

# How Clean Are Hydrogen Fuel Cell Electric Vehicles?

*New hydrogen-powered cars produce substantially less global warming emissions than their gasoline counterparts.*

## HIGHLIGHTS

*The first commercially available hydrogen-powered fuel cell car, the Hyundai Tucson Fuel Cell SUV, produces much lower global warming emissions than the model's gasoline-powered version.*

*Under California's 33 percent renewable hydrogen requirements, global warming emissions are less than half that of a corresponding gasoline vehicle.*

*The emissions from hydrogen fuel cell cars will likely drop with advances in electric vehicle technologies and increased availability of renewable power.*

The automobile industry's first production-version hydrogen-powered fuel cell electric vehicle (FCEV) in the United States was introduced by Hyundai in June 2014. Other automakers plan to bring more models to market over the next few years. Like all electric vehicles, FCEVs have a clean electric motor, but instead of needing to charge they can be quickly refilled with hydrogen fuel at stations similar to those that serve today's gasoline cars. Also like plug-in cars, FCEVs produce no harmful tailpipe emissions. Their *total* emissions, however, depend on how the hydrogen fuel is made and delivered. Full lifecycle "well-to-wheels" global warming emissions analyses<sup>1</sup> show that even when using hydrogen from natural gas, today's early hydrogen-powered FCEVs reduce emissions by over 30 percent compared with conventional gasoline vehicles and under California's renewable hydrogen requirements, reductions are over 50 percent. Future FCEVs will likely be even cleaner.

## Hydrogen Fuel Has Different Sources

The carbon emissions associated with hydrogen-fuel production depend on the source of hydrogen (typically, natural gas or water), the process used to extract it, and the source of the energy driving that process.

Currently, most hydrogen is made by converting natural gas into hydrogen gas and carbon dioxide. The hydrogen can be made either at a central facility and trucked to a filling station or, if natural gas is available on-site, right at the station.

However, hydrogen can also be produced from sources of energy that are lower in carbon than natural gas. Electricity from solar or wind power, for example, can be used to split water into hydrogen and oxygen through electrolysis. Another low-carbon source of hydrogen is methane gas from landfills and sewage treatment facilities, provided that methane leakage is minimized.



## California Leading the Way on Clean-Hydrogen Policies

California is leading the U.S. deployment of FCEVs, thanks in part to the state's Zero Emission Vehicle program and public investments in setting up hydrogen stations. California is slated to have 55 hydrogen filling stations by the end of 2015. The state is also leading the way on lower-carbon hydrogen production.

While natural gas is likely to be a significant source of hydrogen fuel in the short term, California law (SB 1505) requires that at least 33 percent of hydrogen produced at these state-supported stations be generated from low-carbon sources, and the state projects that at least 46 percent of hydrogen will come from renewable sources by the end of 2015 (CARB 2014). This renewable-hydrogen standard will apply to all stations in the state once production of hydrogen reaches 3,500 metric tons per year (enough for about 15,000 cars<sup>2</sup>).

### Global Warming Emissions from Hydrogen Vehicles

To compare the global warming emissions of hydrogen-fueled and gasoline-fueled vehicles, it is necessary to examine the emissions from each stage of the fuel lifecycle, including extraction (in the cases of petroleum and natural gas, both of which are fossil fuels), production or refining, distribution to the fueling station, and, finally, consumption of the fuel in the

vehicle. The hydrogen lifecycle also includes the electricity needed to pressurize the hydrogen gas for dispensing to vehicles. The full lifecycle analyses of both vehicle types capture each stage of fuel production in order to allow an apples-to-apples emissions comparison between fuels.

Emissions are typically measured in grams of carbon dioxide equivalent per mile driven (g CO<sub>2</sub>eq/mile). To make the comparison of emissions easier, we also use mpg<sub>GHG</sub>, which is the combined city/highway fuel-economy rating of a gasoline vehicle that would have global warming emissions equivalent to a fuel cell vehicle.

### How Does the First Production Fuel Cell Vehicle Stack Up?

The first commercially available hydrogen-powered FCEV, the Hyundai Tucson Fuel Cell SUV, produces substantially lower global warming emissions than the Tucson's gasoline version. As shown in Table 1, the Tucson FCEV produces 286 g CO<sub>2</sub>eq/mile if fueled by hydrogen produced from natural gas, equal to the emissions from a 38-mpg gasoline vehicle. As a point of comparison, the most efficient gasoline version of the Tucson gets 25 mpg, which results in 436 g CO<sub>2</sub>eq/mi.<sup>3</sup> When using hydrogen that meets California's 33 percent renewable hydrogen standard (see sidebar), the fuel cell SUV emits 202 g CO<sub>2</sub>eq/mile—the equivalent of a 54-mpg gasoline vehicle, or less than half the global warming emissions of the SUV's gasoline version. By the end of 2015, California is projected to produce 46 percent of its hydrogen fuel from renewable sources, which would render the Tucson FCEV's emissions equal to that of a 63-mpg gasoline car.

TABLE 1. Comparison of Gasoline and Fuel Cell Vehicle Emissions<sup>4</sup>

	Hyundai Tucson (gasoline)	Hyundai Tucson FCEV (hydrogen from natural gas)	Hyundai Tucson FCEV (33% renewable California hydrogen)**	Hyundai Tucson FCEV (46% renewable California hydrogen)***
Gasoline vehicle emissions equivalent (MPG <sub>GHG</sub> )	25	38 <sup>*</sup>	54	63
Global warming emissions per mile (g CO <sub>2</sub> eq/mile)	436	286	202	173
Emissions reduction relative to gasoline		34%	54%	60%

\*The EPA rating for the Hyundai Tucson FCEV is 49 miles/kilogram hydrogen.

\*\*California law (California State Senate 2006) requires a minimum of 33 percent renewable hydrogen content.

\*\*\*The Air Resources Board projects renewable hydrogen content in California for 2015 will be 46% (CARB 2014).

## Future Improvements for Fuel Cell Vehicles

The Hyundai Tucson FCEV provides just one early example of the emissions reductions possible from hydrogen-powered vehicles. For example, the limited-production Honda Clarity fuel cell vehicle is rated at 65 mpg<sub>GHG</sub> on the 33 percent renewable California hydrogen mix, despite using older technology. Similarly, a demonstration-model Toyota Highlander SUV reached the equivalent of 75 mpg<sub>GHG</sub> during on-road testing in Los Angeles in 2009 (Wipke, Anton, and Sprik 2009).

With advances in fuel cell performance and in automotive technologies such as the electric drivetrain, and as lower-carbon hydrogen becomes more widely available, fuel cell vehicles that come to market over the next few years will likely cut emissions relative to gasoline vehicles even more. Such evolution has already been the norm among plug-in electric vehicles, including the Nissan Leaf; in just three years on the market, the Leaf lowered its electricity consumption by more than 10 percent, from 0.34 to 0.30 kWh/mile. And because fuel cell vehicles share many components with plug-in electric vehicles, advances such as improved electric motors or more efficient power systems will benefit fuel cell vehicles too. Policies such as California's, which mandate lower-carbon hydrogen production, will further improve the benefits of switching from gasoline to fuel cell vehicles.

### ENDNOTES

- 1 Well-to-wheel emissions were determined by doing a detailed calculation—with the aid of the Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) 2013 model—of the emissions generated during fuel production, distribution, and use.
  - North American natural gas mix
  - Hydrogen production from centralized steam methane reforming with tube trailer distribution
  - The compression required at the hydrogen filling station is supplied by electricity generated at natural gas-fired power plants
  - The power plant efficiencies reflect the current mix of natural gas power plants (80 percent efficient combined-cycle generation units).

For California hydrogen, the renewable hydrogen portion was assumed to be generated from solar sources and transported using tube trailers. The current California electricity mix was used for determining emissions from gas compression at hydrogen filling stations, both for renewable and natural gas-based hydrogen in California.
- 2 Assumes average vehicle efficiency of 50 miles/kilogram hydrogen and 12,000 miles of annual driving.

- 3 Assumes California reformulated gasoline blend with 10 percent ethanol.
- 4 All data for the models listed in this table were based on front-wheel-drive drivetrains. The gasoline model chosen had a 2.0 L, four-cylinder engine.

### REFERENCES

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