IPHE Renewable Hydrogen Report

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International Partnership for Hydrogen and Fuel Cells in the Economy

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The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) has developed this report in order to highlight the potential of renewably produced hydrogen, while drawing attention to many of the projects that have been successfully implemented in recent years to demonstrate and develop renewable hydrogen.

The report consists of two parts: 1) an introduction summarizing the various methods of producing hydrogen from renewable resources and 2) a collection of project overviews outlining past and current demonstrations, including R&D projects involving hydrogen that is produced from renewable sources. IPHE hopes that sharing this information among researchers will facilitate future international networking and collaboration and serve as a valuable resource to policy makers, researchers, and the general public.

INTRODUCTION

As the world faces unprecedented energy challenges, many countries are looking to include hydrogen and fuel cell technologies as part of a clean, sustainable portfolio of solutions. A key advantage of hydrogen is that it can be produced from a variety of sources, including fossil fuels, nuclear power, biomass, and renewable energy. On a lifecycle basis, hydrogen fuel cells can potentially result in reduced greenhouse gas (GHG) emissions in several application areas, namely transportation and stationary power generation.[1] Hydrogen produced from renewable sources offers the best opportunity for reducing GHG emissions and dependence on petroleum fuels.

Fuel cell vehicles that run on hydrogen are projected to produce less GHG

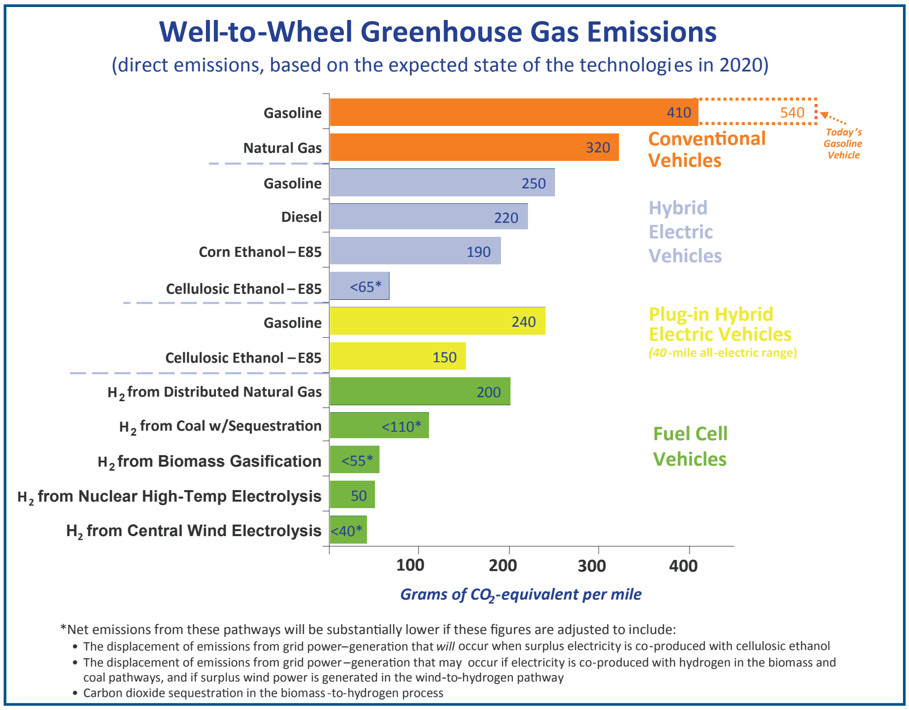


Figure 1. Projections of fuel cell and conventional vehicle well-to-wheels greenhouse gas emissions (U.S.)[2]

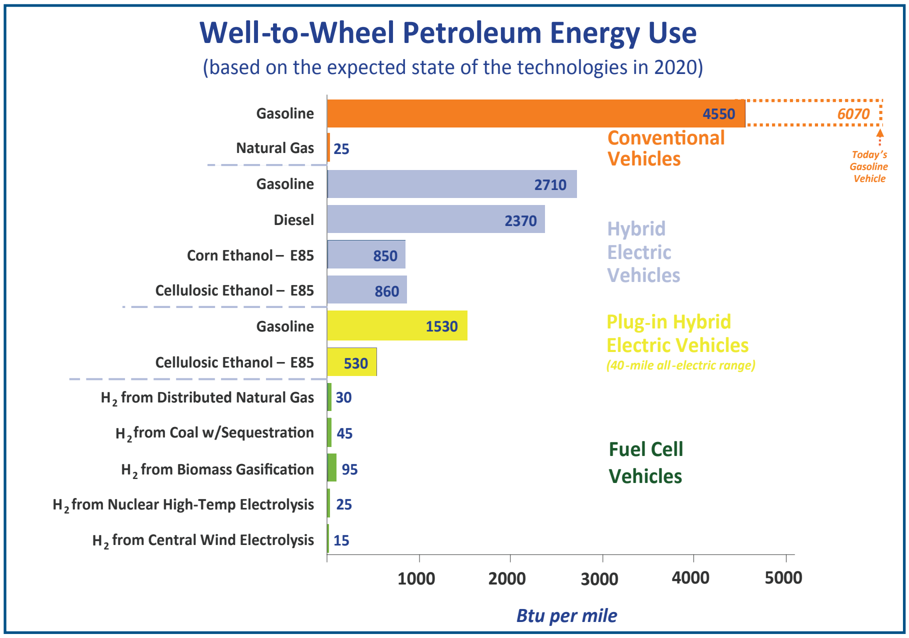


Figure 2. Projections of fuel cell and conventional vehicle well-to-wheels petroleum energy use (U.S.)[2]

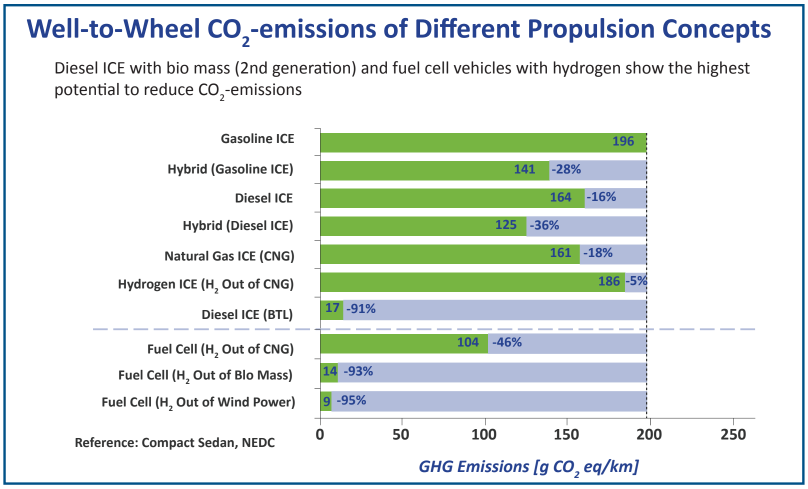


Figure 3. Projections of fuel cell and conventional vehicle well-to-wheels CO_2 emissions (Germany)[3]

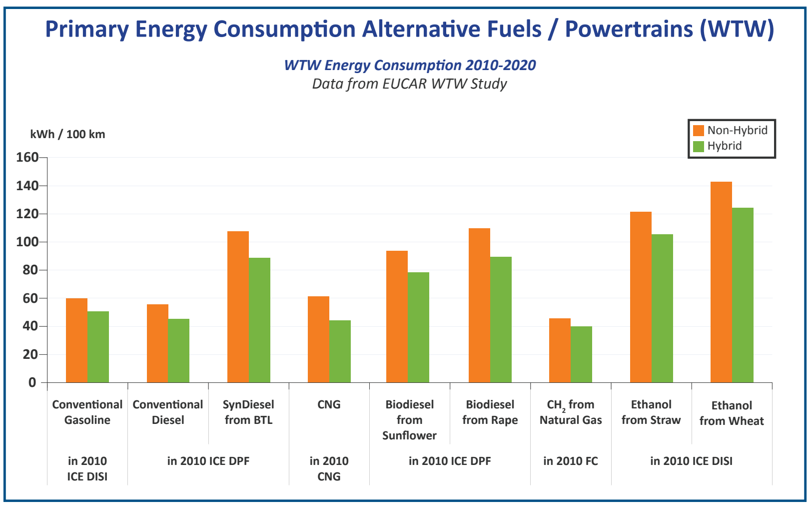


Figure 4. Projections of fuel cell and conventional vehicle well-to-wheels energy consumption (Germany)[3]

on a well-to-wheels basis than cars running on traditional technologies, and using renewable hydrogen increases this advantage significantly. The figures presented in this introduction show the drastic reductions in emissions and petroleum use that is possible with hydrogen fuel cell vehicles when compared to other vehicle technology and fuel pathway options. Figures 1 and 2 highlight data from well-to-wheels studies conducted in the United States, figures 3 and 4 display results from similar studies conducted in Germany, and figures 5 and 6 show study findings from Japan. The results from all three countries indicate that switching to hydrogen fuel cell vehicles is expected to reduce both well-to-wheels GHG emissions and energy use. In comparing the expected capabilities of various advanced vehicle technologies in the year 2020, U.S. analysis predicts GHG emissions reductions ranging from just over 50% for fuel cell vehicles running on hydrogen from distributed natural gas to over 90% for hydrogen produced from central wind electrolysis. Similarly, Germany's analysis projects reductions of approximately 46% for fuel cell vehicles using hydrogen from natural gas, and up to 95% with hydrogen from wind power. Japan's analysis suggests emissions reductions up to 70%.

Today, about 45 billion kilograms of hydrogen are produced annually, but most of it is used for industrial purposes. The majority of today's hydrogen is generated using fossil fuels (largely natural gas) because these technologies are currently the most mature and cost-effective (see Figure 7).

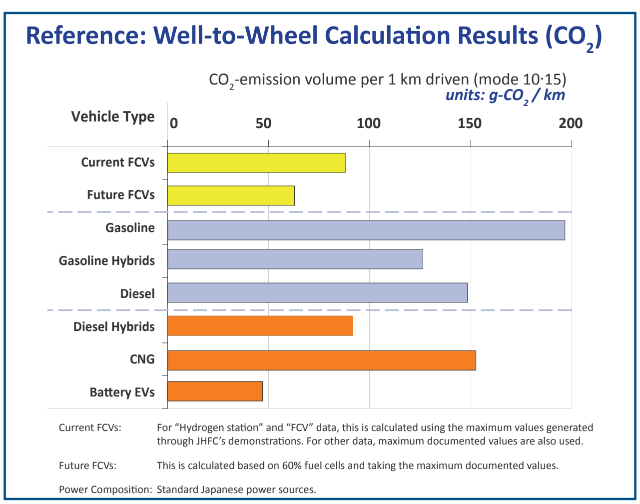


Figure 5. Projected CO_2 emissions for various drivetrains (Japan)[4]

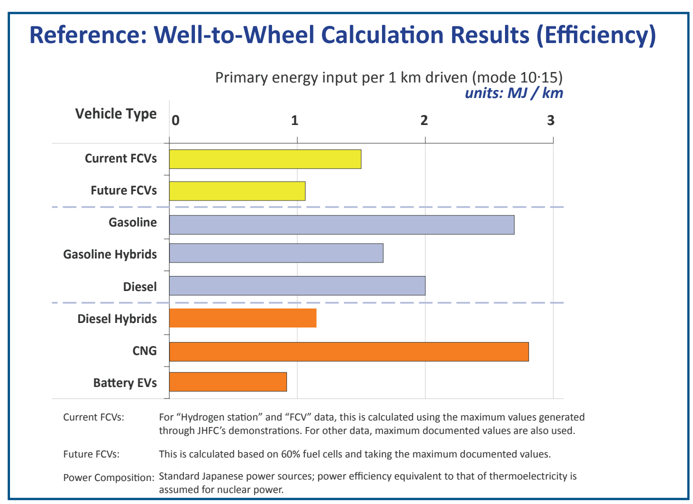


Figure 6. Projected efficiencies for various drivetrains (Japan)[4]

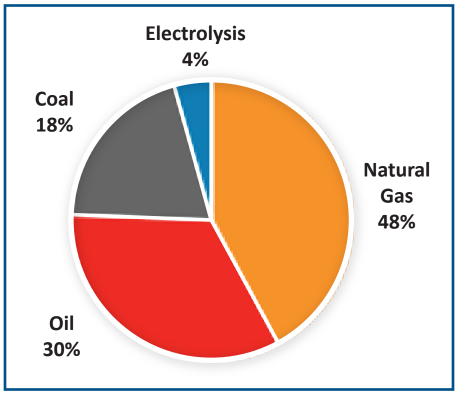


Figure 7. Sources of current worldwide hydrogen production[5]

In hydrogen fuel cell vehicles, hydrogen produced from natural gas still offers significantly less GHG emissions and reductions in petroleum energy use reductions over traditional fuels (see above), but this advantage can be greatly increased using renewable hydrogen. To further enable emissions and energy use reductions, researchers worldwide are working to develop and refine technologies that produce hydrogen in more economical ways from renewable resources. The following section describes several of these processes.

RENEWABLE HYDROGEN PRODUCTION TECHNOLOGIES

While some hydrogen production technologies are already being used—such as natural gas reforming, coal gasification, and electrolysis from both renewable and non-renewable energy sources—others like the photolytic processes are still a long way from commercial use. The greatest technical challenge to the various renewable hydrogen production methods is cost reduction. Current research seeks ways to reduce the cost of capital equipment, operations, and maintenance costs, while improving hydrogen production efficiency. Figure 9 shows data from the United States' Fuel Cell Technologies Program on projected high volume costs for several production methods. This section summarizes various renewable hydrogen production methods and provides a status for each. Figure 8 shows current and future methods for hydrogen production.

Renewable Electrolysis

Electrolysis, in which water is separated into hydrogen and oxygen using electricity, is a common method of hydrogen production. The electricity used can come from any source, including nuclear power, grid power, or renewables.

Renewable electrolysis refers to the process of producing hydrogen from electrolysis using electricity from renewable resources such as wind, solar, hydroelectric, or geothermal power. This is a promising option for future hydrogen production and is currently used in many locations around the world. Currently, cost is the biggest obstacle to this production method—reduced capital cost for electrolysers as well as reduced cost of renewable electricity are needed to make it cost effective. Increasing electrolyser efficiency can also make electrolysis more economical by lowering the impact of the cost of electricity.[8]

Thermal Processes

Thermal processes use the energy in resources including natural gas, coal, or biomass to produce hydrogen. Three renewable-based thermal processes are described below.

Biomass Gasification

Biomass gasification, similar to coal gasification, converts an organic material (such as wood, switchgrass, or sugarcane) into a gaseous mixture of hydrogen, carbon monoxide, carbon dioxide, and other compounds at elevated temperatures in the presence of steam

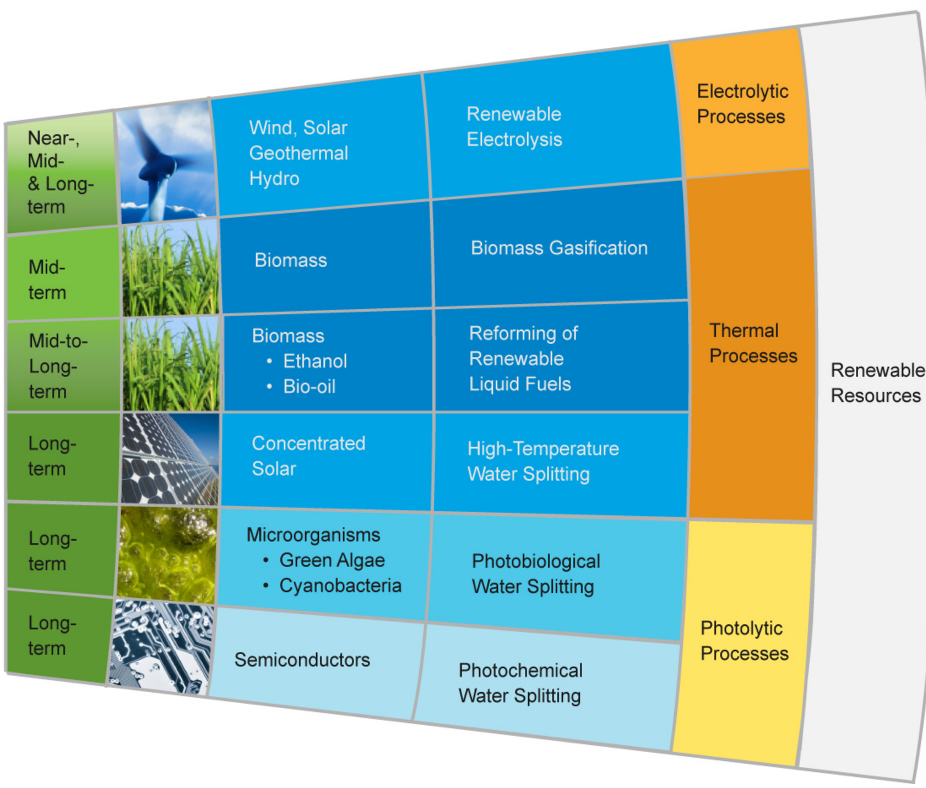


Figure 8. Hydrogen production technologies and methods

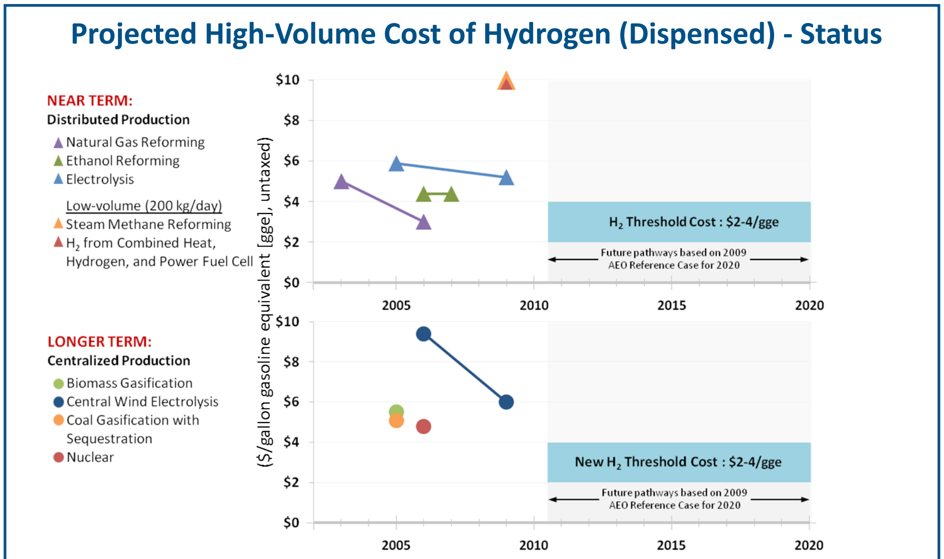
and a controlled amount of air or oxygen. This process is anticipated as a mid-term hydrogen production technology and can utilize feedstocks including agriculture crop and forest residues, crops grown specifically for renewable energy use like switchgrass and willow trees, organic municipal solid waste, and animal wastes. This method results in near-zero net GHG emissions and, when carbon capture and sequestration is incorporated, can result in negative emissions.

Renewable Liquid Fuel Reforming

Biomass can also be used to produce hydrogen by first converting it to liquid fuels such as ethanol or bio-oil. These liquid fuels can be transported at a relatively low cost to an end-use location, such as a refueling station, where it can be reformed to produce hydrogen. Reforming renewable liquid fuels, similar to reforming natural gas, involves reacting the biomass-derived fuel with steam at elevated temperatures to produce hydrogen. This is considered a mid- to long-term hydrogen production method.

High-Temperature Water Splitting

High-temperature water splitting is a method of producing hydrogen in which very high temperatures (up to 2,000°C) drive chemical reactions that produce hydrogen. These high temperatures can be provided by nuclear power or using concentrated solar power. During the reactions, all reactants except for hydrogen, oxygen and water are reused, creating a closed process that produces hydrogen and oxygen from water. Researchers have identified many possible chemical cycles and are currently working to identify and improve the most promising possibilities. Other research challenges with this method include finding appropriate high-temperature construction materials, reducing the cost of solar concentrators, and developing heat-transfer mediums.[9]



Note: Data points are being updated to the 2009 AEO reference case. The 2010 technology validation results show a cost range of $8 to $10/gge for a 1,500 kg/day distributed natural gas and $10 to $13/gge for a 1,500 kg/day distributed electrolysis hydrogen station.

Figure 9. Data from the U.S. Fuel Cell Technologies Program on projected high volume costs of various hydrogen production methods[7]

These processes produce near-zero emissions but are seen as long-term hydrogen production options since they are currently only in early development stages. The feasibility of this method has been successfully demonstrated in the laboratory, but further significant research and development will be required for it to be a practical large-scale option.

Photolytic Processes

Photolytic processes use light energy to split water into hydrogen and oxygen. These processes offer the potential for sustainable hydrogen production with low environmental impact but are still in the very early stages of research.

Photobiological Water Splitting

In this process, hydrogen is produced from water using sunlight and micro-organisms such as green algae and cyanobacteria. Hydrogen is a byproduct of these microorganisms' natural metabolic processes, which require sunlight and consume only water. This technology faces a challenge in that the microorganisms produce hydrogen much too slowly for commercial hydrogen production. Scientists are exploring ways to speed up the process in these microbes, as well as searching for other microbes that may produce hydrogen at higher rates.

Photoelectrochemical Water Splitting

The primary difference between photoelectrochemical and photobiological water splitting is that photoeletrochemical water splitting utilizes semiconductor materials to split water into hydrogen and oxygen. The semiconductor materials used are similar to those used in photovoltaics, and research is currently underway to identify improved materials that will have both increased efficiencies and improved durability.

By-product Hydrogen

Stranded Hydrogen

The term "stranded hydrogen" refers to hydrogen that is produced as a byproduct of industrial processes and is not re-sold or used within the plant where it is produced. In these cases, the hydrogen is essentially a waste product that is commonly vented into the atmosphere. While not a long-term source of hydrogen because there are limited volumes available, stranded hydrogen offers a temporary, near-term source of hydrogen while larger infrastructures are being built.

Excess hydrogen production occurs in industries including chlorine production and other chemical plants, as well as refineries and coking plants in steel mills. Depending on the industrial process that is being used, the excess hydrogen may come from either renewable or non-renewable sources. However, because it is being produced regardless of its end use (the CO_2 emitted in its production is essentially a sunk cost), the non-renewably produced hydrogen can be considered carbon-neutral.

Analyses have been done in several IPHE countries to estimate the amount of stranded hydrogen that could be made available for use as fuel for transport or stationary applications. In Germany, a study conducted in the state of North Rhine-Westphalia (NRW), estimated that there is approximately 35,000 tons of stranded hydrogen available in NRW per year. That is enough to support 6,000 buses or 300,000 fuel cell cars.[10] Further, it is estimated that twice this amount is available in Germany as a whole. In Japan, extra hydrogen production capacity from municipal gas companies and oil refineries is estimated at 4.7 billion normal cubic meters (Nm^3), enough to fuel 5 million fuel cell vehicles.[11] In the U.S., a 2007 Department of Energy/Argonne National Laboratory study found that hydrogen separated from coke oven gas in the U.S. could produce about 370,000 metric tons of hydrogen, enough to fuel 1.7 million vehicles.[12]

RENEWABLE HYDROGEN PRODUCTION PROJECT EXAMPLES

The following section provides overviews of several current and past demonstration projects that involve hydrogen produced from renewable sources, as well as projects demonstrating recent R&D progress for longer-term production methods. The projects presented showcase a wide variety of renewable production methods, including near-, mid-, and long-term processes, and represent regions from around the world.

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