Technology Collaboration Programme
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ANNUAL REPORT

2022

ADVANCED FUEL CELLS
TECHNOLOGY
COLLABORATION
PROGRAMME

The AFC TCP, the Technology Collaboration Programme on Advanced Fuel Cells, is a program of Research, Development and Demonstration on Advanced Fuel Cells organized under the auspices of the International Energy Agency (IEA) but is functionally and legally autonomous. Views, findings, and publications of the AFC TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.
This Annual Report has been prepared by the National Members, Task Managers and the Secretariat of the Executive Committee, who also acted as editor.
You can obtain copies from the program's website at www.ieafuelcell.com or from:

Michael Rex
EE ENERGY ENGINEERS GmbH
Secretary, Advanced Fuel Cells Executive Committee
Munscheidstraße 14
45886 Gelsenkirchen
Germany
secretariat@ieafuelcell.com

Name	Organization	Country
Dr Günter Simader	Austrian Energy Agency	Austria
François Girard	Natural Resources Canada	Canada
René-Pierre Allard	Natural Resources Canada	Canada
Boris Zhang	Society of Automotive Engineers of China	China
Helen Zhao	Society of Automotive Engineers of China	China
Dr Ankica Kovac	University of Zagreb	Croatia
Prof Dr Frano Barbir	University of Zagreb	Croatia
Mads Lyngby Petersen	Danish Energy Agency	Denmark
Dr Jari Kiviaho	VTT Fuel Cells	Finland
Aymeric Canton	Commissariat à l'énergie atomique et aux énergies alternatives	France
Thierry Priem	Commissariat à l'énergie atomique et aux énergies alternatives	France
Prof Dr Detlef Stolten	Research Center Juelich	Germany
Dr R Can Samsun	Research Center Juelich	Germany
Dr Gideon Friedmann	Ministry of Energy	Israel
Ayelet Walter	Ministry of National Infrastructures, Energy & Water Resources	Israel
Dr Viviana Cigolotti	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile	Italy
Dr Stephen McPhail	Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile	Italy
Eiji Ohira	New Energy and Industrial Technology Development Organization	Japan
Dr Sang Jin Moon	Doosan Fuel Cell BG	Korea
Dr Jonghee Han	KENTECH Institute of Hydrogen Energy	Korea
Dr Emilio Nieto Gallego	Centro Nacional del Hidrógeno	Spain
Roberto Campana Prada	Centro Nacional del Hidrógeno	Spain
Emma Westsson	Swedish Energy Agency	Sweden
Dr Hans Pohl	Pohl Research & Innovation AB	Sweden
Dr Stefan Oberholzer	Swiss Federal Office of Energy	Switzerland
Prof Dr David Hart	E4tech Sárl	Switzerland
Dr Dimitrios Papageorgopoulos	Department of Energy	USA
Dr Shailesh Vora	National Energy Technology Laboratory	USA

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Chairman's welcome

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

COVID-19 presented a significant challenge to collaboration within the technology and energy sectors. The restrictions inflicted by the pandemic, such as travel limitations and social distancing measures, hindered the traditional modes of communication and cooperation among international organizations, companies, and institutions. Like many other programs, the AFC TCP faced obstacles in convening meetings, workshops, and conferences, which are essential for fostering research and development in fuel cell technologies. However, despite these challenges, we have adapted by leveraging virtual platforms and digital tools to continue our collaborative efforts. The pandemic has reinforced the importance of flexibility and innovation in maintaining effective global partnerships, and we remain committed to overcoming these obstacles to advance green energy and fuel cell technologies.

In our annual analysis of mobile fuel cell applications, we spotlight the current deployment of fuel cell vehicles in road transport and hydrogen refueling stations around the globe. In this year's analysis, we observed significant global growth of 37% to 72,193 fuel cell electric vehicles with regard to 2021 and a total of 1,022 hydrogen refueling stations. 90 % of all fuel cell vehicles are in operation in only four countries and 40 % of those in the Republic of Korea, followed by the United States, China and Japan.

However, vehicles and their refueling systems need a more progressive trajectory. Notably, encouraging trends have been observed in light commercial vehicles and heavy-duty trucks, where fuel cell vehicles have become an alternative to combustion vehicles. But also, the number of hydrogen refuelling stations in 2022 showed the sharpest increase since 2017, hence, the importance and determination towards fuel cell vehicles by industries, municipalities and governments.

Additionally, there is significant progress in developing and adopting green energy and fuel cell technologies worldwide. The European Union announced plans to invest €470 billion in green energy and transport projects over the next decade as part of its Green Deal initiative, focusing on boosting the production and use of hydrogen as a clean fuel source. The United States Department of Energy also announced a $100 million funding opportunity for research and development of hydrogen and fuel cell technologies, including hydrogen production from renewable sources.

In the automotive sector, Toyota, a leading manufacturer of fuel cell electric vehicles, announced plans to introduce 15 new battery-electric vehicles (BEVs) by 2025 in addition to its existing lineup of fuel cell vehicles. The South Korean government unveiled a roadmap to invest over $2 billion in hydrogen infrastructure and fuel cell vehicles by 2025, to use 2.9 million fuel cell electric vehicles and build 1,200 hydrogen refueling stations by 2040.

These encouraging developments demonstrate the increasing importance of green energy and fuel cell technologies in the global energy landscape. Our AFC TCP Tasks, dedicated to fostering research and development of fuel cells for transportation and stationary uses, are more crucial than ever in helping to drive these technologies forward.

Hence, we invite all companies and institutions from IEA member countries to join our tasks. Also, companies and institutions from non-member states are encouraged to contact us for membership consideration. Companies and institutions making use of the sponsorship schemes for the AFC TCP get the opportunity to participate in the Executive Committee meetings, which provide direct access to the latest global technical discussions on fuel cells and international networking opportunities.

For further information, please refer to the website www.ieafuelcell.com or contact us directly: secretariat@ieafuelcell.com.

Professor Detlef Stolten is Director of the Institute for Energy and Climate Research - Electrochemical Process Engineering at Research Center Julich, Germany. His research focus has been on systems analysis of CO_2-lean energy systems, electrochemistry, and process engineering for DMFC, HT-PEFC and SOFC technology.

Chairman of the AFC TCP

Introduction

The Technology Collaboration Programme on Advanced Fuel Cells aims to contribute to fuel cell technologies' research, development and demonstration (RD&D). 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.

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.

Th IEA is an intergovernmental organisation that was created in 1974 to help co-ordinate a collective response to major disruptions in the supply of oil. While oil security remains a key aspect of the work, the IEA has evolved and expanded significantly since its foundation. 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 TCP

The Technology Collaboration Programme (TCP) is a multilateral mechanism established by the International Energy Agency that was created with a belief that the future of energy security and sustainability starts with global collaboration. The program 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, 38 individual technology collaborations are working across several technology 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 AFC TCP aims to enhance knowledge through a coordinated exchange of information on international research and technology development, as well as conducting systems analysis. The program primarily concentrates on molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC), and polymer electrolyte fuel cells (PEFC), along with their applications in stationary power generation, portable power, and transport. An important aspect of the program involves sharing information through task-related meetings, workshops, and reports. The participating countries collaborate by sharing tasks and contributing an agreed level of effort across the tasks.

Executive committee report

Activities

In 2022, three Executive Committee (ExCo) meetings were held:

MEETINGS	DATE AND PLACE
65th ExCo	January 21, 2022
66th ExCo	June 01-02, 2022
67th ExCo	November 16-17 2022

The first ExCo meeting in January was held as an ad-hoc meeting to discuss a second "Call for collaboration support proposals" within the AFC TCP network, where participants of the AFC TCP were invited to apply for funds for special activities within the AFC TCP. The total fund was limited to € 40,000. The call intended to foster the output of current task-work to (IEA) relevant products such as (technological) reports, policy messages, technological market research, etc. The AFC TCP was not limiting the support to its current task-work but also supported new task ideas and other activities if those would generate IEA/AFC TCP relevant output. The Call was issued in March 2022, and the deadline was end of April 2022.

Due to the short time of application, the AFC TCP received no proposal, although many discussions with interested parties were held. So, during the 66th ExCo meeting in June, the ExCo decided to relaunch the call with the tender deadline in September 2022. The AFC TCP received one proposal from task experts of Task 30: "Initial approaches in benchmarking and interlaboratory tests for alkaline liquid water electrolyzers (LAWE)." The main objective of this proposal is to develop a testing protocol and testing cell for straightforward evaluation of state-of-the-art materials and components for liquid alkaline water electrolyzers and to validate them through an accurate comparison of performance. The participants of this call are Germany, Belgium (Guest), the Czech Republic (Guest), Denmark, Italy, Canada, and the USA.

The 66th ExCo meeting was planed as an in-person meeting with regard to the current COVID-19 restrictions in Madrid, Spain but had to be changed to a digital meeting due to short-term cancellations. In this meeting, Viviana Cigolotti (Italy) was elected as Vice-chair and Detlef Stolten (Germany) was re-elected as Chair of the AFC TCP. Also, the Chair and the AFC TCP secretariat discussed the modernization and amendment of the AFC Implementing Agreement to incorporate the recent 2020 IEA framework for TCPs with the ExCo members. The updated Implementing Agreement was approved on October 12, 2022. As of this date, the term "tasks" is adopted for day-to-day use instead of annexes, annex operating agents are now called task managers and task members are task experts.

In the 67th ExCo meeting, the LAWE proposal was presented and discussed, and the ExCo decided to fund the Collaboration Support Proposal on LAWE. Furthermore, the ExCo also voted to request for an extension of the AFC TCP program within the IEA framework for an additional five years (2024-2029).

Membership

In 2022, the AFC TCP had 15 participating countries and one organizational member (sponsor).

There were a few changes of ExCo-Representatives in 2022. The current list of ExCo representatives can be found on the website of the AFC TCP: http://www.ieafuelcell.com/index.php?id=members.

Financing and Procedures

All activities under the AFC TCP 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 funding arrangements were introduced in 2011. A country´s level of GDP leads to the level of payment.

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.

Future Plans

The AFC TCP's vision is to significantly contribute to addressing the opportunities and barriers to fuel cell commercialization by fostering the development of fuel cell technologies and their applications internationally. The mission of the AFC TCP is to:

- Carry out coordinated research, technology development, and systems analysis in the fuel cell application areas of stationary and transportation power, as well as the technology-driven tasks of polymer electrolyte fuel cells (PEFCs), solid oxide fuel cells (SOFC), and electrolysis systems.
- Conduct modeling work to provide data and results to answer key overarching questions. The work focuses on designing, developing, and applying suites of open-source computational fluid dynamic models of fuel cells and electrolyzers.
- Support the information and dissemination networks facilitated through the CERT, its Working Parties, and the TCP' 's operations, which is strengthened through activities from the AFC TCP in fuel cell technologies.
- Share the knowledge and outcomes and key messages of the TCP work with the R&D community, IEA CERT, its working parties, other TCPs, policymakers, and the public as appropriate and to further advance the state of understanding of all Contracting Parties (CPs) in the field of advanced fuel cells, support their market development as well as their business cases and applications.

The work plan will focus on the analysis of cross-cutting issues, testing and analysis under real-world operating conditions, and commercialization (through increased cooperation with industry and analysis of systems issues). Additional tasks may be created in a timely response to emerging developments in the field of fuel cells or energy research of relevance to fuel cells.

Deployment of fuel cell vehicles and the expansion of hydrogen refueling station network

The deployment of fuel cell-powered vehicles for road transport is experiencing rapid growth worldwide. To assess their current status, the Advanced Fuel Cells Technology Collaboration Programme (AFC TCP), working within the International Energy Agency framework (IEA), conducts an annual data collection spanning member countries and beyond. This article presents the latest survey's findings, capturing the global country-based deployment of fuel cell vehicles as of the end of 2022.

The core group of authors organized the comprehensive data collection effort for fuel cell vehicles and hydrogen refueling stations under the AFC TCP. This survey has been conducted for six consecutive years, starting at the beginning of each year and capturing numbers as of December 31 of the previous year. The survey relies on AFC TCP member input and incorporates additional data sources to ensure a holistic global assessment, including countries not being members of the AFC TCP. This approach facilitates cross-checking of results and utilization of the most up-to-date and precise information for the evaluation. Furthermore, the AFC TCP provided the collected numbers to the IEA for their annual Global Electric Vehicle Outlook (GEVO) publication.

The survey primarily focuses on on-road vehicles, excluding fuel cell material handling vehicles and trains from the analysis. The reported numbers specifically reflect registered vehicles currently in operation, excluding those used in demonstration projects or not yet deployed. Similarly, vehicles that have been produced but not yet put on the road are also not counted.

Regarding hydrogen refueling stations, the survey includes those built and operational while excluding stations under construction or planning. The collected numbers encompass public and non-public stations, although some countries may not have distinct data differentiating between public, private, and private accessible stations. The results section will provide further information, such as the number of public stations, where available.

Regarding fuel cell vehicles, the survey reveals that by the end of 2022, there were 72,193 fuel cell vehicles globally. The majority of these vehicles (92%) were concentrated in four countries: the Republic of Korea (41%), the United States (21%), China (19%), and Japan (11%).

Germany stood out among other countries, having over 2,000 fuel cell vehicles, followed by the United Kingdom, France, and the Netherlands, with more than 500 vehicles each. Several countries, including India, Sweden, Italy, and Austria, surpassed the 50-vehicle mark, while others had fewer than 50 fuel cell vehicles. The survey classified fuel cell vehicles into five classes: passenger cars and vans, buses, light commercial vehicles (LCVs), medium-duty trucks, and heavy-duty trucks. "FCEV" referred to passenger cars and vans specifically, while the broader term "FCV" encompassed all vehicle classes. Overall, this data indicates a growing presence of fuel cell vehicles worldwide, with certain countries leading the adoption and others gradually joining the trend in various vehicle categories.

Figure 1 illustrates the distribution of fuel cell vehicles worldwide. Passenger cars constitute the majority at 80%, while buses account for 9%. Heavy-duty and medium-duty trucks together make up 10%, with each category having a 5% share. Light commercial vehicles represent only 1% of the total number. It's worth mentioning that in certain countries, light commercial vehicles might be included in the passenger car category, but this does not alter the overall trend shown.

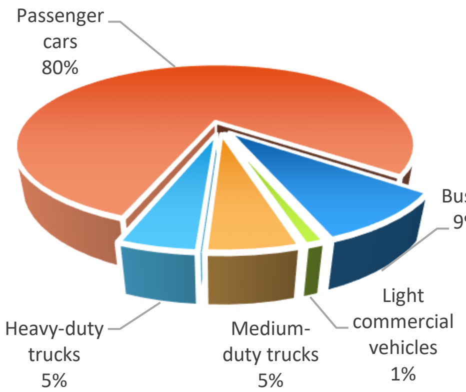


Figure 1: SHARES OF DIFFERENT VEHICLE CATEGORIES AS OF THE END OF 2022.

Figure 2 displays the distribution of fuel cell vehicles across continents. Asia remains the dominant continent, hosting over two-thirds of the vehicles as in previous years. North America comes next, with just over one-fifth of the vehicles, while Europe has a smaller share at 7.7%. Australia accounts for only 0.3% of the total.

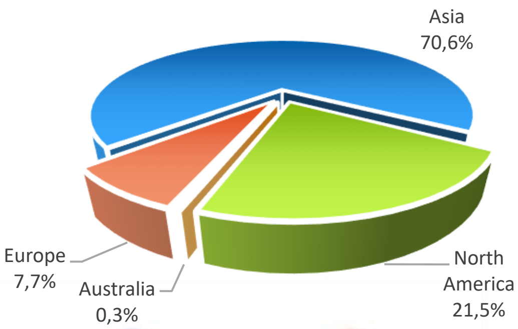


Figure 2: DISTRIBUTION OF FUEL CELL VEHICLES TO CONTINENTS AS OF THE END OF 2022.

The paper furthermore focuses on worldwide data collection regarding hydrogen refueling station (HRS) infrastructure. By the end of 2022, there were a total of 1,022 hydrogen refueling stations across 31 countries, encompassing both public and private stations.

China leads in the number of HRS with 320 stations, followed by the Republic of Korea (213 stations) and Japan (164 stations). These three countries account for 68% of the global HRS infrastructure. Germany (95 stations), the United States (71 stations), and France (58 stations) are the only other countries operating more than 50 HRS. The remaining 25 countries collectively have 1 to 12 stations, representing 10% of the global HRS network.

Asia has the most HRS with 700 stations, followed by Europe with 236 stations (23% of the global HRS network), primarily concentrated in Germany and France. Europe has several countries operating hydrogen refueling stations, which is crucial for the continent's future hydrogen mobility development. North America ranks third, with only 8% of the worldwide HRS infrastructure, and most of these stations (92%) are in the United States.

The report proceeds with analyzing the collected data, focusing on the global deployment of fuel cell vehicles between 2017 and 2022, as depicted in Figure 3.

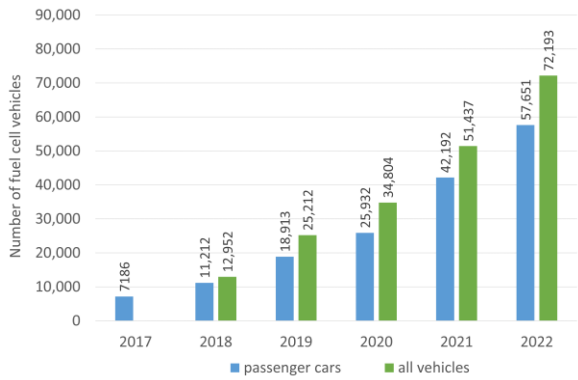


Figure 3: WORLDWIDE DEVELOPMENT OF THE DEPLOYMENT NUMBERS OF FUEL CELL VEHICLES FOR 2017–2022.

In 2017, only fuel cell passenger cars were estimated, as commercial vehicles had minimal representation. From 2018 onwards, the analysis covers both, fuel cell passenger cars (FCEV) and all fuel cell vehicles (FCV), including passenger cars. In 2022, fuel cell passenger cars experienced a 37% annual increase, a slower growth compared to the peak of 69% in 2019 and 63% in 2021. The pandemic-induced chip crisis in the automobile sector contributed to the relatively slower increase in 2022, adding 15,459 fuel cell passenger cars to the fleet, the second-highest absolute increase after 2021.

Similarly, the total number of fuel cell vehicles increased by 40% in 2022, with a comparable growth rate to the passenger cars due to their dominance in the overall fleet. Further analysis reveals a 36% annual increase for buses, while medium-duty trucks exhibited minimal growth (7%). Light commercial vehicles and heavy-duty trucks demonstrated substantial growth, with the number of light commercial vehicles increasing from 49 (2021) to 890 (2022) and heavy-duty trucks rising from 852 (2021) to 3,321 (2022).

Interestingly, 2022 witnessed the highest absolute increase of 20,756 vehicles in one year. In comparison, the highest absolute increase in previous years was in 2021, with 16,633 vehicles added. Monitoring both absolute increase and annual increase rate is crucial to understanding deployment dynamics as the number of vehicles in operation grows.

Moreover, a hypothetical analysis was conducted by combining the number of FCV and HRS in the top six countries with over 50 stations. The goal was to calculate the average number of vehicles per station, regardless of the stations' locations and the vehicles' registration locations.

Among these countries, the United States had the highest number of fuel cell vehicles per station, with an average of 214 vehicles. Republic of Korea followed with 139 vehicles per station. In Japan, the average was 47 vehicles per station, while China had 42 vehicles per station. Germany had a lower average of 25 vehicles, and France had the lowest at 11 vehicles per station.

Higher numbers of vehicles are necessary to ensure the economic operation of the stations. As discussed in previous reports, the ideal number of vehicles per station depends on daily consumption per vehicle and the vehicle category. Comparing these figures with last year's data, we observe an increase in the United States, Germany, Japan, and France. However, China and the Republic of Korea experienced a decrease, as their hydrogen refueling stations showed a stronger annual increase rate than the vehicle increase rate in 2022. On the other hand, the remaining four countries witnessed a stronger increase rate in vehicle numbers.

In conclusion, the number of fuel cell vehicles surpassed 70,000, and the number of hydrogen refueling stations exceeded 1,000 units.

Passenger cars dominate the fuel cell vehicle fleet at 80%, with the majority (94%) concentrated in the Republic of Korea, the United States, Japan, and Germany. In 2022, heavy-duty trucks and light commercial vehicles witnessed a significant increase in numbers. China took the lead in hydrogen refueling stations, and the United States and the Republic of Korea were the only countries with more than 100 vehicles per station.

Despite positive development trends, fuel cell vehicles and their refueling infrastructure require a more progressive approach. Promising trends were seen in light commercial vehicles and heavy-duty trucks as vehicle categories, as well as in refueling stations in China and the Republic of Korea.

For more information, please find the complete publication under www.ieafuelcell.com.

National Overviews

AUSTRIA

ExCo Representatives

Dr. Günter Simader,
Austrian Energy Agency

FRAMEWORK CONDITIONS: AUSTRIAN GOALS, HYDROGEN FACTS AND THE AUSTRIAN HYDROGEN STRATEGY

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. Another effort is the decoupling of economic growth from fossil fuels. To achieve the goals, a national hydrogen strategy was developed and released in June 2022.

Key Energy Figures:

- Gross domestic energy consumption 2020: 1.346 PJ (= 374 TWh).
- Of these, 56,9 % are covered by fossil fuels (oil - 34.2 %; gas - 22.7 %).
- 32,7 % from renewable sources (biomass, hydroelectric power >> wind power > photovoltaic).

Hydrogen related facts:

- Hydrogen and hydrogen technologies are prominently named in the Austrian government program (2020 – 2024).
- Hydrogen strategy published in June 2022.
- Approximately 100 stakeholders are active in the Austrian hydrogen community.
- Current hydrogen demand: about 144.000 t per year (more than 99 % from fossil sources, OMV, Borealis).

Austrian Hydrogen Strategy:

- Climate-neutral hydrogen: Compatibility with the goal of achieving climate neutrality is only ensured through climate-neutral hydrogen.
- Hydrogen use in strategic priority sectors: The contribution of hydrogen to reach climate neutrality is maximized by focusing on sectors, which are otherwise hard to decarbonize.
- Energy efficiency and cost-effectiveness are essential guiding principles regarding the transformation of the energy system.
- Hydrogen infrastructure: On the way to climate neutrality, the gas infrastructure is gradually converted into a targeted hydrogen infrastructure. Further relevant strategies and position papers are: National Energy and Climate Plan (NECP), the Strategy for Research, Technology and Innovation (FTI 2030) and the Mobility Master Plan 2030.
- 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, energy storage, peak load balance, aviation, shipping and long-distance transport.
- The public R&D expenditures in hydrogen and fuel cell technologies amounted to EUR 40 million in 2021 (about EUR 10 million in 2020).

With the Austrian Hydrogen Initiative Flagship Region Power & Gas (WIVA P&G), a funded project-platform 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.

In the mobility sector, most potential is seen with fuel cell applications for heavy duty, long distance transport, off-road vehicles and special machinery. The cities of Vienna and Graz have planned the demonstration operation of a bus line with fuel cell busses in the next years.

Subsidies for purchasing 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.

Support programs for commercial vehicle and fuel infrastructure investment – EBIN and ENIN.

„EBIN“ Funding program (Zero Emission Busses and Infrastructure):

- Dotation: 250 million €.
- 80% of the additional investment costs for the acquisition of zero-emission busses will be funded.
- 40% of the net acquisition costs for charging, overhead cable and hydrogen refueling infrastructure.

MAJOR NATIONAL FUNDING SCHEMES

- Renewable Expansion Act (EAG): Investment subsidies for constructing plants for converting electricity into hydrogen or synthetic gas plus assumption of gas and electricity grid connection costs and exemption from the renewable subsidy flat rate and subsidy contribution for renewable hydrogen plants ≥ 1 MW.
- Important Projects of Common European Interest (IPCEI) are strategic instruments for implementing the European Union (EU) Industrial Strategy. They materialize in large-scale consortia aimed at research and development and the first industrial applications in strategic value chains (the states provide funding budget). 6 Austrian companies participate in 2 thematically structured IPCEI projects: 4 Austrian stakeholders in “Hy2Tech”, 2 Austrian stakeholders in “Hy2Use”. The total Austrian budget is 125 M € (Hy2Tech + Hy2Use).
- Energy research 2023 (via Climate and Energy Fund). Promoting hydrogen technologies is also included in the Climate and Energy Fund's energy research program for 2023.

DEMONSTRATION AND LARGE-SCALE PROJECTS

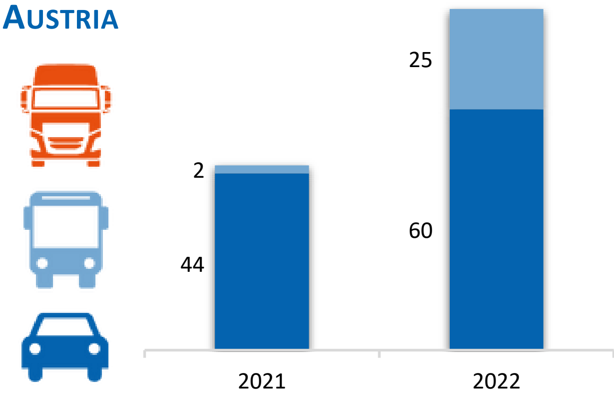
- Whereas in previous years, mainly smaller R&D projects were conducted in Austria, an increased focus is now on large-scale demonstration projects. For example, at the site of the steelmaking company voestalpine in Linz, a six MW PEM electrolyser has been in operation since 11/2019, producing 1,200 m^3 green hydrogen per hour for the integration into the steelmaking process and providing grid services.

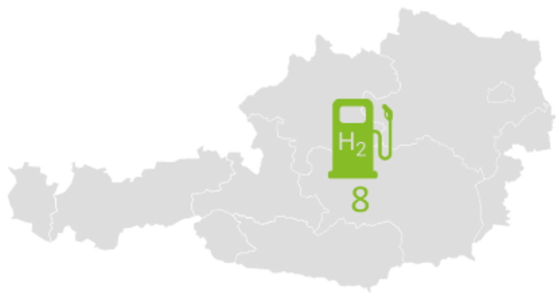
Further selected projects are:

- MPREIS: MPREIS is an Austrian food retailer with (300) stores in the five provinces of Tyrol, Salzburg, Carinthia, Vorarlberg and Upper Austria, as well as abroad in South Tyrol. (Project acronym: Demo4Grid).
- A 3.2 MW pressurized alkaline electrolyzer (Sunfire) is in operation since March 2022 (grid stabilization). According to the company, it’s actually Europe's largest single-stack electrolysis plant.
- Full stage setup: Grid stabilization, fuel (hydrogen) for the company flee, heat for the bakery.

Energie Burgenland with partner VERBUND: In Burgenland, Austria's largest electrolyzer to date will be built (300 MW at full stage). From 2026 on, 9,000 tons of green hydrogen from wind and solar energy will be produced, in the full expansion stage by 2030, this will be 40,000 tons of hydrogen per year.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Austria





The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

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[Austria’s Hydrogen Strategy]

[Update Deployment of FCEV and HRS 2022]

CANADA

ExCo Representatives

François Girard, NRCan
René-Pierre Allard, NRcan

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

The hydrogen landscape in Canada is growing; currently, 303 passenger fuel cell vehicles are in use, six operating and 14 announced hydrogen refuelling stations, seven hydrogen hubs forming or being formed, several blending pilots and studies under way. The Government of Canada recognizes that hydrogen will be a necessary tool to achieving net-zero by 2050, so to help further develop hydrogen technologies, federal and provincial policymakers have announced widespread industry investments and incentives.

In 2021, the Government of Canada released the Hydrogen Strategy for Canada, laying out a framework for actions that will reinforce hydrogen's role in the transition to net-zero. The Strategy focuses on how the use of hydrogen across the country will lower emissions notably in the resource extraction, transportation, and manufacturing sectors, while also establishing Canada as a global leader in hydrogen supply.

Along with the Government of Canada's Hydrogen Strategy, many provinces have established their own Hydrogen Strategies and Roadmaps that address how governments and industry can accelerate hydrogen production, use, and export. For example, British Columbia developed the BC Hydrogen Office as a one-stop-shop for hydrogen in the province. Their priorities currently include the production, distribution, storage, end-use, and export of hydrogen and setting and developing policy and regulatory frameworks. The Government of Alberta established the Hydrogen Centre of Excellence. It supports studies, opportunity analyses, the development of codes and standards, and fostering partnerships to advance hydrogen integration into the energy system.

In order to coordinate efforts across levels of government for infrastructure investment required to meet Canada's 2050 target, the federal government launched Regional Energy and Resource Tables (Regional Tables). These Regional Tables are part of a collaborative initiative with the provinces and territories designed to identify, prioritize and pursue opportunities for sustainable job creation and economic growth for a low-carbon future in the energy, electricity, mining, forestry and clean technology sectors across all of Canada's regions. Some of these tables are anticipated to prioritize infrastructure investments related to the hydrogen economy in Canada in-line with the provincial and territorial interests noted above.

The Government of Canada (GoC) is incentivizing industry investment into hydrogen technologies through various programs and funds that touch various sectors of the value chain. Under Budget 2023, the government committed to investment tax credits for clean hydrogen projects intended to provide a foundational incentive upon which other increasingly targeted measures would build to address more specific barriers to investment and adoption in Canada's energy systems. The program covers between 15 and 40% of eligible project costs, with projects producing the cleanest hydrogen receiving the most support. This program also extends a 15% tax credit to equipment needed to convert hydrogen into ammonia for transport .

The Canada Infrastructure Bank (CIB) provides the next layer of federal incentives as an impact investor through loans toward revenue-generating projects. In September 2022, the CIB launched the 367 million USD Charging and Hydrogen Refuelling Infrastructure Initiative to help reduce greenhouse gas emissions from the transportation sector. The Bank can invest in small modular reactors, clean fuel production, hydrogen production, transportation and distribution, and carbon capture, utilization, and storage. To complement the CIB investment, an additional 294 million USD was announced to recapitalize the Zero Emission Vehicle Infrastructure Program to support the deployment of 84,500 electric vehicle (EV) charging and 25 hydrogen refueling stations in Canada by 2029.

The final layer of incentives is provided through targeted funding, such as the Strategic Innovation Fund and Clean Fuels Funds. The Strategic Innovation Fund, developed to accelerate the growth and expansion of innovative businesses in Canada, encourages investment in research and development activities, and aims to attract and retain large-scale investments across various industries, including hydrogen. The Fund is currently supporting a collaboration between the Governments of Edmonton, Alberta, and Canada with Air Products Canada Ltd. The goal of this project is to advance clean energy in Canada. It involves a 0.9 billion USD net-zero hydrogen production investment, which will lead to the development of a clean hydrogen facility that will be operational by 2024.

Further support for the hydrogen industry comes from the Clean Fuels Fund, which allocated up to 1.1 billion USD to de-risk the capital investment required to build new or expand existing clean fuel production facilities and address gaps and misalignment in codes, standards, and regulations related to the production, distribution, and end-use of clean fuels.

To reduce adopter and market risk and improve technology performance, the Government of Canada is also currently engaging in consultations with the Canadian Standards Association, the Standards Council of Canada, and the National Research Council to identify gaps and update existing or create new codes and standards related to the hydrogen value chain, from production to end use, including exports.

Focusing on the solutions not yet available but required for Canada and other countries to meet their 2050 targets, the GoC maintains research, development and demonstration programs in recent years to help derisk new technologies and address barriers to the uptake of hydrogen and fuel cells. The National Research Council Canada (NRC) has launched four research programs to support the deployment of the hydrogen strategy. The Materials for Clean Fuels Program (MCF) was established in 2018 to develop new materials at low TRL for carbon dioxide conversion into hydrocarbons as well as for hydrogen production. The program's second phase was launched this year with ten new projects, including three related to hydrogen production. Moreover, the program hosts four projects in collaboration with German partners under the umbrella of the 3+2 initiative, which brings together industry and public research organizations from both countries.

A second program is the Advanced Clean Energy Program (ACE), which was launched in 2022 with a focus on energy storage, low carbon fuels and hydrogen. Production of hydrogen through electrolysis, distribution of hydrogen and conversion (fuel cells and combustion) are the elements of the hydrogen pillar of ACE. The hydrogen infrastructure is studied from a pipeline materials perspective while data analytics and machine learning are applied to fuelling stations. This program also hosts the above mentioned activities on codes, standards, and carbon intensity.

Researchers involved in electrolysis research and development (R&D) have joined Task 30 of the International Energy Agency Technology Collaboration Programme (IEA TCP) on Advanced Fuel Cells. The work on fuel cells focused on studying the impact of manufacturing defects on fuel cell performance and durability. Following a series of international workshops co-organized with Fraunhofer ISE and the National Renewable Energy Laboratories (NREL), which generated a functional analysis of fuel cell components, NRC wrapped up in January 2022 the first phase of the above-mentioned study. The next phase aims at establishing a consortium with industry and academia to look further into major manufacturing defects, contributing to the establishment of quality control practices to reduce the manufacturing cost of fuel cell products.

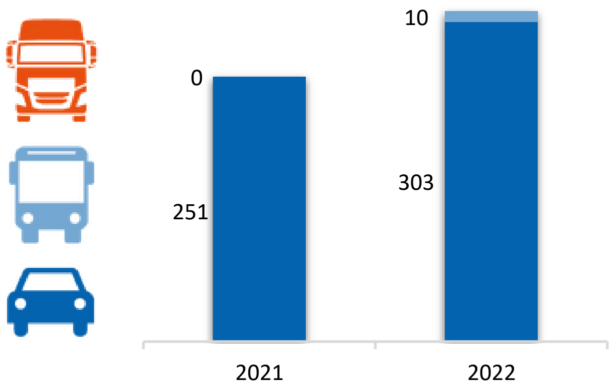
The third and fourth NRC programs were launched in 2022 and include: the Clean and Energy Efficient Transportation Program (CEET), which focuses on ground transportation. Its hydrogen pillar concerns fuel cells and their integration into vehicles, especially heavy-duty and off-road applications. The Low Emission Aircraft Program (LEAP) looks at ways to reduce emissions in the aerospace sector, and hydrogen combustion, fuel cells integration and storage are among the topics of R&D for this program.

In addition to these programs, the NRC and the University of British Columbia launched a Collaboration Centre for the Clean Energy Transition (CC-CET) to exploit synergies between the two organizations. Electrolysis, codes and standards as well as pipeline materials are part of the activities performed under CC-CET.

A final program supporting innovation is the Electric Vehicle Infrastructure Demonstration program, managed by Natural Resources Canada.

The program funds demonstration projects that support innovative and next-generation EV charging and hydrogen refueling infrastructure. The program is co-funding a hydrogen project taking place in the province of Alberta, which involves Class 8 heavy-duty long-haul fuel cell electric trucks and the supporting hydrogen refueling infrastructure.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Canada



Top ten leading countries in total FCEVs

	Country	Total FCEVs
1	Korea	29623
2	USA	15200
3	China	13504
4	Japan	7743
5	Germany	2342
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7	France	623
8	United Kingdom	564
9	Switzerland	344
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The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

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Update Deployment of FCEV and HRS 2022

CHINA

ExCo Representatives

Boris Zhang, SAE China
Helen Zhao, SAE China

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

By the end of 2022, China's fuel cell vehicle population was approximately 12,800, a year-on-year increase of 64%, accounting for 19% of the global population. Driven by the demonstration of five urban clusters, fuel cell vehicles are widely used in various scenarios, such as heavy operations in ports, mines, steel mills, urban construction, and long-distance bulk commodity transportation. The market scale of heavy trucks and large passenger cars has rapidly increased. In 2022, 4,780 commercial vehicles were promoted, accounting for 95% of the total sales volume.

Since “the Development Plan for New Energy Vehicle Industry (2021-2035)” was released in 2020, Chinese government gradually puts effort on fuel cell vehicle industry. In the same year, the policy of carrying out the Demonstration of Fuel Cell Vehicles was released, as of the end of 2021, the Chinese government has approved five urban clusters to carry out demonstration, which is Beijing, Shanghai, Guangdong, Hebei, Henan. The demonstration clusters aim to Support breakthroughs in key core technologies and industrial applications of fuel cell vehicles, and promote the formation of a development pattern of fuel cell vehicles with reasonable layout, different focuses, and coordinated promotion.

The government provides rewards for the demonstration and application of new technologies and the industrialization of key core technologies, accelerating the development and innovation of related basic materials, key components, and vehicle core technologies. Which strives to gradually achieve breakthroughs in key core technologies within about four years, build a complete fuel cell vehicle industry chain, and lay a solid foundation for the large-scale industrialization development of fuel cell vehicles.

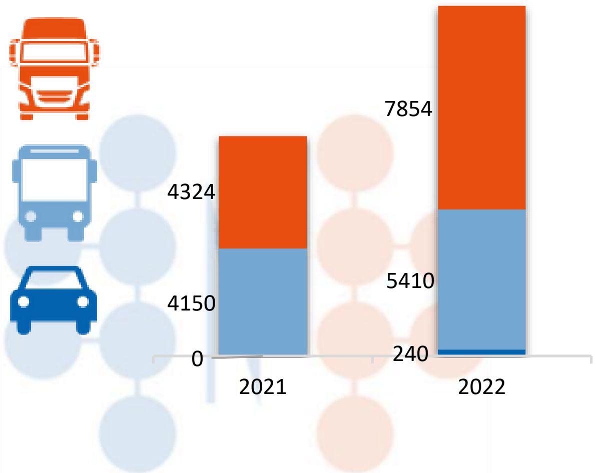
In March 2022, the National Development and Reform Commission released the "Medium and Long Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)", which pushed the development of the fuel cell vehicle industry to a climax. Based on the planning of the "Medium and Long Term Plan for the Development of the Hydrogen Energy Industry (2021-2035)", by 2025, fuel cell vehicles will reach 50,000 units with numbers of hydrogen refueling stations, hydrogen production from renewable energy will reach 100,000-200,000 tons/year, which can contribute to emission reduction 1-2 million tons/yr.

There are differences in the coverage targets between the demonstration city cluster policy and the national hydrogen energy plan. The former mainly focuses on supporting the demonstration application of fuel cell vehicles, and rewards the industrialization and demonstration application of key core technologies of fuel cell vehicles; The latter emphasizes the concept of "large hydrogen energy", which is the top-level design and system deployment for the development of China's hydrogen energy industry. It is not only limited to the transportation field where fuel cell vehicles are located, but also proposes development goals and directions in energy storage, power generation, industry and other fields.

Currently, China's fuel cell industry is developed mainly based on the demonstration cluster policy. Taking Beijing-Tianjin-Hebei cluster as an example, leading by Beijing Beijing Municipal Finance Bureau and Daxing District government, other 11 districts and cities were involved, respectively providing green hydrogen supply, technology R&D, industry chian, key component manufacturing, and application scenarios. The featured application scenarios is mainly contributed by the fuel cell vehicles demonstration during Winter Olympics in 2022. There are over 1,000 fuel cell vehicles with more than 30 hydrogen refueling stations. In which more than 800 fuel cell buses were operated.

Further, fuel cell vehicle demonstration cluster has driven the whole industry development in China. Other than the cities included in five clusters, more regions and cities have published related planning policies to promote local industry to reach the standard of demonstration clusters such as Chengdu, Chongqing, Shanxi Province, etc

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in China



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Update Deployment of FCEV and HRS 2022

DENMARK

ExCo Representatives

Mads Lyngby Peterson,
Danish Energy Agency

DENMARK'S ENERGY POLICY AND GOALS

The Danish Government's long-term goal for the country's energy policy is to be independent of fossil fuels by the year 2050. In a shorter perspective, the political parties in the Danish Parliament formulated a target to reduce Denmark's greenhouse gas emissions by 70% in 2030 compared with 1990.

The green transition of the energy system has accelerated over the past years and the share of fluctuating renewable energy mainly from wind energy and solar power in the Danish energy system has increased significantly. In 2022 wind power production corresponded to 59,6% of the total electricity consumption in Denmark. On March 15th, 2022 Denmark outlined a Power-to-X Strategy aiming for an electrolysis capacity of 4 - 6 GW in 2023. The goal is to be able to convert electricity into electric fuels for use in industry as well as in aircraft, ships and trucks.

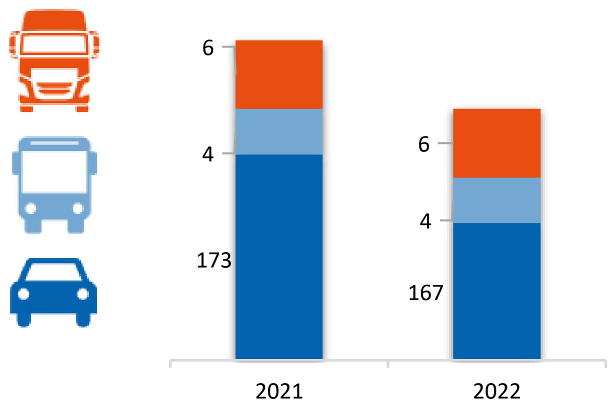
The Danish Government has not defined a separate roadmap regarding the development and implementation of fuel cells. Nevertheless, hydrogen and fuel cell technologies are considered to be part of the future green energy system with a high proportion of fluctuating renewable energy. Thus, the Danish programs for research and development within new energy technology still have a high interest in supporting the development of fuel cell technologies and other applications.

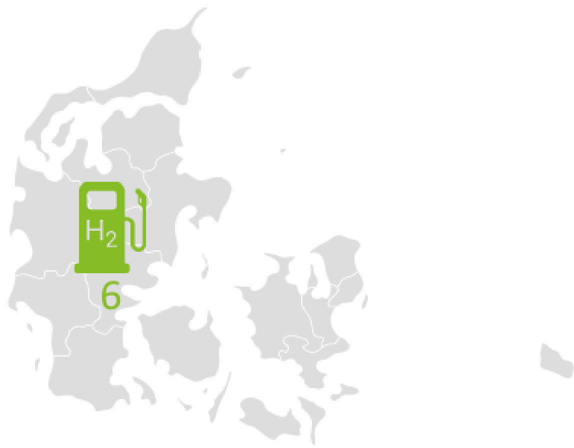
R&D AND RESEARCH PROJECTS

In July 2022, the EU Commission approved 41 Important Projects of Common European Interest ('IPCEI'), including two Danish projects, to support research and innovation, first industrial deployment, and construction of relevant infrastructure in the hydrogen value chain. The Green Fuels for Denmark project was supported for establishing in three phases electrolysis capacity of 10 MW, 100 MW and 300 MW. The HySynergy project was supported for establishing electrolysis capacity of 100MW as part of the upscaling existing plant in Fredericia from 20 MW to 300 MW.

The Danish Partnership for Hydrogen and Fuel Cells 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.

FUEL CELL ELECTRIC VEHICLES (FCEV) AND HYDROGEN REFUELING STATIONS (HRS) IN DENMARK





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Strategy for Power-to-X

Green Fuels for Denmark recieves IPCEI funding

HySynergy 2.0 recieves IPCEI funding

The Danish Partnership for Hydrogen and Fuel Cells

Update Deployment of FCEV and HRS 2022

Finland

ExCo Representatives

Dr. Jari Kiviaho, VTT Fuel Cells

Initiatives, programs and policies on hydrogen and fuel cells

The Finnish Fuel Cell Program aims to speed the development and application of innovative fuel cell and hydrogen technologies for growing global markets. The program has facilitated more than 70 successful projects, involving more than 60 companies. 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. The Finnish industry is now starting to invest in fuel cell applications, especially in marine applications, combined heat and power, working machines, back-up applications, electrolysers and hydrogen applications. Short descriptions of those company activities are the following:

Convion (http://convion.fi) Convion Ltd. is a leading fuel cell system developer commercializing solid oxide fuel cell systems for distributed power generation in industrial and commercial applications. Our products are designed for premium energy efficiency, reliability, and operational flexibility. Convion provides its customers with sustainable power generation solutions for power security, energy independence and unparalleled fuel economy.

Convion Ltd., established in 2012, focuses on developing and commercializing solid oxide fuel cell (SOFC) systems distributed power generation and electrolysis based on solid oxide (SOE) technology for hydrogen production. By commitment, creativity, and agility of Convion team and collaboration with best partners throughout our supply chain, Convion will provide its customers with cost-competitive and environmentally sound power generation solutions that radically improve the reliability of energy supply and efficiency of primary energy use as well as make possible future increases of renewables in energy mix. Convion shareholders include VNT Management and Wärtsilä.

Convion aims to support sustainable energy transition with high-temperature electrochemical solutions based on solid oxide cell (SOC) technology. Solid oxide fuel cells at the heart of our power-generating products are ideal for distributed and small-scale power generation. They make possible clean, dependable power generation at superb electrical efficiency at any scale and co-locating zero local emission power generation with consumption. Convion's proven, proprietary system technology facilitates broad fuel flexibility with no compromise in efficiency. In hydrogen production, solid oxide electrolysis by Convion's technology offers unparalleled efficiency and scalability to meet industrial demand.

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 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, competitiveness of life cycle costs, grid and fuel flexibility and minimal emissions. Convion C60 is a modular power generator capable of combined heat and power generation.

It has an industry leading electrical efficiency, and it can be configured for operating with different fuel gas compositions such as natural gas or biogas. Modular architecture makes possible installation of multiple C60 units in parallel for desired power output and redundancy level. Each module is a separate generator, able to operate independently and autonomously yet connected for remote management and monitoring. C60 is designed to be installed parallel to the power grid but can disconnect from the grid and secure critical power loads in case of a grid outage. A general specification of the C60 product is given in the table below:

Convion C60

Electric power output	60	kW net-AC*
Electrical efficiency	60	% (LHV)*
Thermal output**	24	kW (LHV, exhaust cooled to 55°C)*
Total efficiency	83	% (LHV) (exhaust cooled to 55°C)*
Range of electric output	60 - 30	kW
Electrical efficiency at 50% output	60	% (LHV)*
Standard installation requirements for rated performance	Elevation <1000 m, temperature -20...+40°C, outdoor installatio installation optional.	
Electrical connection, capability	3 x 380-500V AC, 50/60Hz, in accordance with local grid code	
Noise level	< 70	dB(A) at 1 m
Water consumption	None	
Nominal fuel intake	11.5 Nm3/h (natural gas)	
Exhaust gas	200°C, 575 kg/h, dew point 37°C	
EXHAUST EMISSIONS		
Nitrogen oxides, NO_x	≤ 2.6 ppm-v/ ≤0.05 g/kWh (below detection limit)	
Sulphur dioxide, SO_2	≤ 3 ppm-v/ ≤0.07 g/kWh (below detection limit), sulphur remov fuel before use	
Carbon monoxide, CO	≤ 1.7 ppm-v/ ≤0.02 g/kWh (below detection limit)	
Particulates (PM)	Negligible	
Volatile organic compounds	Negligible	
Carbon dioxide, CO_2	330 kg/MWh_e	
SYSTEM DIMENSIONS		
H * L * W	2330 * 2780 * 2090 mm	

Convion has delivered a biogas fuel cell system to Biometaan OÜ in Estonia. Companies plan to cooperate in the Baltic region, where Biometaan is a leading producer of agricultural biomethane and biofertilizers. The first C60 unit has been installed at Siimani farm, generating renewable power and heat from locally produced biogas. A behind-the-meter installation will provide clean, renewable energy for the facility's own consumption and serve as a pilot installation. The system has a nominal electrical output of 60 kilowatts, and over 20 kilowatts of heat. System is already running and produce electricity as planned.

Biomethane production site of Biometaan OÜ

Convion and Shell Global Solutions International form partnership to develop, validate and commercialize advanced Solid Oxide Electrolysers (SOEC) supplied by Convion. Convion will deliver a 1-MW electrolyzers demonstrator to Shell's Energy Transition Campus in Amsterdam. The demonstrator will be based on four Convion C250e electrolyzers modules.

Shell has set a target of becoming a net-zero emissions energy business by 2050 by reducing emissions from its own operations, and from fuels and other energy products it sells to its customers. Convion aims to offer Electrolysers with industry-leading efficiency and flexibility, paving the way for deep decarbonization of energy and industry.

In the partnership, Shell and Convion aim to produce renewable hydrogen by solid oxide electrolysis (SOE) at efficiencies clearly higher than other electrolysis technologies. SOE technology makes possible hydrogen production at 25-30% lower electricity consumption, when waste heat is used for steam generation. The companies will also explore new opportunities for matching the supply and demand of renewable electricity by utilizing Convion electrolysis reversible operation (rSOC) option, enabling both power generation and hydrogen production with the same equipment.

The partnership lays a foundation to address decarbonization challenges throughout the industry. The collaboration leveraging Convion's broad experience of delivering industrial scale SOC (solid oxide cell) systems, and Shell's technical capabilities and transformative business ambitions provide a pathway to opening new business opportunities and commercialization of solutions' technologies.

Elcogen (https://elcogen.com) is the world's most advanced ceramic anode-supported solid oxide cells and stacks manufacturer. 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 20 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.

Whether you are building a CHP system or an off-grid genset, the elcoStack provides the highest efficiency power generation. Your system can run on, e.g., biogas or natural gas today and on hydrogen in the future, providing low OPEX and protecting your investment. High-temperature steam electrolysis using the elcoStack solid oxide cell stacks is the most efficient way to produce green hydrogen. You can maximize the hydrogen production efficiency by integrating our stack technology with industrial waste heat sources or even directly produce syn-gas from water and CO2.

To make the integration of our elcoStack E3000 into your fuel cell, electrolyzers, or reversible system as simple as possible, they are offering a comprehensive range of stack modules. They consist of a compression system, gas manifolds and an air distribution structure, enabling the elcoStack E3000 to reach optimum performance. Modules for one, two or four stacks are available, larger modules and customized designs can be developed specifically for your application.

The Guangzhou Nansha "Multiple in One" Micro-Energy Demonstration project is the first energy demonstration project to be implemented based on the MoU signed between Finland's Ministry of Economic Affairs and Employment and China's National Energy Administration.

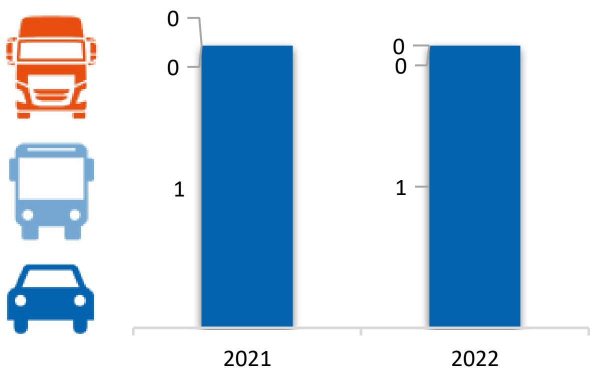
The project uses various leading technologies that enable clean energy production and more efficient use of energy for the city of Guangzhou in China. Convion C60 unit does utilize leading SOFC stack technology provided by Elcogen. Guangzhou is looking to expand its heat production through renewable sources and increase overall energy efficiency. Guangzhou is utilizing Bedrock Thermal Energy Storage to store excessive heat underground which would be used during the winter. The city has also implemented a solar thermal system to generate heat at efficiency levels of 52%. Convion commissioned a C60 SOFC CHP system for use in Guangzhou with local support from Guangzhou Power Supply Bureau staff in the summer of 2022. Commissioning was possible without the presence of Convion personnel thanks to the system's self-diagnostic and autonomous operation features. Design point of 60kWe at >60% electrical net efficiency as well as >85% total efficiency was successfully achieved, and the system continues to operate as part of the microgrid. Very encouraging results have been achieved through the continued high performance of Elcogen's stacks, captured by Convion system. The results to date and the ongoing reliability of the operation have formed a firm foundation for full industrialization of the product and replication of the solution elsewhere.

LEMENE: 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. Lempäälän Energia Oy and leading fuel cell system developer Convion have signed an agreement regarding a delivery of two Convion C60 fuel cell systems to Marjamäki district. The delivery is part of project LEMENE, earmarked by the Finnish government as a key project in helping the country achieve its national energy targets for decarbonization. The LEMENE smart grid system will be powered by a 4MW solar photovoltaic array, an 8MW biogas engine and a battery to deliver a secure and reliable power supply, ensuring energy self-sufficiency for the industrial district of Marjamäki, in south-western Finland. Under the recently signed agreement, the two fuel cell co-generation systems built by Convion will be integrated into the smart grid in the district. At the heart of the combined heat and power (CHP) systems with a total electrical output of 116kW are the next generation of solid oxide fuel cell (SOFC) stacks, from leading fuel cell manufacturer Elcogen.

The unique LEMENE project showcases low-carbon energy generation, energy storage and smart controls, combining to provide a self-sufficient district energy solution. The flagship project has been highlighted by the Finnish Ministry of Economic Affairs and Employment as an example of a solution that can help Finland achieve its national targets and those set by the European Union for 2030. Prime Minister Juha Sipilä's government has called for increasing the use of renewable energy to more than 50 per cent during the 2020s, and self-sufficiency to more than 55 per cent.

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, focusing on off-grid electricity production and storage. They are currently building up their knowhow 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 the 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.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Finland



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REFERENCES

[Update Deployment of FCEV and HRS 2022]

FRANCE

ExCo Representatives

Aymeric Canton, CEA
Thierry Priem, CEA

NEW INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

October 12, 2022 was the 1st anniversary of FRANCE 2030 initiative (54 Md€), the french government released a press kit to remind and review the ten objectives; among them those related to hydrogen:

- To decarbonize our industry.
- To build a low carbon aircraft by 2030.
- To build 2 million zero-emission vehicles by 2030.
- 6,5GW electrolysis capacities to be installed in France by 2030;
- € 2,1 billion public aids through the Hy2Tech IPCEI program (first wave) to deploy gigafactories to manufacture key equipment: electrolyzers, H2 tanks, fuel cells (see details hereafter).
- €775 million to support hydrogen ecosystems.

In March 2022, the Priority Research Program and Equipment on decarbonated hydrogen (named PEPR-H2), co-directed by CEA and CNRS, started with an 80M€ budget for eight years. Its main goal is to support R&D activities with low TRL (1-4) and also to support industrial projects. PEPR-H2 is part of the "France 2030" initiative.

2022 June 15th: State Aid: Commission approves up to €5.4 billion of public support by fifteen Member States for an Important Project of Common European Interest in the hydrogen technology value chain

Ten projects have been selected to receive funds (2,1 billion) from the Hy2tech IPCEI:

- Alstom, to develop:
    - H2 components
    - H2 Locomotive
    - High-power fuel cell wagon for freight transportation
- Arkema, to develop high-performance and sustainable materials dedicated to production, storage and transportation of H2 for mobility.
- Elogen received 86 M€ to develop innovative PEM stacks and to build a factory to mass produce electrolyzers.
- Forvia (formerly known as Faurecia) received 213 M€.
    - To develop and mass produce H2 high-pressure tanks (100 000 units/year are expected by 2024).
    - To develop H2 cryo tanks.
- Genvia, JV between CEA and Schlumberger, received 200 M€ to develop high-temperature electrolyzers/fuel cells.
- Hyvia, JV between Renault and Plug Power, to manufacture FC light duty vehicles.
- John Cockerill, to design a high-capacity alkaline electrolyzer and mass manufacture it (from 350 MW/y in 2023 up to 1 GW/y by 2030).
- McPhy received 114M€ to deploy an alkaline electrolyzer gigafactory .
- Plastic Omnium, to build a H2 high pressure tank megafactory .
- Symbio to develop a new fuel cell generation and mass manufacture it.

2022, September 21st: State Aid: Commission approves up to €5.2 billion of public support by thirteen Member States for the second Important Project of Common European Interest in the hydrogen value chain.

Demonstration, deployments and workface developments update

June 2022: Symbio and Schaeffler create the Innoplate JV to develop bipolar plates for fuel cells.

June 2022: SAFRA announce its new bus Safra Hycity with powertrain is composed by a 130 kWh battery pack and a 45 kW fuel cell.

July 2022: Ile-de-France mobility (public entity responsible for the transportation means in the Parisian region) voted a 48 M€ budget to acquire 47 FC buses with the objective to have a zero-emission float by 2029.

May 2022: INOCEL: GENZ project lead by CEA with Mike Horn, consisting in developing an hydrogen fuel cell powertrain dedicated to rally raid, turns into the creation of the INOCEL company, which has the ambition to industrialize a compact and high power density PEMFC technology for marine, road mobility and stationary applications.

September 2022: EKPO Fuel Cell Technologies (JV between Plastic Omnium and ElringKlinger) received a major command from an European car manufacturer (it seems it is Stellantis)

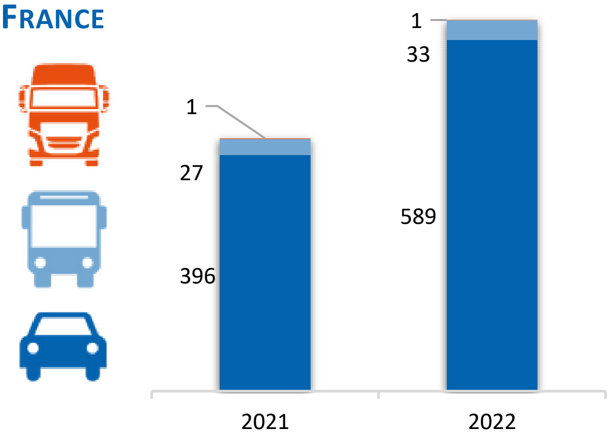
October 2022: Credit Agricole bank and Hopium automotive company signed an agreement for the delivering of 10,000 units of the Hopium FC supercar.

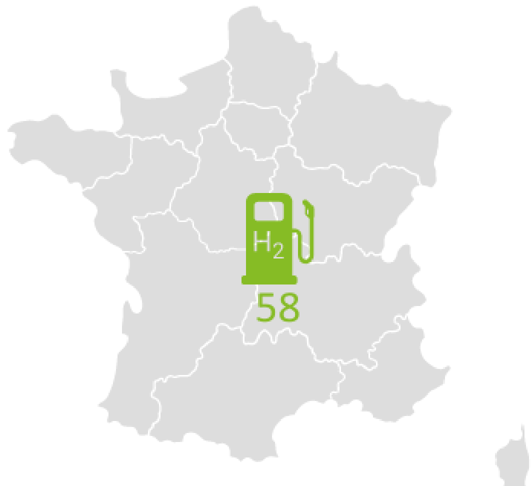
References

PEPR-H2

Update Deployment of FCEV and HRS 2022

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in France





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GERMANY

ExCo Representatives

Prof. Dr. Detlef Stolten, Research Center Jülich

Dr. Remzi Can Samsun, Research Center Jülich

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

The share of renewables in gross electricity consumption increased from 6.3% to 46.2% between 2000 and 2022 in Germany. The share of renewables in gross final energy consumption increased from 6.2% in 2004 to 20.4 % in 2022. The slower pace for the latter category can be explained by the slower switch to renewable energies in the transportation and heating/cooling sectors. Despite the very positive trends, a greater effort is required to achieve the binding 80% target for gross electricity consumption in 2030 set in the amendment to the Renewable Energy Sources Act in 2021. This can only be possible with a considerable expansion of renewable power plant capacities and the electricity grids. Similarly, considerable additional efforts are required to achieve the 30% target for gross final energy consumption for 2030. Meanwhile, emissions of greenhouse gases declined by around 40.4% between 1990 and 2022. Germany aims to reduce greenhouse gases by at least 65% by 2030 compared to 1990. With the reduction level in 2022, the 2020 target of 40% is hardly achieved, after missing the target in 2021 due to an increase in emissions in 2021 compared to the lowest level ever in 2020 due to the pandemics. With the current trend, the 2030 target of 65% reduction presents a big challenge. The ultimate target is to achieve complete greenhouse neutrality by 2045. 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 industry applications and the possibility to store excess electricity produced from renewables as hydrogen via electrolysis provide solutions to achieve the energy goals.

In June 2020, The Federal Government published the National Hydrogen Strategy assigning a key role to green hydrogen in terms of enhancing and completing the energy transition: 1) As an energy source to be used in fuel cells or to produce synthetic fuels; 2) As an energy storage medium to store renewable energy; 3) Playing a key role for sector coupling to decarbonize the energy supply; 4) As a base substance to decarbonize industrial production; 5) To eliminate process-related emissions in the long term. The National Hydrogen Strategy sets several goals and ambitions. It is estimated that 90 to 110 kWh hydrogen will be needed by the year 2030. Part of this demand can be covered by establishing up to 5 GW generation capacity, delivering 14 TWh hydrogen using 20 TWh renewable electricity, assuming 70% electrolysis efficiency and 4000 full-load hours. An additional 5 GW capacity is to be added by the year 2035, latest 2040. With these numbers, it is clear that domestic green hydrogen production cannot meet the demand, and most hydrogen needs to be imported. The National Strategy also defines a two-phase action plan. The first phase until 2023 aims to start the market ramp-up and the second phase until 2030 aims to strengthen the market ramp-up by stabilizing the newly emerging national market, molding the European and the international dimension of hydrogen and using hydrogen in the national industry. The "package for future" from June 3, 2020, adopted by the Coalition made additional 7 billion Euros for speeding the market rollout of hydrogen in Germany and 2 billion Euros for fostering international partnerships. It must be noted here that these funds come on top of the already existing funds. Finally, the National Hydrogen Strategy includes 38 measures for the first phase until 2023. These can be classified under hydrogen production (4 measures), fields of application (15 measures), infrastructure and supply (3 measures), research, education, and innovation (7 measures), European activities (4 measures) and international hydrogen market (5 measures). [2]

Within the first year after the publication of the National Hydrogen Strategy, numerous integrated and research projects have been started. The implementation status of the measures of the National Hydrogen Strategy was analyzed in a report of the Federal Government. This report indicates a number of highlights showing the achieved progress in the first year, including integrated projects along the value chain, as well as within various measures of the strategy such as support for hydrogen and fuel cell technologies, hydrogen refueling infrastructure, competitive supplier industry for fuel cell systems and industrial basis for large scale fuel cell stack production, fuel cell heating units, research offensive "Hydrogen Technologies 2030" and last but not least aviation and maritime. Further achievements were reported in the field of European and international activities and cooperation. [3]

Through the interministerial National Innovation Program 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 the 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 660 million Euros between 2016 – 2024. Accompanied by two funding guidelines, the BMVI funding aims to support those technically ready products but not yet competitive during the market ramp up. The Federal Ministry for Economic Affairs and Climate Action (BMWK) supports applied research and development for hydrogen and fuel cells with an annual budget of 25 million Euros within the 7th Energy Research Program. 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). Since 2016, BMWK also supports private households in purchasing a fuel cell heating device. Within the market activation activities, 14330 devices received approval for funding in the period of 09/2016-09-2020. Between 2017-2020, the BMVI funding for hydrogen and fuel cell technologies exceeded 455 million Euros, whereas the BMWK funding support exceeded 74 million Euros. [4]

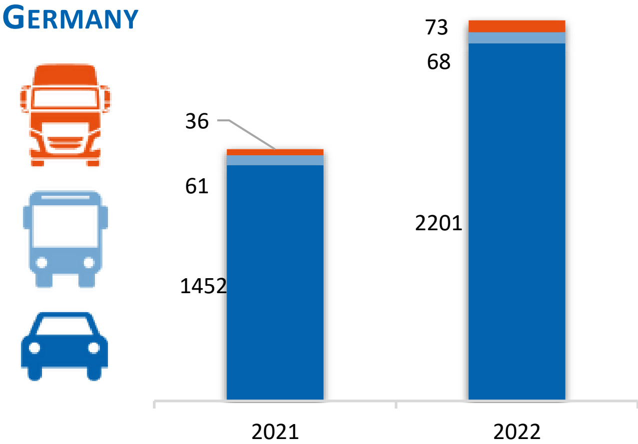
As of the end of 2022, 95 public hydrogen refueling stations were in operation in Germany, with ten additional stations in different stages of development. From 2021, the stations will be built primarily where the demand for commercial vehicles is expected in short term, and a public hydrogen refueling station would make sense for a growing network of passenger cars as well. As of the end of 2021, the system availability of the stations corresponded to 92.9%. 30% of the stations delivered green hydrogen. It was planned that 38 stations will be updated for refuse collection vehicles. 30 stations were in project pipeline, with 16 350 bar extensions. At the end of 2022, more than 2300 fuel vehicles were on German roads, with more than 2200 passenger cars, around 70 buses and 30 trucks. [5-7]

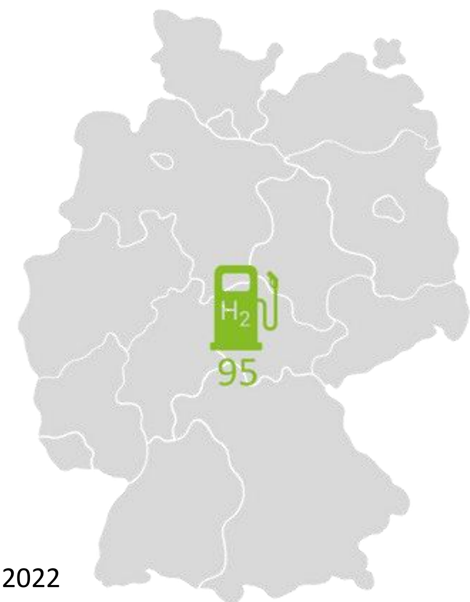
The implementation status of the National Hydrogen Strategy highlights the following flagship programs [8]:

#	Funding Program	Period	Budget
1	Important Project of Common European Interest (IPCEI)	01/21 - 12/27	€ 11 **billion**
2	Carbon Contracts for Difference	01/22 – 12/31	€ 550 million
3	Renewable Fuels Overall Support Concept	from 2021	€ 1.5 **billion**
4	Decarbonization of Industry	01/21 – 06/24	€ 3 **billion**
5	Ideas Competition Hydrogen Republic Germany	04/21 – 09/25	€ 740 million
6	Real Laboratories of the Energy Transition	02/19 – 06/24	€ 100 million pa
7	Innovation and Technology Center (ITZ)	2021 – 2024	€ 290 million
8	HySupply	11/20 - 10/22	€ 1.7 million
9	Implementation of the German-Moroccan Hydrogen Alliance	2021 – 2025	€ 88.5 million
10	Develop green hydrogen economies in South Africa and Brazil	2021 – 2023	€ 74 million
11	H2Global	01/22 – 12/33	€ 900 million

Moreover, selected projects from the second phase of the NIP include H2Sky, BALIS, Go4Hy2 and BETA projects for aviation, GEN5-BZ and AutoStack Industrie projects for passenger cars, E-Cell-Rex, HyPerformFuelCell and Go4City projects for buses, cleanEngine, HyLightCom, FC-Truck and FCS-HD projects for commercial vehicles, H2goesRail and H2-TRAM for railway transport, ELEKTRA II and Pa-X-ell2 projects for maritime, H2FFZ_2 and KION HyPower-24V projects for intralogistics, H2-Fuel, Hy-Lab, HyCavMobil and RSOC projects for hydrogen provision, Hzwo_SuSyMobil, GALLIA, HyPerLife and HyPerformance projects for fuel cell stack and system, ManTys and BZSerie projects for fuel cell stacking and mass production and finally InProPlate, QM-GDL, Oreo, DirectCCM and EMSigBZ projects for fuel cell components. [4]

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Germany





TOP TEN LEADING COUNTRIES IN TOTAL FCEVS

	Country	Total FCEVs
1	Korea	29623
2	USA	15200
3	China	13504
4	Japan	7743
5	**Germany**	**2342**
6	Netherlands	686
7	France	623
8	United Kingdom	564
9	Switzerland	344
10	Canada	313

The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

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ISRAEL

ExCo Representatives

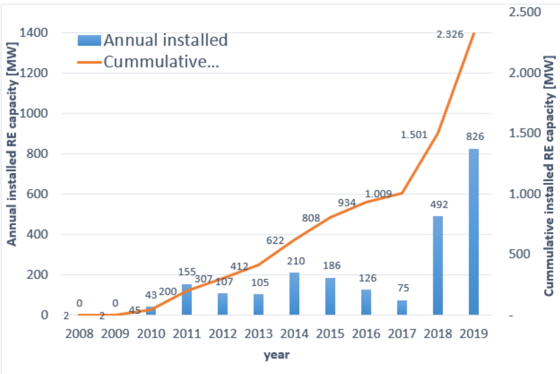
Dr. Gideon Friedmann, Ministry of Energy

Ayelet Walter, Ministry of National Infrastructures, Energy & Water

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

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 1,501MW to 2,326MW (Fig. 1); 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).



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 comprises 14 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 developing advanced corrosion-resistant supports, flow fields and gas diffusion layers 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.

Recently, the Israeli Ministry of Energy established the National Institute for Sustainable Energy, a partnership between Bar-Ilan University and the Technion, funded at a rate of \$40M to accelerate the development of large energy storage technologies. Most of this funding will be used to build R&D infrastructure for high TRL studies (4-6) and for technology acceleration in prototype labs, and for funding directed research in the field. Half of the total funding is allocated to hydrogen technologies.

Industrial Research and Development

Several companies are active in areas related to fuel cells. Hydrolite 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.

Other new startups (listed in the attached list) are in their early stages in Israel.

Market Implementation

The Ministry of Energy is currently supporting the construction of the first Hydrogen refueling station in Israel, which Sonol will build. 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 cell based drones.

References

[Update Deployment of FCEV and HRS 2022]

ITALY

ExCo Representatives

Dr. Viviana Cogolotti, ENEA

ITALIAN HYDROGEN STRATEGIES AND INITIATIVES

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 in order to achieve sustainable growth, promote fundamental role of research and innovation in the cleantech sector and reach the 2030 environmental targets at the European level.

Targets for RES to cover:

- More than 55% of the demand in the electricity field
- 33% of the demand in the thermal sector
- 21% in the transport sector
- The 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's 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 M€ in 2013 to 444 M€ in 2021. Italy joined the MI IC#8 on Hydrogen and actively participated in the Mission innovation "Hydrogen Valleys" workshop 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 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 to 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: "Production, storage and power to gas", "Transport" and "Regulation". This initiative aims to define the priorities and guidelines, make a competitiveness assessment on the Italian hydrogen sector, and 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.

Italy's Recovery and Resilience Plan (RRP) allocates 3.64 billion euros to develop flagship projects for the creation of "hydrogen valleys", use of hydrogen in hard-to-abate sectors, support R&D (160 M€), electrolyser Gigafactories (manufacture of 1 GW per year by 2026), road transport (at least 40 HRS by 2030, priority to strategic areas of heavy street transport) and railway mobility. Italy also supports IPCEI projects (Important Project of Common European Interest on hydrogen) with 12 projects approved under the IPCEI waves "Hy2Tech" and "Hy2Use".

Italy supports other international initiatives such as Mission Innovation 2.0 on "Renewable and Clean Hydrogen", Clean Hydrogen for Europe and the EU Clean Hydrogen Alliance.

R&D AND DEMONSTRATION PROJECTS

Since 2022, hydrogen R&D is also supported through the Italian National plan for the Electric System Research with a budget of 17.5M€. Additional funds enhance participation in Mission Innovation 2.0 on "Renewable and Clean Hydrogen", Clean Hydrogen for Europe and the EU Clean Hydrogen Alliance. Pre-normative studies are carried out on regulation, standards and safety on hydrogen technologies, including H2/natural gas blending.

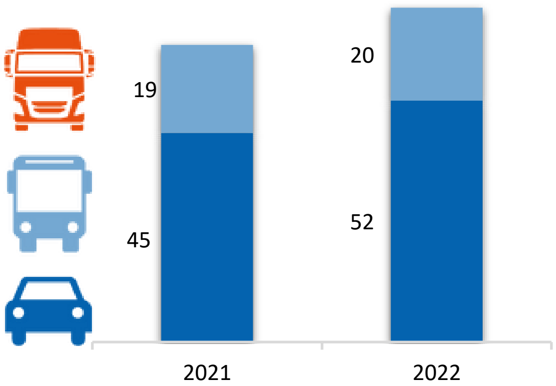
At European level, significant research is being carried out in Italy, mainly through mobilising European funds from the FCH 2 JU (€107M funding per year from the Clean Hydrogen Partnership, supporting over 160 projects and 120 beneficiaries in 13 years spanning the two framework programs). Also, there 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.

Most notable demonstartion projects

- The Bolzano refuelling station is an example of excellence at the European level: hydrogen is produced by electrolysis completely from renewable sources. To date, five hydrogen buses, 10 Hyundai ix35 Fuel Cell cars, and 10 Hyundai Nexo, were 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 were deployed in Sanremo at the end of 2018.
- SNAM (Italian gas Transmission System Operator) initiates the 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.
- In June 2022 a new H2 refuelling station was unveiled in Mestre (close to Venice) with 100kg/day capacity and a captive fleet of 10 Toyota Mirai.

In July 2022, in the framework of the Italian recovery and resilience plan, an Operative Research Plan Project has been financed with 110 M€ by the Ministry of Ecological Transition, aiming to boost low TRL research on hydrogen, involving the main research institutions in the country.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Italy



The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

References

[Update Deployment of FCEV and HRS 2022]

JAPAN

ExCo Representatives

Eiji Ohira, NEDO

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

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.

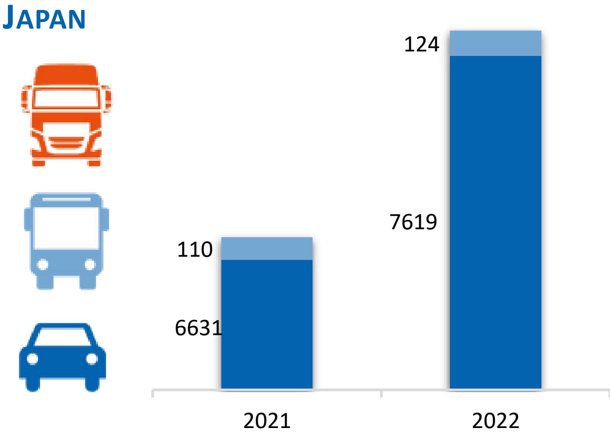
To achieve this common goal, Ministry of Economy, Trade and Industry (METI) revised its "The Strategic Road Map for Hydrogen and Fuel Cells on March 12, 2019. The renewed roadmap defines (i) new targets on the specification of basic technologies and the breakdown of costs, and necessary measures for 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:

- Residential Fuel Cell
  - Installation number: 5.3 million (in 2030)
  - Payback period (price):5 years in (2030)
- Mobility
  - 800k Passenger vehicles and 1.2K Busses in 2030
- Hydrogen Refueling Stations
  - Number of stations: 900 (in 2030)
  - 200M JPY Installations Cost, 25M JPY Operation cost (in 2025)

In light of the current situation, the Japanese Government plans to revise "The Basic Hydrogen Strategy" in 2023. 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 480,000 by the end of March 2020. Since the price of ENE-FARM has been decreasing, METI terminated the subsidy for ENE-FARM once in 2020, METI has resumed it since 2023. About 120 Fuel Cell Buses (Toyota "SORA") are operated regularly by the Bureau of Transportation, Tokyo Metropolitan Government.

FUEL CELL ELECTRIC VEHICLES (FCEV) AND HYDROGEN REFUELING STATIONS (HRS) IN JAPAN



Top ten leading countries in total FCEVs

	Country	Total FCEVs
1	Korea	29623
2	USA	15200
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4	Japan	7743
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The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

References

Update Deployment of FCEV and HRS 2022

Spain

ExCo Representatives

Dr. Emilio Nieto Gallego, CNH2

Dr. Roberto Campana Prada, CNH2

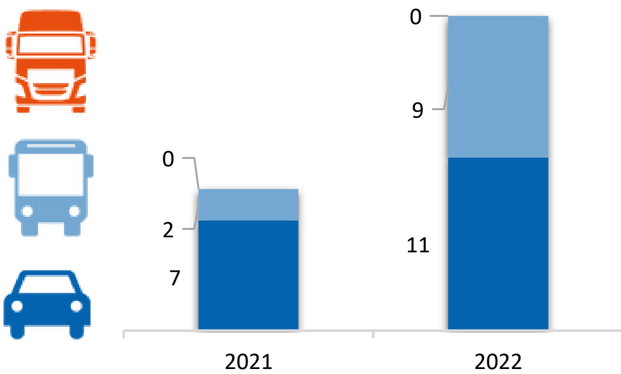
Framework conditions

The Spanish electricity generation park is increasingly renewable. During 2022 the renewable installed power has experienced a growth of 5 GW, reaching a renewable installed power of 69.5 GW. In this way, clean energies now represent 58.8% of the generation capacity in Spain, according to information estimated by “Red Electrica de España” at the end of 2022. Photovoltaic solar energy has also been the technology that has most increased its presence in the generation park this year, but wind power is still the technology with more contribution. Wind power generation represents 22,8% of total generation, second technology only behind combined cycle power plants, and the technology with more contribution on January, March, April, May, November and December. One important project finished this year is the hydroelectric power plant with pumping in Salto de Chira (Canary Islands), with 200 MW generation (36% Gran Canaria demands) and 3,5 GWh storage [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 has a very high potential to produce green hydrogen due to their very nice renewable sources.

With eight operative hydrogen refueling stations and 20 more planned as of the end of 2022, Spain is one of the European countries that have a smaller number of refueling stations [2], far from the target of at least 100 HRS on 2030 defined on Spanish hydrogen roadmap [3]. Regarding hydrogen generation, the roadmap wants to install at least 300 MW on 2024. There are only 35 MW installed (Puertollano, Mallorca and Barcelona) and 33,5 MW in construction, but in this case, many projects are planned to significantly increase this production [4].

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Spain



The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

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Update Deployment of FCEV and HRS 2022

SWEDEN

ExCo Representatives

Emma Westsson, Swedish Energy Agency

Dr. Hans Pohl, Pohl Research & Innovation AB

INITIATIVES, PROGRAMS AND POLICIES ON HYDROGEN AND FUEL CELLS

Sweden has set up a number of amitious climate and energy goals to combat climate change.

- By 2030, energy use will be 50 per cent more efficient, compared with 2005. Target according to the Swedish Energy Agreement.
- By 2030, the emissions from transport are to be 70 percent less than in 2010. Target from the Paris Agreement in 2015.
- The target by 2040 is 100 percent 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.

Rather than setting out specific targets regarding the implementation of hydrogen into the energy system, Sweden has adopted several actions aiming to reduce the negative climate impact of the transport/industry sector as a whole, with hydrogen as one part of the solution.

Sweden's hydrogen and fuel cell activities are driven from the bottom-up by industry, academic research and experts. The Swedish government observes the market and supports industry and universities with national activities. The Swedish government initiated in 2009 a vehicle research program called FFI (Fordonstrategisk Forskning och Innovation - Strategic Vehicle Research and Innovation).

FFI is a major partnership between the Swedish government and the automotive industry, which includes joint funding of research, innovation and development 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). There are also other programs funding or co-funding hydrogen and fuel cell activities. The Swedish Energy Agency also finances participation in fuel cells and hydrogen-related IEA and EU activities (about EUR 80,000 per year). Overall, there are several ongoing fuel cell and hydrogen projects in Sweden.

Recent examples of projects:

- During 2022, several projects have been granted public co-funding for setting up hydrogen refueling stations across the country. Along with the predicted 8 HRS within the "Nordic Hydrogen Corridor" initiative, this would together lead to around 60 new HRS within 2-3 years.
- A Swedish hydrogen valley is currently being built involving local production of hydrogen, fossil-free steel production and hydrogen infrastructure for the transport sector.
- Aiming to create a Nordic hydrogen infrastructure network around the Baltic Sea, Nordion Energy and Gasgrid Finland have joined forces in the first European cross-border initiative for hydrogen pipeline network – “Nordic Hydrogen Route”. This network will connect producers and users, ranging from transport applications to steel production,

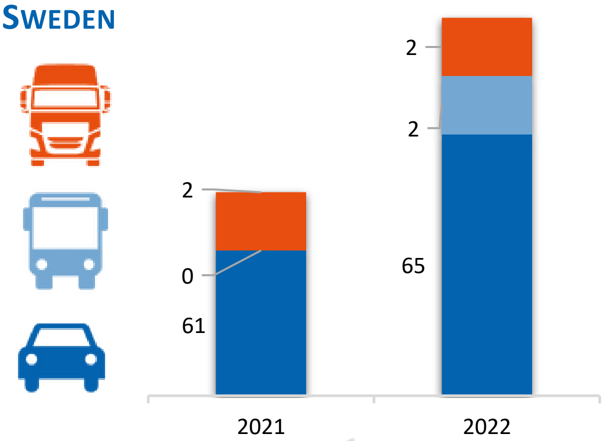
through distribution of hydrogen and e-fuels.

- Volvo Trucks' newest addition to their product portfolio - a fuel cell heavy-duty truck with a range of 1000 km – is currently under evaluation on test tracks.
- Further, Volvo Trucks is now introducing fossil-free steel in its trucks. The hydrogen-reduced steel is produced in collaboration with Swedish SSAB and is expected to reduce carbon footprints as 70% of a truck's weight comes from steel and cast iron.
- The British-American company ZeroAvia accomplished the world's first hydrogen-powered flight in 2020 and are currently experiencing a fast-growing order book of fuel cell airplanes. As a key component, the airplane fuel cell stack is developed in an R&D collaboration project with the Swedish fuel cell company PowerCell.
- A publicly-funded demonstration project for developing a mobile hydrogen refueling station for off-grid and off-road applications has recently been initiated.

Swedish Electromobility Centre is a national Centre of Excellence for e-mobility that unites Sweden's expertise and is a node for interaction between academia, industry and society. The Swedish Energy Agency founded the centre in partnership with the Swedish automotive industry and academia. Energy storage, including fuel cells is one out of five research themes of the centre.

A new national center of excellence for hydrogen research, TechForH2, was commissioned in 2022, focusing on hydrogen technology integration and implementation through collaboration between academia and industry.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Sweden



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References

Update Deployment of FCEV and HRS 2022

SWITZERLAND

ExCo Representatives

Dr. Stefan Oberholzer, Swiss Federal Office of Energy
Prof. Dr. David Hart, E4tech Sárl

New initiatives, programs and policies on hydrogen and fuel cells

The Swiss "Energy Strategy 2050" forms the basis to transform the Swiss energy system in a sustainable and climate-friendly way. It is linked to national climate policy, where Switzerland has committed to halving its emissions by 2030 compared to 1990 as part of the Paris Climate Agreement, with the goal of climate neutrality by 2050. Following the rejection of a total revision of the CO2 Act containing specific measures to achieve these targets in Spring 2021 by the Swiss electorate, the Swiss parliament in 2022 came up with a new compromise as a counter-proposal to a popular climate initiative (the so-called “Glacier Initiative”) with the goal of net zero emissions in 2050. The Parliament approved this compromise, which adopts many elements of the initiative and, for the first time, defines a reduction path with legally binding interim targets. However, the final decision will be taken only in a popular referendum in mid-2023. Concerning hydrogen, the basis for a national hydrogen strategy is being developed, a first report to be published by the end of 2023. An intensive dialogue between politics, administration, industry and other actors is ongoing.

National Research Program on Hydrogen and Fuel Cells

The Swiss Federal Office of Energy (SFOE) runs a RTD program on hydrogen and fuel cells technology involving many stakeholders. The program 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 Swiss Federal Institutes of Technology (ETH) domain, universities of applied sciences and universities.

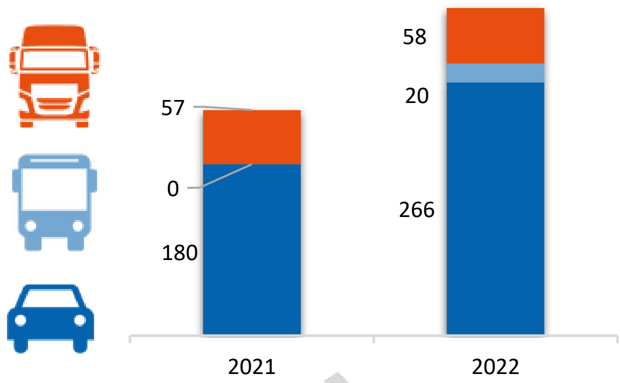
The focus of the SFOE-funded activities is on applied-oriented materials research, system development and demonstration and testing in pilot projects in polymer electrolyte fuel cells PEFC for mobile applications as well as solid oxide fuel cells (SOFC) for use in co-generation plants, increasing efficiency of PEM-electrolyis (new catalyst developments) and also topics regarding system integration. 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

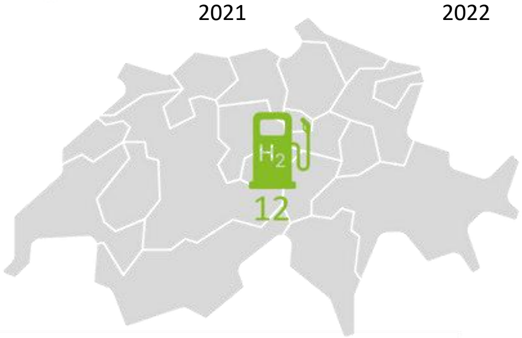
H2 mobility in Switzerland

Hydrogen mobility in Switzerland is being driven forward on private initiative. In 2018, the Association pro H2 mobility Switzerland was founded to establish 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 is on trucks. Currently, some 50 fuel cell trucks are in daily use. The FC truck fleet in Switzerland has already reached a mileage of 5 million km in October last year. The unpredictable distortions in the energy market in 2022 affected the availability and cost of electricity from sustainable energy sources, which also impacted the production costs of green hydrogen.

Since the end of 2022, a second H2 production plant has been commissioned, thus increasing the redundancy of the H2 supply. Currently, 13 filling stations are in operation and six more are under construction. These include filling stations that refuel up to 40 tonnes of H2 annually.

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in Switzerland





Top ten leading countries in total FCEVs

	Country	Total FCEVs
1	Korea	29623
2	USA	15200
3	China	13504
4	Japan	7743
5	Germany	2342
6	Netherlands	686
7	France	623
8	United Kingdom	564
9	Switzerland	344
10	Canada	313

The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

References

Update Deployment of FCEV and HRS 2022

USA

ExCo Representatives

Dr. Dimitrios Papageorgopoulos, Department of Energy

Dr. Shailesh Vora, National Energy Technology Laboratory

New initiatives, programs and policies on hydrogen and fuel cells

As outlined in the Draft U.S. Department of Energy (DOE) National Clean Hydrogen Strategy and Roadmap, the DOE will follow three key strategies to ensure that clean hydrogen is developed and adopted as an effective decarbonization tool and for maximum benefits; 1) target strategic high impact end uses, particularly in sectors that are hard to decarbonize such as medium and heavy-duty trucks and buses, maritime applications, rail, and aviation 2) reduce the cost of clean hydrogen by developing sustainable and supply-resilient pathways, and 3) focus on regional networks by ramping up hydrogen production and end use in close proximity. [1] Funding for the DOE efforts in hydrogen and fuel cells for Fiscal Year (FY) 2022 was USD 330,300,000 which consisted of USD 162,000,000 for the Energy Efficiency and Renewable Energy Hydrogen and Fuel Cells Technology Office, USD 125,300,000 for Fossil Energy and Carbon Management, USD 23,000,000 for Nuclear Energy, and USD 20,000,000 for the Office of Science.[2] Of the USD 162,000,000 for the Energy Efficiency and Renewable Energy Hydrogen and Fuel Cells Technology Office, USD 30,000,000 was appropriated for fuel cell technologies.[3]

In late 2021, the Infrastructure Investment and Jobs Act was signed, providing USD 8 billion over five years for at least four clean hydrogen hubs, USD 1 billion over five years for electrolysis research, development, and demonstration, and USD 0.5 billion over five years for clean hydrogen technology manufacturing and recycling R&D.[2]

Of the USD 162,000,000 for the Energy Efficiency and Renewable Energy Hydrogen and Fuel Cells Technology Office, USD 30,000,000 was appropriated for fuel cell technologies.[3]

In addition, in August 2022, the Inflation Reduction Act was signed into law which provides additional policies and incentives for hydrogen including a production tax credit which will further boost a US market for clean hydrogen.[1]

Key targets:

Fuel cells

- Develop a direct hydrogen fuel cell power system for long-haul heavy-duty (HD) trucks that can achieve 25,000-hour durability and be mass produced at a cost of $80/kW by 2030. [3]
- Develop stationary solid oxide fuel cell power systems with a fuel cell system cost of $900/kW and 40,000-hour durability by 2030. [4]
- Develop reversible fuel cells for energy storage at a system cost of $1800/kW with a durability of 40,000 hours by 2030. [3]

Hydrogen storage

- Reduce cost of on-board hydrogen storage to $9/kWh. [2]

Hydrogen production and delivery

- Reduce cost of hydrogen production to \$2/kg by 2026, \$1/kg by 2031. [2]
- Reduce cost for delivering and dispensing hydrogen to \$2/kg by 2030. [2]
- Develop a low temperature electrolyzer with 73% LHV system efficiency and 80,000 hour durability at a capital cost of \$150/kW by 2030. [2]

KEY ACCOMPLISHMENTS:

Fuel Cells and Vehicles

DOE deployed 1,600 early market fuel cell forklifts and backup power units. In 2022, more than 50,000 fuel cells were deployed in material handling applications in the US.[2] As of December 2022, more than 14,900 fuel cell cars have been sold or leased in California.[5] Eight HD fuel cell trucks and more than 80 Fuel cell buses were active in the US in 2022, with over 100 more buses in development in California. [6,7,8] A driver for the increase in fuel cell bus developments is California's Clean Transit Regulation, which requires that 25% of buses procured by large transit agencies be zero emission in 2023, and targets 100% of buses procured by all transit agencies be zero emission by 2029, with a goal for all buses being zero emission by 2040.[9]

Fuel cell power plants in buses have demonstrated on-road operation surpassing the fuel cell lifetime target set by the DOE and the Department of Transportation's Federal Transit Administration of 25,000 hours.[10] The top bus fuel cell power plant has accumulated >32,000 hours of operation in service.[10]

Initial fuel economy (defined as the fleet average of the first full year in service) for current generation fuel cell buses has also exceeded the DOE/DOT target of 8 mi/dge in service at transit districts in California.[11]

The projected cost for production of HD PEM fuel cells with a 25,000 hour lifetime has decreased in 2021 to \$196/kW at a production volume of 50,000 units/year and to \$185/kW at a production volume of 100,000 units/year.[3] New catalyst layer ionomers developed under DOE programs demonstrated > 2X higher oxygen permeability than conventional ionomer.[3] When incorporated into an MEA the ionomers provided a > 40% reduction in degradation rate, a > 50% increase in mass activity and improved high-current-density performance at low Pt loading compared to a conventional catalyst layer ionomer.[3] Improvements were also achieved in PGM-free catalysts. An adaptive learning design loop with uncertainty quantification was developed to model and guide high-throughput PGM-free catalyst synthesis, resulting in a 70% increase in ORR activity.[3]

Stationary fuel cells

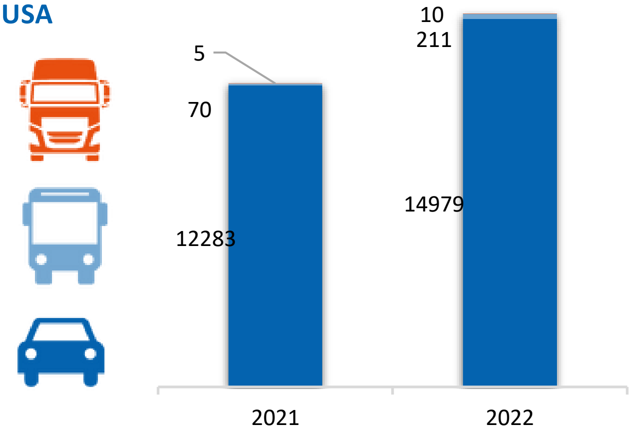
At the beginning of 2022, the U.S. deployed more than 500 MW of stationary fuel cell systems. [2]These systems have demonstrated their reliability and have helped communities through major storms and power outages. In 2020, Bloom Systems provided power to their customers through 335 outages at 67 sites, this includes providing 18 hours of power to a 911 call center in Long Island, New York, during a tropical storm-related outage. [12]

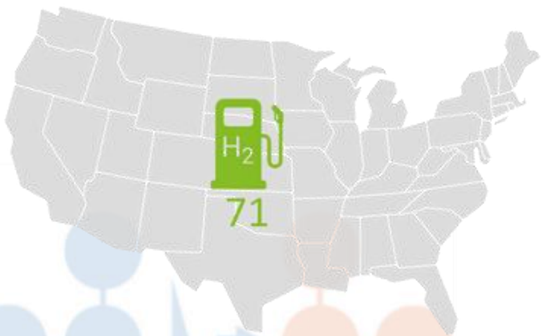
Hydrogen

As of May 2022, current and under construction installations of water electrolyzers in the US totaled over 620 MW[2], more than 3.5 times higher than at the end of 2021. These electrolyzer systems are located in 21 different states spread from the East coast to the West coast, and the power capacity of these systems ranges from 120 kW to 120 MW. The hydrogen produced from these stations is being used for various applications, including as a transportation fuel. The projected H2 levelized cost produced with today's PEM electrolyzer technology can be ≤$4/kg when considering the reported renewable electricity power purchase agreement price range. [13]

There were > 50 retail public hydrogen refueling stations in the US at the end of 2022, with additional stations for refueling buses and heavy-duty vehicles.[2] The California Energy Commission approved a plan to invest up to $115 million to fund up to 111 new hydrogen refueling stations by 2027. [14] Capital costs for the stations vary widely depending on station capacity and mode of delivery, but recent and ongoing deployments have ranged from $1.4-$4.2M/station. [15]

Fuel cell electric vehicles (FCEV) and hydrogen refueling stations (HRS) in the USA





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The data presented here shows the number of registered fuel cell vehicles and Hydrogen refueling stations at the end of the year 2022.

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[2] Dr. Sunita Satyapal, U.S. Department of Energy Hydrogen Program Annual Merit Review and Peer Evaluation Meeting

[3] Dr. Dimitrios Papageorgopoulos,, U.S. Department of Energy Hydrogen Program Annual Merit Review and Peer Evaluation Meeting

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[5] https://cafcp.org/sites/default/files/FCEV-Sales-Tracking.pdf

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[7] Champaign-Urbana Mass Transit District

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TASK UPDATES

TASK 31

Polymer Electrolyte Fuel Cells

Task manager

Dr Di-Jia Liu

Contact

djliu@anl.gov

Members

Summary

The objective of the Polymer Electrolyte Fuel Cells Task 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, Task 31 did not organize in person meetings due to travel restrictions. Instead, a manuscript on high performance polymer electrolyte fuel cell electrode fabrication, prepared through joint effort between the members from Austria (Prof. Viktor Hacker) and US (Dr. Di-Jia Liu) was submitted and published by the Journal of Power Sources. We are also planning to resume in-person meetings in 2023. The tentative plan is to hold the next Task 31 meeting in Germany during the fall of 2023.

Key messages - Facts

- The U.S. Department of Energy (DOE) released the draft DOE National Clean Hydrogen Strategy and Roadmap across multiple sectors to reach 50 MMT of H2 produced per year by 2050.
- Hydrogen provisions in recent US legislation include $9.5 Billion in the Bipartisan Infrastructure Investment and Jobs Act covering: $8 billion for > four clean hydrogen hubs: $1 billion for electrolysis RD&D; and $500 Million for manufacturing and recycling RD&D.
- Reducing cost and improving durability remain to be the top priority for fuel cell material research for the application at mid- heavy-duty applications.
- Concerns on environmental impact by polyfluoroalkyl substances (PFSA) calls for alternatives to replace the current perfluorosulfonic acid materials as the proton exchange membrane.

Key messages - Opinions

- US activities will align with the DOE's Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026.
- Focus on fuel cell technology application is very much dependent on the region of the world, requiring tailored approach in organizing Task activities.
- Major technology breakthroughs, such as high temperature membranes and durable catalysts, are important to light duty as well as heavy duty fuel cell vehicles.

ACTIVITIES

The R&D activities in Task 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 modeling 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 developing the cell materials, investigating the relationship between cell performance and operating conditions, stack and system design and analysis, and investigating 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).

TECHNICAL DEVELOPMENTS

Current fuel cell deployments in the U.S. include over 50,000 fuel cell forklifts and over 14,000 fuel cell electric vehicles. While fuel cell RD&D for stationary applications continues (mainly for solid oxide fuel cells), there has been a shift in focus in supported proton-exchange membrane fuel cell (PEMFC) RD&D towards heavy-duty applications (including trucks).

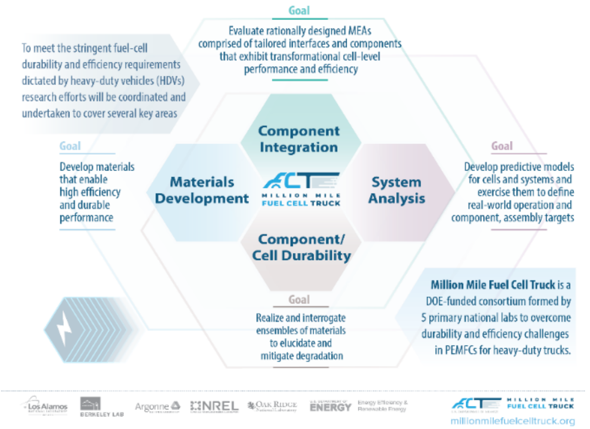


FIGURE 4. TECH STRUCTURE OF M2FCT CONSORTIUM IN US

Efforts target \$80/kW cost and 25,000-hour durability for heavy-duty fuel cell systems by 2030. The analysis estimates the 2022 cost status for heavy-duty fuel cell systems at \$178/kW at 50,000 units/year and \$170/kW at 100,000 units/year. The DOE established the Million Mile Fuel Cell Truck Consortium (M2FCT), which consists of U.S. domestic national labs, universities, and industry partners to conduct RD&D to advance PEMFCs toward meeting the 2030 targets. The key research thrusts and the goal under individual thrust under M2FCT is shown by Fig. 1. These activities will align with the DOE's Hydrogen Shot priorities by directing work to reduce the cost of clean hydrogen to $2 per kilogram by 2026.

Product

A review article, "Recent advancements in high performance Polymer Electrolyte Fuel Cell electrode fabrication – novel materials and manufacturing processes" was submitted and published at Journal of Power Sources https://doi.org/10.1016/j.jpowsour.2023.232734. This article summarizes the trends in material developments and emerging MEA-manufacturing techniques. The materials and techniques are systematically compared in terms of cell performance and scalability. Current and future scientific challenges are identified and analyzed based on published findings over the past five years. Finally, the results of the cited papers have been quantitatively compared to each other and to the internal benchmarks used in each cited work to provide a complete picture of state of the art in PEFC MEA manufacturing.

This work was achieved through a collaboration between Graz University of Technology (Prof. Viktor Hacker) and Argonne National Laboratory (Dr. Di-Jia Liu). It was partially supported by the grant of IEA Research Cooperation (AFC TCP of the International Energy Agency) through a competitive proposal won by Graz University of Technology.

Work plan for 2023

In 2023, Task 31 plans to restart in person meeting with the next workshop scheduled at Technische Universität Darmstadt from September 18 to September 20, to be co-organized with Professor Ulrike Kramm. In addition to the regular Task 31 meeting, Prof. Kramm also plans to expand the format to a broader audience by inviting local academic and industrial fuel cell researchers. We anticipate that such engagement will generate broader interest in IEA AFC TCP through the interaction between the general participants and Task 31 representatives, and potential future collaborations.

Task 31 will also continue to attract new members from participating countries. The fuel cell development is becoming regional dependent with each continent focusing on different aspects of technology implementations from passenger vehicles to mid- and heavy-duty truck and marine applications. The Task 31 activities need to address these needs and find common ground for all participating members.

On the membership side, Task 31 has experienced several changes in representatives among the participating countries. While we have been trying to recruit new members, finding alternates from the existing member countries also requires urgent support from the ExCo committee.

Members

- Graz University of Technology
- Simon Fraser University
- Ballard Power System
- Polytechnique Montréal
- National Research Council Canada
- Dalian Institute of Chemical Physics (DICP)
- Shanghai Jiao Tong University (SJTU)
- VTT
- Institut de Chimie des Matériaux et des Milieux de Poitiers
- Forschungszentrum Jülich
- Technische Universität Darmstadt
- ICT Fraunhofer
- Israel Fuel Cells Consortium (IFCC)
- CNR-ITAE
- Yamanashi University

- University of Sevilla
- Korea Institute of Energy Research (KIER)
- Korea Advanced Institute of Science and Technology (KAIST)
- KTH – Royal Institute of Technology (x3)
- Argonne National Laboratory

TASK 32

Solid Oxide Fuel Cells

Task manager

Dr Jari Kiviaho

Contact

jari.kiviaho@vtt.fi

Members

Summary

Task 32 intends to employ to reach the following overall objectives:

The continuation and intensification of the tasks 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 and discuss a selected topic.

Where possible, these workshops will be linked to other relevant conferences in order to maximize scientific impact and minimize traveling costs. The workshops lead to open discussions relating to common problems and will be organized to have realizable and achievable aims.

Key messages - 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 following:
  - ✓ Capex > 4000 €/kWe
  - ✓ 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 - Opinions

- SOC technology is becoming a significant solution for a variety of applications:
  - SOFC offer fuel flexibility
  - 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.

Activities

Annual meeting was held in the 4th and 5th of July 2022 in conjunction with the European Fuel Cell Forum in Switzerland. Seventeen attendees from eleven countries actively participated in the meeting. During 2022 and 2023, work has been carried out to update the SOFC Yellow Pages document. The new version of the Yellow Pages will probably be published in the beginning of 2024.

Technical developments

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

- Capex < 1500 €/kWe
- 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

.

Work plan for 2023

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 SOFC-XVIII meeting in Boston (USA) in May 2023 will happen in practice. Already 17 people have been registered to the meeting.
The new version of the Yellow Pages will be updated in 2022-2023, and it will be published in the beginning of 2024.

Members

- Risø DTU National Laboratory for Sustainable Energy
- VTT
- Commissariat à l'énergie atomique et aux énergies alternatives (CEA)
- Forschungszentrum Jülich GmbH
- Fraunhofer IKTS
- ENEA Centro Ricerche Casaccia
- Japan Institute of Advanced Industrial Science and Technology (AIST)
- Technova
- Korea Institute of Energy Research (KIER)
- Delft University of Technology
- Department of High Temperature Electrochemical Processes (HiTEP)
- Department of Energy Sciences
- SOLIDpower SpA (HTceramix)
- Pacific Northwest National Laboratory
- National Energy Technology Laboratory (US DOE)
- OxEon Energy LLC

TASK 33

Fuel Cells for Stationary Applications

Task manager

Dr Viviana Cigolotti

Contact

viviana.cigolotti@enea.it

Members

Summary

Task 33 is an application-type task to better understand how stationary fuel cell systems may be successfully deployed 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, focusing on fuels, the 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 Task 33.

Key messages - Facts

- The total installed capacity is forecasted to grow from 220 MW to 612 MW, and the market will be led 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 programs.
- Japan results to be the main leader in CHP installations thanks to the ENEFARM program with more than 430 000 fuel cells installed, with a target of 5.3 million of unit in 2030.
- 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, Korea is leading the pictures, with a cumulated installed capacity of 837 MW.
- Fuel cells applications in remote areas, off-grids, as reversible systems, grid balancing are an increasing market world-wide.

Key messages - Opinions

- The main sectors where stationary fuel cells have been employed are micro-CHP, large stationary applications, and new applications.
- The developers of fuel cells from Japan have 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.

The market for small stationary fuel cells for residential use has increased significantly, but very locally. A **first** major **task** 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 using and producing electricity and heat.

A **second task** is to investigate the implications for stationary fuel cells caused by introducing 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 the 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.

Activities

Task 33 has been organized with two meetings each year during the last working period. Moreover, Task 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 and discuss a selected topic. Where possible, these workshops will be linked to other relevant conferences. In 2022, a joint meeting Task 32 and Task 33 was held in Lucerne, Switzerland, on the 4th and 5th of July 2022, in conjunction with the European SOFC & SOE Forum. The participants came from Sweden, Austria, Denmark, Japan, Switzerland, the USA and Germany.

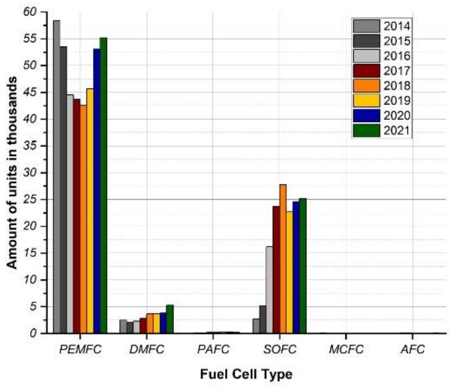
Technical developments

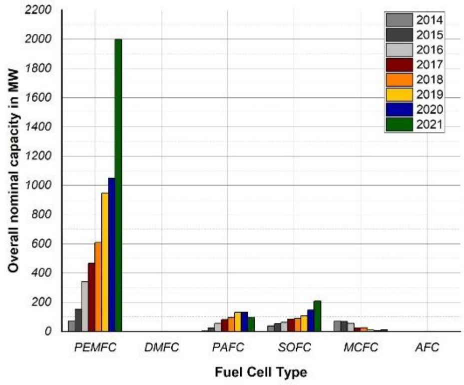
This Task has been focused mainly on information sharing and learning between experts with knowledge and experience in fuel cell technologies for stationary applications. In particular, the technical developments in this Task are described as follows:

Subtask 1 Small stationary fuel cells. This subtask handles markets for residential stationary fuel cells, where there is a viable economic and environmental case, analyzing how the market varies between countries, including energy prices and the framework for using and producing 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 a comparison between different technologies ICE engines, Stirling engines, PEFC and SOFC.

A detailed analysis of Japan has been carried out, where the market activities for small stationary fuel cells for residential use have increased significantly in several places. The outstanding region is Japan, with more than 430 000 fuel cells installed within the Ene-Farm program [1]. Japan is also very active in the transport sector, where 160 HRS have been opened with 7500 FCV running and 120 FC Buses in operation. Panasonic is one of the three suppliers of microCHP systems in the ENE-Farm program. A new model was introduced in 2017 and has 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, SolydEra is a developer and manufacturer of a complete SOFC system. The main product today from SolydEra is a 1,5 kWe unit called BluGen BG15. The electric efficiency is high, about 60 % AC for the complete system. SolydEra is participating in several EU projects, including the PACE project, whose objective is to install 10,000 units in 2020. The next step for SolydEra is to develop larger units from 6 kWe based on the existing in-house technologies.
Worldwide, the proton exchange membrane (PEM) fuel cell, referred to as a polymer electrolyte membrane fuel cell, is the most prevalent type of fuel cell. Figure 1a depicts this fuel cell type as the one that was most commonly installed globally in 2021, followed by Figure 1b depicting SOFC technology as the fuel cell type with the largest installed capacity.





The stationary fuel cell market has been increasing rapidly in recent years, driven by rising usage in different sectors, including data centres, hospitals, and industrial facilities.

The COVID-19 pandemic is predicted to reduce the worldwide Stationary Fuel Cells market size from USD 10240 million in 2022 to USD 49420 million by 2028 with a CAGR of 30.0% throughout the research period (2023-2028) [4]. 0-1 kW range accounted for most of the Stationary Fuel Cells worldwide market in 2021. The top companies in the international Stationary Fuel Cells market are Panasonic, Toshiba, Siemens, and others. Around 45% of the worldwide market is controlled by the top 3 competitors. The two largest markets, Japan and Korea, account for nearly 75% of the worldwide market. The predominant kind, with a more than 40% share, is 0-1 kW. The primary application, with a share of around 50%, is a telecommunications network [4].

Subtask 2 The implementation of New Directives and Regulations. This subtask handles the implications for stationary fuel cells caused by introducing new Directives or relevant legal regulations and standards. Effects on the increase of fuel cell competitiveness have been discussed to provide IEA-qualified input to the ongoing regulatory processes, elaborating recommendations and justifications as needed. Recently, there have been several national and international initiatives:

- The European Commission established the European Clean Hydrogen Alliance in July 2020 with the goal of hastening the development and use of hydrogen technology in Europe. The Alliance brings together business, governments, and other stakeholders to assist the growth of a clean hydrogen economy in Europe.
- Fuel Cell Technology Office (FCTO) 2020–2024 Strategy Plan, U.S. Department of Energy: In December 2020, the FCTO, which is a division of the US Department of Energy, published its strategic plan for 2020–2024. Under the strategy, the FCTO describes its objectives and plans for expanding fuel cell technology in the US, including enhancing performance and cutting prices.
- Japan's Basic Hydrogen Strategy: In December 2017, the Japanese government unveiled its Basic Hydrogen Strategy, which intends to develop hydrogen as a key energy source in Japan. The policy establishes objectives for hydrogen production, delivery, and consumption, and includes steps to assist the development of fuel cell cars and stationary fuel cell systems.
- These are only a few instances of the various directives and rules connected to fuel cells that have been established in recent years. The expansion of the fuel cell business depends on the creation of favorable laws and regulations since they may encourage investment, market acceptance, and research and development.
- There are also several new directives regarding energy issues that will influence the future market for fuel cells. The International Organization for Standardization (ISO) has produced fuel cell-related standards, including those for performance measurement, safety regulations, and environmental effects. The ISO fuel cell standards have recently undergone considerable changes. ISO/TC 197 is a technical committee that develops standards related to hydrogen technologies, including fuel cells. ISO standards are crucial for the development and use of fuel cells to be consistent, safe, and of high quality. These latest developments show that ISO is still actively engaged in creating hydrogen and fuel cell technology standards. The committee is working on several new standards, such as:
- ISO/DIS 24078.2, Hydrogen in energy systems — Vocabulary
- ISO/AWI TR 15916, Basic considerations for the safety of hydrogen systems
- The International Electrotechnical Commission (IEC) is also producing hydrogen and fuel cell technology standards. They include safety criteria for hydrogen technologies as well as standards for hydrogen storage systems, fuel cell power systems, and fuel cell power systems. In 2022, a number of these standards were still being developed. Moreover, two standardization bodies, CEN (the European Committee for Standardization) and CENELEC (the European Committee for Electrotechnical Standardization), collaborate to create European standards. They have created a variety of fuel cell standards for stationary use. These standards address a variety of terminology, fuel cell modules, and power system-related issues in relation to stationary fuel cells. They provide recommendations for stationary fuel cell system design, installation, and operation. Among others:

- FprEN IEC 62282-8-301:2023 (WI=74850), Fuel cell technologies - Part 8-301: Energy storage systems using fuel cell modules in reverse mode - Power-to-methane energy systems based on solid oxide cells including reversible operation - Performance test methods, Under Approval
- prEN IEC 62282-2-400 (WI=76129), Fuel cell technologies - Part 2-400: Fuel cell modules - Calculation of Rated Power and Power Density of a PEM stack and PEM module, Under Drafting
- prEN IEC 62282-3-100 (WI=74620), Fuel cell technologies - Part 3-100: Stationary fuel cell power systems – Safety, Under Drafting
- prEN IEC 62282-3-200 (WI=76202), Fuel cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods, Under Drafting
- prEN IEC 62282-3-201 (WI=76201), Fuel cell technologies - Part 3-201: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems, Under Drafting
- prEN IEC 62282-3-202 (WI=75602), Fuel cell technologies - Part 3-202: Stationary fuel cell power systems - Performance test methods for small fuel cell power systems that can be complemented with a supplementary heat generator for multiple units operation by an energy management system
- prEN IEC 62282-6-101:2022 (WI=72292), Fuel cell technologies - Part 6-101: Micro fuel cell power systems - Safety - General requirements, Under Approval
- prEN IEC 62282-6-106:2022 (WI=72288), Fuel cell technologies - Part 6-106: Micro fuel cell power systems - Safety - Indirect Class 8 (corrosive) compounds, Under Approval
- prEN IEC 62282-6-107:2022 (WI=72290), Fuel cell technologies - Part 6-107: Micro fuel cell power systems – Safety – Indirect water-reactive (Division 4.3) compounds, Under Approval
- prEN IEC 62282-6-401:2022 (WI=74404), Fuel cell technologies - Part 6-401: Micro fuel cell power systems - Power and data interchangeability - Performance test methods for laptop computers, Under Approval
- prEN IEC 62282-7-2 (WI=77103), Fuel cell technologies - Part 7-2: Test methods - Single cell and stack performance tests for solid oxide fuel cells (SOFCs), Under Drafting
- prEN IEC 62282-8-201:2023 (WI=74976), Fuel cell technologies - Part 8-201: Energy storage systems using fuel cell modules in reverse mode - Test procedures for the performance of power-to-power systems, Under Enquiry

The Subtask focuses on Europe but also other regions will be dealt with. Recently, the Clean Hydrogen Alliance released on March 2023, a roadmap on hydrogen standardization [5]. The standardization of hydrogen energy included roughly 400 areas, and important gaps need to be addressed, while a number of standards need updating. In particular, the upcoming EU regulations and directives strongly influence the market uptake of fuel cell systems. This Subtask aims to identify upcoming opportunities or threats from the implementation of the EU directives and regulations in the various countries, such as the Energy Efficiency (EE) Directive, Eco-design and Labelling Directive, Building Directive (EPBD), RES renewable Energy Systems Directive.

Subtask 3 Large scale fuel cell applications. This subtask handles the technology analysis 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. Globally, large-scale fuel cell applications are also expanding significantly, notably in transportation and electricity production domains. Many regions of the globe are developing and implementing large-scale stationary fuel cell applications, especially for power production in the industrial and commercial sectors:

- South Korea: The South Korean government declared intentions to deploy 15 GW of hydrogen fuel cells by 2040 [6], focusing on large-scale stationary fuel cells for power generation in sectors including steel and petrochemicals.
- United States: California-based Bloom Energy has installed large-scale stationary fuel cells for power production in a range of sectors, including telecommunications, data centers, and food processing. In 2021, Bloom Energy announced intentions to create a 1 GW fuel cell facility in Fremont, California.
- Europe: Many European nations are constructing large-scale stationary fuel cell projects for electricity production, with a concentration on the industrial and commercial sectors. For instance, in Italy, starting in 2022, Ferrari is building, at its Maranello facility, a new 1 MW solid oxide fuel cell unit to power the industrial complex.
- In order to generate electricity for the industrial and commercial sectors, Toshiba Energy Systems & Solutions Company is developing large-scale solid oxide fuel cells (SOFCs
- China: The Chinese government is supporting the use of fuel cells for power generation in the industrial and commercial sectors.

Generally speaking, fuel cells provide a flexible and adaptable option for large-scale power production, with applications in a variety of environments and sectors. Overall, the market for large-scale fuel cell applications is likely to continue developing in the future, driven by increased demand for clean energy, favorable government regulations, and the expansion of hydrogen infrastructure. The sectors that can be approached are:

- Microgrids: Especially in rural or off-grid areas, fuel cells may be utilized in microgrids to provide dependable, dependable, and resilient electricity to populations. For instance, multi MW fuel cell-based energy systems were set up in South Korea, supplying electricity to over 4,000 residences.
- Distributed power production places tiny power plants near the point of usage. For instance, FuelCell Energy has set up several MWs of fuel cell capacity for distributed power production in the United States, including at colleges, military facilities, and wastewater treatment plants (3).
- Combined heat and power (CHP): Fuel cells may also be used in combined heat and power (CHP) systems, where the waste heat from electricity production is utilised for heating or cooling. CHP systems may be highly effective and economical in facilities with significant energy needs, like hospitals or colleges.

Subtask 4 <u>Fuel cells in the future energy systems.</u> 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 with high efficiency and limited impact on carbon emissions, able to generate hydrogen and power for use in refueling stations of the 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 the 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.

Moreover, Task 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).

Work plan for 2023

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

Task 33 intends to expand anconduct activities to attract new members, above all from international countries such as the US and Canada.

Members

- Austrian Energy Agency
- University of British Columbia, Ballard
- VTT, Convion
- Engie
- Sunfire
- GenCell
- ENEA (Task Manager), SolydERA
- Toshiba, Panasonic
- KIST
- CNH2
- PowerCell

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[2] Genovese, M.; Schlüter, A.; Scionti, E.; Piraino, F.; Corigliano, O.; Fragiacomo, P. Power-to-Hydrogen and Hydrogen-to-X Energy Systems for the Industry of the Future in Europe. Int J Hydro-gen Energy 2023, doi:10.1016/j.ijhydene.2023.01.194.

[3] E4tech. The Fuel Cell Industry Review 2021.

[4] GLOBAL STATIONARY FUEL CELLS MARKET INSIGHTS AND FORECAST TO 2028, SKU ID : QYR-19998539 | Publishing Date : 14-Jan-2022 | No. of pages : 107, http://www.precisionreports.co/global-stationary-fuel-cells-market-19998539

[5] European Clean Hydrogen (2023), Roadmap on hydrogen standardization, https://hydrogeneurope.eu/ech2a-publishes-h2-standardisation-roadmap/

[6] Korea Hydrogen Economy Roadmap 2040, IEA/IRENA Renewables Policies Database, Last updated: 14 September 2020, https://www.iea.org/policies/6566-korea-hydrogen-economy-roadmap-2040

TASK 34

Fuel Cells for Transportation

Task manager

Dr Rajesh Ahluwalia

Contact

walia@anl.gov

Members

Summary

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

Key messages - Facts

- Commercial fuel cell vehicles from Honda, Hyundai and Toyota are available for purchase or lease.
- GM/Honda, Hyundai and Toyota are engaged in serial production of fuel cell stacks and systems for vehicles.
- At the end of 2021, there were more than 51,400 fuel cell vehicles on the road including ~42,200 passenger vehicles, >4,700 buses, >3,600 medium duty trucks and >850 heavy duty trucks.
- At the end of 2021, more than 700 hydrogen refueling stations were in operation.
- There is a heightened interest in hydrogen and fuel cells for off-road applications (agriculture, construction and mining), maritime, rail, and aviation. Anglo American announced the world's largest 2-MW hydrogen-battery hybrid (800 kW fuel cell, 1.2 MWh battery pack)

Key messages - Opinions

- FCS Cost Status for Heavy Duty Vehicles (HDVs): $323/kW for 1k systems/year, $227/kW for 10k systems/year, and $185/kW for 100k units/year
- 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: $21/kWh status at 10k systems/year, $16/kWh status at 100K/year, $9/kWh projected status at 500K/year; $9/kWh target

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

Activities

To date, the Task has held twelve 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.

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

Fuel cells have a unique thermal management issue in that despite higher efficiency than the diesel engines, the cooling loads are higher because a smaller amount of the waste heat generated in the stack leaves the tail pipe. The lower operating temperature further complicates thermal management in fuel cells.

Table 1 evaluates two approaches of dealing with the thermal management issue by considering heat rejection in a 430-hp (323 kWe) equivalent Class-8 diesel truck during the extreme condition of 6%-grade hill climb for 22 min at 30 mph and 40oC ambient temperature. It indicates that the diesel engine can be replaced with a hybrid FCH-175 platform consisting of a 175-kWe fuel cell system (FCS) and an 82.5 kWh energy storage system (ESS) operated in a charge depleting mode while maintaining the same radiator frontal area and fan. A 45% larger radiator frontal and fan are required in FCH-275 hybrid that has a larger 275-kWe FCS and a smaller 46-kWh ESS. In both platforms, the FC stack operates at 90oC during hill climb.. The abbreviation CEM stands for compressor-expander module, AC for cabin air conditioner, and CAC for diesel charged air cooler. Ref.: R.K Ahluwalia and X. Wang, "Performance, Durability and Cost of Fuel Cells for Class-8 Long Haul Trucks," IEA TCP-AFC Task 34 Meeting, December 8, 2022.

*21st Century Truck Partnership	Units	Diesel	FCH-175	FCH-275
Powertrain				
Power @ 6% Grade	kW_e	323	400	400
Engine / FC stack, w/o Fan	kW_e	363	238	358
CEM Parasitic	kW_e		20	30
AC Compressor	kW_e		16	13
Radiator Fan	kW_e	23	22	32
FCS Net Power	kW_e		175	275
Battery Discharge Power	kW_e		225	125
Heat Duty Parameters				
High Temperature Radiator	kW	163	193	292
CAC / Low Temperature Radiator	kW	57	37	56
AC Condenser	kW	12	23	18

Table 1 Table 1 FCS heat rejection in Class 8 heavy duty trucks

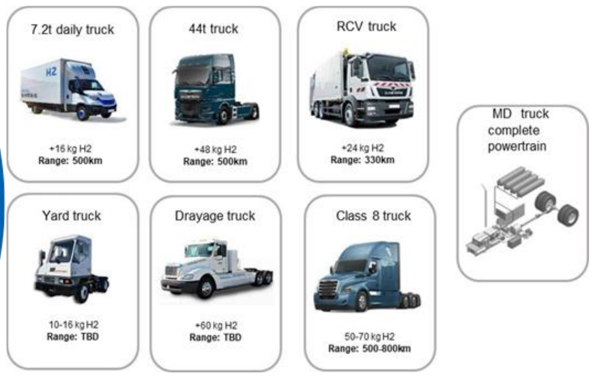

Figure. 1 Hydrogen storage and vehicle driving range in various commercial truck platforms. Ref.: S. Knights, "Zero Emission Fuel Cell Trucks," IEA TCP-AFC Task 34 Meeting, December 12, 2022.

As shown in Fig. 1, on-board H2 storage systems with sufficient capacity have been integrated into commercial fuel cell trucks to provide practical driving ranges: 16-70 kg of stored H2 for 330-800 km driving ranges in 7.2t daily truck, 44t truck, RCV (refuse collection vehicle) truck, yard truck, drayage truck, and Class-8 truck.

Subtask B: Fuel Infrastructure

According to a recent study, the present levelized cost of hydrogen (LCOH) for a 10 MW electrolysis system powered by different renewable energy sources in Austria is between 4 and 8 €/kg. As shown in Fig. 2, LCOH depends on the annual capacity factor and the levelized cost of electricity (LCOE) that varies between 40 and 82 €/MWh for wind, 31 and 109 €/MWh for photovoltaic (PV) and has a mean value of 55 €/MWh for hydropower.

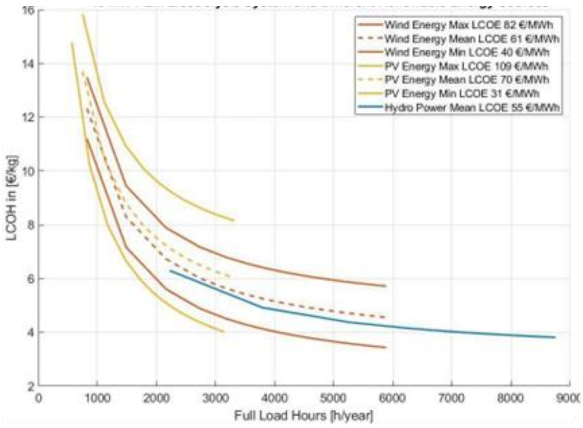

Figure. 2 Levelized costs of hydrogen for a 10 MW PEM electrolysis system and different renewable energy sources. Ref.: M. Aggarwal, "HyCentA Research GmbH," IEA TCP-AFC Task 34 Meeting, December 12, 2022.

Subtask C: Technology Validation

Fuel cells are becoming viable after many years of rigorous technology and product development, multiple generations of fuel cell stack and system fabrication, and >100 million miles of fleet testing of fuel cell buses and trucks. Ballard stacks and systems are operating in more than 3,600 heavy-duty fuel cell buses and trucks, showing 97% availability and >30,000 h lifetime. The heavy-duty stacks have reached >4.5 L/kW power density.

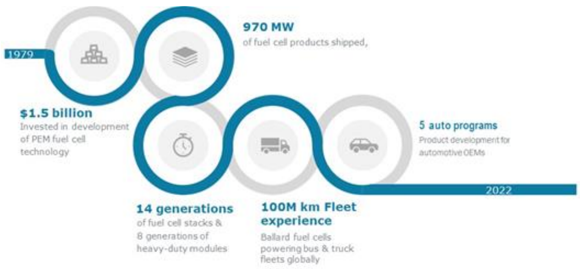

Figure 3 Technology validation across multiple generations of fuel cell modules for heavy-duty vehicles. Ref.: S. Knights, "Zero Emission Fuel Cell Trucks," IEA TCP-AFC Task 34 Meeting, December 12, 2022.

An approach has been developed to reach a 25,000-h electrode lifetime on a Class-8 long-haul truck duty cycle. It involves a) voltage clipping to 813 mV in FCH-175 (820 mV in FCH-275), b) limiting idle power to 50 kW in FCH-175 (70 kW in FCH-275) by reducing cathode stoichiometry, c) distributing load between fuel cell and energy storage (battery) systems to manage potential cycling, d) catalyst overloading for 0.45 mg/cm2 total Pt in cathode and anode electrodes, and e) active membrane area oversizing by 44% in FCH-175 (67% in FCH-275) to limit the electrochemical surface area (ECSA) loss to 38% for 750 mW/cm2 power density at end of life (EOL). Figure 4 summarizes the degradation adjusted FCS cost at high-volume manufacturing and fuel economy (FE) on the reference duty cycle.

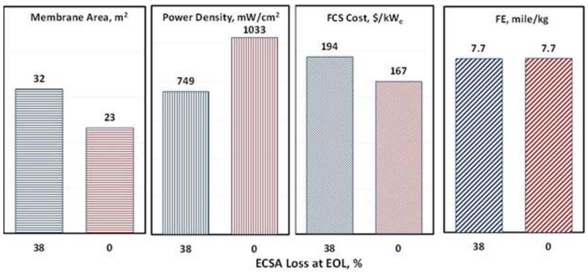

FIGURE 4 DEGRADATION ADJUSTED FCS PERFORMANCE AND COST. REF.: R.K AHLUWALIA AND X. WANG, "PERFORMANCE, DURABILITY AND COST OF FUEL CELLS FOR CLASS-8 LONG HAUL TRUCKS," IEA TCP-AFC TASK 34 MEETING, 15 DECEMBER 2022.

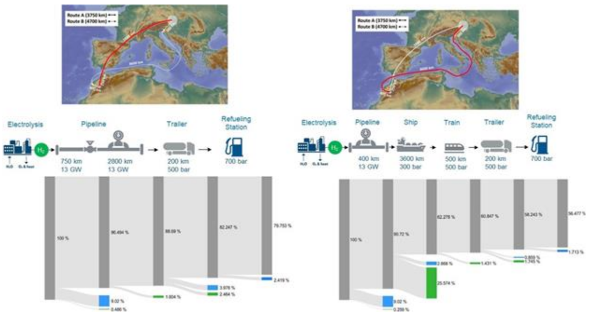

FIGURE 5 HYDROGEN TRANSPORT EFFICIENCY ON ALTERNATIVE PATHWAYS FROM MOROCCO TO VIENNA. REF.: M. AGGARWAL, "HYCENTA RESEARCH GMBH," IEA TCP-AFC TASK 34 MEETING, DECEMBER 12, 2022.

Figure 5 presents the well-to-tank (WTT) efficiencies of producing hydrogen in 13-GW electrolyzers in Moroccco and transmitting it to Vienna by two alternate routes that lead to 700-bar dispensing at the refueling stations. Route A consists of a 750-km land and undersea pipeline in Morocco, 2800-km pipeline in Europe, and 200-km transmission in 500-bar tube trailers. Route B consists of a 400-km land pipeline in Morocco, 3600-km transmission in 300-bar containers by ships, 500 km transmission in 500-bar containers by trains, and 200 km transmission in 500-bar tube trailers. The WTT efficiencies are ~80% for Route A and ~56% for Route B.

A recent study has compared the total cost of ownership of light-duty (LDV) and heavy-duty (HDV) vehicles with internal combustion engines (ICE) and battery (BEV), overhead battery (OBEV), fuel cell (FCEV) and hybrid (HEV) electric drivetrains over 2020-to-2050-time frame. As summarized in Fig. 6, electrified vehicles become the cheapest option in all passenger car, bus and freight platforms studied. Years of earliest cost parity with ICEVs are 2025 for BEVs in city car, 2026 for FCEVs in city bus (2026), and 2021 for BEVs in urban cargo. FCEVs are competitive or cheaper than BEVs in long-distance cars, buses (city, rural, coach), garbage vehicle and long-haul semi-truck.

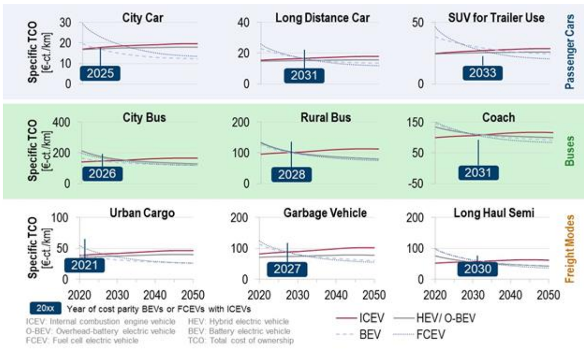

FIGURE 6 TOTAL COST OF OWNERSHIP OF ELECTRIFIED VEHICLES. REF.: KRAUS, S., REUL, J., GRUBE, T., LINSSEN, J., STOLTEN, D., "VEHICLE COST ANALYSIS FOR ROAD VEHICLES UNTIL 2050." IN PROCEEDINGS: 30TH AACHEN COLLOQUIUM SUSTAINABLE MOBILITY, AACHEN/GERMANY, OCT

WORK PLAN FOR 2023

Some of the key areas that the Task 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 transportation, and potential of reduction of GHG emissions and fossil fuel consumption. Future work will emphasize heavy-duty trucks, agriculture, maritime, mining, rails, and aviation applications.

MEMBERS

- A3PS
- Ballard Power Systems
- Tsinghua University, Sunrise Power Co
- EWII (IRD Fuel Cells)
- CEA Liten
- Forschungszentrum-Jülich GmbH
- Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
- KIST, Hyundai Motor Corporation
- Volvo Technology Corporation, PowerCell
- Argonne National Laboratory (ANL)

TASK 37

Modelling of Fuel Cell Systems

Task manager

Prof Dr Steven Beale

Contact

s.beale@fz-juelich.de

Members

Summary

Summary of Task objective and work process

The task members developed a major review paper on solid oxide cell modelling at continuum level: Continuum Scale Modelling and Complementary Experimentation of Solid Oxide Cells. 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). This was published in Progress in Energy and Combustion Science, 85, 100902, 2021, https://doi.org/10.1016/j.pecs.2020.100902 . With 36 (google scholar) citations, this is the first major review to encompass multi-scale modelling in fuel cells and electrolyzers in one place.

Key messages - Facts

- Virtual prototyping is an important component in the product cycle of electrochemical 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 - Opinions

- 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.

A book of invited chapters from member countries was published as Electrochemical Cell Calculations with OpenFOAM. Lecture Notes in Energy, 42. Springer-Nature, Eds. S.B. Beale and W. Lehnert (Germany), Springer, 2022. ISBN: 3030921778. This included contributions by members from Canada, China, Germany, Korea, and Spain.

Round-robin tests of low-temperature polymer electrolyte fuel cells. Participating organizations: TU Graz (Austria), KIT (Germany), CNR (Italy), FZ Jülich (Germany), Tsinghua U (China). In conjunction with Tasks 31 and 35. Work was terminated due to corona outbreak necessitating mandatory laboratory shutdowns.

Activities

The task 37 manager attended the following ExCo meeting:

67th ExCo meeting November 2022, (online web conference).

Technical developments

Significant expansion to several software suites, multi-phase capabilities with evaporation condensation.

Further expansion of codes from fuel cells to electrolyzers and beyond

France (CEA) and Germany (FZ-Jülich) conducted a collaborative research program of software evaluation and comparison involving PEFC benchmark cases

Work plan for 2023

Next face-to-face task meeting scheduled for Duisburg, Germany, in conjunction with ModVal 2023 conference for March.

Release of major upgrade to open source code "openFuelCell" in summer 2023.

Re-engineer results of round-robin testing of PEFCs work, based on established methodologies and available experimental data.

Expansion of scope of Task 37 activities to include micro-scale and nano-scale activities.

Members

- TU Graz
- Queen's U, U Alberta
- Tsinghua U, Hong Kong Poly U, U Science and Tech
- Zagreb U
- DTU, SerEnergy
- CEA-Liten
- DLR, FZ Jülich, KIT, Wikki, HZ Dresden-Rossendorf, KIST Europe
- ENEA, CNR
- Donguk U, KIST
- U Carlos III
- Lund U.
- LBNL, MichiganTech U, GM

Appendix: Fuel Cell Companies

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Austria				
AVL	System	Simulation software, monitoring technique, system tests and development		All-in-one system for generation, storage and useage of H2, mobility ened use technologies
Bosch Austria	System	PEMFC, SOFC		Automotive and stationary applications
Magna Steyr	Storage	Compressed (700 bar) and liquefied H2 storage		Hydrogen refuelling stations
RAG	Storage	-		All-in-one system for generation, storage and useage of H2
Energie Steiermark	System	System development		Stationary applications (network supporting systems, grid balancing)
Plastic Omnium New Energies Wels GmbH	Stack/system	PEMFC stacks, bipolar plates, key stack equipment		Integrated systems for automotive OEMs

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Christoph Industries	System	SOEC		Prototype production, small scale production
EEG Elements Energy GmbH	System	PEMFC		Uninterruptable power systems, storage systems
Hoerbiger	System	Components		Pressue control units, hydrogen refueling data interface
Miba	Stack	Components		Metallic bipolar plates
SAG (Salzburger Aluminium Group)	System	Components		Cryo-tanks
Worthington Industries	System	Components		Low and high pressue H2 cylinders
Wolftank Adisa GmbH	System	Components		Storage, elektrolyzer, fuel station
Peak Technology	System	Components		Storage, material development tanks

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Canada				
Ballard Power Systems	stack/system	PEM		multiple
cellcentric	stack	PEM		transport
Unilia Fuel Cells Canada	stack	PEM		transport
Loop Energy	stack/system	PEM		transport
Accelera by Cummins	stack/system	PEM		multiple
FTXT	stack	PEM		multiple
Fuel Cell Energy	stack/system	SOFC/MCFC		stationary
AVL Fuel Cells Canada	stack/system	PEM		mainly transport
Illuming Power	stack	PEM		unknown

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
SFC Energy	system	DMFC/PEM		stationary, mobility
China				
REFIRE Group	System			automobile, ship, construction machinery, material handling
Sinosynergy	System/stack			public transport vehicles, logistics transportation, rail, back-up power
SPIC hydrogen energy tech	System			bus, logistics vehicles, sanitation, locomotives, emergency power vehicles, UAVs
Shanghai H-RISE New Energy Technology Co., Ltd.	stack			Passenger cars, buses, commuting buses, heavy trucks, logistics vehicles, sanitation vehicles, medium transportation
Sinohytec	System/stack			commercial vehicles
Fenergy	stack			Heavy trucks, public transportation, and logistics vehicle

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Troowin	System/stack			Vehicle, marine, distributed generation and power supply
SUNRISE POWER CO., LTD.	System/stack			vehicles
Denmark				
Ballard Power Systems Europe	Systems and service	LT PEMFC		UPS/APU, vehicles (service) and maritime
Danish Power Systems	Stack components	MEA for HT-PEMFC		All applications for HT-PEMFC
IRD Fuel Cells	Stack components	MEA and BPP- flow plates		Automotive, back-up power and stationary
Elplatek	Surface treatments and coatings	-		Advanced catalytic coatings for electrodes and FC
Green Hydrogen.dk	Systems	Alkaline		Alkaline Electrolysis
Haldor Topsoe A/S	Components and stacks	SOEC/SOFC		Mainly Electrolysis
NEL Hydrogen	Hydrogen Fuelling Stations	Gaseous hydrogen		Transportation

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Blue World Technologies	stacks	Methanol FC		Automotive and mobile applications
Advent (former know as SerEnergy)	stacks	Methanol FC (HT PEM FC)		Automotive, telecom, industria, maritime
Rotrex A/S	H2 compressor	-		Automotive systems
EV Metalværk A/S	Hydrogen valves	-		Several applications
France				
Ad-venta	Components			Storage, FC systems
Areva H2 Gen	Production	PEM Electrolyser	Tens to Hundreds kW	Storage, Transportation, backup
Helion Hydrogen Power	Systems	PEFC + electrolyser	Hundreds kW	Grid stabilisation/emergency back-up systems
Ataway	System		0.5kW to 50 kW	Clean and autonomous power supply for off-grid sites and transportation

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
CEA	Component/stack/ system	SOFC, PEFC, SOEC, PEWE	10 W to 360 kW	R&D
CNR	System			Green energy storage
CNRS	Component/stack/system			R&D
ENGIE	System			Energy provider
GRT Gaz	System			Energy provider, power to gas
HDF industry	System	PEMFC (from Ballard technology)	>1MW	power supply for the grid, auxiliary power unit, heavy mobility (rail and maritime)
INERIS	System			Safety
INOCEL	System	PEMFC	module of 300kW	Transportation, stationary

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Mayhtec	Storage	Compressed, Hydride, Hybrid		Transportation, stationary
McPhy Energy	Production/Storage	Electrolyser, HRS		Stationary storage, transportation
Powidian	System	PEFC, Electrolysers	100W – 200 kW	Smart autonomous energy storage stations
Pragma Industries	Stack, test equipment, electronic loads, hydrogen storage	Roll to roll PEFC	10 – 100W	Portable tools, bikes
Raigi	Storage	High pressure gas		Transportation
Sylfen	System	Reversible SOFC	1-10 kW	Energy storage
Symbio	System	PEFC	5 kW, 20-300kW	Integrated cuel cells systems for Range Extenders (5kW) and Full Power heavy duty vehicles (20 – 300kW)
WH2	System	Methanol, Hydrogen, PEFC	25-4kW	Clean and autonomous power supply from green H2

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Germany				
Ätztechnik Herz GmbH & Co. KG	Stack (BPP)			
Audi AG	Stack/system (FCV)	Transportation (PEFC)		
balticFuelCells GmbH	Stack/system	Stationary/transportation/portable (PEFC)		
Bosch (Robert Bosch GmbH)	Stack/system	Transportation (PEFC) / Stationary (SOFC)		
Buderus	System	Stationary		
Clariant Produkte (Deutschland) GmbH	System (reformer catalysts)			
Continental	System components	Transportation (PEFC)		
Daimler AG	Stack/system (FCV)	Transportation (PEFC)		
DBI Gas- und Umwelttechnik GmbH	System	Stationary		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Technical Thermodynamics	Stack/system	Stationary/transportation (PEFC/SOFC)		
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Networked Energy Systems	Stack/system	Stationary/transportation (PEFC)		
EBZ Entwicklung- und Vertriebsgesellschaft Brennstoffzelle mbH	System	Stationary/transportation (SOFC)		
e.GO Rex GmbH	System	Transportation (PEFC)		
Eisenhuth GmbH & Co. KG	Stack (BPP)			
EnBW Energie Baden-Württemberg AG	System (utility)	Stationary		
ElringKlinger AG	Stack	Transportation (PEFC)		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
E.ON Technologies GmbH	System	Stationary		
EWE AG	System (utility)	Stationary		
Forschungszentrum Jülich GmbH	Stack/system	Stationary/transportation/portable (SOFC/PEFC)		
Fraunhofer IMM	System (fuel processor)			
Fraunhofer-Institut für Keramische Technologien und Systeme IKTS	Stack/system	Stationary/portable (SOFC)		
Fraunhofer-Institut für Solare Energiesysteme ISE	Stacks/system	Transportation/portable (PEFC)		
Fraunhofer-Institut für Chemische Technologie ICT	Stacks/system	Transportation/portable (AFC/PEFC)		
Freudenberg Performance Materials	Stack components/ system components	Stationary/Transportation/Portable (PEFC)		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Freudenberg Sealing Technologies GmbH & Co. KG	Systems	Stationary (PEFC)		
FCP Fuel Cell Powertrain GmbH	Systems	Stationary / Transportation		
FuelCell Energy Solutions GmbH	Stack/system	Stationary		
FuMA-Tech GmbH	Stack (membranes)			
Horiba FuelCon GmbH	System (Test systems)	PEFC/SOFC		
Greenerity GmbH	Stack components (MEA)	Transport / Stationary (PEFC)		
Gräbener Machinentechnik GmbH	Stack components (BPP)			
GSR Ventiltechnik GmbH & Co. KG	System components (valves)			

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
HAW Hamburg	System	Stationary/transportation		
Heliocentris Academia International GmbH	System (Teaching)	Stationary		
HIAT gGmbH, Hydrogen and Informatics Institute of Applied Technologies	Stack components /systems	PEFC		
Hydrogenious Technologies GmbH	Systems (storage)			
H2 Mobility Deutschland GmbH & Co. KG	Systems (hydrogen infrastructure)	Transportation		
inhouse engineering GmbH	Stack/system	Stationary (PEFC)		
Karlsruher Institut für Technologie (KIT)	Systems, stack components	Stationary/transport		
Linde Material Handling GmbH	System	Transportation		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Maximator GmbH	System components (hydrogen)			
NPROXX Jülich GmbH	System components (hydrogen storage)	Transportation		
N2telligence GmbH	System	Stationary		
Polyprocess GmbH	Stack components (sealings)			
Proton Motor Fuel Cell GmbH	Stack/system	Stationary/Transportation (PEFC)		
Quin Tech	Stack/system	Supplier for Stationary / Transportation / Portable		
SenerTec Kraft-Wärme-Energiesysteme GmbH	System	Stationary		
SFC Energy AG	Stacks/system	Portable (PEFC)		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
SGL Carbon	Stack components	PEFC		
SOLIDpower GmbH	System	SOFC		
Sunfire GmbH	Stacks/system	Stationary/Transportation/Portable (SOFC)		
TU Bergakademie Freiberg	System	Stationary/transportation/portable		
Ulmer Brennstoffzellen Manufaktur GmbH	Stacks/system	Stationary/Transportation (PEFC)		
Umicore AG	Stack (Catalysts)			
Vaillant Deutschland GmbH & Co. KG	System	Stationary (SOFC)		
Viessmann Werke GmbH & Co. KG	System	Stationary (PEFC)		

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Viessmann Werke GmbH & Co. KG	System	Stationary (PEFC)		
WS Reformer GmbH	System	Stationary (PEFC)		
Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW)	Stacks/system	Stationary/Transportation/Portable (PEFC)		
Israel				
Hydrolite	Stationary Energy Applications	AEM Electrolyzers and AEMFCs		Stationary
Phinergy	Al-Air battery			Automotive
GenCell	Stationary Fuel Cells and	AFC		Stationary Fuel Cell
Elbit Systems	Airborne	PEM		Drones

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Electriq Global	Hydrogen Storage	Borohydride		Automotive
Energy StorEdge	Hydrogen Storage	Formate		Automotive
H2Pro	Hydrogen generation	Electrolysis		
FontoPower	Stationary Fuel Cells	SOFC		Commercial buildings
RefHuel	Stationary Fuel Cells	Direct Quinone Fuel Cell		Buildings
HevenDrones	Airborne	PEMFCs		Drones
Conduce	Stationary	AEMFCs		buildings
QD-Sol	Hydrogen generation	Photocatalysis		Solar farms

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
HydroX	Hydrogen Storage	Hydrogen Carriers		
Purammon	Hydrogen generation	Waste to hydrogen		
Italy				
Arco Technologies	Stack and System	PEMFC, AEM Electrolyser		Mobility (PEMFC) and hydrogen production (AEM)
Enapter	Stack and System	AEM Electrolyser		Hydrogen Production
Genport	Stack	PEM, SOFC		Portable units
McPhy	Stack and System	ALK, PEM Electrolysers		Hydrogen Production, Mobility, Industry
SolydERA	Stack and System	SOFC, SOEC		Hydrogen production and stationary application
Hyter	Stack and System	AEM Electrolyser		Hydrogen Production
Bluenergy revolution	Integratori	PEM Electrolyser		Hydrogen Production

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Erredue Gas	Stack and System	ALK, PEM Electrolyser		Hydrogen Production
IMI Vivo	Stack and System	PEM Electrolyser		Hydrogen Production
H2energy	Stack and System	ALK, PEM, AEM Electrolyser		Hydrogen Production
Cefla	Stack and System	SOFC		Hydrogen production and stationary application
ILT energia	Stack and System	ALK Electrolyser		Hydrogen Production
De Nora	Electrodes			Hydrogen Production

Japan

Aisin	System	SOFC	1kW class	Stationary
Fuji Electronic	Stack/ystem	PAFC	100KW	Stationary

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Honda Motor	Stack/System	PEFC	100kW class	Transport
Kyocera	Stack/System	SOFC	1kW/3kw class	Stationary
Mitsubishi Heavy Industries	System	SOFC	250kW class	Stationary
Miura	System	SOFC	4.2 kW class	Stationary
Morimura SOFC	Stack	SOFC	N/A	Stationary
Panasonic	Stack/System	PEFC	1kW, 5kWclass	Stationary
Toshiba Energy Systems	Stack/System	PEFC	100kW class	Stationary/Transport
Toyota Motor	Stack/System	PEFC	60, 80, 100kW	Transport/Stationary
Toyota Industryies	Stack/System	PEFC	8kW class	Transport/Stationary

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Toyota Industryies	Stack/System	PEFC	8kW class	Transport/Stationary
Hitachi Zosen	System	SOFC	20kW class	Stationary
Brother Industries	System	PEFC	4.4kW class	Stationary
Spain				
AJUSA	STACK & SYSTEM	PEM FC	1-12 kW	Mobile and Stationary
CENTRO NACIONAL DEL HIDRÓGENO (research)	STACK & SYSTEM	PEMFC & SOFC	0.01–150 kW	Mobile and Stationary
CIEMAT (research)	STACK & SYSTEM	PEMFC & SOFC & MCFC	0.01–30 kW	Mobile and Stationary
CSIC (research)	STACK & SYSTEM	PEMFC	0.01–10 kW	Mobile and Stationary
TECNALIA (research)	STACK & SYSTEM	PEMFC & SOFC	0.01–15 kW	Mobile and Stationary

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
INTA (research)	STACK & SYSTEM	PEMFC	0.01–60 kW	Mobile and Stationary
AICIA (research)	STACK & SYSTEM	PEMFC	1–60 kW	Mobile and Stationary
CENER (research)	STACK & SYSTEM	SOFC	1-50 kW	Stationary
Fundación Hidrógeno de Aragón (research)	STACK & SYSTEM	PEMFC	-	Mobile and Stationary
Universidad de Sevilla (research)	STACK	PEMFC	0.01-0.5 kW	Stationary
Sweden				
Catator	Systems			Small independent fuel cells system, for example instance unmanned aircrafts
Cell Impact	Manufacturing			Stamping of bipolar plates
Cellfion AB	Membranes			Fuel cell membranes

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Cellkraft	Stack			Offgrid (PEFC)
Celsibus AB	Fuel cell system			Development and manufacturing of fuel cell systems
Höganäs AB	Material			Manufacturer of metal powders. Developer of interconnect materials for SOFC.
Impact coating	Material			PVD coatings for fuel cell bipolar plates
Insplorion Sensor system AB	Hydrogen sensors			Development and manufacturing of hydrogen sensors
myFC	Stack/system			PEFC system integration
PowerCell AB	Stack/system			100 kWe PEFC stack for automotive Back-up power, powerpacks and APU for trucks (PEFC and diesel reformer)
Sandvik MT AB	Material			Developer and manufacturer of metallic bipolar plates and interconnectors.

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
USA				
Plug Power	Fuel cell stacks and systems	PEM		Material handling, Backup power , (telecommunications)
AvCarb	For fuel cell stacks	Gas diffusion systems		Fuel cell – both mobile and stationary
Bloom Energy	Fuel cell system	SOFC		Stationary – data centers, microgrids, etc.
HyAxiom	Fuel cell system	PAFC		Stationary
3M	Ionomers	PEM		Fuel cells, electrolyzers
Chemours	Ionomers, membranes	PEMFC, Electrolyzers		Fuel cells, electrolyzers
W.L. Gore and Associates	Membranes, MEAs	PEMFC		Fuel cells
Pajarito Powder	Catalyst supports, PGM-free catalysts	Graphite, Fe-N-C materials		Fuel cells
Proton/Nel	Electrolyzer	PEM		Water electrolyzer

COMPANY NAME	AREA (STACK/SYSTEM)	TYPE OF TECHNOLOGY	SCALE/ RANGE	APPLICATION
Giner, Inc.	membranes	PEM		Fuel cells, electrolyzers
Treadstone	Coatings for electrochemical systems	Bipolar plates		Fuel cells, electrolyzers
Cummins (Accelera)	electrolyzer systems, fuel cell systems	PEME, PEMFC, SOFC		Electrolyzers, stationary FC, transportation
GM	Fuel cell systems	PEMFC		HD vehicles, rail, aviation
pH Matter	PGM and PGM-free catalysts, catalyst supports	PEMFC, AFC		Fuel cells