on each FCPP as of 9/30/18. Source: DOE Annual Merit Review presentation: https://www.hydrogen.energy.gov/pdfs/review18/tv008_eudy_2018_o.pdf

The performance of the state-of-the-art (SOA) fuel cell system in Toyota Mirai has been benchmarked. As shown in Figure 15, the maximum electric power outputs are 110 kW at FC stack, 105 kW at FC boost converter, and 90 kW at FC system level. The peak stack and system efficiencies are 66% and 63.7%, respectively.

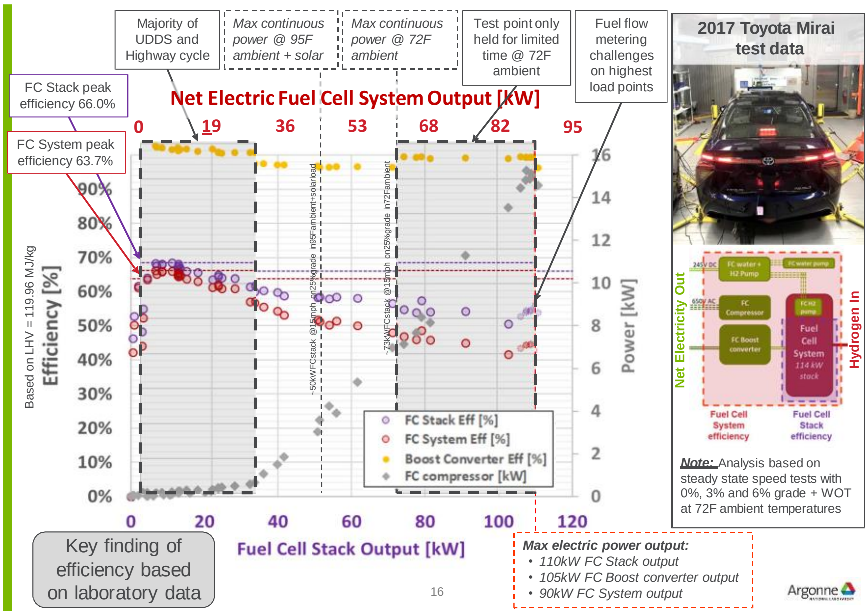


Figure 15: Technology Assessment of a Fuel Cell Vehicle: 2017 Toyota Mirai. Ref. Henning Lohse-Busch, US DOE Hydrogen and Fuel Cells Program, 2018 Annual Merit Review and Peer Evaluation Meeting, Washington D.C., June 13-15, 2018

Table 14: Benchmarking of SOA Components in Mirai. Ref. FC135: FC-PAD: Fuel Cell Performance and Durability Consortium, 2018 DOE Fuel Cell Technologies Office Annual Merit Review benchmarks the materials in the state-of-the-art fuel cell components in Toyota Mirai. The MEA has PtCo/C alloy catalyst in cathode with 0.315 mg/cm^2 Pt loading, Pt/C catalyst in

anode with 0.05 mg/cm^2 Pt loading, for a total Pt loading of 0.365 mg/cm^2. The PTFE-reinforced membrane is 10-10.5 μm thick, has 900 equivalent weight, and is stabilized with a high concentration of CeO_x particles in the anode and cathode microporous layers (MPL). The titanium bipolar plate has 3-D structured flow field in cathode and a serpentine flow field in anode.

Cathode
- PtCo/C: Pt = 87mole%, 0.315 mg_{Pt}/cm^2
- Cathode layer ~9 μm; decreases to ~8.1 μm
  300 h: 4.86 nm – Pt-Pt: 2.747
  3000 h: 4.96 nm – Pt-Pt: 2.745

Anode
- Anode layer ~ 2.3 mm; 0.050 mg_{Pt}/cm^2

GDLs
- Anode: ~150 μm total with ~60 μm MPL
- Cathode: ~160 μm total with ~40 μm MPL
- High concentration of CeO_x particles in MPLs: ~60 $\mu g_{Ce}/cm^2$ on cathode; ~120 $\mu g_{Ce}/cm^2$ on anode

Membrane
- ~10 – 10.5 μm with ePTFE; Nafion side chain
- EW of membrane ionomer ~ 901±1 g/meq

Bipolar Plate
- Cathode Ti foil, with Ti porous mesh; ~ 80 nm carbon coating
- Anode serpentine; ~ 80 nm carbon coating

Catalyst AST (0.6 – 0.95V square wave)
- ~25% ECSA loss after 30k cycles; CL thinning to 6μm
- VIR performance loss: ~ 25 mV at 1.0 A/cm^2
- XRD/TEM show particle growth and loss of Co
- Particle growth from 4.7 to 6.7 nm

Carbon Corrosion AST
- Electrode structure is more resistant to carbon corrosion than Pt/HSAC
- Catalyst support fails performance test at 5000 cycles

Table 14: Benchmarking of SOA Components in Mirai. Ref. FC135: FC-PAD: Fuel Cell Performance and Durability Consortium, 2018 DOE Fuel Cell Technologies Office Annual Merit Review

Subtask D: Economics

Figure 16 compares the preliminary costs for fuel cell systems for medium-duty (MDV) and light-duty vehicles. The MDV cost curves are shallower due to low-volume manufacturing assumptions/criteria representative of the bus system. The large cost differences between LDV and MDV systems at 100k units/yr are due to Pt loading (0.125 vs. 0.35 mg_{Pt}/cm^2), parasitic power of the air management system, and non-vertical integration (application of extra markup and job shop for trucks).

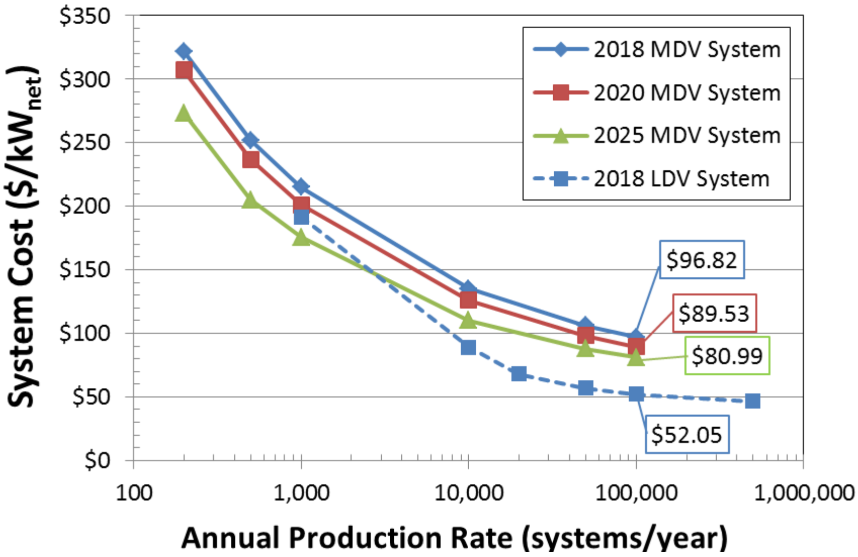


Figure 16: Preliminary cost results for MDV systems. Ref. Strategic Analysis, US DOE Hydrogen and Fuel Cells Program, 2018 Annual Merit Review and Peer Evaluation Meeting, Washington D.C., June 13-15, 2018:

4.5.3. Work Plan

Some of the key areas that the Annex are focusing on for future work include investigating the niche applications that are attractive for market entry of fuel cell vehicles, investigating the main cost and durability barriers to mass adoption of fuel cells for light duty vehicles and looking into the future competitors to help address the questions of reduction of GHG emissions and fossil fuel consumption. Future work will also emphasize heavy-duty applications for trucks, rails, maritime and airplanes.

COUNTRY	COMPANY / INSTITUTION
AUSTRIA	A3PS
CHINA	Tsinghua University, Sunrise Power Co
DENMARK	EWII (IRD Fuel Cells)
FRANCE	CEA Liten
GERMANY	Forschungszentrum-Jülich GmbH
ITALY	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
KOREA	KIST, Hyundai Motor Corporation
SWEDEN	Volvo Technology Corporation, PowerCell
USA	Argonne National Laboratory (ANL)

4.6. ANNEX 35: FUEL CELLS FOR PORTABLE APPLICATIONS

The Annex 35 is a dedicated collaboration platform for the development of fuel cell-based applications in the field of portable systems.

The portable fuel cell market has evolved significantly in the last two years. The already well-established market of forklift systems provided the hard bottom over which other technology developments are undergoing, with significant cost reduction and system reliability. The wider use of unmanned systems, both airborne and waterborne, has pushed fuel cells (PEM technology) as battery replacement or inside hybrid systems. Besides, the request for small range extender applications for light-duty vehicles (1-20 kW) is growing and represents a further impulse to market penetration.

In 2018 and 2019 no annex meeting took place due to organizational challenges. It is planned to hold an annex meeting in the end of 2020 which will include a new partner proposal and the need to foster the collaboration with industry partners, creating a stronger link between research and industry.

4.7. ANNEX 36: SYSTEMS ANALYSIS

Fuel cells are distinguished with their high efficiency and low emissions. They are seen as competitive products which can replace conventional energy conversion technologies. However, conventional technologies are further improved and additionally there are other competitive technologies. Therefore, it is necessary to identify the current technology level and the future potential of fuel cells based on sound technical and scientific studies.

The aim of Annex 36 is to assist the development of fuel cells through analysis to enable a better interpretation of the current status, and the future potential, of the technology. This work provides a competent and factual information base for technical and economic studies. The leaders for this Annex, acting as the Operating Agent, are Professor Detlef Stolten of Forschungszentrum Jülich, Germany and Dr. Nancy Garland of United States Department of Energy (DOE).

In the report period, the Systems Analysis Annex acted as a supporting platform for ad hoc analysis as well as data collection.

4.7.1. ACTIVITIES

Based on a webinar with participants from Germany, U.S., Italy, Spain, South Korea, France and New Zealand (guest status) at the end of 2017, the annex defined the following topics of interest:

- Global overview of hydrogen refueling stations looking at the technical details of stations, different technologies present at different countries,
- International analysis of different applications for cars, trains, buses, trucks, boats etc. with respect to the infrastructure,

- Global info on vehicles and infrastructure including hydrogen refueling stations,
- Analysis of applications where fuel cells are economically the best choice, e.g. electricity storage, grid support, vehicles, etc.
- Analysis of international opportunities for hydrogen import.

Among these activities, the focus of the Annex was given to two aspects in the reporting period. Firstly, due to the rapid developments on fuel cell electric trucks for heavy-duty application, the Executive Committee defined the topic “Heavy-duty Transport with Fuel Cells” as the focus topic for its 57th Meeting in Linz. The Systems Analysis Annex contributed to this focus topic with three presentations. In the first presentation, fuel cell electric trucks, Dr. Remzi Can Samsun (Forschungszentrum Jülich, Germany) reported on the motivation for fuel cell electric trucks, truck classification, state-of-the-art on fuel cell electric trucks and announcements, analysis of storage and system concepts and benchmarking, challenges and chances and concluded with lessons learned. Secondly, Dr. Nancy Garland (U.S. Department of Energy) reported on the recent developments in the U.S. on hydrogen fueled heavy-duty vehicles. In the third presentation, Simonas Cerniauskas (Forschungszentrum Jülich, Germany) discussed some considerations on infrastructure for road and rail applications, showing that hydrogen is cost competitive with conventional fuels (after-tax) by 2024-2029 and a cost competitive hydrogen infrastructure can be developed within 5-10 years of investment. These three analysis presentations contributed to the discussion in the Executive Committee, which took the decision to set-up a subtask on heavy-duty vehicles in Annex 34: Transportation as the next step in order to explore the topic more intensively in AFC TCP.

In agreement with the topics defined in the 2017 webinar, the second focus of activities was given to monitoring the development of the number of fuel cell vehicles and infrastructure worldwide. The Systems Analysis Annex offered the platform for data collection, analysis and reporting for the annual surveys. The first survey gave a closer look at the deployment of fuel cell electric vehicles as of end of 2017 and was published in 2018. More than 7000 passenger vehicles were on the road that time, with Toyota Mirai being the most-sold fuel cell electric vehicle in the world with more than 6000 units. In addition, more than 250 fuel cell electric buses were on the road in North America, Europe and China as of end of 2017. The 2019 survey, which summarized the numbers as of end of 2018, showed that the total stock of fuel cell vehicles increased to 12,900 vehicles. From that, the number of passenger cars registered was 11,212. The number of hydrogen refueling stations increased to 376 at the end of 2018. At the end of 2019, the total number of fuel cell vehicles on the road (all vehicle types) was estimated as more than 25,000 by the AFC TCP data collection effort, whereas the number of hydrogen refueling stations increased to 470. The data collection was accompanied by analyses on the distribution of vehicles to different vehicle types, countries and continents as well as a theoretical analysis allocating each registered vehicle to a station in the six countries with the highest numbers of hydrogen refueling stations worldwide. Apart from announced targets, visions and projections on a country or regions basis, which are updated annually, the recent analysis also contained information on selected vehicles, subsidy schemes and purchase prices of vehicles in selected countries as well as available technical information on hydrogen refueling stations.

4.7.2. Work plan

The System Analysis Annex will support the Executive Committee and the IEA Secretariat further with coordinating the data collection and analysis effort. Additional topics within the above-defined scope will be handled as ad hoc topics, as it was case with the presentations on heavy-duty transportation with fuel cells in 2018.

COUNTRY	COMPANY / INSTITUTION
GERMANY	Forschungszentrum Jülich GmbH
UNITES STATES	Department of Energy
FRANCE	Alternative Energies and Atomic Energy Commission (CEA)
SOUTH KOREA	Korea Institute of Science and Technology

Table 15: List of participating organizations in Annex 36

4.8. Annex 37: Modelling of fuel cells

KEY MESSAGES ANNEX 37 – FACTS

- Virtual prototyping is an important component in the product cycle of fuel cells
- Open source software allows the engineer complete technical control over the entire model
- By sharing the interface among groups (public access), development is accelerated, without compromising the specific application which remains private
- The AFC TCP is an excellent catalyst for bringing together and focusing international modeling groups in a synergistic manner

KEY MESSAGES ANNEX 37 – OBSERVATIONS

- Best people to develop fuel cell models are fuel cell engineers/scientists, assisted by numerical specialists, not CFD specialists with limited knowledge of electrochemical processes
- By invoking object-oriented principles, it is possible to build better models, without re-inventing the wheel, but rather by re-using and re-cycling existing classes, wherever possible
- The open source paradigm is best suited to a shared environment where individuals from different organizations and backgrounds collaborate ‘at a distance’

- Calculations may readily be performed on high performance computers taking advantage of massively parallel architectures

Annex 37 of the Advanced Fuel Cells Technology Collaboration Programme (AFC TCP) spearheads the development and application of open-source fuel cell modelling code, as well as the knowledge base (data) to facilitate the rapid advancement of fuel cell technology. This is done through the development and application of advanced open-source computational fluid dynamics (CFD) models of fuel cells, electrolyzers and other electrochemical processes and products in a shared environment. The present focus is directed equally at solid oxide fuel cell and electrolyzer (SOC) and polymer electrolyte fuel cell and electrolyzer (PEC) technologies.

4.8.1. Activities

Development of a review paper on solid oxide cell modelling at continuum level: Revised manuscript now in preparation. Authors: Steven B. Beale (Germany), Martin Andersson (Sweden), Carlos Boigues-Muñoz (Italy), Henrik L. Frandsen (Denmark), Zijing Lin (China), Stephen J. McPhail (Italy), Meng Ni (China), Bengt Sundén (Sweden), André Weber (Germany) and Adam Z. Weber (USA)

Development of a book of invited chapters from member countries: ”Electrochemical cell calculations with OpenFOAM” editors: Steven Beale and Werner Lehnert (Germany). In preparation.

Round robin tests of low temperature polymer electrolyte fuel cells. Participating organisations: TU Graz (Austria), KIT (Germany), CNR (Italy), FZ Jülich (Germany), Tsinghua U (China). In conjunction with Annexes 31 and 35. Work in progress.

Annex 37 meetings held in 2018-2019:

- 18 April 2018 Brussels, Belgium (Host ENEA Italy)
- 4 October 2018 Cancun, Mexico (Host ECS USA)
- 14 March 2019, Brunswick, Germany (Host ModVal Germany)

Annex 37 operating agent attended the following ExCo meetings:

- 56th ExCo meeting February 2018, Tokyo, Japan
- 58th ExCo meeting PyeongChang, S. Korea
- 59th ExCo meeting September 2019, Rugao, China

4.8.2. Technical Developments

- Significant expansion to several software suites, multi-phase capabilities with evaporation condensation.
- Development of technical protocol for round robin tests of PEFCs
- Expansion of codes from fuel cells to electrolyzers

4.8.3. Work plan

Next annex meeting was scheduled to co-locate with PRiME conference in Honolulu, 4-9 October 2020, but has had to be cancelled due to health considerations. Instead a virtual meeting will be held in Q4 2020.

Further activities will be:

- SOC review paper to be submitted Q3 2020
- Book of chapters to be submitted to Springer by end of Q4 2020. 2-3 related conference calls have/will be held in 2020.
- Round robin tests of PEFCs to recommence when universities/research labs reopen their laboratories.
- France (CEA) and Germany (FZ-Jülich) to commence collaborative research program of software evaluation and comparison, Q4 2020.

COUNTRY	COMPANY / INSTITUTION
AUSTRIA	TU Graz
CANADA	Queen’s U
CHINA	Tsinghua U, Hong Kong Poly U, U Science and Tech
CROATIA	Zagreb U
DENMARK	DTU, SerEnergy
FRANCE	CEA-Liten
GERMANY	DLR, FZ Jülich, KIT, Wikki, HZ Dresden-Rossendorf, KIST Europe
ITALY	ENEA, CNR
KOREA	Donguk U, KIST
SPAIN	U Carlos III
SWEDEN	Lund U.
USA	LBNL, MichiganTech U, GM

Table 16: List of participating organizations in Annex 37

APPENDICES

APPENDIX 1: MEMBERSHIP INFORMATION

Further details on our activities can be found on our website at www.ieafuelcells.com. For further information regarding the International Energy Agency please visit www.iea.org.

For more information regarding specific Annex details, please contact the Operating Agents or key members of their teams from the information below.

CHAIR AND VICE CHAIR			
CHAIR	Prof. Dr. Detlef Stolten	Forschungszentrum Jülich GmbH, Germany	(+) 49 2461 613076 d.stolten@fz-juelich.de
VICE CHAIR	Yali Zheng	Society of Automotive Engineers of China (SAE China)	(+)86-15-201284639 zhengyl@sae-china.org

These details are correct at the time of publication (August 2020).

DESK OFFICERS AND SECRETARIAT			
IEA DESK OFFICER	Jacob Teter	International Energy Agency Paris, France	(+) 33 1 4057 6798 jacob.teter@iea.org
EXCO SECRETARIAT	Michael Rex	EE ENERGY ENGINEERS GmbH, Gelsenkirchen, Germany	(+) 49 211 86642284 secretariat@ ieafuelcell.com

These details are correct at the time of publication (August 2020).

Operating Agents of AFC TCP Annexes	Name	Organisation	Contact Details
Annex 30 - Electrolysis	Dr. Marcelo Carmo	Forschungszentrum Jülich GmbH,Germany	(+)49-2461-61-5590 m.carmo@fz-juelich.de
Annex 31 - Polymer Electrolyte Fuel Cells	Dr Di-Jia Liu	Argonne National Laboratory,USA	(+)1-630-252-4511 djliu@anl.gov
Annex 32 - Solid Oxide Fuel Cells	Dr Jari Kiviaho	VTT Fuel Cells,Finland	(+)358-20-722-5298 jari.kiviaho@vtt.fi
Annex 33 - Fuel Cells for Stationary Applications	Dr Viviana Cigolotti	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA),Italy	(+)39-081-772-3241 viviana.cigolotti@enea.it
Annex 34 - Fuel Cells for Transportation	Dr Rajesh Ahluwalia	Argonne National Laboratory,USA	(+)1-630-252-5979 walia@anl.gov
Annex 35 - Fuel Cells for Portable Applications	Dr Fabio Matera	Istituto di Technologie Avanzate per l'Energia (ITAE),Italy	(+)39-090-624-279 fabio.matera@itae.cnr.it
Annex 36 - Systems Analysis	Professor Dr Detlef Stolten	Forschungszentrum Jülich GmbH,Germany	(+)49-2461-613076 d.stolten@fz-juelich.de
	Dr Nancy Garland	Department of Energy,USA	(+)1-202-586-5673 nancy.garland@ee.doe.gov
Annex 37 - Modelling of Fuel Cells Systems	Professor Dr Steven Beale	Forschungszentrum Jülich GmbH,Germany	(+)49-2461-61-8856 s.beale@fz-juelich.de

These details are correct at the time of publication (August 2020).

APPENDIX 2: FUEL CELL COMPANIES

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION	WEBSITE
AUSTRIA					
AVL	System	Simulation software, monitoring technique, system ests and development		Automovite applications wih PEMFC; different applications with SOFC: range extender, CHP, electrolysis and Power-o-Gas	www.avl.com
Fronius	System	System developmen		All-in-one system for generation, storage and useage of H2	www.fronius.com
Bosch Austria	System	PEMFC		Automotive	www.bosch.at
Magna Steyr	Storage	Compressed (700 bar) and liquefied H2 storage		Automotive	https://www.magna.com/
OMV	HRS	700 bar H2 refuelling stations		Hydrogen refuelling stations	www.omv.com
RAG	Storage	-		Storage/Power to gas	http://www.rag-energy-storage.at
Energie Steiermark	System	System development		All-in-one system for generation, storage and useage of H2	https://www.e-steiermark.com/
ElringKlinger Fuelcell Systems Austria GmbH	Stack/system	PEMFC stacks, bipolar plates, key stack equipment		Mobile applications within industry sector; Integrated systems for automotive OEMs	https://www.elringklinger.com/
CHINA					
Weichai Power Co., Ltd.	System	Powertrain			https://www.weichai-power.com

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Wuhan Xiongtao Hydrogen Fuel Cell Technology Co., Ltd	System	Battery		UPS, communication, forklift, hydrogen fuel bus, power and other industrie	hydra-vision.com
Fujian Snowman Co., Ltd	System	Compressor		Hydrogen fuel cell air compresso	https://www.snowkey.com
Jiangsu Huachang Chemical Co., Ltd	System				www.huachang-group.com
Beijing SinoHytec Co., Ltd.	System			buses, logistic trucks, passenger cars, forklifts, trams, and stationary power supplies	www.sinohytec.com
Edelman hydrogen energy equipment co., LTD	System			Buses and logistic trucks	www.cemt-cn.com
ShanghaiRe-Fire Technology Co.,Ltd	System			Buses and logistic trucks	www.re-fire.com
SunrisePowerCo., Ltd.	System				www.fuel-cell.com.cn/sunrisepower/
Foresight Energy Co., Ltd				passenger cars, logistics vehicles, special vehicles, tour cars, tele-communication backup power supplies and other fields.	en.foresight-energy.cn

DENMARK

Ballard Power Systems Europe (formerly Dantherm Power)	Systems and service	PEFC		UPS/APU, vehicles (service) and maritime	http://ballard.com/about-ballard/ballardeurope/
Danish Power Systems	Stack components	MEA for HT-PEFC		All applications for HT-PEFC	www.daposy.com

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
IRD Fuel Cells	Stack components	MEA and BPP- flow plates		Automotive, back-up power and stationary	http://irdfuelcells.com/
Elplatek	Surface treatments and coatings	-		Advanced catalytic coatings for electrodes and FC	http://www.elplatek.dk/
Green Hydrogen.dk	Systems	PEM and alkaline		Alkaline Electrolysis	http://greenhydrogen.dk/
Haldor Topsoe A/S	Components and stacks	SOFC/SOEC		Mainly Electrolysis	http://www.topsoe.com/
NEL Hydrogen (Formerly H2Logic)	Hydrogen Fuelling Stations	Gaseous hydrogen		Transportation	https://nelhydrogen.com/
Blue World Technologies	stacks	MFC		automotive and mobile applications	https://www.blue.world/
Serenergy	stacks	MFC		Automotive, telecom, industrial	https://serenergy.com/
Rotrex A/S	H2 compressor	-		Automotive systems	www.Rotrex.com
EV Metalværk A/S	Hydrogen valves	-		Several applications	https://www.evmetal.dk/hydro-ball-valves/

FINLAND

Convion Oy	System	SOFC	20 – 300kW	Stationary	www.convion.fi
Elcogen Oy	Single cells and stacks	SOFC	1 – 10kW	Stationary	www.elcogen.com
ABB Oy	Power supply system solutions	PEMFC	10 kW – 3 MW	Marine	new.abb.com/marine
THT-Control Oy	System	PEMFC	<100 kW	Backup, stationary	www.thtcontrol.com

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION	WEBSITE
Oy Hydrocell Ltd.	Portable fuel cells	DMFC (EFOY PRO and SFC Defence)	<120 W	Recreational, back-up, military	www.hydrocell.fi

FRANCE

Ad-venta	Components			Storage, FC systems	www.innovative-gas-engineering.com/en/
Areva H2 Gen	Production	PEM Electrolyser	Tens to Hundreds kW	Storage, Transportation, backup	www.arevah2gen.com/
Helion Hydrogen Power	Systems	PEFC + electrolyser:	Hundreds kW	Grid stabilisation/emergency back-up systems	https://helion-hydrogen-power.com/
		Greenergy Box™			
Ataway	System		0.5kW to 50 kW	Clean and autonomous power supply for off-grid sites and transportation	http://atawey.com/
CEA	Component/stack/ system	SOFC, PEFC, SOEC, PEWE	10 W to 360 kW	R&D	www-liten.cea.fr/index_uk.htm
CNR	System			Green energy storage	http://www.cnr.tm.fr/en
CNRS	Component/stack/system			R&D	www.cnrs.fr
ENGIE	System			Energy provider	www.engie.fr/
GRT Gaz	System			Energy provider, power to gas	www.grtgaz.com/en
INERIS	System			Safety	www.ineris.fr/en
Mayhtec	Storage	Compressed, Hydride, Hybrid		Transportation, stationary	www.mahytec.com/fr/accueil.html

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION	WEBSITE
McPhy Energy	Production/Storage	Electrolyser,		Stationary storage, Transportation	www.mcphy.com/fr/
		Hydrogen Refiling Sta-tions			
Powidian	System	PEFC, Electrolysers	100W – 200 kW	Smart autonomous energy storage sta-tions	www.powidian.com
Pragma Industries	Stack, test equipment, electronic loads, hydrogen storage	Roll to roll PEFC	10 – 100W	Portable tools, bikes	www.pragma-indus-tries.com
Raigi	Storage	High pressure gas		Transportation	www.raigi.com/
Sylfen	System	Reversible SOFC	1-10 kW	Energy storage	www.sylfen.com
Symbio	System	PEFC	5kW,	Integrated cuel cells systems for Range Extenders (5kW) and Full Power heavy duty vehicles (20 – 300kW)	https://www.sym-bio.one/
			20 – 300kW		
WH2	System	Methanol, Hydrogen, PEFC	25-4kW	Clean and autonomous power supply from green H2	www.wh2.fr

GERMANY

Ätztechnik Herz GmbH & Co. KG	Stack (BPP)				Ätztechnik Herz GmbH & Co. KG
Audi AG	Stack/system (FCV)	PEFC		Transportation (PEFC)	Audi AG
balticFuelCells GmbH	Stack/system	PEFC		Stationary/transportation/portable (PEFC)	balticFuelCells GmbH

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Bosch (Robert Bosch GmbH)	Stack/system	PEFC, SOFC		Transportation (PEFC) / Stationary (SOFC)	Bosch (Robert Bosch GmbH)
Buderus	System			Stationary	Buderus
Clariant Produkte (Deutschland) GmbH	System (reformer catalysts)				Clariant Produkte (Deutschland) GmbH
Continental	System components	PEFC		Transportation (PEFC)	Continental
Daimler AG	Stack/system (FCV)	PEFC		Transportation (PEFC)	Daimler AG
DBI Gas- und Umwelttechnik GmbH	System			Stationary	DBI Gas- und Umwelttechnik GmbH
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Technical Thermodynamics	Stack/system	PEFC, SOFC		Stationary/transportation (PEFC/SOFC)	Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Technical Thermodynamics
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Networked Energy Systems	Stack/system	PEFC		Stationary/transportation (PEFC)	Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Networked Energy Systems
EBZ Entwicklung- und Vertriebsgesellschaft Brennstoffzelle mbH	System	SOFC		Stationary/transportation (SOFC)	EBZ Entwicklung- und Vertriebsgesellschaft Brennstoffzelle mbH
e.GO Rex GmbH	System	PEFC		Transportation (PEFC)	e.GO Rex GmbH
Eisenhuth GmbH & Co. KG	Stack (BPP)				Eisenhuth GmbH & Co. KG
EnBW Energie Baden-Württemberg AG	System (utility)			Stationary	EnBW Energie Baden-Württemberg AG
ElringKlinger AG	Stack	PEFC		Transportation (PEFC)	ElringKlinger AG

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
E.ON Technologies GmbH	System			Stationary	E.ON Technologies GmbH
EWE AG	System (utility)			Stationary	EWE AG
Forschungszentrum Jülich GmbH	Stack/system	SOFC, PEFC		Stationary/transportation/portable (SOFC/PEFC)	Forschungszentrum Jülich GmbH
Fraunhofer IMM	System (fuel processor)				Fraunhofer IMM
Fraunhofer-Institut für Keramische Technologien und Systeme IKTS	Stack/system	SOFC		Stationary/portable (SOFC)	Fraunhofer-Institut für Keramische Technologien und Systeme IKTS
Fraunhofer-Institut für Solare Energiesysteme ISE	Stacks/system	PEFC		Transportation/portable (PEFC)	Fraunhofer-Institut für Solare Energiesysteme ISE
Fraunhofer-Institut für Chemische Technologie ICT	Stacks/system	PEFC		Transportation/portable (AFC/PEFC)	Fraunhofer-Institut für Chemische Technologie ICT
Freudenberg Performance Materials	Stack components/ system components	PEFC		Stationary/Transportation/Portable (PEFC)	Freudenberg Performance Materials
Freudenberg Sealing Technologies GmbH & Co. KG	Systems	PEFC		Stationary (PEFC)	Freudenberg Sealing Technologies GmbH & Co. KG
FCP Fuel Cell Powertrain GmbH	Systems			Stationary / Transportation	FCP Fuel Cell Powertrain GmbH
FuelCell Energy Solutions GmbH	Stack/system			Stationary	FuelCell Energy Solutions GmbH
FuMA-Tech GmbH	Stack (membranes)				FuMA-Tech GmbH
Horiba FuelCon GmbH	System (Test systems)	PEFC/SOFC		PEFC/SOFC	Horiba FuelCon GmbH

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Greenerity GmbH	Stack components (MEA)	PEFC		Transport / Stationary (PEFC)	Greenerity GmbH
Gräbener Machinentechnik GmbH	Stack components (BPP)				Gräbener Machinentechnik GmbH
GSR Ventiltechnik GmbH & Co. KG	System components (valves)				GSR Ventiltechnik GmbH & Co. KG
HAW Hamburg	System			Stationary/transportation	HAW Hamburg
Heliocentris Academia International GmbH	System (Teaching)			Stationary	Heliocentris Academia International GmbH
HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies	Stack components /systems	PEFC		PEFC	HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies
Hydrogenious Technologies GmbH	Systems (storage)				Hydrogenious Technologies GmbH
H2 Mobility Deutschland GmbH & Co. KG	Systems (hydrogen infrastructure)			Transportation	H2 Mobility Deutschland GmbH & Co. KG
inhouse engineering GmbH	Stack/system	PEFC		Stationary (PEFC)	inhouse engineering GmbH
Karlsruher Institut für Technologie (KIT)	Systems, stack components			Stationary/transport	Karlsruher Institut für Technologie (KIT)
Linde Material Handling GmbH	System			Transportation	Linde Material Handling GmbH
Maximator GmbH	System components (hydrogen)				Maximator GmbH
NPROXX Jülich GmbH	System components (hydrogen storage)			Transportation	NPROXX Jülich GmbH
N2telligence GmbH	System			Stationary	N2telligence GmbH

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Polyprocess GmbH	Stack components (seal-ings)				Polyprocess GmbH
Proton Motor Fuel Cell GmbH	Stack/system	PEFC		Stationary/Transportation (PEFC)	Proton Motor Fuel Cell GmbH
Quin Tech	Stack/system			Supplier for Stationary / Transporta-tion / Portable	Quin Tech
SenerTec Kraft-Wärme-Energie-systeme GmbH	System			Stationary	SenerTec Kraft-Wärme-Energiesysteme GmbH
SFC Energy AG	Stacks/system	PEFC		Portable (PEFC)	SFC Energy AG
SGL Carbon	Stack components	PEFC		PEFC	SGL Carbon
SOLIDpower GmbH	System	SOFC		SOFC	SOLIDpower GmbH
Sunfire GmbH	Stacks/system	SOFC		Stationary/Transportation/Portable (SOFC)	Sunfire GmbH
TU Bergakademie Freiberg	System			Stationary/transportation/portable	TU Bergakademie Freiberg
Ulmer Brennstoffzellen Manufak-tur GmbH	Stacks/system	PEFC		Stationary/Transportation (PEFC)	Ulmer Brennstoffzellen Manufaktur GmbH
Umicore AG	Stack (Catalysts)				Umicore AG
Vaillant Deutschland GmbH & Co. KG	System	SOFC		Stationary (SOFC)	Vaillant Deutschland GmbH & Co. KG
Viessmann Werke GmbH & Co. KG	System	PEFC		Stationary (PEFC)	Viessmann Werke GmbH & Co. KG
WS Reformer GmbH	System	PEFC		Stationary (PEFC)	WS Reformer GmbH

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Stacks/system	PEFC		Stationary/Transportation/Portable (PEFC)	Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)
ZBT GmbH	Stacks/system	PEFC		Stationary/Transportation/Portable (PEFC)	ZBT GmbH

ITALY

Arco fuel cell	Stack and System	PEM		Back up / mobility	https://lnx.arco-fc.com/
CTS H2	System			Back up, Industry, Mobility	https://www.ctsh2.com/it/
Enapter	Stack and System	AEM Electrolyser		PTG	https://www.enapter.com/it
Genport	Stack	PEM, SOFC		Portable units	http://www.genport.it/la-nostra-missione/
McPhy	Stack and System	Electrolysers		Mobility – Industry - Ptg	https://mcphy.com/it
SolidPower	Stack and System	SOFC		Stationary units	https://www.solidpower.com/it/
SPI Consulting	Stack	Electrolysers		Ptg	http://spiconsulting.it/

ISRAEL

PoCell Energy	Automotive and Stationary Energy Applications			Automotive and Stationary	http://pocelltech.com/

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Phinergy	Al-Air Fuel Cell			Automotive Fuel Cell	http://www.phinergy.com/
GenCell	Stationary Fuel Cell and Hydrogen Storage	AFC		Stationary Fuel Cell	http://www.gencellenergy.com/
Elbit Systems	Flight	PEM		Drones	https://elbitsystems.com/
Electriq Global	Hydrogen Storage	Borohydride		Automotive	https://www.electriq.com/
Energy StorEdge	Hydrogen Storage	Formate		Automotive	https://www.nrgstoredge.com/
H2Pro	Hydrogen generation	Electrolysis			https://www.h2pro.co/

JAPAN

Aisin Seiki	System	SOFC	1kW class	Stationary	www.aisin.com/
Fuji Electronic	Stack/ystem	PAFC	100KW	Stationary	www.fujielectric.com/
Honda Motor	Stack/System	PEFC	100kW class	Transport	http://world.honda.com/
Kyocera	Stack	SOFC	1kW class	Stationary	http://global.kyocera.com/
Mitsubishi Hitachi Power Systems	System	SOFC	250kW class	Stationary	www.mhi.co.jp/en/index.html
Miura	System	SOFC	4.2 kW class	Stationary	www.miuraz.co.jp/en/
Murata Manufacturing	Stack	SOFC	1kW class	Stationary	www.murata.com/index.html

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Morimura SOFC	Stack	SOFC	1kW class	Stationary	N/A
Panasonic	Stack/System	PEFC	1KW class	Stationary	http://panasonic.net/
Toshiba Energy Systems	Stack/System	PEFC	1kW	Stationary	www.toshiba.co.jp/pro-duct/fc/ (in Japanese)
			100kW class		
Toyota Motor	Stack/System	PEFC	100kW class	Transport	www.toyota-global.com/

KOREA

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Doosan Fuel Cell	Stack & System	PAFC/PEFC	400kW, PAFC 1~10kW, PEFC	Distributed Power	www.doosanheavy.com
Hyundai Motors	Stack & System	PEFC	80–300kW	FCV and bus	www.hyundai.com
POSCO Energy	Stack & System	MCFC	300kW–2.4MW 100MW/yr production	Distributed Power/APU for Ship	www.poscoenergy.com
S Fuel Cell	Stack & System	PEFC	1~10kW	Building Power	www.fuelcell-power.co.kr/eng/in-dex.php

SPAIN

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
AJUSA	STACK & SYSTEM	PEM FC	1-10 kW	Stationary	https://ajusath.es/
CENTRO NACIONAL DEL HIDRÓGENO (research)	STACK & SYSTEM	PEMFC & SOFC	0.01–150 kW	Mobile and Stationary	https://cnh2.es/
CIEMAT (research)	STACK & SYSTEM	PEMFC & SOFC & MCFC	0.01–30 kW	Mobile and Stationary	https://cimat.es/
CSIC (research)	STACK & SYSTEM	PEMFC	0.01–10 kW	Mobile and Stationary	https://csic.es/
TECNALIA (research)	STACK & SYSTEM	PEMFC & SOFC	0.01–15 kW	Mobile and Stationary	https://tecnalia.com/
INTA (research)	STACK & SYSTEM	PEMFC	0.01–60 kW	Mobile and Stationary	https://inta.es/
AICIA (research)	STACK & SYSTEM	PEMFC	1–60 kW	Mobile and Stationary	https://aicia.es/

SWEDEN

PowerCell	Stack/system			100 kWe PEFC stack for automotive Back-up power, powerpacks and APU for trucks (PEFC and diesel reformer)	http://www.power-cell.se/
Cellkraft	Stack			Offgrid (PEFC)	http://cellkraft.se/fuel-cells/
myFC	Stack/system			PEFC system integration	
Impact coating	Material			PVD coatings for fuel cell bipolar plates	
Cell Impact	Manufacturing			Stamping of bipolar plates	

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION	WEBSITE
Catator	Systems			Small independent fuel cells system, for example instance unmanned air-crafts	
Sandvik MT AB	Material			Developer and manufacturer of metal-lic bipolar plates and interconnectors.	
Höganäs AB	Material			Manufacturer of metal powders. De-veloper of interconnect materials for SOFC.	

USA

Plug Power	Fuel cell stacks and systems	PEM	200, 1000, 2500, 5000 W	Backup power (telecommunications)	www.plugpower.com
Plug Power	Fuel cell systems	PEM	1400, 1500, 1600, 1700, 1900 W	Material handling equipment	www.plugpower.com
AvCarb	For fuel cell stacks	Gas diffusion systems	Electrical re-sistivity = 10-22 mΩ-cm2 at 1 MPa	Fuel cell – both mobile and stationary	https://www.avcarb.com/
Bloom Energy	Fuel cell system	SOFC	200-300 kW, modular up to 10s of MW	Stationary – data centers, microgrids, etc.	https://www.bloomenergy.com/
Doosan	Fuel cell system	PAFC	440 kW, fuel is hydrogen or natural gas	Stationary	https://www.doosanfuelcell.com/en/tech/tech-0102/
3M	Ionomers	PEM	725, 800 EW	Fuel cells, electrolyzers	https://www.3m.com/3M/en_US/oem-tier-us/applications/propul-sion/fuel-cell/

Company Name	Area (stack/system)	Type of technology	Scale/ range	Application	Website
Pajarito Powder	Catalyst supports	Graphite	400 m2/g (and higher)	Fuel cells	https://pajaritopow-der.com/
Pajarito Powder	PGM-free catalysts	e.g., Fe-N-C materials		Fuel cells	https://pajaritopow-der.com/
Proton/Nel	Electrolyzer	PEM	200, 400, 600 sccm; 4.8, 9.4, 18.8 SLPM	Water electrolyzer	https://www.proto-nonsite.com/
Giner, Inc.	membranes	PEM	700 EW	Fuel cells, electrolyzers	https://www.gine-rinc.com/
Treadstone	Coatings for electrochemi-cal systems	Bipolar plates	Units can coat up to 300,000 parts/year (automotive size fuel cell parts) and can coat parts up to 1 m2	Fuel cells, electrolyzers	http://www.treadstone-technologies.com/