ANL 22/04

2020 Hydrogen and Fuel Cell Technologies Market Report

Cover Photo Credits
Upper middle left: Argonne National Laboratory.
Top right: Photo courtesy of PlugPower
Upper middle right: Alstom grants permission to the U.S. Department of Energy and Argonne National Laboratory to use image for the 2020 Hydrogen and Fuel Cell Technologies Market Report. Photo © Alstom/M. Brey
Bottom right: FuelCell Energy grants the use of this image for the 2020 U.S. Department of Energy Hydrogen & Fuel Cell Technologies Market report.
All others: Shutterstock

About Argonne National Laboratory
Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Lemont, Illinois 60439. For information about Argonne and its pioneering science and technology programs, see www.anl.gov.

DOCUMENT AVAILABILITY

Online Access: U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free at OSTI.GOV (http://www.osti.gov/), a service of the U.S. Dept. of Energy's Office of Scientific and Technical Information.

Reports not in digital format may be purchased by the public from the National Technical Information Service (NTIS):

U.S. Department of Commerce
National Technical Information
Service 5301 Shawnee Rd
Alexandria, VA 22312
www.ntis.gov
Phone: (800) 553-NTIS (6847) or (703) 605-6000
Fax: (703) 605-6900
Email: **orders@ntis.gov**

Reports not in digital format are available to DOE and DOE contractors from the Office of Scientific and Technical Information (OSTI):

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
www.osti.gov
Phone: (865) 576-8401
Fax: (865) 576-5728
Email: reports@osti.gov

ANL-22/04

2020 Hydrogen and Fuel Cell Technologies Market Report

Prepared by
The Fuel Cell and Hydrogen Energy Association
Argonne National Laboratory, Chemical Sciences and Engineering Division

Edited by John Kopasz
Chemical Sciences and Engineering Division, Argonne National Laboratory

Authors and Acknowledgements

This report, managed and reviewed by Argonne National Laboratory, was compiled, written, and edited by Connor Dolan, Jennifer Gangi, and Quailan Homann, with contributions from Trip Johnson and Gio Liguori, of the Fuel Cell and Hydrogen Energy Association (FCHEA), Washington, D.C.

The *2020 Hydrogen and Fuel Cell Technologies Market Report* covers major activities and advancements in the global hydrogen and fuel cell industry up to December 31, 2020. The information in this report was gathered from public websites, reports, articles, and conference presentations, as well as through personal contact and communication with fuel cell and hydrogen companies, governmental agencies, and international organizations and trade associations.

International currencies converted to U.S. dollars are based on either a stated amount from company materials at time of release or converted by the author using "Yearly Average Exchange Rates for Converting Foreign Currencies into U.S. Dollars" for 2020 by the Internal Revenue Service. (See https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.)

Notice

This report was supported by the U.S. Department of Energy's (DOE's) Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE) under Contract No. 0F-60022, Supplemental Agreement No. M0001, between FCHEA and UChicago Argonne LLC, as operator of Argonne National Laboratory for the DOE under Prime Contract No. DE-AC02-06CH11357. As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by DOE.

Contents

Tables

Abbreviations and Terms

AFC	Alkaline fuel cell
AI	Artificial intelligence
ARPA-E	Advanced Research Projects Agency–Energy
BES	Office of Basic Energy Sciences
CARB	California Air Resources Board
CO_2	Carbon dioxide
CEC	California Energy Commission
CHP	Combined heat and power
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EV	Electric vehicle
FCHEA	Fuel Cell and Hydrogen Energy Association
FCH JU	Fuel Cells and Hydrogen Joint Undertaking
FECM	Office of Fossil Energy and Carbon Management
FOA	Funding Opportunity Announcement
GW	Gigawatt
HFTO	Hydrogen and Fuel Cell Technologies Office
IPHE	International Partnership for Hydrogen and Fuel Cells in the Economy
kW	Kilowatt
MEA	Membrane electrode assembly
MHE	Material handling equipment
MOU	Memorandum of Understanding
MW	Megawatt
NE	Office of Nuclear Energy
OEM	Original equipment manufacturers
ORNL	Oak Ridge National Laboratory
PEM	Proton exchange membrane
PPE	Personal protective equipment
R&D	Research and development
SBIR	Small Business Innovation Research
SMR	Steam methane reformation
SOEC	Solid oxide electrolyzer cells
SOFC	Solid oxide fuel cell
STTR	Small Business Technology Transfer
TCI-P	Transportation and Climate Initiative Program
UAV	Unmanned aerial vehicle
UK	United Kingdom
ZEV	Zero emission vehicle

Industry Overview: 2020

This report features summaries of relevant hydrogen and fuel cell activity in 2020, consistent with prior annual reports across applications and sectors. However, 2020 was no ordinary year. Despite pandemic hardships, the hydrogen and fuel cell industry not only stepped up to assist with humanitarian and healthcare efforts but saw continued momentum in several growing market sectors with numerous partnerships, initiatives, and investments. Using hydrogen and fuel cell technologies to provide an environmental and economic pathway to clean, reliable power was a key feature of world economic recovery and energy infrastructure plans.

Today, hydrogen energy and fuel cell systems are being developed and deployed in a range of stationary power, portable power, and transportation applications around the world. Throughout 2020, there were significant achievements in each sector, building on years of research and development (R&D), field testing, large-scale demonstration projects, and real-world customer experience.

The heavy-duty truck market in particular continued to make substantial gains, with new players entering the space and a coalition of companies pledging to produce and deploy more than 100,000 fuel cell trucks in the next two decades. To provide hydrogen for trucks and other end users, larger and larger electrolyzer projects were announced throughout the year. Collectively, there were more than 430 megawatts (MW) of electrolyzer systems either deployed, ordered, or proposed around the world.

This 2020 report also provides special “Spotlights” on the collective industry response to the COVID-19 pandemic as well as international commitments and hydrogen strategies, providing overviews of significant activity during and after the initial onset of COVID-19 around the world.

Business Development

This section provides an overview of fuel cell and hydrogen company business activities in 2020, including sales and shipments, mergers and acquisitions, collaborations and joint ventures, industry investments, and company expansions of manufacturing facilities. Overall, there was a substantial number of significant accomplishments that collectively moved the needle throughout the year, increasing attention to and expansion of hydrogen and fuel cell technologies around the world.

2020 Sales/Shipments

Collectively, the total estimated power of fuel cell systems shipped globally for all applications in 2020 was more than 1 gigawatt (GW). This is a small decrease from 2019 but still a positive indicator of growth, as much of the manufacturing world was impacted by global shutdowns, supply chain disruptions, and workforce reductions due to the COVID-19 pandemic. The total estimated number of fuel cell system units shipped was approximately 75,000, an incremental increase from 2019.

A continuing trend from 2019 is the dominating contribution from the transportation sector, which includes fuel cell systems in light-duty passenger cars, material handling equipment (MHE), and medium- and heavy-duty vehicles. MHE represented approximately 35 MW, with fuel cells for cars, buses, trucks, trains, and other vehicles collectively totaling more than 850 MW. The stationary sector, including both large-scale and small-scale systems, totaled around 170 MW, with the majority attributable to several large-scale orders.

To generate these numbers, the authors of this report surveyed fuel cell manufacturers, original equipment manufacturers (OEMs) and other key stakeholders around the world. The authors also compiled publicly available information on company sales and shipments, including annual reports and investor presentations.

Table 1: Annual Worldwide Fuel Cell Shipments 2016-2020[1,2,3]

Annual Worldwide Fuel Cell Shipments 2016–2020		
Year	Estimated Number of Units Shipped	Estimated Total Power
2016	62,000	500 MW
2017	70,000+	670 MW
2018	68,000	800 MW
2019	70,000	1.1+ GW
2020	75,000	1 GW

On the large-scale hydrogen production side, there were more than 430 MW of electrolyzer projects deployed, ordered, or proposed worldwide, with individual projects ranging from 1 MW to 200 MW.

More details on 2020 sales, shipments, and deployments can be found in the respective sections of this report.

Company Acquisitions

Several fuel cell and hydrogen companies expanded business activities through acquisitions throughout the year.

In June, Latham, New York-based Plug Power completed the acquisition of two hydrogen companies, United Hydrogen and Giner ELX, expanding its hydrogen generation capability and product portfolio.[4] United Hydrogen is one of the largest privately held merchant hydrogen producers in North America. Giner ELX's product portfolio includes large-scale proton exchange membrane (PEM) hydrogen generators, grid-level renewable energy storage solutions, and on-site hydrogen generation systems for fuel cell vehicle refueling stations and industrial uses.

Towards the end of 2020, there were other sales and acquisitions in the fuel cell and hydrogen sector:

- Honeywell International purchased Ballard Power Systems' unmanned aerial vehicle (UAV) business assets and employee workforce in October.[5]
- Also in October, Chart Industries completed the acquisition of the cryogenic trailer and hydrogen trailer assets of Worthington Industries, Inc.[6]
- In Norway, Everfuel A/S signed an agreement to acquire H2CO AS, a Uno-X owned company, which has two hydrogen fueling stations as well as hydrogen distribution assets.[7]

Collaborations, Joint Ventures, and Memorandums of Understanding

The year also saw many joint ventures, partnership agreements, and memorandums of understanding (MOUs) as companies agreed to collaborate on complementary product and market goals, share technological expertise, and leverage stakeholder resources. Many of the MOUs focused on product development for the fuel cell heavy-duty truck sector and large-scale hydrogen generation projects.

- FCHEA, the national trade association for the fuel cell and hydrogen industry in the U.S., and Korea's Hydrogen Convergence Alliance, also known as H2Korea, signed an MOU in February pledging to work together to advance the hydrogen and fuel cell industry around the world.[8] The MOU outlines different areas of cooperation, including information-sharing, codes and standards advancement, message development, and encouraging growth of the fuel cell industry and expansion of hydrogen supply.

- Also in February, fuel cell manufacturer PowerCell Sweden signed an exclusive distribution agreement with Japanese trading company Inabata & Co. that allows Inabata to market and sell PowerCell's fuel cell systems in Japan.[9]
- In March, Nel ASA announced a collaboration agreement with Kvaerner, a Norwegian engineering company, to standardize large-scale hydrogen production plants and other green hydrogen projects.[10] Nel and Kvaemer were already working on a standardization process for a 20 MW system that could eventually be scaled up to several hundred MW.
- Uniper and Siemens Gas and Power signed a cooperation agreement in April to focus on decarbonizing power generation and promoting sector coupling of energy for transportation and industrial applications. The agreement also includes evaluating the use of hydrogen at Uniper's existing gas turbines and gas storage facilities.[11]
- In May, as part of the South Korean Ministry of Environment's plan to increase hydrogen availability and subsidize private infrastructure, Hyundai Motor Company entered into an MOU with Air Liquide Korea, Hydrogen Energy Network (HyNet), a United Kingdom (UK)-based hydrogen company, and the Incheon International Airport Corporation to transform the airport in Incheon, South Korea, into a low-carbon and eco-friendly airport.[12]
- Hyundai signed an MOU in February with Yeosu Gwangyang Port Corporation to develop and demonstrate fuel cell heavy-duty trucks for logistics transportation and support hydrogen fueling infrastructure to be built in Gwangyang Port in Busan, South Korea.[13]
- Later in the year, Hyundai entered into an MOU with Chinese companies Shanghai Electric Power Co., Shanghai Sunwise New Energy System Co., and Shanghai Ronghe Electric Technology Financial Leasing Co. to establish a hydrogen mobility ecosystem around Shanghai and the Yangtze River Delta.[14] In addition, a similar MOU was signed with China Iron and Steel Research Institute Group and Hebei Iron and Steel Group for hydrogen development in the Jing-Jin-Ji area. The agreements focus on collaboration to deploy hydrogen refueling stations and on financing of fuel cell vehicle fleets. Under the MOUs, Hyundai aims to supply 4,000 fuel cell trucks to China by 2025.
- Hyundai also signed an MOU with INEOS to explore new opportunities for the production and supply of hydrogen as well as the worldwide deployment of hydrogen applications and technologies in Europe.[15] The agreement also includes the evaluation of Hyundai's proprietary fuel cell system for the INEOS Grenadier 4x4 vehicle.
- In July, Air Products and thyssenkrupp Uhde Chlorine Engineers signed a strategic cooperation agreement to collaborate in key regions on green hydrogen projects.[16]
- Also in July, Air Products, ACWA Power and NEOM, a sustainable living and innovation hub, signed a US$5 billion agreement for a world-scale renewable hydrogen-based ammonia production facility.[17] The project will be located in Saudi Arabia, where NEOM is located, and the facility will produce 650 tons of hydrogen per day.

- Air Liquide and the Port of Rotterdam Authority launched a joint initiative in July to deploy 1,000 hydrogen fuel cell trucks in the Netherlands, Belgium, and Germany by 2025.[18] Other partners include truck manufacturers, fuel cell suppliers, and transport/logistic companies.
- Toyota and Honda announced a partnership in August to develop a mobile power generation system, "Moving e," consisting of a fuel cell bus, hydrogen storage tanks, portable batteries, and portable external power output devices.[19]
- Honda also signed an MOU with General Motors in September to establish a North American Automotive alliance, building on a previous agreement signed in April that focused on electric vehicles.[20] The MOU includes a range of vehicles to be sold under each brand, including continued collaboration on fuel cell vehicles as well as cooperation in purchasing, research and development, and connected services.
- In September, Ballard Power Systems announced a collaboration agreement with automotive supplier MAHLE to develop fuel cell systems for various classes of commercial trucks.[21] Ballard also entered into an MOU with Audi AG in September for the use of Ballard's FCgen®-HPS product in commercial trucks and passenger cars. In October, Ballard then signed a patent license agreement and an amendment to expand the MOU agreement.[22]
- Hyzon Motors signed an MOU with Australian industrial technology company WarpForge to develop a fuel cell powered "SuperBus."[23] Development of the prototype SuperBus will take place at WarpForge's facilities in Perth, Western Australia. Hyzon is collaborating with Australian Transit Management Pty (ATG) on the use of the SuperBus on its bus routes.[24] The company is also collaborating with Hiringa Energy in New Zealand to deploy fuel cell powered trucks in that country.[25]
- Siemens Energy and Siemens Mobility signed an MOU to develop hydrogen solutions for rail transport in Germany and other areas of Europe.[26] In September, Siemens Energy was spun off from the Siemens Group.
- In November, Cummins announced it was working with Navistar International Corporation, a commercial vehicle and engine company, to integrate Cummins' fuel cell power modules into Navistar's International RH Series Class 8 truck.[27] Also that month, Cummins finalized its NPROXX joint venture with Enrichment Technology Company (ETC) that will offer NPROXX's type 4 hydrogen pressure vessels and other hydrogen products for on-highway and rail applications. [28]
- Nel entered an MOU with Everfuel A/S in which Everfuel received a majority stake in H2 Fuel Norway AS, previously a fully owned Nel company, to create a new company called Everfuel Norway Retail AS.[29] Everfuel Norway Retail AS will focus on developing hydrogen fueling stations in Norway.
- SFC Energy, based in Brunnthal, Germany, announced several business agreements in 2020. Its partner adKor GmbH entered into an equipment sales agreement with Ballard Power Systems Inc. for 500 of Ballard's FCgen®-1020ACS fuel cell stacks to integrate

into SFC's Jupiter backup power systems.[30] These systems will be deployed at radio tower sites in Germany per adKor contracts. The project has the potential for up to 1,500 add-on tower sites. Other SFC activities included:

  - In September, SFC signed a cooperation agreement with VINCORION, a German-based mechatronics producer, to develop and market a sustainable, portable energy management system, P2M2, that incorporates SFC's EFOY Pro 12000 Duo fuel cell.[31]
  - In November, SFC signed an exclusive sales and partner agreement with Toyota Tsusho Corporation, the trading arm of the Toyota Group.[32] Under the agreement, Toyota Tsusho will be SFC's exclusive partner for promoting and selling SFC's hydrogen and methanol fuel cell products in Japan in all industrial and civilian market segments.

- In December, Daimler Truck AG, IVECO, OMV, Shell, and the Volvo Group formed H2Accelerate and committed to working together to increase public, policy maker, and regulatory support for the mass market rollout of hydrogen trucks in Europe.[33]
- Also in December, the Alliance for Logistics Innovation through Collaboration in Europe (ALICE) and Hydrogen Europe entered into an MOU to focus on integrating hydrogen solutions for transport and logistics.[34]
- Chart Industries completed its investment in Hydrogen Technology & Energy Corporation (HTEC) in December, investing C$20 million (US$15.7 million) for 15.6% of its capital stock on a fully diluted basis.[35] In conjunction with this strategic investment, Chart and HTEC also signed a binding commercial MOU to establish commercial collaboration and equipment supply arrangements for Chart to supply HTEC projects.

Business Development and Expansions

- Hyzon Motors, also known as Hydrogen Mobility Powered by Horizon, was launched in March as a new business of Horizon Fuel Cell and will focus on the heavy-duty transportation market.[36] The company opened its U.S. headquarters at the former General Motors fuel cell facility in Honeoye Falls, New York, and its European headquarters and hydrogen truck manufacturing center in Groningen, the Netherlands. Hyzon announced partnerships with ReCarbon, Inc. and Holthausen Clean Technology B.V. in 2020.[37]
- In September, Ballard expanded manufacturing capacity for production of its proprietary membrane electrode assemblies (MEAs) at its headquarter facility in Vancouver, BC.[38] The upgraded capacity allows production of 6 million MEAs annually. Ballard received a US$7.7 million purchase order from Guangdong Synergy Ballard Hydrogen Power Co., Ltd. in July for MEAs for use in manufacturing FCvelocity®-9SSL fuel cell stacks.[39] Guangdong Synergy Ballard Hydrogen Power Co., Ltd.is a joint venture in which Ballard holds a 10% ownership interest.

- UK-based Johnson Matthey completed and commissioned a £7.5 million (~US$9.8 million) fuel cell component facility in Shanghai, China, in October.[40] The facility will have the capacity to make 4 million MEA components per year.
- In December, Hyundai announced HTWO, a new brand that represents "hydrogen and humanity, the two main pillars of Hyundai's fuel cell business."[41] The new brand will facilitate Hyundai's global fuel cell business and promote hydrogen worldwide.
- Doosan Fuel Cell, based in Korea, unveiled its plan for development of its third-generation solid oxide fuel cell and announced the investment of ₩72.4 billion (US$61 million) to build manufacturing facilities for cells, stacks, and systems.[42] Doosan also signed a joint development agreement with UK solid oxide fuel cell (SOFC) company Ceres Power to work together on critical SOFC components.

Investments

- Israeli fuel cell manufacturer GenCell received a US$10 million investment from Paz Oil Company Ltd. in January and was added to TDK Corporation subsidiary TDK Ventures Inc.'s investment portfolio in September.[43]
- In March 2020, Cummins increased its cash investment in Loop Energy, a Canadian provider of fuel cell range extenders for medium- and heavy-duty vehicles, an investment first made in September 2019.[44]
- In October, Total Carbon Neutrality Ventures, the venture capital arm of Total SE, led an investment in Hyzon Motors that also included Ascent Hydrogen Fund, Hydrogen Capital Partners, and Audacy Ventures Ltd.[45]
- Plug Power completed an equity deal totaling approximately US$1 billion in capital in November and announced plans to build five regional green hydrogen facilities in the United States.[46]

U.S. Hydrogen Investment Road Map

Twenty companies and organizations from the energy, transportation, fuel cell manufacturing, and electric power industries and FCHEA worked with McKinsey & Company to release *Road Map to a US Hydrogen Economy,*[47] a comprehensive report that details how, with the proper investment and policy support, hydrogen could provide economic and environmental benefits to the U.S. This includes the potential to create 700,000 jobs and US$140 billion in revenue by 2030 and 3.4 million jobs and US$750 billion in revenue by 2050, while achieving substantial reductions in greenhouse gas emissions, specifically reducing carbon dioxide levels by 16% and nitrous oxide levels by 36%.

The executive summary of the report was unveiled at the 2019 Fuel Cell Seminar & Energy Exposition in Long Beach, California. Due to COVID-19 restrictions, the official launch of the report was in October 2020, with several in-depth virtual briefings that included presentations from key companies that funded the study as well as other technical experts.[48]

U.S. Federal Activity

In the United States, the U.S. Department of Energy (DOE) is the main agency supporting R&D for fuel cell and hydrogen systems and components as well as real-world demonstration projects to show the commercial viability of the technologies.

Several offices within DOE fund research, development, demonstration, and deployment (RDD&D) to advance hydrogen and fuel cell technologies, including the Office of Energy Efficiency and Renewable Energy (EERE) Hydrogen and Fuel Cell Technologies Office (HFTO), the Office of Fossil Energy and Carbon Management (FECM),[*] the Office of Nuclear Energy (NE), the Office of Science, and the Advanced Research Projects Agency–Energy (ARPA–E). Hydrogen and fuel cell activities are coordinated by HFTO, which also serves in a coordination role for hydrogen RDD&D among other federal agencies.[†] In 2020, DOE released its Hydrogen Program Plan describing strategic, high-level focus areas for the DOE's activities in hydrogen and related technologies across all relevant offices. These activities include the entire value chain of hydrogen technologies from production through end use, including fuel cells, turbines, and industrial end uses of hydrogen.[49] This was the first comprehensive DOE-wide strategic plan for hydrogen in nearly a decade. DOE also continued funding activities in support of its H2@Scale[50] initiative to advance affordable hydrogen production, transport, storage, and utilization to enable decarbonization and revenue opportunities across multiple sectors.

In 2020, DOE offices made several major funding award announcements , including:

- EERE's Hydrogen and Fuel Cell Technologies Office announced approximately US$64 million of funding for 18 H2@Scale projects in July, including manufacturing technologies for electrolyzers, development of carbon fiber for hydrogen storage tanks on board trucks, components and fuel cell systems for medium- and heavy-duty trucks, hydrogen use in steelmaking, training and workforce development in the hydrogen and fuel cell industry, and large-scale demonstrations of hydrogen and fuel cells in port and data center applications. HFTO selected projects on electrolyzer manufacturing and carbon fiber in collaboration with EERE's Advanced Manufacturing Office and Vehicles Technologies Office, respectively.[51]
- In September, US$1 million was awarded to Cummins, Inc., through a joint effort between DOE (HFTO), the U.S. Department of Defense, and the U.S. Department of Homeland Security Science and Technology Directorate, to develop H2Rescue, a hydrogen fuel cell truck to be used at emergency disaster relief sites.[52]
- In November, HFTO selected five projects from the 2020 H2@Scale CRADA call focused on advancing technologies for fueling medium- and heavy-duty vehicles and

[*] In 2021, The Office of Fossil Energy was renamed the Office of Fossil Energy and Carbon Management.
[†] See www.hydrogen.energy.gov and www.hydrogen.gov

enabling hydrogen blending in natural gas pipelines, in support of DOE's HyBlend initiative.[53]

- In September, FECM awarded US$34 million to 12 projects under the Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development funding opportunity announcement (FOA) .[54] The selected projects involve small-scale SOFC systems and reversible SOFC systems, solid oxide electrolyzer cells (SOECs), components for SOFCs and SOECs, and modular fuel cell systems at data centers.[55]
- In October, NE, in collaboration with HFTO, selected two projects to provide US$24 million of Federal assistance to demonstrate flexible operation of integrated hydrogen production systems at nuclear power plants. These selections included Connecticut-based FuelCell Energy US$10 million, to develop a solid oxide electrolysis system to be used in conjunction with a nuclear plant; and Northern States Power Company – Xcel Energy (Minnesota) to carry out planning, design, installation, testing, demonstration, and evaluation of non-electric, hybrid energy technologies connected to a light-water reactor (LWR) power plant.[56, 57]

Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) selections included:

- Four Phase II awards to make ionomers and membranes for heavy-duty fuel cells, nozzles for hydrogen dispensing, quality control processes for membrane manufacturing, and onboard monitoring of damage in carbon fiber hydrogen storage tanks.
- One Phase IIA award to make multifunction catalysts for fuel cells.
- Three Phase I awards to produce hydrogen from offshore wind.[58]

In October, the U.S. and the Netherlands issued a statement of intent through DOE's EERE and the Dutch Ministry of Economic Affairs and Climate Policy's Directorate General for Climate and Energy to collaborate and share information on electrolyzer R&D and performance progress.[59] The countries will also work together on safety, codes and standards, and blending hydrogen and natural gas.

Also in October, DOE's HFTO formed two new consortia to focus on fuel cell and hydrogen R&D for heavy-duty trucks. HFTO announced plans to invest up to US$100 million over five years in support of the Million Mile Fuel Cell Truck (M^2FCT) and H2NEW, with DOE national laboratories leading the R&D efforts with industry.[60] Los Alamos and Lawrence Berkeley National Laboratories are co-leads of M2FCT, working on fuel cell durability, performance, and cost, and the National Renewable Energy Laboratory and Idaho National Laboratory are co-leads of H2NEW, developing large-scale electrolyzer systems.

In December, DOE announced a US$33 million solicitation to support innovative hydrogen and fuel cell R&D, infrastructure supply chain development and validation, and cost analysis activities in support of H2@Scale and the M2FCT and H2NEW consortiums.[61]

Also in December, DOE announced a US$6.4 million solicitation under the University Turbine Systems Research program to solicit and competitively award university-based R&D projects

that address and resolve fundamental scientific challenges and applied engineering technology issues associated with advancing the performance and efficiency of combustion turbines fueled with pure hydrogen, hydrogen and natural gas mixtures, and other carbon-free hydrogen containing fuels (e.g., ammonia) in combined and simple cycle. applications. [62]DOE invested in a range of other projects via different programs and funding mechanisms throughout 2020. In addition to an overview of how DOE-funded R&D projects enabled various companies to assist during the COVID-19 pandemic—featured in the Spotlight: The Hydrogen and Fuel Cell Industry's Response to the COVID-19 Pandemic—the Appendix includes a comprehensive list of 2020 federal funding awards for the fuel cell and hydrogen sector.

On the legislative side, in late December, the U.S. House of Representatives and Senate passed H.R. 133, Omnibus Appropriations and Emergency Relief, a US$2.3 trillion package split into US$1.4 trillion to fund the government and US$900 billion for COVID-19 relief.[63] This legislation, later signed by President Biden, also included crucial provisions for the fuel cell and hydrogen industry:

- Provided one-year extensions for the section 30(b) fuel cell vehicle credit and the 30(c) hydrogen refueling station credit that were set to expire at the end of 2020
- Extended the phase-out for the section 48(a)(7)(A) fuel cell investment tax credit (ITC) by two years
- Provided US$150 million for DOE's HFTO Office and US$30 million for the FECM SOFC program

U.S. State and Regional Activity

In 2020, state governments across the U.S. were largely focused on the COVID-19 pandemic and its broader impact on the economy. One solution that many of these governments turned to was policy to enhance the development of hydrogen energy and fuel cell technologies.

State Energy Plans and Roadmaps

Throughout the year, several states announced or published new plans to support the decarbonization of energy and transportation systems, including the increased adoption of hydrogen and fuel cells.

In March, Oregon announced that it would pursue transportation electrification to meet its long-term decarbonization goal of an 80% reduction by 2050.[64]

Also that month, New Jersey issued its energy master plan outlining how it will reach its goal of 100% clean energy and maximum transportation and building electrification by 2050.[65] In June, the state also established a new fuel cell task force to support the growth of fuel cell companies, expand state use of fuel cell systems, provide educational resources, and develop a plan to expand hydrogen infrastructure in New Jersey.[66]

The California Energy Commission (CEC) approved a US$384 million clean transportation plan in October that focuses on increasing the adoption of zero-emissions cars and trucks and closes gaps in zero-emissions fuels and infrastructure to support an executive order phasing out the sale of new gasoline-powered passenger vehicles by 2035.[67] In addition to funding for light-duty electric vehicle (EV) charging infrastructure and workforce development, the plan included the following:

- US$129.8 million for medium- and heavy-duty zero emissions vehicles (ZEVs) and infrastructure
- US$70 million for hydrogen refueling infrastructure
- US$25 million for zero- and near-zero-carbon fuel production and supply
- US$9 million for ZEV manufacturing

In December, the CEC approved a plan to invest up to US$115 million to fund up to 111 new hydrogen stations by 2027.[68] The companies awarded funding include FirstElement Fuel, Shell Hydrogen (Equilon Enterprises LLC [dba Shell Oil Products US]), and Iwatani. Iwatani is partnering with Toyota on stations that will utilize Nel Hydrogen's H2Station technology.[69] Shell Hydrogen's award covers the installation of hydrogen refueling equipment at 48 existing Shell retail stations, an upgrade to two current Shell Hydrogen stations, and the addition of light-duty fueling dispensers and positions at one existing Shell Hydrogen heavy-duty truck station.[70]

Also in December, the Massachusetts Energy and Environmental Affairs secretary announced a goal of reducing emissions to 45% of 1990 levels by 2030 and issued *Interim Clean Energy and Climate Report for 2030* outlining how to accomplish this task.[71] In addition, the Massachusetts Executive Office of Energy and Environmental Affairs issued *Massachusetts 2050 Decarbonization Roadmap,* which defines steps toward achieving the goal of net-zero emissions by 2050.[72] These plans are a significant step in the right direction to identify, develop, and enact near- and long-term policies to advance hydrogen energy and fuel cell technology policies to support decarbonization efforts.

Medium- and Heavy-Duty Vehicle Policy

Several policy developments in 2020 were aimed at expanding medium- and heavy-duty fuel cell vehicle deployment.

In August, the California Air Resources Board (CARB) expanded its efforts to support ZEV medium- and heavy-duty vehicles by instituting a new advanced clean truck program that would require all new medium- and heavy-duty vehicles sold in California to be ZEV by 2045.[73] This program includes fuel cell electric vehicles. To reach this goal, a certain percentage per year of automakers' medium and heavy-duty vehicles sold are required to be zero-emission vehicles, starting in model year 2024. Manufacturers would be able to earn credits selling zero-emission medium and heavy-duty vehicles beginning in model year 2021, and credits can be banked and traded.

In November, CARB also announced a new zero-emission bus grant to enable replacing existing gasoline, diesel, natural gas, and propane fueled buses with battery electric or fuel cell electric vehicles.[74]

The Michigan Department of Environment, Great Lakes, and Energy began its grant program for the adoption of zero-emissions and alternatively fueled on- and off-road vehicles and equipment in November as well.[75] This program includes freight vehicles (medium- and heavy-duty trucks and port drayage trucks), shuttle and transit buses, port cargo handling equipment and forklifts, airport ground support equipment, and others.

Regional Efforts

A significant development in advancing policies supportive of hydrogen and fuel cell deployment is expanded regional collaboration in the Northeast and Mid-Atlantic through the Transportation and Climate Initiative Program (TCI-P). In December, Massachusetts, Connecticut, Rhode Island, and the District of Columbia launched TCI-P, a regional collaboration to reduce emissions in the transportation system through a new cap-and-invest program to support clean transportation and emission reduction initiatives.[76] Connecticut, Delaware, the District of Columbia, Maryland, Massachusetts, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, and Virginia shared a statement of support for the TCI-P effort.

Another regional effort with news in 2020 was the Zero Emission Vehicle Task Force. The task force was formed in response to a May 2014 MOU signed by the governors of California, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont to support the deployment of 3.3 million ZEVs by 2025. In July 2020, a new MOU was signed by the governors of California, Colorado, Connecticut, District of Columbia, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington to expand these efforts and develop a multi-state action plan to reach the goal of having 30% of all new medium- and heavy-duty vehicles sales be ZEVs by 2030 and 100% by 2050.[77]

Spotlight: The Hydrogen and Fuel Cell Industry's Response to the COVID-19 Pandemic

The fuel cell and hydrogen industry reacted, adapted, and offered support to assist the COVID-19 response in various ways around the world. This section highlights different efforts made by fuel cell and hydrogen companies and organizations, based on public records. While extensive, it is not definitive. Many other companies and affiliated organizations, foundations, and people led initiatives, provided humanitarian relief, and donated critical equipment, funding, and other essential items to help alleviate the pain and suffering caused by the pandemic.

In early 2020, The National Association of Manufacturers conducted a member survey to gauge the pandemic's potential impact on supply chain and operations, financial expectations, and whether companies had emergency response plans.[78] The responses from more than 550 companies showed that more than 35% of those companies were already experiencing disruptions in their supply chain, with a significant 78% majority predicting negative financial impact from the pandemic. While half of respondents reported having emergency response plans, many of these did not specifically include infectious disease outbreaks.

Essential Operations

While many industries closed operations to control the spread of the virus, several states in the U.S. granted special waivers or exemptions to critical manufacturing operations and other essential businesses, including fuel cell and hydrogen companies.

Companies reported on the safety measures undertaken to mitigate the spread of the virus. Employees who could work from home did, and those who were physically working at manufacturing facilities, warehouses, and distribution centers reported following strict safety protocols with staggered shifts and specifications to keep workers spread out and sanitized.

Connecticut defined Nel Hydrogen, an electrolyzer manufacturer based in Wallingford, as an essential business, allowing the company's manufacturing plant to continue production.[79] Similarly, Pennsylvania issued a waiver to PDC Machines of Warminster to remain open, designating it a "life-sustaining business."[80] PDC Machines products were used by gas companies to provide medical gases necessary in healthcare operations, which included New York City hospitals and nursing homes.[81]

In California, local orders clarified by the CEC declared that all elements of the fuel supply chain, including fuel providers, were considered essential services and were to remain open during the COVID-19 response.[82] California included hydrogen fueling stations in the list of eligible fuel providers to support the state's fuel cell vehicles, including passenger cars, buses, heavy-duty trucks, and others. Industrial gas companies continued to supply hydrogen for fueling stations and oxygen for hospitals and other facilities.

Several fuel cell and hydrogen companies shifted focus from manufacturing fuel cell systems or hydrogen-related components to helping fill the needs of frontline workers, first responders, and local citizens by producing materials and parts needed to refurbish critical ventilators. Companies also began manufacturing respirators and personal protective equipment (PPE), such as N95 masks and face shields. Some converted operations to produce hand sanitizer, donating that, as well as other PPE, to local medical personnel.

Bloom Energy, based in Sunnyvale, California, was also deemed essential by the state. However, when there was urgency to ensure that hospitals and medical centers had enough working ventilators and other critical equipment, the company quickly halted manufacturing of its solid oxide fuel cell systems and adjusted to help. Bloom joined with Almo Corporation, a national distributor of appliances, A/V equipment, furniture and housewares, to refurbish idle, unused, and out-of-warranty ventilators to restore them to working condition.[83] Almo has more than 2.5 million square feet of distribution space in eight warehouses across the country, so the collaboration utilized Almo's national logistics network to ship the ventilators to and from Bloom's manufacturing facilities in California and Newark, Delaware, for refurbishment and then out to the state agencies and hospitals that need them the most. Bloom ultimately supplied 1,200 refurbished ventilators in a little more than three weeks, from both of its facilities, for use in California, Delaware, and Pennsylvania.

W. L. Gore, a fuel cell membrane supplier based in Newark, Delaware, rapidly shifted to engineering prototype reusable mask covers using the company's proprietary Gore high-flow filtration laminate.[84] The reusable water-repellent covers provide more than 99% aerosolized virus particle protection to supplement healthcare workers' primary face masks.

Utah-based Power Innovations, which manufactures fuel cell systems, among other power generation products, redirected its efforts to building ventilator and N95 mask parts in April, using the company's expertise in high resolution 3D printing, machining, flat metal fabrication, welding, and assembly to shift quickly as needed.[85] Power Innovations also distributed N95 masks to local first responders at no cost.

Other companies involved in the hydrogen and fuel cell sector also reported manufacturing and distributing critical PPE and other equipment for healthcare workers around the world:

- Faurecia, though its Valencia, Spain, facility, used 3D printers to provide local frontline services with mask shields. Staff were able to use Faurecia R&D Center's 3D printers remotely to produce around 150 mask shields each day.[86] In addition, the company also donated 100,000 surgical masks to the Civil Hospitals of Colmar.[87]
- France's Ministry of Health ordered 1,000 respirators from Air Liquide Medical Systems to deliver to health facilities in March.[88] The government also requested an investigation to see if 10,000 respirators could be produced in 50 days. Air Liquide led a group of French industrial companies, including Groupe PSA, Schneider Electric, and Valeo, to develop a plan to deliver the respirators within six weeks.

- In Japan, Mitsubishi Motors Corporation produced approximately 1,500 face shields per month at its Okazaki Plant in Aichi Prefecture, Pajero Manufacturing Co., Ltd. in Gifu Prefecture, and other facilities to provide to local medical institutions.[89]
- Shell Oil Company converted several of its plants to produce more than 7,700 gallons of liquid hand sanitizer, which it then donated to various emergency and healthcare facilities and schools. In addition, Shell donated 132,000 gallons of isopropyl alcohol for use in the production of surgical grade disinfectant wipes.[90]

U.S. Department of Energy Supported Efforts

A DOE webinar in May 2020, *Leveraging Hydrogen and Fuel Cell Tech to Help Coronavirus Relief Efforts,*[91] highlighted examples of how several companies that received EERE funding for hydrogen and fuel cell R&D activities used the assets, expertise, and technologies supported through that funding to assist during the COVID-19 crisis. The companies' contributions to the pandemic effort included the design and manufacture of health care devices, protective equipment, and hand sanitizer, among others.

- Air Co., a company based in New York City, New York, sustainably produces vodka via a patented technology that transforms carbon dioxide captured from the air into impurity-free alcohols that can be used in spirits, fragrances, sanitizers, and a variety of consumer industries.[92] Air Co. leveraged electrolyzer company Nel's renewable hydrogen production technology to produce ethanol, which it distilled and used to make 80% ethanol-based hand sanitizers. The company donated it to healthcare workers in several states, including Mount Sinai Hospital, The Brooklyn Hospital Center, Custom Collaborative Women's Organization, the New York Police Department via Black 6 Project, and Vassar Brothers Medical Center in New York; Cape Cod Healthcare in Hyannis, Massachusetts; Strafford EMS in Strafford, Connecticut; Grady Memorial Hospital in Atlanta, Georgia; and the Portsmouth Naval Hospital in Portsmouth, Virginia.
- E-Spin Technologies, a customized nanofiber manufacturing company based in Chattanooga, Tennessee, received a Small Business Innovation Research program award in 2019 under the Fuel Cells topic for its *Nanostructured Proton Exchange Membrane*.[93] To help protect healthcare workers, E-Spin shifted to using its nanofiber technology for surgical face masks instead of fuel cells, manufacturing masks that are 95% efficient. E-Spin also ramped up to produce protective masks with disposable nanofiber filtration inserts for the general public, producing more than 9,000 per day.[94]
- Giner ELX, an electrolyzer company based in Newtown, Massachusetts, which was acquired by Plug Power in June 2020, fabricated surgical face masks and ventilator parts using equipment funded through DOE.[95] Giner purchased a 3D printer through a funding award from DOE (for *Portable Sensor for Detection of Micro-Organisms in Groundwater*) to fabricate components for field-deployable microbial monitoring systems as well as components for the company's electrolyzer systems and fuel cell stacks. Giner was able to shift gears to print parts needed for ventilators as well as use laser cutters to fabricate complete parts for face shields. The company was able to manufacture more

than 840 per week to donate to local organizations Harbor Health and Boston Health Care for the Homeless.

- Stanford University in California used the experience gleaned from DOE-supported R&D on optimizing oxygen concentrations for fuel cell operation and electrolysis, applying it to re-engineer more comfortable and breathable N95 masks.

The Carbon Fiber Technology Facility at Oak Ridge National Laboratory (ORNL), located in Oak Ridge, Tennessee, developed filtration materials that were used to produce N95 masks in coordination with the U.S. Department of Health and Human Services. These efforts were funded in part by DOE's Advanced Manufacturing Office in EERE and the Office of Science National Virtual Biotechnology Laboratory consortium.

This work led to collaborations with Cummins and DemeTECH, which ramped up production capability of the precursor materials for carbon fiber production to 9,000 masks per hour.[96] DemeTECH is a Florida-based medical device manufacturer and the state's only National Institute for Occupational Safety and Health certified producer of the respirator masks. DemeTECH hired 500 workers to assist with the mass production.[97]

In March 2020, ORNL launched the COVID-19 High Performance Computing Consortium with six other DOE national laboratories, the White House Office of Science and Technology Policy, and public and private organizations.[98] ORNL, Argonne National Laboratory, Idaho National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Sandia National Laboratory joined with leading technology companies, universities, and others, to combine high-performance computing capabilities, expertise, and manpower to collect and analyze data and research on the SARS-CoV-2 virus.[99]

In addition to the laboratories' participation, DOE is involved in the leadership of the Consortium as well as the Science & Computing Executive Committee. In May, the group became global, as the Partnership for Advanced Computing in Europe (PRACE) and UK Research and Innovation joined the consortium, expanding capability and supercomputer processing power.[100, 101]

The Consortium is still working and has reported providing more than 600 petaflops of computing capacity, as well as critical components such as computer chips, memory, and storage. There have been approximately 100 approved projects that have focused on different aspects of the virus, including virus structure using simulations, countermeasures using artificial intelligence (AI), and resource management.

Relying on Fuel Cells

Several utilities in the U.S. have fuel cells deployed to supplement or support the electric grid and substations, and fuel cell systems have been providing reliable and efficient backup and primary power to a long list of customer facilities in the U.S. and around the world for decades. This includes the data centers and technology companies supporting many online services and communications. Fuel cells are installed around the country at hospitals and medical centers, ensuring continuous power and, in some cases, providing heating and cooling through combined heat and power (CHP). Other key customers include grocery stores, retail sites, data centers, banks, cellular and radio towers, and critical first responder and communications networks.

Microgrids are a way to decentralize power generation, increase reliability and—most importantly—ensure continuous service to emergency services including police, fire, and ambulances. Since fuel cells can operate in conjunction with or parallel to the electric grid, microgrids that consist solely of a fuel cell system or that have integrated fuel cells are already in service in California, Connecticut, and New York.

In April, Bloom stepped up to assist efforts again, this time deploying its fuel cell systems, configured as microgrids, to power auxiliary hospitals that were set up in California to handle the overflow of COVID-19 patients.[102] The fuel cell benefits of quiet operation, low vibrations, and reduced emissions were especially advantageous due to the sensitive nature of COVID-19 induced respiratory issues.

The first project was at a national hospital system in Vallejo, that already had 1.2 MW of Bloom fuel cells installed. The three-day deployment of the fuel cells in the main hospital parking lot was completed five days ahead of schedule. The second project, a 400 kW fuel cell microgrid, was deployed at the Sleep Train Arena in Sacramento, powering a 100-bed field hospital. That effort took less than two weeks to set up and begin operation.

In South Africa, several public and private entities came together to deploy 1 Military Hospital, a field hospital powered by fuel cells, for COVID-19 patients.[103] The country's Department of Science and Innovation (DSI), Department of Public Works and Infrastructure, and Department of Defense worked with Johannesburg-based Bamblii Energy Group, which works with Hydrogen South Africa (HySA), a DSI program, on commercialization efforts involving HySA intellectual property. Other companies involved included fuel cell manufacturers Horizon Fuel Cell Technologies, PowerCell Sweden, HyPlat, and Element 1.

Seven hydrogen fuel cell systems, five from Horizon and two from PowerCell, were deployed to provide primary power for the COVID-19-focused field hospital, with the Eskom electricity grid serving as back-up. The hospital's services included COVID testing and screening and an intensive care unit with ventilators. The hospital also provided hands-on training for government officials and unemployed college graduates with N4 electrical engineering (light and heavy current) qualifications.

Air Products South Africa, Protea Chemicals, and Sasol all supplied fuel, methanol, and hydrogen for the fuel cell systems. Sasol also donated 10,000 liters of methanol and 600 kg of hydrogen monthly through April 2021 to help power the field facility.

In December, Bloom Energy, in partnership with El Camino Health, launched the University of Illinois' Shield T3 COVID-19 facility.[104] The mobile testing facility and laboratory is powered by Bloom Energy's fuel cells and is located at Bloom's manufacturing facility in Sunnyvale, California. The mobile lab serves local businesses and schools with rapid saliva tests. The lab also donated test kits to Gardner Health Services, a non-profit working with at-risk and impacted communities.

Fuel cells have been keeping operations running smoothly and seamlessly at grocery and retail stores, providing primary or backup up power well before the COVID-19 crisis and all throughout it. Fuel cell powered MHE is also operating in warehouses, distribution centers, and frozen food facilities across the country, making sure store shelves are stocked with food, toiletries, and other goods that people rely on. Fuel cell powered MHE in the tens of thousands supports more than 30% of the retail food distribution chain in the U.S.

Charitable Contributions

Many other companies in the fuel cell and hydrogen sector undertook humanitarian and charity efforts to assist during the pandemic in a wide range of ways:

- Doosan Fuel Cells America, based in South Windsor, Connecticut, donated 3,000 nitrile gloves, 36 face shields, 320 lab coats and aprons, and a powered air purifying respirator setup to Hartford Hospital.[105]
- In April, PDC China secured and shipped 2,000 masks to PDC Machines in Pennsylvania,[106] which the company donated to local healthcare workers.[107]
- Shell Oil Company contributed more than one million pieces of PPE, including face shields, non-medical masks, and nitrile gloves to communities and medical care facilities around the U.S. Shell also donated meals, fuel, and cash contributions to community relief organizations, food banks, mental health services and, through a national employee match program, more than 175 local organizations across 24 states.[108]
- TechnipFMC collectively donated thousands of facemasks, surgical gloves, and hundreds of liters of hand sanitizer to various organizations, hospitals, and first responders in Spain, France, the U.S., and Malaysia.[109]
- Hexagon Purus GmbH in Germany donated server capacity to Folding@home, a computing project that focuses on simulations and analysis of diseases. In this case, Folding@home focused on SARS-CoV-2, the virus that causes COVID-19, and the human proteins the virus interacts with.[110] The company provided unused computer power for Folding@home software as well as donating 200 respiratory masks to a local German Red Cross hospital.

Many other companies involved in hydrogen and fuel cells extended very generous contributions to charities, food banks, and other wellness initiatives to help local communities deal with the economic and emotional effects of the pandemic.

- Alstom, a transport and sustainable mobility company based in Germany that has deployed the world's first commercial hydrogen train, made investments in the beginning months of the pandemic to speed up the development of health and wellbeing mobility initiatives for its employees and passengers[111] and donated to children's charities in Chile.[112,113]
- CNH Industrial, through its foundation, entered a partnership with Feeding America® and donated US$300,000 to help communities in need. CNH Industrial's US$2 million Solidarity Fund initiative supported communities impacted by the COVID-19 pandemic.[114]
- In February, Schaeffler AG donated €800,000 (US$900,000) to Chinese first responder organizations and provided support for Red Cross activities in China.[115]
- The Total Group provided €50 million (US$56 million) worth of gasoline vouchers to healthcare workers at French hospitals to use at Total stations.[116]
- Itochu of Japan donated used tablets to special needs education schools in Tokyo and all elementary and junior high schools in Minato, Japan. The company also held an emergency blood drive at its headquarters and launched a takeout map to support restaurants in the area.[117]
- Toyota Tsusho Corporation and CFAO SAS, one of its subsidiary companies, through the Toyota Group's Kokoro Hakobu, donated face shields, disinfectant, and food to United Nations (UN) agencies and governmental and public institutions in Africa.[118] The companies also provided maintenance parts free of charge for Toyota Land Cruisers owned by UN agencies in Africa, and, in collaboration with Toyota dealerships across Africa, offered free vehicle leasing services and maintenance parts to national and local African governments, as well as other organizations. The companies shifted production of its factories in Côte d'Ivoire and the Republic of Congo to manufacturing disinfectant.

While this section outlines many of the efforts undertaken throughout the year, there was certainly much more undertaken by companies and organizations within the fuel cell and hydrogen industry, and there is still much more to be done.

Post-Pandemic Recovery

To recover from the economic impact of the COVID-19 pandemic, countries are implementing a wide-range of infrastructure, energy, environmental, and stimulus efforts and initiatives. The plans that were introduced in 2020 are covered in the Spotlight: 2020 International Hydrogen and Fuel Cell Strategies and Roadmaps section that follows.

Spotlight: 2020 International Hydrogen and Fuel Cell Strategies and Roadmaps

Faced with dual challenges of the COVID-19 pandemic and the continuing threat of climate change, governments worldwide are turning to hydrogen technologies as a way to stimulate the economy while providing a pathway to deep decarbonization of many industries. Governmental support for hydrogen increased dramatically throughout 2020, with policies, funding, roadmaps, and strategies announced to guide the future of the hydrogen economy.

Moreover, the volume of countries casting an interested eye on hydrogen was equaled by their diversity, and they included governments from Europe, Asia, North and South America, and Oceania. Global participation in the planning of the hydrogen economy has helped to boost the technology into the mainstream and created significant speculation on *how soon*—not *if*—it will become an integral part of the worldwide energy supply.

While many hydrogen developments have occurred internationally, this section focuses on governmental support announced and policies planned throughout 2020.

Table 2: 2020 International Hydrogen Plans and Strategies

2020 International Hydrogen Strategies or Initiatives			
Country/Region	**Date Announced**	**Title**	**Funding**
Funding amounts have been converted from each country's national currency to USD.			
China	March	*14th Five-Year Plan*[119]	N/A
The Netherlands	March	Government's Vision on Hydrogen[120]	US$39 million annually
Australia	May	*Advancing Hydrogen Fund*[121]	US$233 million
Germany	June	*National Hydrogen Strategy*[122]	US$10.8 billion
European Union (EU)	July	*A Hydrogen Strategy for a Climate-Neutral Europe*[123]	Funding is part of a larger US$850 billion package
France	September	*National Strategy for the Development of Decarbonized and Renewable Hydrogen in France* [124]	US$7.9 billion through 2030 ($3.84 billion through 2023)
Spain	October	*Hydrogen Roadmap: A Commitment to Renewable Hydrogen*[125]	Estimated cost of US$10.8 billion with private and public funding
Alberta, Canada	October	*Getting Alberta Back to Work: Natural Gas Vision and Strategy*[126]	N/A
Chile	November	*National Green Hydrogen Strategy*[127]	US$50 million
Finland	November	*National Hydrogen Roadmap for Finland*[128]	N/A

2020 International Hydrogen Strategies or Initiatives			
Country/Region	**Date Announced**	**Title**	**Funding**
Italy	November	National Hydrogen Strategy Preliminary Guidelines[129]	US$12 billion through 2030
Scotland	December	Scottish Government Hydrogen Policy Statement[130]	US$141 million between 2021 and 2026
Canada	December	*Hydrogen Strategy for Canada*[131]	Proposes US$4 billion to US$5.5 billion in investments

The most significant push for hydrogen development in 2020 was from the European Union's European Commission. Urged by Germany, France, the Netherlands, Austria, and Luxemburg,[132] the commission pledged to allocate part of a €750 billion (~US$825 billion) coronavirus recovery fund to support a clean hydrogen economy.[133] That promise was followed by the publication of the EU *Hydrogen Strategy*[134] in July, which set goals of installing 6 GW of electrolyzer systems by 2024 and 40 GW by 2030. By 2050, Europe intends to integrate renewable hydrogen technologies through all hard-to-decarbonize sectors, establishing it as a standard energy source.

- In June, Germany doubled down by adopting its own national hydrogen strategy as part of a broader COVID-19 stimulus package.[135] Out of a total of €9 billion (~US$10.8 billion), Germany has pledged to invest €7 billion (~US$7.9 billion) in new businesses and research as well as an additional US$2 billion to foster international hydrogen partnerships. By 2040, Germany wants 10 GW of hydrogen electrolyzers to power its energy industry.
- France, also calling for EU's increase in hydrogen investment, included €2 billion (~US$2.34 billion) for developing a renewable hydrogen sector in its COVID-19 recovery plan.[136] In addition, France plans to meet its goal of 6.5 GW of electrolyzers by 2030 by launching a €7 billion (~US$8.52 billion) clean hydrogen plan to invest in infrastructure and research.[137]
- Spain approved a plan focusing on clean hydrogen production, estimating that it will cost €8.9 billion (~US$10.83 billion) over the next ten years.[138] Spain is counting on the private sector to fund the transition, aiming to install 4 GW of electrolyzers by 2030.
- Using the public funding organization Business Finland, Finland released its *National Hydrogen Roadmap*, focusing on low carbon hydrogen production, hydrogen for green chemicals and fuels, and storage, transport, and end use over the next ten years.[139] Finland sees this roadmap as an important component of the larger goal of achieving net neutrality by 2035.
- The Netherlands released the "Government's vision on hydrogen" letter in March,[140] aiming to scale up production for the country by providing €35 million (~US$39 million) annually to ramp up hydrogen technology deployment.

- Italy has committed to a hydrogen future through a draft document called the "National Hydrogen Strategy Preliminary Guidelines," which calls on the Italian Industry Ministry to invest €10 billion (~US$12 billion) in the hydrogen sector by 2030.[141] Half of the money will come from European funds and private investments. The document lays out the goal of installing 5 GW of renewable electrolysis by 2030. Italy estimates that by 2030, hydrogen could make up 2% of the country's final energy demand while eliminating 8.8 million tons of carbon dioxide (CO_2), creating more than 200,000 jobs, and contributing €27 billion (~US$32.9 billion) to Italy's gross domestic product.
- Throughout September and October, the UK's House of Lords discussed the development of a UK hydrogen strategy.[142] The House of Lords noted that the global hydrogen economy could be worth US$2.5 trillion and could create 30 million jobs by 2050.
- In December, Scotland released its Hydrogen Policy Statement, confirming hydrogen as a key element of the country's decarbonization and energy plans. The policy statement describes the role that hydrogen can play in the energy network, including a goal of 5 GW of renewable and low-carbon hydrogen by 2030, with 25 GW of electrolyzers by 2045.[143] The statement is paired with a £100 million investment in hydrogen.

Outside the EU and UK, other major economic blocs also committed significant funding and commitments to deploying hydrogen and fuel cell projects to create economic opportunities.

- China's *2020 Five-Year Plan* includes a scale-up of electric vehicles, calling for half of all vehicles to be electric or fuel cell powered by 2035.[144]
- In May, the Australian Minister for Energy and Emissions Reductions created the Advancing Hydrogen Fund, offering A$300 million (~US$207 million) to finance hydrogen projects in Australia.[145]
- India's burgeoning hydrogen industry received a boost in October, when the government announced that it was developing a hydrogen roadmap to explore ways to create a large market for hydrogen and to allow private industry to scale up renewable hydrogen developments.[146]
- In June, the Canadian Province of Alberta released its *Natural Gas Vision and Strategy*, which focused on growing hydrogen developments and production methods using steam reformed methane in combination with carbon capture and storage.[147] In December, Canada's national government released a national hydrogen strategy requiring approximately C$5 billion to C$7 billion (~US$3.93 billion to US$5.50 billion) in near-term investments to grow the hydrogen industry.[148] Though no new money was pledged, a fund of C$1.5 billion for low-carbon fuels, including hydrogen, had been announced the previous week.
- The Chilean government announced a national hydrogen strategy with the goal of reaching 5 GW of electrolyzers by 2025 and 25 gigawatts by 2030. Chile has committed an initial US$50 million to begin work on these projects.[149]

Hydrogen

Hydrogen is receiving significant attention from a variety of stakeholders, governments, and industries. Aside from its potential to decarbonize energy-intensive industries, it also offers a low- or zero-emissions energy generation pathway. Hydrogen can also provide energy security, as it can be generated from domestic fuel feedstocks, such as natural gas, as well as through renewable methods, including solar or wind-powered electrolysis and biomass. There are also R&D and demonstration projects studying hydrogen production from coal paired with carbon capture and sequestration.

Hydrogen is versatile both in source and distribution, as it is most commonly produced on-site near the point of use or at large production facilities and delivered to end users.

As outlined in the U.S. and international sections of this report, many governments and other entities around the world made financial, policy, and environmental commitments in 2020 that include hydrogen as a key component.

New Products

- In May, Air Liquide announced a new high-capacity hydrogen station design with two 700 bar filling positions that can dispense up to 1,000 kilograms of hydrogen per day, with a footprint of 24.6 square meters (~264.8 square feet).[150]
- Two months after acquiring electrolyzer company Giner ELX (June), Plug Power delivered a 25 kW GenFuel electrolyzer to Nagasaki, Japan, in August, marking its first entry into the Japanese renewable hydrogen market.[151]
- In September, Haskel's Hydrogen Systems Group launched new compact plug-and-play hydrogen fueling stations—Nano and Nano Pro—for small fleet customers.[152]

Hydrogen Stations

Hydrogen fueling stations are being constructed around the world to support fuel cell vehicles of all sizes. According to Ludwig-Bölkow-Systemtechnik (LBST), 107 hydrogen stations opened in 2020: 29 in Europe, 72 in Asia, and 6 in North America,[153] including 14 in Germany, 18 in China, 26 in Korea, and 28 in Japan. LBST also reports that 553 hydrogen stations were in operation worldwide, with more than 230 in development stages.[154]

The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) was formed in 2003 to encourage international cooperation on hydrogen and fuel cell R&D, codes and standards, and infrastructure development. There are currently 22 partner countries in IPHE, and of those, 14 of the IPHE partner countries with deployed hydrogen stations reported more than 445 stations collectively as of December 2020, with 27 in development.[155] While not necessarily all-inclusive, these numbers are up to date as of the end of 2020.

Table 3: Reported Hydrogen Stations in IPHE Partner Countries[156]

Reported Hydrogen Station Progress in IPHE Partner Countries	
Country	**Hydrogen Stations**
Austria *(as of July 2020)*	5
Brazil *(as of December 2020)*	1, with 1 in development
Canada *(as of December 2018)*	9
China *(as of August 2020)*	35
France *(as of December 2020)*	41
Germany *(as of December 2020)*	68
Italy *(as of July 2020)*	4
Japan *(as of December 2020)*	161, with 26 in development
Korea *(as of December 2020)*	52
Netherlands *(as of December 2020)*	6
Norway *(as of August 2020)*	6
South Africa *(as of December 2020)*	1
United Kingdom *(as of January 2020)*	13
United States *(as of July 2020)*	>45

Table 4 highlights a selection of the year's publicly reported hydrogen station openings, which spanned the globe: the U.S., France, China, Japan, South Korea, Germany, Poland, the Czech Republic, and Australia.

Table 4: Examples of 2020 Hydrogen Fueling Station Openings and Orders

Examples of 2020 Hydrogen Fueling Station Openings and Orders				
Company	**Location**	**Partner/Customer**	**Number**	**Details**
Air Products	Santa Ana, California	Orange County Transportation Authority (OCTA), Center for Transportation and the Environment, CARB, South Coast Air Quality Management District, New Flyer and Trillium	1	January: The station, located at an OCTA bus depot, opened.[157]
FirstElement Fuel	Fountain Valley, California	California Energy Commission, CARB, Toyota, Honda, Mitsui, Air Liquide, and the station owner	1	July: The first large capacity station to have four fueling positions with a total of five nozzles opened.[158] The station is open 24/7 and offers 100% renewable hydrogen.
FirstElement Fuel	Mission Hills, California	N/A	1	November: 24/7 station with a capacity of 1,200 kg and four fueling positions with a total of five nozzles opened.[159]
Shell	San Francisco, California	California Energy Commission	3	February: Hydrogen dispensers at three different existing Shell stations offer 100% renewable hydrogen from biogas.[160]
IVYS Energy Solutions/ PDC Machines	Philadelphia, Pennsylvania	Lincoln Financial Field	1	PDC Machines and the Philadelphia Eagles football team announced sustainability partnership to equip Lincoln Financial Field with a SimpleFuel hydrogen refueling unit.[161]
	Washington, DC	U.S. Department of Energy	1	February: PDC Machines, DOE, Hyundai, and IVYS Energy Solutions announced plans to install a SimpleFuel hydrogen refueling station.
Air Liquide	Fos-sur-Mer, France	Carrefour, Coca-Cola European Partners and Monoprix	1	Large capacity hydrogen station (700 bar, 1,000 kg/day) will enable up to 20 truck and bus fuelings per day.[162] Funding provided by the Provence-Alpes-Côte d'Azur Region and the Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

Examples of 2020 Hydrogen Fueling Station Openings and Orders				
Company	**Location**	**Partner/Customer**	**Number**	**Details**
	France	Hype	3	Air Liquide awarded funding from the French Environment & Energy Management Agency (ADEME) to develop three new hydrogen fueling stations and electrolyzer facilities to support fuel cell taxis.
	Zhangjiakou City, China	Zhangjiakou Jiaotou Hydrogen and New Energy Technology Co., Ltd.	1	Contract signed in April.[163]
H2 Mobility	Biebelreid, Germany	Air Liquide, Linde, Daimler, OMV, Shell, and TOTAL	1	Opened in January.[164]
	North Rhine-Westphalia, Germany	Air Liquide, Linde, Daimler, OMV, Shell, and TOTAL	1	Opened in May.
Japan H2 Mobility, LLC	Kasugai Katsugawa, Japan	Toyota Motor Corporation, Nissan Motor Co., Ltd., Honda Motor Co., Ltd., JXTG Nippon Oil & Energy Corporation, Idemitsu Kosan Co., Ltd., Iwatani Corporation, Tokyo Gas Co., Ltd., Toho Gas Co., Ltd., Air Liquide Japan Ltd., Toyota Tsusho Corporation, Development Bank of Japan Inc.	1	Opened in May.
	Kita-Nagoya Yamanokoshi, Japan		1	Opened in April.
Nel Hydrogen	Poland	ZE PAK SA	1	October: Polish energy company ZE PAK SA, ordered an H2Station hydrogen refueling station to service passenger vehicles and buses.[165] Purchase order is valued at €3.2 million (~US$3.75 million).
	South Korea	Hydrogen Energy Network (HyNet)	3	June: Nel Korea Co., Ltd., received €4 million (~US$4.55 million) purchase order from HyNet for three H2Station hydrogen refueling stations.[166]

Examples of 2020 Hydrogen Fueling Station Openings and Orders				
Company	**Location**	**Partner/Customer**	**Number**	**Details**
Haskel Hydrogen Group	Czech Republic	Bonett Group for Unipetrol	N/A	December: Haskel announced it will provide its Geno hydrogen refueling stations for deployment at Unipetrol public fueling stations throughout the Czech Republic.[167]
Tokyo Gas Co Ltd	Tokyo, Japan		1	The station is the fourth and largest hydrogen refueling station in Tokyo. Capable of refueling 20 fuel cell buses per day.[168]
Hyundai	Incheon, South Korea	Air Liquide Korea, Hydrogen Energy Network (HyNet), and the Incheon International Airport Corporation (IIAC)	1	May: The companies signed an MOU As part of it, Hyundai will construct a hydrogen station at Incheon Airport's Terminal 2 to service twelve Hyundai fuel cell buses that will operate between terminals, parking lots, and logistics complexes.[169]
	Jeonju, South Korea	N/A	1	June: Hyundai's first hydrogen station for commercial vehicles in Korea opened, located at Hyundai's Jeonju plant. Will be available for buses, trucks, and passenger vehicles.
	Canberra, Australia	N/A	1	June: Fueling station opened.
McPhy	Centre Val de Loire, France	N/A	1	April: McPhy was selected to install its McFilling 20-350 to convert surplus renewable energy from wind and solar installations to hydrogen.[170]
	Grand Quest region, France	N/A	1	March: First test phase of the fueling station was successful.
	Dijon Métropole, France	Dijon Métropole Smart EnergHy (DMSE	2	August: McPhy was selected to provide a 1 MW electrolyzer to supply two McPhy hydrogen stations, one with both 350 and 700 bar capabilities.[171]

Also in November, Nel Hydrogen announced that it had partnered with Tenaris, a pipeline infrastructure company, to establish a hydrogen refueling network for trucks in California.[172]

In addition to news of hydrogen stations to fuel vehicles, BayoTech, a manufacturer of scalable, modular on-site hydrogen generation systems based in Albuquerque, New Mexico, signed multiple deals in 2020 to grow its partner network into different regions.

Table 5: 2020 BayoTech Partner Agreements

2020 BayoTech Partner Agreements		
Company	**Region**	**Details**
ENEFIN Holdings Company	Italy	Partnership announced in August[173]
H2 ZEZT Pvt. Ltd.	India	Authorized agent added in September[174]
Hydrogen to Go Pty Limited (H2toGo)	Australia and New Zealand	Authorized agent added in December[175]
Intralink	Japan	Agreement signed in June[176]
La Puerta Columbia	Latin America and the Netherlands	Authorized agent added in September[177]
New Mexico Gas Company	New Mexico	Collaborative agreement announced in October[178]

BayoTech's other agreements in 2020 expanded its business as well as offered opportunities for customers:

- Worked with iGas, a British oil and gas explorer and developer, to utilize iGas' existing resources to generate hydrogen.[179]
- Partnered with Cross River Infrastructure Partners, a sustainable infrastructure development platform, to form a company to provide customers in North America with hydrogen gas as a service,[180] i.e., enable customers to purchase hydrogen directly from BayoTech without having to spend capital on infrastructure.
- Partnered with DLL, a global vendor finance company, to create a leasing program for BayoTech hydrogen generators.[181]
- Signed a letter of intent with Ariel Re, part of Argo Group, a property and casualty insurance company, in September to develop a performance risk solution guaranteeing uptime and output of BayoTech's hydrogen generators.[182]

BayoTech also reported progress with sales/leasing of its product:

- A lease agreement with Nutrien, a provider of crop inputs and services, for a hydrogen generator to use at a Nutrien fertilizer plant.[183]

- A hydrogen supply agreement with Hyzon Motors Inc., to support hydrogen fueling infrastructure for Hyzon's customers.[184]

Large-Scale Hydrogen Production

While some stations generate hydrogen onsite, others are supplied via an expansive hydrogen production and delivery network. Millions of metric tons of hydrogen are produced annually in the U.S. for the petroleum, ammonia (fertilizer), chemical, and food industries. The primary production method is industrial-scale natural gas reformation, known as steam methane reformation (SMR), and uses natural gas and steam to generate hydrogen with a byproduct of carbon dioxide.

As the world looks towards ambitious decarbonization goals, a growing method of large-scale hydrogen production is electrolysis, a process that "splits" hydrogen from water molecules with an electrical current. Like fuel cells, electrolyzer systems can be scaled up in size, and the most common types of electrolyzers use proton exchange membrane (PEM), alkaline, or solid oxide as their core components. Electrolyzers can also be coupled with solar arrays, wind farms, and even nuclear power plants to generate renewable hydrogen. This hydrogen can provide long-term and large-scale seasonal renewable energy storage to balance the intermittent renewable electricity supply in the electric grid.

The U.S. DOE reported that as of December 2020, there was more than 14 MW of PEM electrolyzer capacity either installed or in development in the U.S.[185] Power capacity of the 27 reported electrolyzer systems ranges from 120 kW to 5000 kW (5 MW), and locations include California (9), Ohio (3), New York (2), Massachusetts (2), Texas (2), Arizona (1), Florida (1), Illinois (1), New Jersey (1), North Carolina (1), Pennsylvania (1), Minnesota (1), Rhode Island (1), and Washington (1).

Globally, 2020 saw a significant increase in deployments. The International Energy Agency reports that as of 2020, there was 150 MW of electrolyzer capacity in the world.[186] Throughout the year, more than 430 MW in electrolyzer projects were either deployed, ordered, or proposed.

Table 6: Examples of Large-Scale Electrolyzer Orders and Deployments

Examples of 2020 Large-Scale Electrolyzer Orders and Deployments				
Company	**Location**	**Customer**	**Size**	**Details**
Cummins	Washington, U.S.	Douglas County Public Utility District	5 MW	August: Announced a hydrogen facility will electrolyze water from Wells Dam on the Columbia River powered by hydropower.[187]
ITM Power	United Kingdom	N/A	8 MW	April: Signed an agreement to supply an 8MW electrolyzer in the UK.[188] Agreement, including associated project costs, has a total value of £10 million (US$11 million).
	Scotland	Green Hydrogen for Scotland, a partnership of ScottishPower Renewables, BOC (a Linde company) and ITM Power	10 MW	September: Green Hydrogen for Glasgow announced they will utilize wind and solar power to generate hydrogen.[189]
McPhy	Dijon Métropole, France	Dijon Métropole Smart EnergHy (DMSE)	1 MW	The electrolyzer will support two hydrogen stations.[190] The fleet using the stations will initially be made up of 27 buses, 9 garbage trucks and around 15 light vehicles.
	Rostock-Laage, Germany	Apex Energy	2 MW	June: McPhy delivered and installed a McLyzer 400-30 to supply the Group headquarters and a commercial area with electricity and heating.[191]
Nel Hydrogen	Boulder, Colorado	National Renewable Energy Laboratory (NREL)	1.25 MW	NREL ordered the containerized PEM electrolyzer to support its Advance Research on Integrated Energy Systems (ARIES) research initiative in October.[192] Under the contract, valued at US$2 million, NREL has the option of expanding the capacity to 2.5 MW.
	Urbana, Illinois	Trillium Transportation Fuels, LLC	1 MW	The electrolyzer will produce green hydrogen for a fleet of up to 12 fuel cell electric buses at the Champaign-Urbana Mass Transit District.[193] The project is supported by the Federal Transit Administration and the State of Illinois.

Examples of 2020 Large-Scale Electrolyzer Orders and Deployments				
Company	**Location**	**Customer**	**Size**	**Details**
	U.S.	Confidential	1.5 MW	November: Received an order from a large industrial client in the U.S. worth approximately US$2.7 million.[194]
	U.S.	Nikola Corporation	85 MW	June: Announced a purchase order with a value of more than US$30 million that will support five initial stations with 8 ton per day hydrogen production capacity.[195]
	U.S. and UK	Raytheon´s Collins Aerospace Division	N/A	November: Nel reported receiving more than US$9.1 million in orders in 2020 for its PEM electrolyzer stacks from Raytheon's (formerly United Technologies) Collins Aerospace to produce oxygen for U.S. and U.K. Navy crews on multiple classes of nuclear-powered submarines.[196]
	Bouin, France	Lyhfe Labs SAS	60 MW	Following a purchase order for an A150 alkaline electrolyzer to support fuel cell buses in March, the companies entered an agreement in April for 20 additional electrolyzers, totaling 60 MW, intended to be purchased over the next 4 years.[197]
	Mo Industripark, Norway	Statkraft AS	40-50 MW	Nel signed a letter of intent in October with Statkraft, which is working with Celsa Armeringsstål AS, a steel producer, and Mo Industripark, to utilize renewable hydrogen for industrial use in high temperature processes for steel.[198]
	Spain	Iberdrola	200 MW	Nel and Iberdrola signed an MOU to construct a 200 MW renewable hydrogen production plant in Spain.[199]
	Europe	N/A	2.5 MW	June: Received an order valued at more than US$3 million from A European customer for a 2.5 MW PEM® containerized electrolyzer system.[200]
Siemens	Yanqing District, Beijing, China	Beijing Green Hydrogen Technology Development Co., Ltd.	1 MW	Located in one of the three main competition areas for the 2022 Winter Olympics, the green hydrogen system will help guarantee the hydrogen supply for public transportation before and after the event.[201]

Significant announcements throughout the year about other large-scale hydrogen production projects are noted below.

- Air Products agreed to a US$530 million purchase of five SMR hydrogen production plants from PBF Energy Inc., an independent petroleum refiner, in March, along with a long-term hydrogen supply agreement.[202] The plants, located in Torrance and Martinez, California, and Delaware City, Delaware, have a combined production capacity of 300 million standard cubic feet of hydrogen per day.
- The Intermountain Power Agency (IPA), which owns an 1,800 MW coal-fired power plant in Delta, Utah, announced plans to move forward on a state-of-the-art new generation facility that will initially run on a mix of natural gas and hydrogen before transitioning to operate solely on hydrogen.[203] Plans involve using excess renewable energy from across the Western U.S. to generate hydrogen via electrolysis and store it in an underground salt dome. The IPA plant serves customers in Utah, Nevada, and California, including the Los Angeles Department of Water and Power.
- Enbridge Gas, a Canadian natural gas distribution company, announced a US$5.2 million pilot project with Cummins to blend renewable hydrogen into a portion of the local natural gas network in Markham, Ontario, Canada. The project is supported by Sustainable Development Technology Canada.[204]
- Shell Nederland announced in May that it was working with Eneco, through the CrossWind joint venture, to create a green hydrogen hub that would include a wind farm in the Port of Rotterdam in the Netherlands.[205]
- In May, Glomfjord Hydrogen, owned in part by Nel, signed a letter of intent with Air Liquide to develop a large-scale green hydrogen production and liquefaction center at the Glomfjord Industrial Park in Glomfjord, Norway.[206]
- Air Liquide Engineering & Construction signed an agreement with Doosan Heavy Industries in December to support the construction of a liquid hydrogen production plant in Changwon, South Korea, which will provide hydrogen to refueling stations across the country.[207]

On the storage side, Hexagon Purus won new contracts and orders in 2020 for its hydrogen tanks, which are used in several different applications.

Table 7: 2020 Hexagon Purus Contracts and Orders

2020 Hexagon Purus Contracts and Orders			
Month	**Customer**	**Transaction**	**Application**
April	Everfuel	Order for two X-STORE high pressure hydrogen distribution modules.	The modules can hold 958 kg of hydrogen compressed at 300 bar (~4351 psi) and will be used to transport hydrogen to refueling stations serving fuel cell taxis and buses in Denmark.[208]
May	CIMC ENRIC	Term sheet for a strategic and joint venture agreement.	To establish manufacturing facilities to produce and assemble cylinders and storage systems in China.[209]
June	Toyota North America	Supply contract valued at US$1 million.	For Toyota's heavy-duty fuel cell truck.[210]
November	Stadler Rail	Contract	Hydrogen cylinders are for a hydrogen commuter train planned to deploy in California.[211]

Fuel Cells

Fuel cells electrochemically combine hydrogen and oxygen to produce electricity, water, and heat. Unlike batteries, fuel cells continuously generate electricity as long as a source of fuel is supplied. Fuel cells do not burn fuel, making the process quiet, pollution-free, and efficient.

Fuel cells can be scaled up to various specifications and energy needs. There are three main markets for fuel cells: transportation, stationary power, and portable power. Within those markets, there are numerous applications and end uses. Transportation applications include motive power for light-, medium-, and heavy-duty vehicles such as passenger cars, buses, delivery vans, trucks, municipal vehicles, trains, and MHE. In recent years, the transportation paradigm has grown to include motive power in the air and on the sea, including fuel cell powered planes, drones or UAVs, ships, and ferries. Stationary power includes any application in which the fuel cells are operated at a fixed location for primary power, backup power, or CHP. Portable/off-grid applications include fuel cells that are not permanently installed or fuel cells in a portable device, such as systems that provide power for equipment used in rural or remote areas or act as battery chargers.

The list of environmental and economic benefits that fuel cells offer includes reduced greenhouse gas and criteria pollutant emissions, reduced oil consumption, highly efficient energy conversion and reliability, fuel flexibility, and quiet operation. In addition to using hydrogen, fuel cells can generate power from a variety of other fuels, including natural gas and renewable fuels, such as methanol or biogas.

To power this diverse array of applications, there are several types of fuel cells in operation, typically denoted by the different electrolyte used in the electrochemical cell. The portfolio of fuel cells includes molten carbonate fuel cells, solid oxide fuel cells, phosphoric acid fuel cells, alkaline fuel cells, low- and high-temperature proton exchange membrane (PEM) fuel cells, and direct methanol fuel cells.

Transportation Fuel Cells

Fuel cell technology is being developed for and integrated into different vehicle platforms, ranging from light-duty passenger cars and sport utility vehicles to medium- and heavy-duty buses, vans, and trucks to trains, planes, and ships. In addition, fuel cell powered MHE and logistics vehicles are being deployed in distribution centers, ports, and airports around the world.

Despite global shutdowns of manufacturing and supply chain facilities, *Clean Jobs America*, a report from Environmental Entrepreneurs (E2) showed that the effects of the pandemic weren't as bad as had been feared for the clean energy sector. There was a reported small decline in jobs in this space, from 3.36 million in 2019 to 3 million in 2020, mainly attributed to COVID-19, but one of the sectors with an increase in jobs was the electric vehicle market.[212] The report showed a 3% increase in electric and other "clean" vehicle manufacturing jobs and a 6% increase, or 12,000 additional jobs, in electric and hybrid electric vehicle manufacturing.[213] This is attributed to automakers committing to produce electric cars, trucks and buses.

Fifteen IPHE participants have publicly reported on the deployment status of fuel cell powered cars, buses, trucks, and forklifts. As shown in Table 8, the cumulative reported number of vehicles in those countries as of December 2020 totals as follows:

- Cars: 25,011
- Buses: 3,139+
- Trucks: 1,226
- Forklifts: 36,154+

Table 8: Reported Fuel Cell Vehicle Progress in IPHE Partner Countries[214]

Reported Fuel Cell Vehicle Progress in IPHE Partner Countries				
Country	**Cars**	**Buses**	**Trucks**	**Forklifts**
Austria *(as of July 2020)*	41	N/A	N/A	N/A
Brazil *(as of December 2020)*	1	1 hybrid	N/A	N/A
Canada *(as of December 2018)*	17	1	2	>400
China *(as of August 2020)*	50	2,800	1,200	2
France *(as of July 2020)*	375	21	0	325
Germany *(as of December 2020)*	951	79	2	162
India *(as of December 2020)*	N/A	10	N/A	N/A
Italy *(as of July 2020)*	15	10	0	5
Japan *(as of December 2020)*	3,947	99	N/A	250
Korea *(as of December 2020)*	10,041	27	N/A	N/A
Netherlands *(as of December 2020)*	314	7	22	0
Norway *(as of August 2020)*	159	5	N/A	10
South Africa *(as of December 2020)*	0	0	0	2
United Kingdom *(as of January 2020)*	100	20	0	N/A
United States *(as of July 2020)*	~9,000	>60	Demonstrations underway	>35,000

New Products

Throughout the year, several companies launched new fuel cell systems for the material handling, off-road, and medium- and heavy-duty vehicle sectors, including the following:

- Ballard Power Systems: FCgen®-HPS PEM fuel cell stack, designed with Audi AG for light-, medium-, and heavy-duty vehicles[215]
- Nuvera Fuel Cells: E-60 fuel cell engine for electric powertrains for material handling equipment, buses, trucks, and other on- and off-road vehicles[216]
- Plug Power: 125 kW ProGen hydrogen fuel cell engine for Class 6, 7, and 8 trucks, transit buses, and port applications[217]

In November, Plug Power and Gaussin, a transportation and logistics engineering company, announced plans to collaborate on a commercial suite of Gaussin vehicles, including terminal tractors that utilize Plug's ProGen fuel cell systems and hydrogen electrolyzers.[218]

Light-Duty Vehicles

COVID-19 had a definitive impact in the light-duty vehicle sector, with a substantial swath of the working population shifting from commuting to the office to telecommuting. The fuel cell vehicle market in the U.S. saw a decrease in sales in 2020, with only 937 sold in California, the only state in the U.S. where the vehicles are commercially available. That is a 55% decrease from 2019, when 2,089 were sold in the state, according to the California Fuel Cell Partnership, using data from Baum and Associates.[219]

Table 9: Monthly Fuel Cell Vehicle Sales in California—2020[220]

Monthly Fuel Cell Vehicle Sales in California—2020												
Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Total
101	130	60	24	54	50	62	98	81	87	149	41	937

- Early in the year before the pandemic hit, Hyundai amped up its marketing of the NEXO fuel cell vehicle by joining with Korean pop band BTS. Hyundai created a promotional campaign that included BTS traveling to the Grammy music awards in the vehicle.[221]

  Hyundai reported selling 6,781 NEXO fuel cell vehicles: 5,786 in Korea, and 995 exported to Europe, the U.S., and elsewhere.[222] This is a 40% increase from 2019's reported total sales of 4,818 vehicles.
- BMW released the details of its upcoming hydrogen NEXT fuel cell vehicle, expected to be released in 2022, in March.[223] The NEXT will have a 25 kW fuel cell powertrain and two 700 bar tanks that can hold a total of six kilograms of hydrogen.
- Toyota unveiled its completely redesigned Mirai fuel cell vehicle in December.[224] The new Mirai can hold up to 5.6 kg of hydrogen, an increase of approximately 20% over the previous model, increasing the vehicle's cruising range to 850 km (~528 miles).

- In January, Hype, a French taxi company, received support from France's Hydrogen Mobility Ecosystems program to expand its fleet of Toyota Mirais from 100 to 600.[225] In September, Toyota delivered a Mirai to the ZeroAvia headquarters at Cranfield Airport in Bedfordshire, England. The Mirai will be fueled by a hydrogen airport refueling system (HARE), a self-contained, on-airport zero emissions hydrogen production, storage and refueling system.[226]

Heavy-Duty Vehicles

The heavy-duty vehicle sector, which includes fuel cell powered trucks and buses as well as marine, aviation, and rail applications, continued to gain interest, investment, and significant achievements in 2020, including two significant milestones:

- In August, Ballard Power Systems' fuel cell systems operating in ~1,000 buses and 2,200 commercial trucks accumulated more than 31 million miles (50 million km) in 15 countries. Approximately 70% of the total distance was achieved in China and the remainder in Europe and North America.
- In March, a Wuhan Tiger bus in China powered by PowerCell S2 fuel cell stacks accumulated ~24,000 miles (more than 40,000 km).

Trucks

The 2019 edition of the *Fuel Cell Technologies Market Report* [227] contained an extensive overview of the origins, initial programs, and current landscape of the heavy-duty vehicle sector, specifically Class 6, 7, and 8 trucks. This market saw substantial momentum throughout 2020, with new players, programs, and sales/orders making headlines.

In November, a new coalition of OEMs, fuel cell and hydrogen technology companies, freight services, and truck operators issued a statement committing to reducing greenhouse gas emissions in the European transport and logistics industry by 90% within the next 30 years through the widespread adoption of hydrogen fuel cell trucks. The statement, signed by Toyota, Hyundai, Honda, BMW Group, Hyzon Motors, Ballard Power Systems, Michelin, Total, Engie, Shell, and others, committed to deploying 100,000 heavy-duty fuel cell trucks and up to 1,500 hydrogen fueling stations by 2030.[228]

Before this announcement and commitment, there were several other notable activities in the heavy-duty truck sector, including the introduction of one of the companies participating in that coalition: Hyzon Motors (Hydrogen Mobility Powered by Horizon). Hyzon launched in March as a new business of Horizon Fuel Cell.

In Europe, there were several notable projects and deployments throughout the year:

- In January, ADEME's Hydrogen Mobility Ecosystems program awarded Air Liquide funding for the hydrogen in Aix-Marseille for an ecological and sustainable mobility (HyAMMED) project, which will deploy fuel cell trucks that will use low-carbon hydrogen produced in the area of the Marseille Fos port.[229]

- In April, ASKO, a Norwegian wholesale grocer, began operating four trucks built by Swedish manufacturer Scania, each with a Cummins 90 kW HyPM HD fuel cell power module.[230]
- The Netherlands began demonstration projects testing fuel cell trucks in 2020, supported by funding from the EU, including the following:
    - H2 Share, a 27-tonne hydrogen fuel cell rigid truck built by VDL, started its first demonstration with Breytner in Schelluinen in April.[231] The truck is fueled by a mobile hydrogen refueler from Wystrach GmbH.
    - REVIVE (refuse vehicle innovation and validation in Europe), a fuel cell refuse truck, began operation in October in the city of Breda.[232] The project, co-financed by FCH JU, a public–private organization, integrates a fuel cell system from Proton Motor as a range extender.

Several automakers with commercially available fuel cell light-duty vehicles expanded efforts into the medium- and heavy-duty sector:

- At the start of the year, Honda's R&D arm announced a two-year collaboration with Isuzu Motor Co. to integrate Honda's fuel cell systems into Isuzu's heavy-duty trucks.[233]
- In September, GM announced it was partnering with Nikola Motors[‡] to develop an electric pickup truck, called the Badger, with both fuel cell and battery variations.[234] GM will receive a US$2 billion equity stake in Nikola in exchange for its technology contributions, and the Badger will retain the Nikola brand name.
- Hyundai Motor Company shipped 10 Hyundai XCIENT fuel cell trucks, the world's first mass-produced fuel cell heavy-duty trucks, to Switzerland in July,[235] and in October announced that seven of those trucks were delivered to customers.[236] In October, Hyundai officially unveiled the XCIENT—virtually, due to COVID-19.[237]
- Toyota delivered its first two Kenworth T680 Class 8 heavy-duty fuel cell trucks built as part of California's Zero and Near Zero Freight Forwarding program to the Ports of Los Angeles and Long Beach in December.[238] Toyota Logistics Services and Southern Counties Express will use the trucks for drayage operations at the ports.
- In December, Nuvera Fuel Cells (based in Billerica, Massachusetts), Hyster-Yale Group and Capacity Trucks announced that they will develop hydrogen-powered terminal tractors, using Nuvera fuel cell technology, for use at ports.[239]

Buses

Deployments and orders of fuel cell buses continued in 2020, primarily in Europe.

In Denmark, the first three fuel cell buses began operation in the Municipality of Aalborg in March. The Van Hool A330 buses use fuel cells from Ballard Power Systems and were funded in part by the 3Emotion project.[240] One bus will be operated by transit operator Keolis and the other

[‡] However, GM pulled out just two months later. https://www.environmentalleader.com/2022/01/nikola-corporation-to-pay-125-million-settlement-for-defrauding-investors/.

two by Arriva. All three will refuel at a hydrogen station operated by Green Hydrogen, a Danish company. The 3Emotion project also deployed four VDL buses in June in South Holland that are operated by Connexxion.[241] These VDL buses are 12-meter Citea SLF-120 electric buses that have a battery and fuel cell range extender.

In addition to providing systems to VDL, throughout the year, Ballard Power Systems received several orders for its fuel cell systems to power buses, including 45 FCmove™-HD 70 kW fuel cell modules from Solaris Bus & Coach S.A. that were supported by the European Joint Initiative for Hydrogen Vehicles Across Europe (JIVE 2) funding program. That program and the original JIVE were co-financed by FCH JU, and in October both programs collectively had ordered more than 200 fuel cell buses, with 50 buses already in operation.[242]

Ballard's Solaris orders included the following:

- Twenty-five fuel cell systems, ordered in March, will be used for Solaris Urbino 12 hydrogen buses in Germany, with 15 planned for deployment in Cologne and 10 for Wuppertal.[243]
- In April, Solaris added 20 more fuel cell systems for its Urbino 12 buses for South Holland in the Netherlands, to be operated by Connexxion.[244]

In June, Ballard received follow-on purchase orders from Wrightbus for 15 FCveloCity®-HD 85-kW fuel cell modules for buses planned for deployment in the UK.[245]

Fortescue Metals Group, an Australian iron ore mining company, announced in August that it would be integrating 10 full-sized hydrogen fuel cell buses from Hyzon Motors into the fleet of one of its mines. Fortescue will also install a refueling station that will generate renewable hydrogen to support the buses.[246]

Marine

The marine sector is often considered hard to decarbonize due to its widespread use of inexpensive low-grade fuels as well as the high energy requirements of long voyages. Hydrogen is increasingly being studied and demonstrated to provide a pathway to low-carbon fuel for shipping, whether via ammonia or synthetic fuel or on its own in liquid or gas form.

- In the EU, the FCH JU funded the ShipFC project, in which a fuel cell system that uses ammonia will be installed on the Viking Energy, an offshore vessel.[247] The project will focus on scaling up a 100 kW fuel cell to 2 MW as well as investigating the use of fuel cells on offshore construction and cargo vessels.
- PowerCell Sweden delivered its MS-30 fuel cell system to Fincantieri S.p.A, an Italian shipbuilding company, in February.[248] In April, the company signed a 77 million kr (~US$7.67 million), three-year contract with an unspecified European shipyard to develop a 3 MW marine fuel cell system.[249]
- In June, Bloom Energy and Samsung Heavy Industries, a part of Samsung Group, signed a joint development agreement to design and develop fuel cell powered ships.[250] Another

stationary fuel cell company, Doosan Fuel Cell, announced in November it would be providing a SOFC system to Navig8, a Singaporean shipping company, to power a 50,000-ton ship.[251]

- A Japanese consortium led by NYK Line, a shipping and logistics company, announced plans in September to develop a 100-passenger fuel cell tour boat.[252]
- SFC Energy received a follow-up order for its EFOY fuel cells in September from AuroraHuts Oy, a Finnish manufacturer of igloo houseboats.[253]

Aviation

Aviation is another sector in the hard-to-decarbonize category, and September 2020 was the month for major announcements by several companies in this space. The examples below focus on direct use of hydrogen, although hydrogen may also be used to produce sustainable aviation liquid fuels to replace today's jet fuel.

- Plug Power joined Universal Hydrogen to develop a commercially viable hydrogen fuel cell based propulsion system for commercial regional aircraft.[254] The companies will initially develop and test a full-scale, ground-based powertrain prototype, known as an iron bird, before retrofitting the powertrain into the aircraft.
- As part of the UK government-funded HyFlyer project, ZeroAvia integrated a PowerCell MS-100 fuel cell system into a Piper Malibu six-seater plane and completed the world's first flight of a commercial single-engine aircraft powered by a fuel cell.[255] The flight lasted eight minutes, reaching a speed of around 115 miles per hour (100 knots) and an altitude of 1,000 feet. In the months leading up to that flight, ZeroAvia completed a successful test of the plane from its Cranfield base, making it the first electric-powered flight of commercial-scale aircraft from a UK airfield as well as Europe's largest zero-emission aircraft.[256]
- Airbus, a leading aircraft manufacturer, introduced three new ZEROe concept planes.[257] These include a turbofan design that could hold up to 200 passengers with a range of 2,000+ nautical miles, a "blended-wing body" concept, also with a 200-passenger capacity, and a turboprop design for up to 100 passengers and short-haul trips. All three would use hydrogen in modified gas-turbine engines.

UAVs are covered in the Portable Power Fuel Cells section of this report.

Rail

Alstom, a rolling stock manufacturer, continued making strides with its Coradia iLint fuel cell train. Throughout the year, Alstom reported several key milestones, including a 10-day, 65 km route in the Netherlands in March.[258] A three-month demonstration trial on ÖBB's (Austrian Federal Railways) regional lines in Austria, announced in September,[259] ended successfully at the end of the year.[260]

Medium-Duty Vehicles

- In February, Plug Power announced a partnership with Colorado-based Lightning Systems to design several fuel cell powered Class 6 trucks capable of supporting middle-mile delivery logistics between warehouses and distribution centers.[261]
- In December, PowerCell Sweden received an order for two MS-100 fuel cell systems from a global American agriculture equipment manufacturer to test the electrification of tractors.[262]

Material Handling Equipment

MHE is used for the movement, storage, control and protection of materials, goods and products throughout the process of manufacturing, distribution, consumption and disposal.

- At the end of 2020, Plug Power reported more than 38,000 of its fuel cell systems are deployed in material handling applications. One major customer, Walmart, with more than 9,500 vehicles at 37 locations powered by Plug's GenDrive fuel cell systems, expanded its relationship with Plug Power in December. Plug Power will be supplying Walmart with sustainable solutions for the retail company's online retail services network. [263]
- Hyundai Mobis, a South Korean auto parts company, collaborated with Hyundai Motor Company and Hyundai Construction Equipment on a prototype for a mid-to large-sized hydrogen fuel cell forklift, using a Hyundai Motors fuel cell system.[264]

Stationary Fuel Cells

The stationary sector includes fuel cell systems that operate at a fixed location for primary power, backup power, or CHP. Fuel cells are being developed for both large-scale (100 kW and over) and small-scale (up to 100 kW) applications and deployed to a wide range of customers, including retail operations, data centers, residences, telecommunications, utilities, and many more.

As of December 2020, eight of the 22 IPHE partner countries reported a total of 346,548 fuel cell systems deployed, with the majority being small-scale residential fuel cell systems in Japan. The U.S. and Korea reported more than 1,000 MW, primarily large-scale fuel cell installations.

Table 10: Reported Stationary Fuel Cell Deployments in IPHE Partner Countries[265]

Reported Stationary Fuel Cell Deployments in IPHE Partner Countries	
Country	**Stationary Fuel Cells**
Austria *(as of July 2020)*	1
China (as of August 2020)	51
European Commission *(as of December 2020)*	2,066

Reported Stationary Fuel Cell Deployments in IPHE Partner Countries	
Country	**Stationary Fuel Cells**
France *(as of December 2020)*	112
Germany *(as of December 2020)*	10,255
Italy *(as of July 2020)*	41
Japan *(as of December 2020)*	333,712
Korea *(as of December 2020)*	567 MW
South Africa *(as of December 2020)*	310
United States *(as of July 2020)*	>500 MW

Large-Scale Stationary

As outlined in the COVID-19 Spotlight, Bloom Energy spent a good part of 2020 assisting efforts to provide critical equipment to hospitals and other organizations. Despite that unexpected shift, the company announced news and progress in deploying its fuel cell systems. In 2020, Bloom reported that its systems supported customers' power needs through 335 outages at 67 sites, including 18 hours powering a 911 call center in Long Island, New York, during a tropical storm related outage.[266]

The company also announced its intention to enter the commercial hydrogen market in July with the addition of hydrogen-powered fuel cell systems and solid oxide electrolyzer technology to its portfolio.[267] Bloom is working with SK Engineering and Construction, an affiliate of SK Group in Korea, to introduce the products into the Korean market. Table 11 outlines several projects the partnership announced in 2020.

Utah-based Power Innovations[§] completed a landmark test of a full data center load using its 250 kW PEM fuel cell system in partnership with Microsoft.[268] The hydrogen fuel cell powered 10 racks of data center servers for 48 hours.

Doosan Fuel Cell announced several business arrangements with Korean organizations throughout the year and a development agreement with Ceres Power, a UK-based SOFC fuel cell manufacturer, to jointly develop a SOFC system to be produced in Korea by 2024.[269]

[§] As of 2021, Renewable Innovations.

Doosan's other partnerships included:

- A joint effort with KT to develop a fuel cell smart auto control platform using AI technology from KT to run the fuel cell autonomously.[270]
- An MOU with Kyonggi University for joint research, job training and apprenticeships.[271]
- An MOU with LS Electric, Hanwha Power Systems and Hanwha Asset Management to develop and commercialize fuel cell linked reduced-pressure power generation system technology to use unused energy from governor stations.[272] Governor stations lower the pressure of natural gas to supply city gas to houses.

Hyundai Motor Company entered the non-automotive world and began shipping its proprietary fuel cell system to Europe in September for stationary power. Customers include GRZ Technologies Ltd., a hydrogen solution firm based in Switzerland.[273] The fuel cell is the same as those used in Hyundai's NEXO FCV, and GRZ plans to produce a power supply system with it.

Table 11: Examples of Publicly Disclosed Large-Scale Fuel Cell Orders and Installations—2020

Examples of Publicly Disclosed Large-Scale Fuel Cell Orders and Installations—2020			
Customer/Partner	**Location**	**Power**	**Details**
Bloom Energy			
KeHE	Stockton, CA	600 kW	KeHE, a wholesale food distributor, will power its food distribution center with the Bloom fuel cell system.[274]
Southern California Gas Co. (SoCalGas)	Los Angeles, CA	1.9 MW total	SoCalGas installed 950 kW Bloom Energy Servers configured as AlwaysON Microgrids at two of its largest Los Angeles-area facilities.[275]
Stop & Shop	Massachusetts and New York	N/A	January: Grocery store chain Stop & Shop announced it would power 40 of its stores in Massachusetts and New York with Bloom Energy Servers in an AlwaysON Microgrid configuration.[276]
SK Engineering and Construction (SK E&C)	Changwon, Korea	1.8 MW	Bloom and SK E&C won a competitive RFP under the RE100 program to supply hydrogen-powered SOFCs that will be integrated into an industrial complex.[277]
	Hwasung, Korea	19.8 MW	September: Became the largest Bloom Energy project in South Korea to date and the company's second largest in the world.[278]
	Paju, Korea	8.1 MW	This plant generates energy for the city and rural residents with natural gas via new city pipelines.
The Kraft Group	Foxborough, Massachusetts	2 MW	July: Announced that 2MW of fuel cells were installed at Gillette Stadium and will supply nearly 50% of the 65,878-seat stadium's energy needs.[279]
Port Authority of New York and New Jersey	New York, New York	1.2 MW	December: Announced the 1.2 MW fuel cell would be the first indoor system installed at One World Trade Center.[280]

Examples of Publicly Disclosed Large-Scale Fuel Cell Orders and Installations—2020			
Customer/Partner	**Location**	**Power**	**Details**
Doosan Fuel Cell America			
Montville Water Pollution Control Authority (WPCA)	Montville, Connecticut	460 kW	Fuel cell system was delivered to the WPCA in April. [281]
Doosan Fuel Cell (Korea)			
Daesan Green Energy	Seosan, Korea	50 MW	Doosan Fuel Cell joined with Hanwha Energy, Korea East-west Power Co., and Daesan Green Energy to install the system in July. The fuel cells utilize by-product hydrogen from local petrochemical facilities.[282]
FuelCell Energy			
Triangle Street Project	Danbury, Connecticut	3.7 MW	Commercial operation of SureSource 4000 power plant began in April.[283]
U.S. Navy	Groton, Connecticut	7.4 MW	Two SureSource 4000 power plants will be deployed at U.S. Navy Substation.
PowerCell			
ENGV	Denham, Australia	100 kW	December: Ordered a fuel cell to be used in a demonstration project that includes a 348 kW electrolyzer, a 704 kW solar farm and the 100 kW MS-100 fuel cell.[284] The project was funded by the Australian Renewable Energy Agency (ARENA) and the Western Australian Government.

Small-Scale Stationary

Smaller stationary fuel cells (100 kW or less) are commercially available from different manufacturers around the world. They are installed to provide primary or backup power or in a CHP configuration at homes and businesses. As with large-scale stationary systems, there is a range of fuel cell options—PEM, SOFC, alkaline—that run on different fuels, including hydrogen, natural gas, propane, methanol, and ammonia.

In the U.S., small-scale fuel cells are primarily deployed to extend or fortify communications networks with reliable backup power when needed. Altergy Systems, based in Folsom, California, announced in September that its fuel cell systems were used in the western part of the U.S. to provide continuous power during outages caused by wildfires that exceeded the California Public Utilities Commission 72-hour backup power mandates.[285]

In Japan, Ene-Farm branded micro-CHP fuel cell systems are manufactured by several companies (Panasonic, Toshiba, and others) and offer capacity ranges from 0.3 kW to 1 kW. According to Japan's New Energy and Industrial Technology Development Organization's Agency for Natural Resources and Energy, more than 31,000 Ene-Farm residential fuel cell systems were sold in 2020,[**] bringing the cumulative number since the units were first introduced, in 2009, to 344,000. There are several companies manufacturing both PEM and SOFC fuel cells under the Ene-Farm brand.

In addition to the orders listed below, GenCell Energy announced the successful integration of Enapter's alkaline electrolyzer system with its alkaline fuel cell in September.

[**] According to data sent to FCHEA.

Table 12: Examples of Publicly Disclosed Small-Scale Fuel Cell Orders and Installations—2020

Examples of Publicly Disclosed Small -Scale Fuel Cell Orders and Installations—2020			
Customer/Partner	**Location**	**Number of Units**	**Details**
Ballard Power Systems			
adKor GmbH and SFC Energy AG	Germany	500	January: Ballard signed equipment sales agreements for the provision of an initial 500 FCgen®-1020ACS fuel cell stacks to adKor GmbH and SFC Energy AG, to be integrated into adKor's Jupiter backup power systems for deployment at radio tower sites in Germany through the end of 2021.[286]
GenCell Energy			
Delta Land Development Ltd.	British Columbia, Canada	1 (5 kW)	A GenCell G5 fuel cell will be installed with a 32-kW photovoltaic and battery system to power an off-grid demonstration project in British Columbia.[287]
Comisión Federal de Electricidad® (CFE)	Mexico	37	December: GenCell was contracted to deliver 37 fuel cells and provide service and maintenance for the systems, which will be installed at substations across Mexico.[288] The deal is valued at US$6,000,000 and has the potential to be increased to 74 systems.
Tier 1 Telecom Provider	Europe	1 (5 kW)	September: the telecom company deployed a GenCell G5 hydrogen fuel cell based long-duration backup solution at an active cell tower site in Europe.
Intelligent Energy			
MBR Global	Malaysia	2 (3.7 kW total)	June: Intelligent Energy supplied a 1.2 kW FCM801 and a 2.5 kW FCM802 fuel cell system to MBR to deploy in microgrids at two remote villages in Malaysia.[289]

Portable Power Fuel Cells

In December 2020, SFC Energy Group announced that beginning January 1, 2021, all of its subsidiaries will operate under the name SFC Energy.[290] This includes Simark Controls (Canada), PBF Group (Netherlands) and PBF Power (Romania). Also in December, SFC expanded its distribution network by partnering with Axsol GmbH, based in Würzburg, Germany.

Earlier in the year, SFC and its subsidiaries publicized several orders (see Table 13).

Table 13: Publicly Announced 2020 Orders from SFC Energy and Affiliated Companies

Publicly Announced 2020 Orders from SFC Energy and Affiliated Companies			
Customer	**Product**	**Value**	**Notes**
SFC Energy			
FKS GmbH, Lower Saxony, Germany	EFOY ProCube	€106,000 (US$120,000)	February: Fuel cells to ensure the back-up power supply of the Meissen district administration's BOS radio system.[291]
adKor GmbH, Wildau, Germany	JUPITER	€2.5 million (US$2.8 million)	June: Fuel cells to be installed in switch cabinets at up to 1,500 radio sites at more than 100 locations in Germany. [292]
Beijing Green Century Energy Technology Co. Ltd. Beijing, China	EFOY Pro	N/A	November: 48 additional systems ordered for a Chinese wind company for offshore measuring stations.[293]
Oneberry Technologies, Singapore	EFOY	€1.4 million (US$1.6 million)	March: The 1,000th SFC EFOY fuel cell was deployed in Singapore to provide off-grid power to public health and safety infrastructure.[294]
Simark Controls			
SiteWatch Safety Inc., Calgary Canada	EFOY Pro 2400 Duo	C$325.000 (US$256,000)	June: For reliable hybrid power source for their SiteWatch SENTRY SKID remote video surveillance package. This equipment will be used along 980 km of new pipelines during the construction phase of the project.[295]
Canadian gas production company, Central Alberta, Canada	EFOY Pro 500 W	C$250,000 (US$197,000)	November: The complete solution will supply power to customer's off-grid well pad.[296]
Calgary-based communications company	EFOY ProTrailer 4120T	C$400,000 (US$315,000)	December: Order for 6 mobile power platforms for critical communications and video monitoring infrastructure.[297]

Unmanned Aerial Vehicles

A UAV, generally known as a drone, is defined as a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload.[298] There are multiple fuel cell manufacturers working in the UAV sector, and others are collaborating with the military on other related applications, such as unmanned underwater or ground vehicles and portable soldier power.

Plug Power, which acquired EnergyOr in 2019 to enter the UAV space, launched a new 1 kW ProGen fuel cell system for this market, as well as small-scale robotics, automatic guided vehicles, and other aerospace applications, in August.[299]

Doosan Mobility Innovation (DMI), based in Korea and with a presence in California, offers several products in the fuel cell UAV space, and throughout 2020 it entered into several business arrangements with different companies:

- In January, DMI entered into a strategic partnership with Microsoft to develop mobile hydrogen fuel cell pack drone software using the cloud and AI.[300] The company also signed an MOU with LG Uplus to deploy "smart hydrogen drones" that will be equipped with LTE and 5G communication functions at the LG Science Park in Seoul, Korea.[301] The two companies will develop both control services that can remotely manage the drone's flight path and performance and a video service to transmit images in real time.
- DMI and Hanyang Co., Ltd. are working together to develop a solar inspection solution using drones.[302] The drones use optical and thermal imaging cameras to inspect photovoltaic complexes and communicate real-time transmission of information via LTE, AI-based image/video automatic analysis, and analysis results.
- DMI entered into a business agreement with POSCO International to promote DMI's hydrogen fuel cell pack and hydrogen drone products and to develop and demonstrate solutions for hydrogen drone utilization in industrial sites, targeting the global market.[303]
- In October, DMI signed a preliminary deal with the Korea Electric Power Research Institute (KEPRI), a R&D subsidiary of the state-run Korea Electric Power Corp., to share patent technologies and sales networks. KEPRI's automated power cable checking system will be applied to DMI's fuel cell drones.[304]
- DMI also partnered with public-safety drone consultancy Skyfire Consulting and hydrogen fuel service provider ReadyH2 to deploy a hydrogen-powered octocopter for a 6-month pipeline inspection project for an unnamed American company.[305]
- In April, Intelligent Energy entered a distributor deal to provide its 2.4 kW fuel cell system to RoboDEX Inc., a Japanese UAV development company.[306]

In the U.S., ARPA-E awarded more than US$12.85 million to fuel cell projects as part of its range extenders for electric aviation with low carbon and high efficiency (REEACH) program in August.[307] More details about the companies and projects awarded funding can be found in the Appendix.

Conclusion

This report is a snapshot in time: extensive but not all-inclusive. There have been decades of R&D, investment, testing, and innovation by countless government agencies, companies, universities, laboratories, research facilities, and customers, all working towards the common goal of a decarbonized energy network that includes hydrogen and fuel cell technologies.

While 2020 was a challenging year on many levels, the fundamentals of the hydrogen and fuel cell industry remained steadfast, the foundation for continued market growth and opportunities. As more stakeholders and outside industries realize the vast potential hydrogen and fuel cells offer for decarbonization of energy intensive operations and electricity generation, as well as for clean, stable, and continuous power, 2021 may look even brighter.

Appendix: Federal Funding Awards

The following chart outlines funding awards the DOE, other federal agencies, and branches of the U.S. military released in 2020.

DOE provides fuel cell and hydrogen funding primarily through FOAs and other solicitations from its various offices: EERE, HFTO and the H2@Scale initiative, FECM, Office of Basic Energy Sciences (BES), NE, and ARPA–E.

The technology offices (EERE, FECM, NE, etc.) provide a portion of their funding to DOE's Office of Technology Transitions (OTT) and coordinate with OTT to administer the Technology Commercialization Fund (TCF). The TCF in turn matches funds from the private sector to advance the commercialization of promising energy technologies and to strengthen partnerships between DOE's national laboratories and private sector companies to deploy these technologies to the marketplace.

DOE also provides funding through the SBIR/STTR program, which other agencies, such as the National Science Foundation, the National Aeronautics and Space Administration, and branches of the military, also use to fund fuel cell and hydrogen research projects.

Table A. U.S. Department of Energy Federal Funding Awards

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
3M Company	Saint Paul, MN	US$4,854,808	EERE HFTO H2@Scale New Markets FOA Topic 1: Electrolyzer Manufacturing R&D	Advanced Manufacturing Processes for Gigawatt-Scale Proton Exchange Membrane Water Electrolyzer Oxygen Evolution Reaction Catalysts and Electrodes
		US$999,889	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3A: Membranes for Heavy-Duty Applications	Extending PFSA Membrane Durability Through Enhanced Ionomer Backbone Stability
Alchemr	Boca Raton, FL	US$206,500	EERE SBIR Phase I Release 2: Fuel Cells	AEM Water Electrolyzer for Hydrogen Production from Off-Shore Wind
Amsen Technologies, LLC	Tucson, AZ		BES SBIR Phase I Release 1: Membranes for Electrochemical Applications	Novel Reinforced Anion Exchange Membranes for Solar-to-Hydrogen Generators
Aris Energy Solutions, Inc.	Mount Vernon, NY	US$2,659,212	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 1: Small-scale Distributed Power Generation SOFC Systems	Modular Fuel Cells Providing Resiliency to Data Centers and Other Critical Power Users
Battelle Energy Alliance, LLC	Idaho Falls, ID	US$2,999,610	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Performance Validation of a Thermally Integrated 50 kW High Temperature Electrolyzer System

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
Caterpillar, Inc.	Mossville, IL	US$6,000,000	EERE HFTO H2@Scale New Markets FOA Topic 5: H2@Scale New Markets Demonstrations; Subtopic 5B: Data Center	System Demonstration for Supplying Clean, Reliable and Affordable Electric Power to Data Centers using Hydrogen Fuel
Celadyne Technologies	Austin, TX		BES SBIR Phase I Release 1: Membranes for Electrochemical Applications	Nanoionics Proton Conducting Electrolyte
Collaborative Composite Solutions Corporation	Oak Ridge, TN	US$2,700,540	EERE HFTO H2@Scale New Markets FOA Topic 2: Advanced Carbon Fiber for Compressed Hydrogen and Natural Gas Storage Tanks	Melt Spun PAN Precursor for Cost-Effective Carbon Fiber in High Pressure Compressed Gas Tankage
Cummins, Inc.	Columbus, IN	US$1,000,000	H2Rescue interagency solicitation (EERE HFTO, VTO and DOD)	EERE joined DoD and the U.S. Department of Homeland Security Science and Technology Directorate to award Cummins this funding to develop *H2Rescue*, a hydrogen fuel cell truck that will travel to disaster relief sites and provide power, heat, and water.
		US$3,000,000	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3B: Domestically Manufactured Fuel Cells for Heavy-Duty Applications	Cummins PEM Fuel Cell System for Heavy Duty Applications
		US$2,601,046	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 1: Small-scale Distributed Power Generation SOFC Systems	Improving Cost and Efficiency of the Scalable SOFC Power System

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
		US$2,100,825	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Cummins R-SOFC System Development
Electric Power Research Institute, Inc. (EPRI)	Palo Alto, CA	US$2.000.000	EERE HFTO H2@Scale New Markets FOA Topic 6: Training and Workforce Development for Emerging Hydrogen Technologies	Developing a Workforce for a Hydrogen Technology Economy
		US$9,400,000	FECM FOA Net-Zero Carbon Electricity and Hydrogen Plants	Gasification of Coal and Biomass: The Route to Net-Negative-Carbon Power and Hydrogen
Fuceltech Inc.	Princeton Junction, NJ	US$1,656,438	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	Extremely Lightweight Fuel Cell Based Power Supply System for Commercial Aircrafts – to develop a monopolar wound fuel cell potentially as high as 10kW rating and a novel stacking approach to deliver hundreds of kW of power from a single small and lightweight stack. Fuceltech will use ethanol as a fuel and a reformer that delivers extremely low CO concentration in the reformate to the fuel cell.
FuelCell Energy	Danbury, CT	US$200,000	BES STTR Phase I Release 1: Membranes for Electrochemical Applications	Protonic Ceramic Membranes with Unprecedented Electrochemical Efficiency
		US$3,000,000	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Performance Improvements for Reversible Solid Oxide Fuel Cell Systems

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
FuelCell Energy/Idaho National Laboratory		US$12,500,000	NE/EERE HFTO FOA U.S. Industry Opportunities for Advanced Nuclear Technology Development	Solid Oxide Electrolysis Demonstration
General Electric Company, GE Research	Niskayuna, NY	US$2,529,340	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	FueL CelL Embedded ENgine (FLyCLEEN) will leverage the robustness and efficiency of metal-supported solid oxide fuel cells that are integrated with the combustion chamber of a gas turbine engine-generator, yielding a hybrid system operating on synfuel with performance that maximizes the power density and energy efficiency of each component.
Giner ELX, Inc.	Newton, MA	US$4,592,664	EERE HFTO H2@Scale New Markets FOA Topic 1: Electrolyzer Manufacturing R&D	Integrated Membrane Anode Assembly & Scale-up
		US$199,992	BES SBIR Phase I Release 1: Membranes for Electrochemical Applications	Anion Exchange Membrane for High Efficiency Solar-to-Hydrogen Generation
		US$199,998	EERE SBIR Phase I Release 2: Fuel Cells	Low Total Cost of Hydrogen by Exploiting Off-Shore Wind and PEM Electrolysis Synergies
		US$999,623	BES STTR Phase II Release 1: Membranes for Electrochemical Applications	Novel Membranes for Electrochemical Compressors
Greenway Energy, LLC	Aiken, SC	US$199,999	EERE SBIR Phase I Release 2: Fuel Cells	Production of Low-cost Hydrogen from Off-shore Wind Power - Efficient and low-cost hydrogen production by wind power driven water electrolysis

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
Hexagon R & D LLC	Lincoln, NE	US$2,599,945	EERE HFTO H2@Scale New Markets FOA Topic 2: Advanced Carbon Fiber for Compressed Hydrogen and Natural Gas Storage Tanks	Carbon Composite Optimization Reducing Tank Cost
Hornblower Yachts	San Francisco, CA	US$7,994,208	EERE HFTO H2@Scale New Markets FOA Topic 5: H2@Scale New Markets Demonstrations; Subtopic 5A: Maritime Demonstrations	Marine Hydrogen Demonstration
InnoSense, LLC	Torrance, CA	US$206,499	BES SBIR Phase I Release 1: Membranes for Electrochemical Applications	Cationic-Backbone Ionic Polymer-based Robust and High Hydroxide Ion Transporting Membranes for Alkaline Solar-to-Hydrogen Generators
Intelligent Fiber Optic Systems Corporation	San Jose, CA	US$233,630	FECM SBIR Phase I Release 2: Fuel Cells	Multi-Variable, Distributed, Real-Time Fiber-Optic Sensing System for Solid Oxide Fuel Cells
The Lubrizol Corporation	Wickliffe, OH	US$1,000,000	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3A: Membranes for Heavy-Duty Applications	Antioxidant Functionalized Polymers for Extended HD Polymer Electrolyte Membrane Lifetimes
Missouri University of Science & Technology	Rolla, MO	US$4,000.000	EERE HFTO H2@Scale New Markets FOA Topic 4: H2@Scale New Markets R&D-HySteel	Grid-Interactive Steelmaking with Hydrogen (GISH)
Mohawk Innovation Technology, Inc.	Albany, NY	US$249,790	FECM SBIR Phase I Release 2: Fuel Cells	Additively Manufactured High Temperature Centrifugal Impellers for Low Cost SOFC Recycle Blower
NanoSonic, Inc.	Pembroke, VA	US$1,100,000	EERE SBIR Phase II Release 2: Fuel Cells	High-Pressure, Low Temperature Composite Nozzles for Long-Term H2 Dispensing

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
NexTech Materials, Ltd. dba Nexceris, LLC	Lewis Center, OH	US$250,000	FECM SBIR Phase I Release 2: Fuel Cells	Three-Dimensional Fabrication of Metal-Supported SOFC Cells
		US$3,000,000	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Reversible Solid Oxide Fuel Cell System
Nikola Corporation	Phoenix, AZ	US$998,376	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3A: Membranes for Heavy-Duty Applications	Advanced Membrane and MEA for HD Fuel Cell Trucks
Northern States Power Company—Xcel Energy	Minneapolis, MN	US$13,769,630	NE/EERE HFTO FOA U.S. Industry Opportunities for Advanced Nuclear Technology Development	Light-Water Reactor (LWR) Integrated Energy Systems Interface Technology Development & Demonstration
Pacific Northwest National Laboratory	Richland, WA	US$3,000,000	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Low Cost, Large Area SOEC Stack for Hydrogen and Chemicals
pH Matter, LLC	Columbus, OH	US$1,150,000	BES SBIR Phase II Release 1: Membranes and Materials for Energy Efficiency	Multi-Functional Catalyst Support

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
Phillips 66	Bartlesville, OK	US$3,000,000	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	A Highly Efficient and Affordable Hybrid System for Hydrogen and Electricity Production
Plug Power	Latham, NY	US$2,987,181	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3B: Domestically Manufactured Fuel Cells for Heavy-Duty Applications	Domestically Manufactured Fuel Cells for Heavy-Duty Applications
Precision Combustion, Inc.	North Haven, CT	US$249,879	FECM SBIR Phase I Release 2: Fuel Cells	Advanced Solid Oxide Fuel Cell Components Enabled through Additive Manufacturing
		US$249,989		Novel Process for CO2 Capture from Natural Gas Fueled SOFC Generators
		US$1,750,590	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	SOFCs for FLIGHT
Proton Energy Systems, Inc.	Wallingford, CT	US$4,400,000	EERE HFTO H2@Scale New Markets FOA Topic 1: Electrolyzer Manufacturing R&D	Enabling Low-Cost PEM Electrolysis at Scale Through Optimization of Transport Components and Electrode Interfaces
Redox Power Systems, LLC	Beltsville, MD	US$2,660,653	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 1: Small-scale Distributed Power Generation SOFC Systems	Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
Saint-Gobain Ceramics and Plastics	Northboro, MA	US$2,390,992	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Reversible SOFC-SOEC Stacks Based on Stable Rare-Earth Nickelate Oxygen Electrodes
SkyHaven Systems, LLC	Steamboat Springs, CO	US$256,500	FECM SBIR Phase I Release 2: Fuel Cells	Solid Oxide Fuel Cell Multi-Gas Sensors
TDA Research, Inc.	Wheat Ridge, CO	US$1,100,000	EERE SBIR Phase II Release 2: Fuel Cells	Onboard Monitoring Method for Detection of Damage to Carbon Fiber Composite Overwrap on Hydrogen Fuel Tanks
Tennessee Technological University	Cookeville, TN	US$1,437,287	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	High Power Density Carbon Neutral Electrical Power Generation for Air Vehicles will combine a solid oxide fuel cell (SOFC) stack with a gas turbine combustor to address challenges faced in all electric propulsion-based aviation.
Tetramer Technologies, LLC	Pendleton, SC	US$999,999	BES SBIR Phase II Release 1: Membranes for Electrochemical Applications	Improved Membranes for Solar Fuels Generators
		US$1,099,966	EERE SBIR Phase II Release 2: Fuel Cells	Improved Ionomers and Membranes for Fuel Cells
University of California: Irvine	Irvine, CA	US$4,043,993	EERE HFTO H2@Scale New Markets FOA Topic 4: H2@Scale New Markets R&D-HySteel	Solid Oxide Electrolysis Cells (SOEC) integrated with Direct Reduced Iron plants (DRI) for the production of green steel

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
University of California, San Diego	San Diego, CA	US$2,131,246	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	High-Efficiency and Low-Carbon Energy Storage and Power Generation System for Electric Aviation. Develop a high-efficiency and low-carbon energy storage and power generation (ESPG) system operating on bio-LNG for electric aviation. The proposed system concept is a fuel cell, battery, and gas turbine hybrid system that incorporates a novel solid oxide fuel cell (SOFC) stack technology.
	La Jolla, CA	US$2,999,125	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 2: Hybrid Systems Using Solid Oxide Systems for Hydrogen and Electricity Production	Efficient, Reliable and Cost-Effective Reversible Solid Oxide Cell Technology for Hydrogen and Electricity Production
University of Kentucky	Lexington, KY	US$2,415,576	EERE HFTO H2@Scale New Markets FOA Topic 2: Advanced Carbon Fiber for Compressed Hydrogen and Natural Gas Storage Tanks	Low-Cost, High-Strength Hollow Carbon Fiber for Compressed Gas Storage Tanks
University of Louisiana at Lafayette	Lafayette, LA		ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	High Performance Metal-Supported SOFC System for Range Extension of Commercial Aviation - will design and optimize an ESPG system for aircraft propulsion.
University of Maryland	College Park, MD	US$2,798,489	ARPA-E REEACH—Range Extenders for Electric Aviation with Low Carbon and High Efficiency	Hybrid SOFC Turbogenerator for Aircraft

2020 U.S. Department of Energy Federal Funding Awards				
Awardee	**Location**	**Amount**	**Program**	**Project**
University of North Dakota	Grand Forks, ND	US$3,999,944	FECM FOA Small-Scale Solid Oxide Fuel Cell Systems and Hybrid Electrolyzer Technology Development; AOI 3: Cleaning Process for Coal-derived Syngas to be Used as SOFC Fuel and Testing of Single and Multiple Cells on Syngas	Solid Oxide Fuel Cell Technology Development
University of Tennessee: Knoxville	Knoxville, TN	US$1,000,000	EERE HFTO H2@Scale New Markets FOA Topic 3: Fuel Cell R&D for Heavy-Duty Applications; Subtopic 3A: Membranes for Heavy-Duty Applications	A Systematic Approach to Developing Durable, Conductive Membranes for Operation above 120°C
University of Virginia	Charlottesville, VA	US$2,701,552	EERE HFTO H2@Scale New Markets FOA Topic 2: Advanced Carbon Fiber for Compressed Hydrogen and Natural Gas Storage Tanks	Low-Cost, High-Performance Carbon Fiber for Compressed Natural Gas Storage Tanks

Endnotes

1 https://www.energy.gov/sites/default/files/2017/10/f37/fcto_2016_market_report.pdf
2 https://www.e4tech.com/news/2018-fuel-cell-industry-review-2019-the-year-of-the-gigawatt.php
3 Original research by FCHEA. Other FCHEA reports are available at https://www.fchea.org/reports
4 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Inc-Completes-Acquisitions-of-United-Hydrogen-and-Giner-ELX-continuing-to-execute-on-its-five-year-plan/default.aspx
5 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/10/15/ballard-sells-uav-business-to-honeywell
6 https://www.chartindustries.com/News-Events/News/Chart-Acquires-Worthington-Industries%E2%80%99-Cryogenic-T
7 https://hydrogeneurope.eu/news/everfuel-acquire-h2co-uno-x-and-take-over-two-hydrogen-fueling-stations-norway
8 https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e41d1c9e14f6e738f12e9a3/1581371849638/H2+Korea+MOU+Press+Release.pdf
9 https://news.cision.com/powercell-sweden-ab/r/powercell-and-inabata---co-ltd--sign-exclusive-distribution-agreement-for-the-japanese-market,c3036884
10 https://news.cision.com/nel-asa/r/press-release--enters-into-strategic-collaboration-agreement-with-kvaerner,c3051743
11 https://press.siemens-energy.com/global/en/pressrelease/siemens-and-uniper-join-forces-decarbonize-power-generation
12 https://www.hyundainews.com/en-us/releases/304
13 https://www.greencarcongress.com/2020/02/20200217-hyundai.html
14 https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-motor-joins-hands-with-chinese-partners-to-lead-hydrogen-mobility-ecosystem-development-in-china-0000016567
15 https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-motor-company-and-ineos-to-cooperate-on-driving-hydrogen-economy-forward-0000016582?selectedVal=&selection=&pageNo=4&searchKey=&rowCount=9&type=RES&type=IMG&listPageUrl=release.all
16 https://www.airproducts.com/news-center/2020/07/0705-air-products-and-thyssenkrupp-agreement-for-electrolysis-plants-to-generate-green-hydrogen
17 https://www.airproducts.com/news-center/2020/07/0707-air-products-agreement-for-green-ammonia-production-facility-for-export-to-hydrogen-market
18 https://en.media.airliquide.com/news/air-liquide-and-port-of-rotterdam-launch-partnership-to-foster-hydrogen-powered-trucks-and-infrastructure-225b-56033.html
19 https://global.toyota/en/newsroom/corporate/33598951.html?padid=ag478_from_kv
20 https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2020/sep/0903-mou.html
21 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/28/ballard-and-mahle-to-collaborate-on-fuel-cell-propulsion-systems-for-heavy--and-medium-duty-trucks
22 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/10/29/ballard-and-audi-sign-definitive-agreements-regarding-use-of-industry-leading-high-power-density-fuel-cell-stack-for-vehicle-propulsion
23 https://hyzonmotors.com/hyzon-motors-signs-mou-with-warpforge-for-superbus-development/
24 https://hyzonmotors.com/hyzon-hydrogen-superbus-concept-advances-atg-mou-signed
25 https://hyzonmotors.com/new-zealand-firms-sign-up-for-fuel-cell-trucks-network/
26 https://press.siemens-energy.com/global/en/pressrelease/siemens-mobility-and-siemens-energy-jointly-drive-development-hydrogen-mobility
27 https://www.cummins.com/news/releases/2020/11/11/cummins-and-navistar-collaborate-heavy-duty-class-8-truck-powered-hydrogen
28 https://www.cummins.com/news/releases/2020/11/13/cummins-closes-nproxx-joint-venture-hydrogen-storage
29 https://nelhydrogen.com/press-release/nel-asa-signs-mou-with-everfuel-for-further-development-of-h2-fuel-norway/
30 https://www.sfc.com/en/sfc-energy-and-adkor-sign-equipment-sales-agreement-with-ballard-for-fuel-cell-stacks-to-support-backup-power-systems-at-german-radio-towers/

31 https://www.sfc.com/en/sfc-energy-and-vincorion-sign-an-extensive-cooperation-agreement-for-the-development-and-distribution-of-the-sustainable-portable-energy-management-system-p2m2/
32 https://www.sfc.com/en/sfc-energy-ag-und-toyota-tsusho-corporation-unterzeichnen-exklusiven-vertriebs-und-partnerschaftsvertrag-fuer-wasserstoff-und-methanol-brennstoffzellen-fuer-den-japanischen-markt/
33 https://www.shell.com/energy-and-innovation/new-energies/new-energies-media-releases/h2-accelerate-new-collaboration-for-zero-emission-hydrogen-trucking-at-mass-market-scale.html
34 https://hydrogeneurope.eu/sites/default/files/20201215%20MOU%20between%20Hydrogen%20Europe%20and%20ALICE.pdf
35 https://ir.chartindustries.com/news-and-events/press-releases/news-details/2020/Chart-Industries-Acquires-15-Ownership-of-HTEC-Hydrogen-Technology--Energy-Corporation-and-Signs-Strategic-Commercial-Hydrogen-MOU/default.aspx
36 https://www.einpresswire.com/article/512118876/hyzon-motors-inc-is-officially-launched-with-a-hydrogen-fuel-cell-heavy-vehicle-integration-facility-in-ny-state-usa
37 https://hyzonmotors.com/hyzon-motors-and-recarbon/
38 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/28/ballard-expanding-mea-production-capacity-6x-to-meet-expected-growth-in-fuel-cell-electric-vehicle-demand
39 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/07/02/ballard-announces-$7.7m-mea-order-from-synergy-joint-venture-in-china
40 https://matthey.com/en/news/2020/jm-expands-fuel-cell-component-manufacturing-operations-into-china
41 https://www.prnewswire.com/news-releases/hyundai-motor-group-launches-htwo-dedicated-fuel-cell-system-brand-301190137.html
42 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=66&page=0&
43 https://www.gencellenergy.com/news/tdk-ventures-and-paz-oil-company-invest-in-gencell-energys-ammonia-to-energy-technology/?utm_source=Website&utm_medium=Organic&utm_content=TDK_and_Paz_Investments_BP&utm_campaign=Blog
44 https://www.newswire.ca/news-releases/cummins-increases-investment-in-loop-energy-and-fuel-cells-for-commercial-transport-applications-883485953.html
45 https://hyzonmotors.com/french-broad-energy-company-total-leads-strategic-investment-into-hyzon-motors/
46 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Raises-Approximately-1B-to-Accelerate-the-First-Nation-Wide-Green-Hydrogen-Network/default.aspx –
47 https://static1.squarespace.com/static/53ab1feee4b0bef0179a1563/t/5e7ca9d6c8fb3629d399fe0c/1585228263363/Road+Map+to+a+US+Hydrogen+Economy+Full+Report.pdf
48 https://www.fchea.org/us-hydrogen-study
49 https://www.hydrogen.energy.gov/pdfs/hydrogen-program-plan-2020.pdf
50 https://www.energy.gov/eere/fuelcells/h2scale
51 https://www.energy.gov/articles/energy-department-announces-approximately-64m-funding-18-projects-advance-h2scale
52 https://www.energy.gov/eere/articles/energy-department-announces-multi-agency-award-industry-project-develop-disaster
53 https://www.energy.gov/eere/fuelcells/hyblend-opportunities-hydrogen-blending-natural-gas-pipelines
54 https://www.energy.gov/articles/doe-invests-34-million-develop-small-scale-solid-oxide-fuel-cell-sofc-systems
55 https://www.energy.gov/fe/articles/project-selections-foa-2300
56 https://investor.fce.com/press-releases/press-release-details/2020/FuelCell-Energy-Announces-U.S.-Department-of-Energy-Project-Award-96ef11d0a/default.aspx
57 https://www.energy.gov/ne/articles/us-department-energy-announces-269-million-advanced-nuclear-technology
58 https://www.energy.gov/eere/fuelcells/articles/phase-i-sbir-program-project-selections-include-efforts-hydrogen-and-fuel
59 https://www.energy.gov/eere/articles/collaboration-between-united-states-and-netherlands-focuses-hydrogen-technology
60 https://www.energy.gov/eere/articles/doe-launches-two-consortia-advance-fuel-cell-truck-and-electrolyzer-rd
61 https://www.energy.gov/eere/articles/energy-department-announces-33-million-advance-hydrogen-and-fuel-cell-rd-and-h2scale
62 https://netl.doe.gov/node/10369
63 https://rules.house.gov/sites/democrats.rules.house.gov/files/BILLS-116HR133SA-RCP-116-68.pdf
64 http://www.oregon.gov/gov/admin/pages/executive-orders.aspx
65 https://nj.gov/emp/

66 https://www.nj.gov/governor/news/news/562020/20200619a.shtml
67 https://www.energy.ca.gov/news/2020-10/cec-approves-384-million-plan-accelerate-zero-emission-transportation
68 https://www.energy.ca.gov/news/2020-12/energy-commission-approves-plan-invest-115-million-hydrogen-fueling
69 https://pressroom.toyota.com/iwatani-corporation-of-america-and-toyota-collaborate-to-bring-seven-new-hydrogen-refueling-stations-to-southern-california/
70 https://www.shell.us/media/2020-media-releases/shell--toyota-and-honda-plan-expansion-of-hydrogen-refueling-net.html
71 https://www.mass.gov/info-details/massachusetts-clean-energy-and-climate-plan-for-2030
72 https://www.mass.gov/info-details/ma-decarbonization-roadmap
73 https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks
74 https://ww2.arb.ca.gov/our-work/programs/volkswagen-zero-emission-vehicle-zev-investment-commitment
75 https://www.michigan.gov/egle/0,9429,7-135-70153_70155_3585_57765_78496-397560--,00.html
76 https://www.transportationandclimate.org/statements-state-leaders-launch-tci-p
77 https://www.nescaum.org/documents/multistate-truck-zev-governors-mou-20200714.pdf
78 https://www.nam.org/wp-content/uploads/2020/03/NAM-SPECIAL-CORONA-SURVEY.pdf
79 https://news.cision.com/nel-asa/r/operational-update--2-from-nel-asa-in-relation-to-covid-19,c3069191
80 https://www.linkedin.com/posts/kareemafzalpdcmachines_pdc-machines-has-received-a-waiver-from-the-activity-6648600585069223937-2hAk/
81 https://www.linkedin.com/posts/pdc-machines-inc_pdc-machines-is-operating-safely-and-serving-activity-6654418436996767744-88pk
82 https://www.energy.ca.gov/news/2020-03/state-clarifies-fuel-providers-are-open-business-essential-services-during-covid
83 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-state-california-almo-partner-refurbish-ventilators-healthcare
84 https://www.gore.com/news-events/alert/supporting-solutions-to-coronavirus
85 https://powerinnovations.com/from-military-aircrafts-to-covid-19-masks-priorities-change-change-overnight/?fbclid=IwAR0Z2mE-Gp_YuMpHRWyXcxR_YaEsMKrqqS_MFlbdqcIzgq0uld6z9sXPPZ8
86 https://www.faurecia.com/en/newsroom/faurecia-staff-print-mask-shields-frontline-public-services-spain
87 https://www.faurecia.com/en/newsroom/donation-10000-masks-local-hospitals
88 https://en.media.airliquide.com/news/air-liquide-groupe-psa-schneider-electric-valeo-rise-to-the-challenge-of-producing-10-000-air-liquide-medical-systems-respirators-in-response-to-the-french-government-request-2aa2-56033.html
89 https://www.mitsubishi-motors.com/en/newsrelease/2020/detail1268.html
90 https://www.shell.us/media/2020-media-releases/shell-to-provide-over-one-million-pieces-of-ppe-to-us-communities.html
91 https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office-webinars
92 https://aircompany.com/
93 https://www.sbir.gov/sbirsearch/detail/1639843
94 https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cells-newsletter-february-april-2020
95 https://www.energy.gov/sites/prod/files/2020/06/f75/H2IQ%20Hour%20May%2027.pdf
96 http://compositesmanufacturingmagazine.com/2020/09/cummins-and-ornl-carbon-fiber-technology-facility-collaborate-to-produce-1m-face-masks-a-day/
97 https://www.ornl.gov/news/ornl-industry-collaboration-enables-job-growth-n95-mask-production-florida
98 https://covid19-hpc-consortium.org/
99 https://www.energy.gov/articles/running-speed-science-race-against-covid-19
100 https://www.datacenterdynamics.com/en/news/europes-prace-and-ukri-join-covid-19-hpc-consortium/
101 ibid
102 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-powering-two-california-sites-response-covid-19-pandemic
103 https://www.dst.gov.za/index.php/media-room/latest-news/3144-dsi-deploys-hydrogen-fuel-cell-systems-to-power-covid-19-field-hospital
104 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-and-el-camino-health-deploy-shield-t3-curb-covid-19

105 https://www.linkedin.com/posts/adavidgiordano_communities-fuelcells-cleanenergy-activity-6655837791592726528-6ID4
106 https://www.linkedin.com/posts/pdc-machines-inc_thanks-to-pdc-china-pdc-machines-was-able-activity-6655491666868264960-h8rR
107 https://www.linkedin.com/posts/pdc-machines-inc_today-were-celebrating-these-everyday-heroes-activity-6653721146300653568-VxnN
108 https://www.shell.us/media/2020-media-releases/shell-to-provide-over-one-million-pieces-of-ppe-to-us-communities.html
109 https://www.technipfmc.com/en/media/news/2020/04/covid-19-how-we-are-helping-the-community-and-serving-our-clients/
110 https://foldingathome.org/
111 https://www.alstom.com/press-releases-news/2020/6/alstom-forefront-hygiene-safety-innovation-transport-mobility-covid-19
112 https://www.alstom.com/press-releases-news/2020/8/alstom-donates-corpaliv-corporation-welcomes-and-educates-children
113 https://www.alstom.com/press-releases-news/2020/12/alstom-donated-100-000-pln-charity-year-poland
114 https://www.cnhindustrial.com/en-us/media/press_releases/Documents/2020/december/20201217_PR_CNH%20Industrial_Feeding%20America%20Partnership.pdf
115 https://www.schaeffler.com/content.schaeffler.com/en/news_media/press_office/press_releases/press_releases_detail.jsp?id=87505856
116 https://www.total.com/media/news/press-releases/covid-19-total-mobilized-support-hospital-healthcare-staff-france-providing-them-50-million-euros
117 https://www.itochu.co.jp/en/csr/social/covid19/index.html
118 https://www.toyota-tsusho.com/english/press/detail/200604_004631.html
119 https://crsreports.congress.gov/product/pdf/IF/IF11684
120 https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen
121 https://www.minister.industry.gov.au/ministers/taylor/media-releases/backing-australian-hydrogen-industry-grow-jobs-economy-and-exports
122 https://www.bmwi.de/Redaktion/EN/Publikationen/Energie/the-national-hydrogen-strategy.html
123 https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf
124 https://www.bdi.fr/wp-content/uploads/2020/03/PressKitProvisionalDraft-National-strategy-for-the-development-of-decarbonised-and-renewable-hydrogen-in-France.pdf
125 https://energia.gob.es/en-us/Novedades/Paginas/publicacion-hoja-de-ruta-del-hidrogeno-apuesta-hidrogeno-renovable.aspx
126 https://open.alberta.ca/publications/getting-alberta-back-to-work-natural-gas-vision-and-strategy
127 https://energia.gob.cl/sites/default/files/national_green_hydrogen_strategy_-_chile.pdf
128 https://www.businessfinland.fi/4abb35/globalassets/finnish-customers/02-build-your-network/bioeconomy--cleantech/alykas-energia/bf_national_hydrogen_roadmap_2020.pdf
129 https://www.mise.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf
130 https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/
131 https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf
132 https://www.reuters.com/article/us-eu-energy-hydrogen/six-eu-countries-lead-push-for-clean-hydrogen-support-idUSKBN23M18G
133 https://ec.europa.eu/commission/presscorner/detail/en/ip_20_940
134 https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1259
135 https://www.euractiv.com/section/energy/news/germany-plans-to-promote-green-hydrogen-with-e7-billion/
136 https://renews.biz/62904/french-recovery-bets-on-hydrogen/
137 https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/france-launches-8364-7b-clean-hydrogen-plan-with-early-focus-on-industrial-emissions-60260381
138 https://www.reuters.com/article/us-spain-energy-hydrogen/spain-approves-hydrogen-strategy-to-spur-low-carbon-economy-idUSKBN26R2AF
139 https://www.h2-view.com/story/finland-launches-national-hydrogen-roadmap/

140 https://www.euractiv.com/section/energy-environment/news/dutch-outline-clean-hydrogen-vision-aim-at-global-market/
141 https://www.reuters.com/article/us-italy-hydrogen-idUSKBN27W1VI
142 https://renews.biz/62883/house-of-lords-to-debate-uk-hydrogen-strategy/
143 https://www.gov.scot/publications/scottish-government-hydrogen-policy-statement/
144 https://crsreports.congress.gov/product/pdf/IF/IF11684
145 https://www.minister.industry.gov.au/ministers/taylor/media-releases/backing-australian-hydrogen-industry-grow-jobs-economy-and-exports
146 https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/102820-india-looks-to-roll-out-hydrogen-roadmap-in-pursuit-of-cutting-energy-imports
147 https://www.mccarthy.ca/en/insights/blogs/canadian-energy-perspectives/alberta-releases-hydrogen-strategy
148 https://www.reuters.com/article/us-canada-hydrogen/canada-unveils-hydrogen-strategy-to-kick-start-clean-fuel-industry-idUSKBN28Q2XC
149 https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/110320-chile-aims-to-become-major-hydrogen-producer-by-2030
150 https://energies.airliquide.com/air-liquide-adds-high-capacity-hydrogen-station-dual-filling-positions-vehicles-us
151 https://www.plugpower.com/plug-power-leverages-entrance-into-new-green-hydrogen-market-electrolyzers-now-deployed-in-japan/
152 https://hydrogeneurope.eu/news/haskel-hydrogen-systems-unveils-new-hydrogen-refuelling-stations-expand-small-fleet
153 https://www.h2stations.org/press-release-2021-record-number-of-newly-opened-hydrogen-refeulling-stations-in-2020/
154 https://www.h2stations.org/
155 www.iphe.net
156 www.iphe.net
157 https://www.airproducts.com/company/news-center/2020/01/0131-air-products-supplies-hydrogen-bus-fueling-innovation-to-octa-in-california
158 https://www.truezero.com/true-zeros-21st-station-fountain-valley-grand-opening-july-3rd/
159 https://www.truezero.com/truezeros-22nd-station-opening-in-mission-hills/
160 https://www.fiedlergroup.com/architecture-engineering-project-recaps/shell-opens-san-franciscos-first-hydrogen-stations/
161 https://www.pdcmachines.com/about-us/news/
162 https://en.media.airliquide.com/news/air-liquide-will-build-the-first-high-pressure-hydrogen-refueling-station-for-long-haul-trucks-in-europe-803c-56033.html
163 https://energies.airliquide.com/air-liquide-will-contribute-beijing-2022-winter-olympics-its-hydrogen-equipment-and-technology
164 https://www.now-gmbh.de/en/news/pressreleases/new-h2-filling-station-in-biebelried/
165 https://news.cision.com/nel-asa/r/nel-asa--receives-first-h2station--order-in-poland,c3215759
166 https://news.cision.com/nel-asa/r/nel-asa--receives-purchase-orders-for-three-additional-hydrogen-fueling-stations-in-korea,c3129701
167 https://investors.irco.com/news/news-details/2020/Haskel-Hydrogen-Systems-Supports-Hydrogen-Mobility-in-the-Czech-Republic-Announces-Refueling-Station-Sale-to-Bonett-Group-for-Unipetrol/default.aspx
168 https://www.reuters.com/article/us-tokyo-gas-hydrogen/tokyo-gas-opens-new-hydrogen-station-ahead-of-olympics-in-clean-energy-drive-idUSKBN1ZF0Z9
169 https://www.hyundainews.com/en-us/releases/3042
170 https://mcphy.com/en/press-releases/projects-in-zero-emission-mobility/
171 https://mcphy.com/en/press-releases/new-contract-high-capacity-hrs-ely/
172 https://www.tenaris.com/en/newsroom/news-listing/tenaris-partners-with-nel-hydrogen--09215746620
173 https://www.bayotech.us/news/bayotech-partners-with-enefiin
174 https://www.bayotech.us/news/strongbayotech-selects-h2-zest-to-lead-push-into-indian-hydrogen-energy-marketstrong
175 https://www.bayotech.us/news/bayotech-selects-hydrogen-to-go-to-lead-push-into-australia
176 https://www.bayotech.us/news/bayotech-partners-with-intralink-japan
177 https://www.bayotech.us/news/bayotech-partners-with-la-puerta-colombia
178 https://www.bayotech.us/news/bayotech-and-new-mexico-gas-company-announce-collaborative-agreement

179 https://www.bayotech.us/news/bayotech-and-igas-team-up-for-hydrogen-development
180 https://www.bayotech.us/news/strongbayotech-and-cross-river-infrastructure-partners-announce-hydrogen-gas-as-a-servicestrong
181 https://www.bayotech.us/news/bayotech-and-dll-establish-revolutionary-hydrogen-generator-leasing-program
182 https://www.bayotech.us/news/bayotech-announces-performance-guarantee
183 https://www.bayotech.us/news/bayotech-announces-deal-with-nutrien
184 https://www.bayotech.us/news/hyzon-motors-signs-agreement-with-bayotech
185 https://www.energy.gov/sites/default/files/2021/02/f82/hydrogen-electrolyzer-locations.pdf
186 https://www.iea.org/reports/world-energy-investment-2020/rd-and-technology-innovation
187 https://www.cummins.com/news/releases/2020/08/26/cummins-using-hydrogen-technology-enable-renewable-energy-public-utilities
188 https://www.itm-power.com/news/funding-award-to-supply-an-8mw-electrolyser
189 https://www.itm-power.com/news/first-project-to-deliver-a-10mw-electrolyser-to-glasgow-facility
190 https://mcphy.com/en/press-releases/new-contrat-hydrogen-mobility/
191 https://mcphy.com/en/press-releases/2-mw-of-electrolysis-in-germany/
192 https://news.cision.com/nel-asa/r/nel-asa--receives-purchase-order-for-a-1-25-mw-containerized-pem-electrolyser-from-nrel,c3221495
193 https://news.cision.com/nel-asa/r/nel-asa--received-purchase-order-for-a-1-mw-containerized-pem-electrolyzer-in-the-us,c3047594
194 https://nelhydrogen.com/press-release/nel-asa-received-purchase-order-for-a-1-5-mw-pem-electrolyser-in-the-us/
195 https://nelhydrogen.com/press-release/nel-asa-receives-purchase-order-from-nikola-2/
196 https://nelhydrogen.com/press-release/nel-asa-receives-purchase-orders-for-u-s-navy-pem-electrolyser-stacks/
197 https://news.cision.com/nel-asa/r/nel-asa--enters-into-framework-agreement-for-delivery-of-electrolysers-in-france,c3093166
198 https://news.cision.com/nel-asa/r/nel-signs-loi-with-statkraft-for-a-green-hydrogen-project-with-up-to-50mw-of-electrolyser-capacity,c3228323
199 https://news.cision.com/nel-asa/r/nel-asa--enters-into-mou-with-iberdrola-to-develop-large-scale-green-hydrogen-project-and-the-hydrog,c3239785
200 https://nelhydrogen.com/press-release/nel-asa-receives-purchase-order-for-a-2-5-mw-pem-electrolyser-in-europe/
201 https://press.siemens-energy.com/global/en/pressrelease/siemens-energy-launches-its-first-megawatt-green-hydrogen-production-project-china
202 https://www.airproducts.com/company/news-center/2020/03/0330-air-products-to-acquire-hydrogen-plants-and-provide-long-term-supply-to-pbf-energy
203 https://energy.utah.gov/2020/08/12/green-hydrogen-project-underway/
204 https://www.newswire.ca/news-releases/enbridge-gas-announces-a-5-2m-hydrogen-blending-pilot-project-to-further-explore-greening-of-the-natural-gas-grid-849137548.html
205 https://www.shell.nl/media/nieuwsberichten/2020/wind-als-energiebron-voor-groene-waterstoffabriek-in-rotterdam.html
206 http://www.glomfjordhydrogen.no/ac/pressemelding
207 https://www.engineering-airliquide.com/air-liquide-supports-development-liquid-hydrogen-plant-south-korea
208 https://www.globenewswire.com/news-release/2020/04/03/2011302/0/en/Hexagon-Purus-receives-order-for-hydrogen-distribution-systems-from-Everfuel.html#.XocBkFtHsI8.twitter
209 https://hexagongroup.com/news-release/?newsid=2031610
210 https://hexagongroup.com/news-release/?newsid=2042651
211 https://www.globenewswire.com/news-release/2020/11/06/2121714/0/en/Hexagon-Purus-to-supply-composite-high-pressure-cylinders-for-the-development-of-the-first-hydrogen-powered-commuter-train-in-the-U-S.html
212 https://e2.org/reports/clean-jobs-america-2021/
213 https://www.powermag.com/wp-content/uploads/2021/04/e2-2021-clean-jobs-america-report-04-19-2021.pdf
214 www.iphe.net
215 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/14/ballard-launches-industry-leading-high-power-density-fuel-cell-stack-for-vehicle-propulsion
216 https://www.nuvera.com/blog/nuvera-expands-product-line-with-launch-of-e60-fuel-cell-engine
217 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Launches-Heavy-Duty-ProGen-Hydrogen-Engine-for-On-Road-Applications/default.aspx

218 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-and-Gaussin-Collaborate-on-Hydrogen-Powered-Transportation-Vehicles/default.aspx
219 https://cafcp.org/sites/default/files/FCEV-Sales-Tracking.pdf
[220] https://cafcp.org/sites/default/files/FCEV-Sales-Tracking.pdf
221 https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-nexo-takes-bts-to-grammy-awards--0000016395?selectedVal=&selection=&pageNo=17&searchKey=&rowCount=9&type=RES&type=IMG&listPageUrl=release.all
222 https://www.hyundai.com/kr/ko/company-intro/ir-information/sales/sales-record
223 https://www.press.bmwgroup.com/global/article/detail/T0306930EN/the-powertrain-for-the-bmw-i-hydrogen-next
224 https://global.toyota/en/newsroom/toyota/33558148.html
225 Two Air Liquide initiatives awarded by ADEME as part of a call for proposals | Air Liquide Energies
226 https://mag.toyota.co.uk/toyota-mirai-helps-zeroavia-fly-high-on-hydrogen/
227 https://publications.anl.gov/anlpubs/2021/08/166534.pdf
228 https://hyzonmotors.com/100000-hydrogen-trucks-on-the-road-by-2030/
229 Two Air Liquide initiatives awarded by ADEME as part of a call for proposals | Air Liquide Energies
230 https://www.cummins.com/news/2020/04/29/norways-largest-grocery-wholesaler-gives-hydrogen-spin
231 https://hydrogeneurope.eu/sites/default/files/Press%20release%20Demo%20H2Share_ENG.pdf
232 https://h2revive.eu/wp-content/uploads/sites/1/2020/10/REVIVE-Press-Release-1_DEF.pdf
233 https://www.reuters.com/article/us-honda-fuelcell/honda-isuzu-power-up-fuel-cell-partnership-for-heavy-duty-trucks-idUSKBN1ZE0UB
234 https://investor.gm.com/news-releases/news-release-details/nikola-and-general-motors-form-strategic-partnership-nikola
235 https://www.hyundai.com/worldwide/en/company/newsroom/world%E2%80%99s-first-fuel-cell-heavy-duty-truck%2C-hyundai-xcient-fuel-cell%2C-heads-to-europe-for-commercial-use-0000016484?selectedVal=&selection=&pageNo=11&searchKey=&rowCount=9&type=RES&type=IMG&listPageUrl=release.all
236 https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-motor%E2%80%99s-delivery-of-xcient-fuel-cell-trucks-in-europe-heralds-its-commercial-truck-expansion-to-global-markets-0000016544?selectedVal=&selection=&pageNo=7&searchKey=&rowCount=9&type=RES&type=IMG&listPageUrl=release.all
237 https://www.hyundainews.com/en-us/releases/3168
238 https://pressroom.toyota.com/first-heavy-duty-fuel-cell-electric-trucks-set-for-delivery-to-pilot-program-customers-at-ports-of-l-a-and-long-beach/
239 https://www.nuvera.com/blog/nuvera-to-supply-fuel-cells-for-electric-terminal-tractors
240 https://3emotion.eu/news/first-fuel-cell-buses-operation-denmark
241 https://3emotion.eu/news/new-milestone-project-4-vdl-fuel-cell-buses-road-province-south-holland
242 https://hydrogeneurope.eu/news/jive-projects-celebrate-milestone-over-200-fuel-cell-buses-have-been-ordered
243 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/03/12/ballard-announces-order-from-solaris-for-25-fuel-cell-modules-to-power-buses-in-germany
244 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/04/28/ballard-announces-follow-on-order-from-solaris-for-20-fuel-cell-modules-to-power-buses-in-the-netherlands
245 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/06/18/ballard-receives-follow-on-orders-for-15-fuel-cell-modules-from-wrightbus-to-power-u.k.-buses
246 https://hyzonmotors.com/fortescue-to-roll-out-hydrogen-powered-buses-at-christmas-creek/
247 https://www.fch.europa.eu/news/major-fch-ju-funded-project-will-install-world%E2%80%99s-first-ammonia-powered-fuel-cell-vessel
248 https://news.cision.com/powercell-sweden-ab/r/powercell-delivers-fuel-cell-system-to-the-italian-ship-building-company-fincantieri-s-p-a,c3031391
249 https://www.powercell.se/en/newsroom/press-releases/detail/?releaseId=B21EF8BDA18ED4C8
250 https://www.bloomenergy.com/newsroom/press-releases/samsung-heavy-industries-and-bloom-energy-advance-plans-clean-power-ships
251 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=73&page=0&
252 https://www.maritime-executive.com/article/nyk-leads-project-to-develop-hydrogen-powered-ferry
253 https://www.sfc.com/en/follow-up-order-for-efoy-fuel-cells-for-aurorahuts-houseboat-igloos/

254 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Partners-with-Universal-Hydrogen-on-Hydrogen-Fuel-Cell-Propulsion-System-for-Regional-Turboprop-Aircraft/default.aspx
255 https://www.zeroavia.com/press-release-25-09-2020
256 https://www.zeroavia.com/press-release-23-06-2020
257 https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html
258 https://www.alstom.com/press-releases-news/2020/3/alstoms-hydrogen-train-coradia-ilint-completes-successful-tests
259 https://www.alstom.com/press-releases-news/2020/9/alstoms-hydrogen-train-enters-regular-passenger-service-austria
260 https://www.alstom.com/press-releases-news/2020/12/alstoms-hydrogen-train-successfully-completes-three-months-testing
261 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Partners-with-Lightning-Systems-to-Build-Zero-Emission-Middle-Mile-Delivery-Solution/default.aspx
262 https://www.powercell.se/en/newsroom/press-releases/detail/?releaseId=088C68196AE3480F
263 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Expands-Hydrogen-and-Fuel-Cell-Solutions-into-Walmart-eCommerce-Applications/default.aspx
264 https://www.prnewswire.com/news-releases/hyundai-mobis-succeeds-in-jointly-developing-a-hydrogen-fuel-cell-forklift-301139554.html
265 www.iphe.net
266 https://www.bloomenergy.com/sites/default/files/2020-bloom-energy-sustainability-report.pdf
267 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-announces-initial-strategy-hydrogen-market-entry
268 https://news.microsoft.com/innovation-stories/hydrogen-datacenters/
269 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=66&page=0&
270 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=56&page=0&
271 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=58&page=0&
272 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=64&page=0&
273 https://www.hyundai.com/worldwide/en/company/newsroom/charged-up-hyundai-motor-advances-hydrogen-strategy-with-export-of-fuel-cell-systems-to-europe-0000016522?selectedVal=&selection=&pageNo=9&searchKey=&rowCount=9&type=RES&type=IMG&listPageUrl=release.all
274 https://www.kehe.com/news-releases/stockton-ca-emissions-reduced-with-kehe-distributors-and-bloom-energy/
275 https://www.bloomenergy.com/newsroom/press-releases/socalgas-now-powering-two-los-angeles-facilities-bloom-energy-alwayson
276 https://www.bloomenergy.com/newsroom/press-releases/stop-shop-convert-40-stores-bloom-energy-alwayson-microgrids-better-serve
277 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-and-sk-ec-win-competitive-bid
278 https://www.bloomenergy.com/newsroom/press-releases/bloom-energy-and-sk-ec-announce-28-megawatt-deployment-fuel-cell-technology
279 https://www.bloomenergy.com/newsroom/press-releases/kraft-group-scores-touchdown-sustainability-with-bloom-energy-servers
280 https://www.panynj.gov/port-authority/en/press-room/press-release-archives/2020-press-releases/port-authority-to-install-first-indoor-all-electric-fuel-cell-te.html
281 https://www.theday.com/article/20200415/NWS01/200419669
282 https://www.doosanfuelcell.com/en/media-center/medi-0101_view/?id=62&page=0&
283 https://investor.fce.com/press-releases/press-release-details/2020/Triangle-Street-Project-Begins-Commercial-Operation-SureSource-4000-High-Efficiency-Fuel-Cell/default.aspx
284 https://www.powercell.se/en/investors/press-releases/detail/?releaseId=420723ECDA861A80
285 https://www.altergy.com/news/sustained-operations-through-wildfires/
286 https://www.ballard.com/about-ballard/newsroom/news-releases/2020/01/14/ballard-signs-esas-for-fuel-cell-stacks-to-support-backup-power-systems-at-german-radio-towers
287 https://www.gencellenergy.com/news/gencell-energy-supplies-resilient-all-weather-power-to-delta-land-developments-fully-zero-emissions-hyper-high-performance-sustainable-off-grid-hybrid-power-demonstration-project/?utm_source=Website&utm_medium=Organic&utm_content=Delta_PR_BP&utm_campaign=Blog

288 https://www.gencellenergy.com/news/gencell-energy-selected-to-supply-resilient-long-duration-backup-power-to-cfe-mexico-in-a-deal-valued-at-us6000000/?utm_source=Website&utm_medium=Organic&utm_content=CFE_BP&utm_campaign=Blog
289 https://www.intelligent-energy.com/news-and-events/company-news/2020/06/04/intelligent-energy-fuel-cells-selected-for-two-microgrid-projects-to-providing-off-grid-power-in-malaysia/
290 https://www.sfc.com/en/sfc-energy-unifies-its-brand-identity/
291 https://www.sfc.com/en/sfc-energy-delivers-efoy-procube-fuel-cell-solution-as-back-up-power-supply-to-bos-radio-stations-in-meissen/
292 https://www.sfc.com/en/sfc-energy-receives-call-off-order-for-hydrogen-fuel-cells-in-the-amount-of-more-than-eur-2-5-million-broad-support-program-boosts-the-process-of-replacing-diesel-generators/
293 https://www.sfc.com/en/sfc-energy-receives-order-for-efoy-pro-fuel-cell-systems-from-a-chinese-wind-industry-company/
294 https://www.sfc.com/en/1-000th-efoy-pro-fuel-cell-deployed-in-singapore-to-support-public-safety-and-health/
295 https://www.sfc.com/en/sfc-energy-simark-controls-receives-efoy-pro-fuel-cell-order-from-sitewatch-safety-to-power-remote-video-surveillance-equipment-on-major-pipeline-construction-project/
296 https://www.sfc.com/en/sfc-energy-simark-controls-receives-order-from-canadian-gas-production-company-for-efoy-pro-fuel-cells-to-power-scada-system/
297 https://www.sfc.com/en/sfc-energy-simark-controls-receives-order-for-fuel-cells-from-major-communications-company-for-turnkey-efoy-protrailer-hybrid-power-solutions-to-provide-clean-power-for-a-mobile-mine-site-communicati/
298 https://www.militaryfactory.com/dictionary/military-terms-defined.asp?term_id=5656
299 https://www.ir.plugpower.com/Press-Releases/Press-Release-Details/2020/Plug-Power-Develops-1kW-ProGen-Fuel-Cell-System-for-Robotics-and-Drone-Applications/default.aspx
300 https://www.doosanmobility.com/en/about-us/news-events/view/?seq=20173306
301 https://www.doosanmobility.com/en/about-us/newsevents/view/?seq=21000012
302 https://www.doosanmobility.com/en/about-us/news-events/view/?seq=20173297
303 https://www.doosanmobility.com/en/about-us/news-events/view/?seq=21000011
304 https://www.doosanmobility.com/en/about-us/news-events/view/?seq=21000141
305 https://www.doosanmobility.com/en/about-us/news-events/view/?seq=20173307
306 https://www.intelligent-energy.com/news-and-events/company-news/2020/04/16/intelligent-energy-agrees-distributer-agreement-with-japanese-customer-and-drone-specialist-robodex/
307 https://arpa-e.energy.gov/news-and-media/press-releases/department-energy-announces-33-million-funding-carbon-neutral-hybrid

Chemical Sciences and Engineering Division
Argonne National Laboratory
9700 South Cass Avenue, Bldg. 241
Lemont, IL 60439

www.anl.gov

Argonne National Laboratory is a U.S. Department of Energy
laboratory managed by UChicago Argonne, LLC