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Hydrogen Fuel Cells

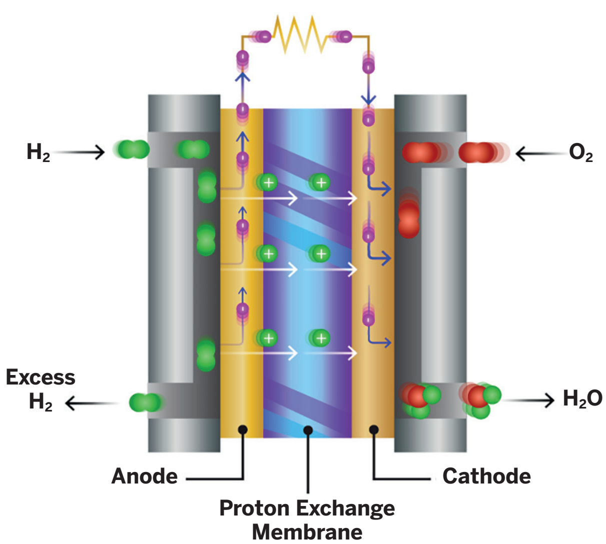
ANSWERS TO FOUR COMMON QUESTIONS

What are fuel cells?

Fuel cells work much like batteries, using electrochemical reactions to generate electricity. They do not need to be recharged like batteries, but they do need a fuel source to produce electricity. A fuel cell consists of a negative and positive electrode wrapped around an electrolyte. A fuel (such as hydrogen, natural gas, or ammonia) is supplied to the positive electrode, and air is supplied to the negative electrode. A catalyst separates the fuel into protons and electrons, and the electrons go through an external circuit, thus creating a flow of electricity.[1]

Figure 1

A PEM Hydrogen Fuel Cell



Source: *Nanomaterial Chemistry and Technology*, (2021)

While there are several types of hydrogen fuel cells, the most common type is **the polymer electrolyte membrane (PEM) fuel cell** (see Figure 1). PEM fuel cells need only hydrogen, oxygen from the air, and water to operate. They are typically fueled with pure hydrogen supplied from storage tanks.[2]

Fuel cells usually do not *produce* hydrogen, even though they run on hydrogen fuel. An electrolyzer is needed to produce hydrogen from water; it uses an electric current to split water molecules into oxygen and hydrogen. Like a fuel cell, an electrolyzer also consists of an anode and a cathode separated by an electrolyte (see Figure 2, p. 2). **Flexible fuel cells** are the only hydrogen fuel cells that can be run in reverse as an electrolyzer, thus generating hydrogen that can be stored and then run through the fuel cell to generate electricity.

What are common uses of fuel cells?

Fuel cells have been used for many years for both transportation applications as well as to generate electricity for buildings.

Light Use Vehicles: Though several auto manufacturers produce hydrogen fuel cell vehicles for personal use, these vehicles are primarily offered in markets where hydrogen fueling stations already exist, such as in California and Hawaii.[3] Without the buildout of additional hydrogen fueling infrastructure, it is unlikely that personal hydrogen fuel cell vehicles will be competitive with battery-powered electric vehicles nationally any time soon.

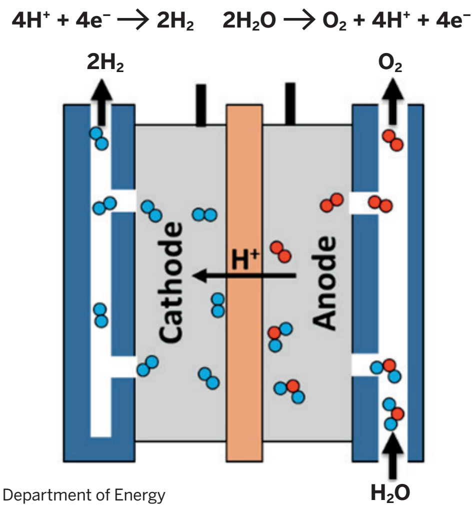
1 U.S. Dept. of Energy, "Fuel Cells," *Energy.gov*, https://www.energy.gov/eere/fuelcells/fuel-cells (accessed September 1, 2021).

2 U.S. Dept. of Energy, "Types of Fuel Cells," *Energy.gov*, https://www.energy.gov/eere/fuelcells/types-fuel-cells (accessed September 27, 2022),

3 U.S. EPA, "Hydrogen Fuel Cell Vehicles," *epa.gov*, last updated September 13, 2022, https://www.epa.gov/greenvehicles/hydrogen-fuel-cell-vehicles (accessed September 27, 2022).

Figure 2

How an Electrolyzer Works to Produce Hydrogen



Source: U.S Department of Energy

- **Heavy Use Vehicles:** The energy density of hydrogen makes hydrogen fuel cells a good option for decarbonizing heavy-duty vehicles such as trucks, buses, and forklifts. The refueling time and driving range of a hydrogen fuel cell heavy-duty vehicle is comparable to that of a gasoline powered truck, and these vehicles often have predictable routes, making it easier to concentrate the buildout of hydrogen fueling stations.[4]
- **Shipping:** Using hydrogen or ammonia fuel cells for shipping is still relatively new, but early studies show that this is a promising concept for decarbonizing long-distance shipping routes. Recent studies show that 99 percent of container ship voyages in the corridor between China and the United States—the busiest shipping corridor in the world—could be powered by hydrogen fuel cells with only minor changes to fuel capacity or operations, such as adding one additional port of call to refuel.[5]
- **Short-Haul Air Travel:** Hydrogen's energy density also makes it a good option for decarbonizing short-haul air travel. A large hydrogen fuel cell stack can power propulsion and on-board operations for most regional flights. Aircraft manufacturer Airbus has stated that research and development is underway to produce a fully decarbonized aircraft for longer duration travel by 2035.[6] It should be noted that some hydrogen-powered aircraft combust hydrogen for propulsion, which is not emissions-free. Hydrogen is only emissions-free when run through a fuel cell.
- **Microgrids:** Hydrogen's ability to be generated and stored on-site can make it a valuable addition to a microgrid for energy users who cannot risk an interruption in power. One such example is a public housing complex in Vårgårda, Sweden, which installed 5,400 square feet of solar PV. The electricity generated by the solar is first used to fill a battery, and then the remainder is run through an electrolyzer to generate green hydrogen. This hydrogen is then stored onsite to fuel six 5-kilowatt fuel cells, one in each building of the complex, in the event the battery runs out of electricity. This hybrid model, using both battery storage and fuel cells, can reduce the costs and improve the efficiency of developing a fuel cell microgrid.

What are the drawbacks to hydrogen fuel cells?

Capacity

The amount of power produced by a fuel cell depends on several factors, including fuel cell type, cell size, temperature at which it operates, and pressure at which the gases are supplied to the cell. A single fuel cell produces less than 1.16 volts—barely enough electricity for even the smallest applications.[7] To increase the amount of electricity generated, individual fuel cells are combined in series into a fuel cell "stack." A typical fuel cell stack may consist of hundreds of fuel cells.

Cost

The costs associated with using a fuel cell can quickly escalate depending on its use. A stationary hydrogen fuel cell system requires several components to be incorporated beyond the fuel cell itself, to guarantee power production. These components include storage containers and/or pipeline infrastructure to receive and transport hydrogen fuel.

4 Eberle, Ulrich and Rittmar von Helmolt, "Sustainable Transportation Based on Electric Vehicle Concepts: A Brief Overview," *Energy & Environmental Science,* Issue 6, (2010): 689, https://doi.org/10.1039/C001674H (accessed September 27, 2022).

5 Mao, Xiaoli, Dan Rutherford, Liudmila Osipova, and Brian Comer, "Refueling Assessment of a Zero-Emission Container Corridor between China and the United States: Could Hydrogen Replace Fossil Fuels?" *TheICCT.org,* March 3, 2020, https://theicct.org/publication/refueling-assessment-of-a-zero-emission-container-corridor-between-china-and-the-united-states-could-hydrogen-replace-fossil-fuels (accessed September 27, 2022).

6 Airbus, "The Green Hydrogen Ecosystem for Aviation, Explained," *Airbus.com*, June 17, 2021, https://www.airbus.com/en/newsroom/news/2021-06-the-green-hydrogen-ecosystem-for-aviation-explained (accessed September 27, 2022).

7 U.S. Dept. of Energy, "Fuel Cell Animation (Text Version)," *Energy.gov,* https://www.energy.gov/eere/fuelcells/fuel-cell-animation-text-version (accessed August 25, 2022).

If green hydrogen is being generated onsite, additional components would be needed; these would include a renewable energy source, such as solar panels, as well as electrolyzers to generate hydrogen, unless flexible fuel cells can be used. Flexible fuel cells are becoming more common and scaling this technology could bring down the costs of using fuel cells for applications such as microgrids providing backup power.

A fuel cell may be more cost effective in transportation rather than for power generation, as a smaller "stack" is needed to power a vehicle. Fuel cell vehicles need access to hydrogen fueling stations, rather than requiring onsite storage of hydrogen fuel, such as at a home or business facility, where hydrogen storage could raise serious safety concerns.[8]

Low Efficiency

Because of the multiple steps involved in using a fuel cell to generate electricity, they are much less efficient than batteries. With a hydrogen fuel cell, efficiency loss occurs on multiple levels: the electrolysis process to generate green hydrogen fuel, the costs for transport and storage of the hydrogen, the AC/DC current inversion losses, and the hydrogen to electricity conversion losses. When accounting for these losses, the lifecycle efficiency of a hydrogen fuel cell is 33 percent.[9] A battery's lifecycle efficiency is about 86 percent.

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For more information about hydrogen use in the power sector, visit Clean Energy Group's website at www.cleanegroup.org/ceg-projects/hydrogen.

What are potential benefits of hydrogen fuel cells?

Resilience

Despite the drawbacks of fuel cells, they can still be a valuable tool for resiliency for energy-intensive facilities. A fuel cell can provide continuous power if fuel is available. This can make them a suitable backup source for large energy users such as hospitals and data centers, which cannot risk an interruption in power. Hydrogen is an energy dense fuel and can be stored onsite until it is needed, or generated onsite using renewable energy technology such as solar.

No Combustion and Reduced Emissions Potential

When hydrogen is run through a fuel cell, combustion does not occur and the only by-product is water, making fuel cells a cleaner use for hydrogen fuel. When hydrogen is combusted alone or with natural gas, such as in a power plant or for home heating, it produces air pollutants that are harmful to public health.[10] It should be noted that if the hydrogen that is used in a fuel cell is generated from natural gas, currently the most common form of hydrogen production, there are still significant emissions impacts upstream. This is due to the increase in methane emissions associated with transporting and storing natural gas, activities that often result in unintended leaks of methane, which is a potent and harmful greenhouse gas.[11] Hydrogen produced via electrolysis powered by renewable energy does not have as many emissions concerns, although there is a growing body of research examining the global warming impacts of hydrogen that is released into the atmosphere.[12]

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8 ARUP Department for Business, Energy & Industrial Strategy, "Hy4Heat Safety Assessment Conclusions Report," *static1.squarespace.com*, May 2021, https://static1.squarespace.com/static/5b8eae345cfd799896a803f4/t/60e399b094b0d322fb0dadc4/1625528759977/conclusions+inc+QRA.pdf%20 (accessed September 27, 2022).

9 Tsakiris, Aristeidis, "Analysis of Hydrogen Fuel Cell and Battery Efficiency," *c2e2.unepccc.org*, March 2019, p. 8, https://c2e2.unepccc.org/wp-content/uploads/sites/3/2019/09/analysis-of-hydrogen-fuel-cell-and-battery.pdf (accessed September 27, 2022).

10 Cellek, Mehmet Salih and Ali Pınarbaşı, "Investigations on Performance and Emission Characteristics of an Industrial Low Swirl Burner While Burning Natural Gas, Methane, Hydrogen-Enriched Natural Gas and Hydrogen as Fuels," *International Journal of Hydrogen Energy*. 43, no. 2 (January 11, 2018): 1194–1207, *sciencedirect.com*, https://doi.org/10.1016/j.ijhydene.2017.05.107 (accessed September 27, 2022).

11 Howarth, Robert W, "A Bridge to Nowhere: Methane Emissions and the Greenhouse Gas Footprint of Natural Gas," *Energy Science & Engineering* 2, no. 2 (June 1, 2014): 47–60, *onlinelibrary.wiley.com*, https://doi.org/10.1002/ese3.35 (accessed September 27, 2022).

12 Ocko, Ilissa B., and Steven P. Hamburg, "Climate Consequences of Hydrogen Emissions," *Atmospheric Chemistry and Physics* 22, no. 14 (July 20, 2022): 9349–68, *Acp.copernicus.org*, https://doi.org/10.5194/acp-22-9349-2022 (accessed September 27, 2022).