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FACT SHEET

Fulfilling the Potential of Fuel Cell Electric Vehicles

The Impact of Hydrogen Production Methods on Global Warming Emissions

HIGHLIGHTS

Fuel cell electric vehicles (FCEVs) powered by hydrogen have zero tailpipe emissions, like a plug-in electric vehicle, but they can also be refueled quickly, like a conventional gasoline-powered car. And because the hydrogen fuel itself can be produced using methods that have low environmental impacts and low or no petroleum use, FCEVs represent a transportation solution that can reduce both oil use and harmful emissions. The current method of producing hydrogen from natural gas results in vehicles that emit less global warming pollution than most current gasoline vehicles, but future advances in hydrogen production technology and increased use of renewable electricity will enable FCEVs to reduce these emissions even further.

Fuel cell electric vehicles (FCEVs) are starting to become available in the United States. These hydrogen-powered vehicles have zero tailpipe emissions, like a plug-in electric vehicle, but they can also be refueled quickly, like a conventional gasoline-powered car. While a plug-in vehicle simply stores electricity in a battery, a fuel cell actually *generates* electricity by converting hydrogen and oxygen to water. And like electricity, hydrogen fuel can be produced using methods that have low environmental impacts and low or no petroleum use, giving FCEVs the potential to become a transportation solution that reduces both oil use and harmful emissions.

Hydrogen is abundant—it exists in water, organic material, fossil fuels, and many other compounds. However, because it is rarely found in nature in the gaseous form needed to power FCEVs, hydrogen must be separated from its source material and purified. The hydrogen gas also needs to be pressurized, delivered to a refueling station, and dispensed into a tank onboard the vehicle. As an FCEV uses this hydrogen, it emits only water vapor from its tailpipe. However, the ways in which the hydrogen is sourced, produced, purified, and distributed all affect the total global warming emissions generated by an FCEV.

The current method of producing hydrogen from natural gas results in vehicles that emit less global warming pollution than most current gasoline vehicles, but future advances in hydrogen production technology and increased use of renewable electricity will enable FCEVs to reduce these emissions even further (UCS 2014).

Image courtesy of Air Products and Chemicals, Inc.

This fuel cell electric vehicle is being refueled with hydrogen produced from a sewage treatment facility. Biological sources of hydrogen result in much lower net global warming emissions than hydrogen produced from natural gas.

Hydrogen Production

HYDROGEN FROM METHANE

Steam methane reforming (SMR). This is the most common industrial method for hydrogen production due to low cost and ease of large-scale production (EERE n.d.). SMR causes methane (the principal component of natural gas) to react with steam, producing carbon monoxide and hydrogen. The carbon monoxide can then undergo further reaction with steam, producing more hydrogen and carbon dioxide—the gas primarily responsible for climate change. Thus, this method of hydrogen production does result in global warming emissions.

Even when an FCEV is fueled by hydrogen produced from natural gas, its emissions are often lower than a conventional gasoline vehicle due to the higher efficiency of the fuel cell electric system. But when SMR is paired with biological sources of methane (such as biogas from landfills, animal waste, or wastewater treatment facilities) instead of natural gas, it produces hydrogen with much lower net global warming emissions.

HYDROGEN FROM WATER

Electrolysis. Electrolysis uses electricity to split water molecules into the gaseous forms of hydrogen and oxygen. No global warming emissions are produced in this process, though the total emissions depend on the source of the electricity. Combining this process with renewable electricity (generated by solar or wind power), therefore, can produce hydrogen with very little global warming emissions. The technology used for electrolysis can operate intermittently, making this method feasible for smaller-volume applications, and can be paired with intermittent electricity sources like the sun and wind (NREL 2014).

Photochemical production. Hydrogen can be made from sunlight by using photovoltaic solar panels to generate electricity and then using that electricity to perform electrolysis. It is also possible to split water molecules with light directly (a process sometimes called artificial photosynthesis), which would be more efficient than the two-step process involving solar panels and electrolysis (Marshall 2014), but more research is needed to develop the materials that would make artificial photosynthesis commercially viable.

Thermochemical production. High-temperature (850°C to over 1,800°C) chemical reactions are another option for splitting water molecules (Perret 2011). Concentrated solar power has been used to demonstrate that this technology can create hydrogen with low emissions (Van Noorden 2008). However, the currently low efficiency of this process and high cost of solar concentration and reactor equipment are barriers to commercial hydrogen production at the present time.

Biophotolysis. Some green algae can produce hydrogen gas using energy from sunlight. This process has attractive commercial potential, but the amount of hydrogen that can be produced is currently low compared to the energy needed to drive the process. Improving the hydrogen yield is an active area of research (Volgusheva, Styring, and Mamedov 2013).

HYDROGEN FROM BIOLOGICAL MATERIALS

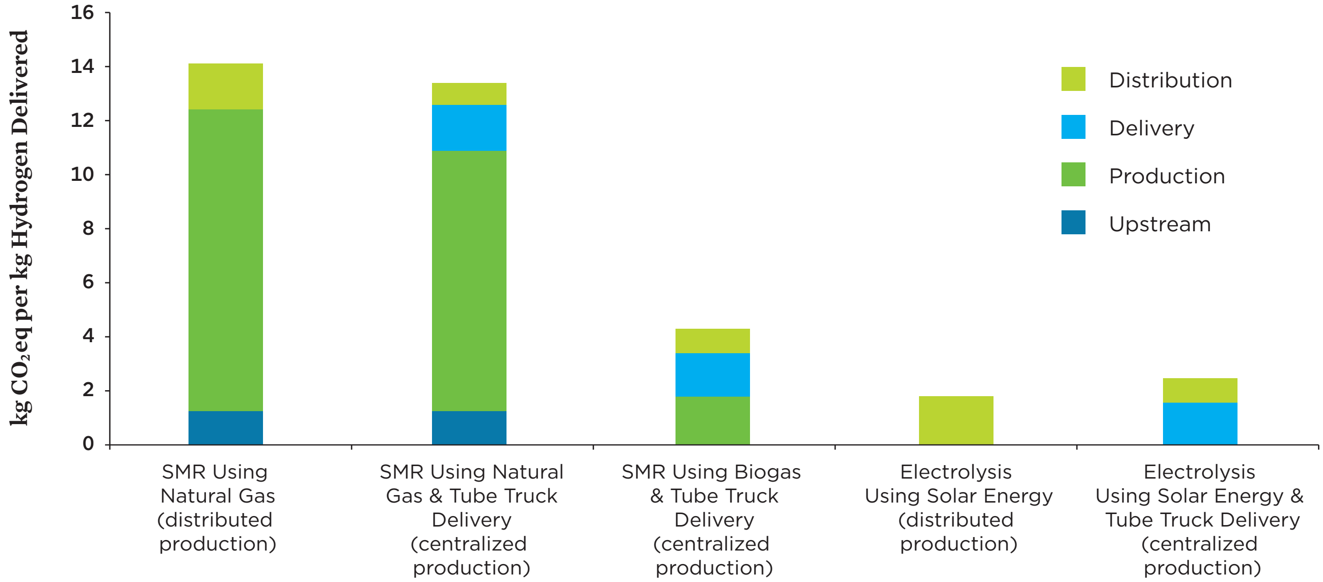
Biomass gasification. Biomass (plant material) can be heated under conditions in a gasifier that ultimately produces hydrogen and carbon dioxide. Because the carbon dioxide from biomass originated in Earth's atmosphere (entering the plants via the natural process of photosynthesis), the net impact on global warming emissions can be low. Because of the

Current and Potential Hydrogen Production Pathways

	Steam Methane Reforming	Electrolysis	Biomass Gasification	Biological	Photochemical	Thermochemical
Commercial Availability	Most common	Specialty applications	R&D stage	R&D stage	R&D stage	R&D stage
Feedstock/ Energy Source	Natural gas or biogas	Electricity	Biomass	Solar energy and/or organic wastes	Solar energy	Solar or nuclear energy
Production and Distribution Model	Centralized or distributed	Centralized or distributed	Centralized	Centralized	Centralized	Centralized

There are a number of ways in which hydrogen can be produced for use in fuel cell electric vehicles, though several require further research before they will be considered commercially viable. Those that hold the most promise for reducing global warming emissions will use a renewable feedstock such as solar energy or biomass.

Global Warming Emissions from Different Hydrogen Production Pathways



When hydrogen gas for use in fuel cell electric vehicles is produced from a renewable resource such as solar energy or biogas, it will result in much less global warming pollution than hydrogen produced from natural gas (a fossil fuel)—even if the hydrogen must be trucked to refueling stations. The best option would be distributed (or local) production powered by renewable energy, which eliminates the need for trucking.

Note: This analysis calculated "well-to-wheel" emissions—the total emissions generated during fuel production, distribution, and use—with the aid of the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) 2013 model. For electricity emissions related to hydrogen compression, our calculations used the California average.

equipment required for gasification and the logistics of handling large volumes of biomass, hydrogen production would likely occur at a centralized facility.

Fermentation. Certain types of bacteria are known to produce hydrogen gas. This type of hydrogen production can require either chemical energy (a process called dark fermentation) or light (a process called photofermentation). Dark fermentation can use wastewater with organic material such as dairy whey or winery wastes as a feedstock; photofermentation often involves organic acids in addition to light. However, neither fermentation method currently provides cost-effective hydrogen production (Hallenbeck, Abo-Hashesh, and Ghosh 2012). Researchers are attempting to improve microbial hydrogen production to the point where it becomes commercially viable.

Hydrogen Delivery and Distribution

Hydrogen not only needs to be produced, but also delivered and made available to drivers. Distribution depends on the manner of hydrogen production:

- **Centralized production.** Some processes, like SMR, are more efficient at larger scales, in which case it is most economical to produce the hydrogen at a central facility and then distribute it to local refueling stations. The hydrogen can be trucked as a gas in high-pressure cylinders on so-called tube trucks, which is the current method of distribution for many stations in California. Larger quantities of hydrogen can be liquefied and trucked in special liquid hydrogen trailers. Liquefaction requires more energy than compressing hydrogen gas, but increases the amount of hydrogen a single truck can deliver. It is also possible to build distribution pipelines for hydrogen similar to current natural gas pipelines, which could lower delivery-related costs and emissions.
- **Distributed production.** Hydrogen can also be produced at the refueling station, either by SMR or electrolysis. In general, this approach is less efficient and/or more costly than centralized production, but distributed production eliminates the need for trucking and pipelines.

Finally, once the hydrogen is at the refueling station, it needs to be available at high pressure (5,000 to 10,000 psi) for the rapid refueling of vehicles. Dispensing pumps with the onsite compression (powered by electricity) that is usually required to provide such high pressure can completely refuel an FCEV in 3 to 10 minutes.

Image courtesy of Air Products and Chemicals, Inc.

The hydrogen gas that powers fuel cell electric vehicles is often transported from a central production facility to refueling stations in high-pressure tube trucks like this. Centralized hydrogen production is generally more cost-effective than distributed (or local) production.

The Future of Hydrogen Production and Distribution

The most common method of producing hydrogen is currently SMR using natural gas as a feedstock, and the most common method of distributing hydrogen to existing refueling stations is currently truck delivery. However, under California's renewable hydrogen standard, at least one-third of the hydrogen used for vehicles must come from renewable sources rather than a fossil fuel like natural gas—and the state estimates that 46 percent of its hydrogen will come from renewable sources by the end of 2015 (CARB 2014). To accomplish this, California has facilities that are producing hydrogen by way of solar-powered electrolysis and SMR using biogas from a wastewater treatment plant. A fuel cell-powered sport utility vehicle can lower global warming emissions 34 percent compared with the gasoline-powered model when using hydrogen produced from natural gas, and more than 50 percent when using hydrogen that meets California's renewable hydrogen standard (UCS 2014).

With appropriate fuel policies like those already enacted in California, more hydrogen can be produced from low-emissions sources, bringing FCEVs closer to becoming both a clean and economically viable transportation option.

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