Where Does Hydrogen Fuel Come From?

What is hydrogen fuel?

Hydrogen is the simplest and most common element in the universe. It is a colorless, odorless, and tasteless gas that has the highest energy content per unit of weight of any known fuel. Hydrogen is very chemically active and rarely stands alone as an element. It usually exists in combination with other elements, such as oxygen in water, carbon in methane, and in trace elements as organic compounds. Hydrogen therefore must be broken from its bonds with other elements in order to be used as a fuel. There are numerous processes that can be used to break these bonds.

How is hydrogen produced?

One of the benefits of hydrogen fuel is that it can be produced from a diverse array of potential feedstocks, including water, fossil fuels and organic matter. Described below are the most common and best understood hydrogen production pathways. Each of these pathways has its own pros and cons that should be considered in terms of cost, emissions, feasibility, scale, and logistics.

Table 1- Hydrogen Production Pathways

Source	Conversion	Process		Product
Crude Oil		Reformer		Hydrogen
Coal		Reformer		Hydrogen
Natural Gas		Reformer		Hydrogen
Nuclear	Power Plant		Electrolyte	Hydrogen
Solar	Generator		Electrolyte	Hydrogen
Hydro	Generator		Electrolyte	Hydrogen
Wind	Generator		Electrolyte	Hydrogen
Wave	Generator		Electrolyte	Hydrogen
Geothermal	Power Plant		Electrolyte	Hydrogen
Wood		Reformer		Hydrogen
Org. Waste		Reformer		Hydrogen
Biomass		Reformer		Hydrogen

What is the likely hydrogen production scenario for California?

While it there are many variables that will determine how California ultimately sources hydrogen fuel, there is emerging consensus that in the short term hydrogen will be produced and supplied from natural gas, thereby taking advantage of the existing infrastructure and distribution networks. Over the medium to long term, hydrogen will likely be produced via electrolysis using clean renewable power from solar, wind, and geothermal sources as well as via biomass gasification.

Reformation of Natural Gas

Process - In this process, natural gas (for example methane, propane, or ethane) is combined with high temperature steam (700-1000°C) where it reacts in presence of a catalyst, thereby breaking the bonds of the natural gas and creating hydrogen, carbon monoxide, and carbon dioxide. A subsequent shift reaction then treats the carbon monoxide with more high temperature steam thereby producing more hydrogen and carbon dioxide. The unwanted carbon dioxide is then removed from the mixture using absorption or membrane separation and the final result is pure hydrogen. [1]

Pros - Steam reformation of natural gas is currently the most common method of bulk hydrogen production. It is also one of the best understood and least expensive methods. Steam reformation currently accounts for approximately 80% of global hydrogen production.[2] Using this pathway would allow for the use of existing natural gas infrastructure and is easily scalable.

Cons – This method of hydrogen production is dependent on a potentially limited and volatile natural gas supply. The process results in moderate emissions of CO2.

Biomass Gasification

Process - In this process, biomass such as forestry by-products, straw, municipal solid waste or sewage is heated at high temperatures in a reactor where the bonds in the molecules forming the biomass are broken. This creates gas consisting mainly of hydrogen, carbon monoxide, and methane (CH4). Using the same steam reformation process described above, the methane is converted into hydrogen and carbon dioxide.

Pros - Carbon dioxide emissions from biomass gasification do not to contribute to a net increase in greenhouse gas emissions.[3] Biomass gasification is currently one of the

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most advanced and least expensive methods of producing hydrogen from renewable resources.[4] A wide variety of agricultural wastes and other biomass sources can be used to produce hydrogen, and the mobility of these sources enables this method to be employed at or near the point of use, reducing costs. Opportunities exist for municipalities to convert sewage and other organic waste into a source of income.

Cons – Research continues on ways to perfect the conversion of sewage into hydrogen fuel.

Electrolysis of Water

Process – Electrolysis of water involves passing an electric current though water, thereby splitting the water molecules into their basic elements of hydrogen and oxygen. Hydrogen gas rises from the negative cathode and oxygen gas collects at the positive anode.

Pros - After steam reformation of natural gas, this is the most common method of hydrogen production and is very well understood. Hydrogen produced using electrolysis has the potential to be completely emissions free if the electricity used is generated from clean, renewable sources such as wind and solar.[5]

Cons – Large amounts of electricity are required during electrolysis, making it one of the most energy intensive methods of hydrogen production. If the electricity used during electrolysis is generated from dirty sources, such as coal, oil, or even natural gas, the greenhouse gas emissions will be comparatively high.

Coal Gasification

Process - The basic process of coal gasification begins with converting the coal into a gaseous state by heating the coal in a reactor at very high temperatures. The gaseous coal is then treated with steam and oxygen and the result is the formation of hydrogen gas, carbon monoxide, and carbon dioxide.[6]

Pros - Coal gasification is the oldest method of hydrogen production; plants have long been operating in Europe, South Africa, and the U.S. There are large supplies of coal in the U.S., North America, and the World. This method of production becomes economically viable if CO2 is sequestered and used to recover methane trapped in unminable coal beds.[7]

Cons – It is almost twice as expensive to produce hydrogen from coal as from natural gas due to the ratio of hydrogen to carbon, which in natural gas is 4:1 and in carbon is 0.8:1.[8] Unless sequestered at the point of production, there are significant emissions of carbon dioxide associated with coal gasification. There are also emissions of other pollutants such as sulfur and carbon monoxide.

Carbon Black & Hydrogen Process

Process – The only inputs in the CB&H process are electric power and hydrocarbons.[9] In the CB&H process carbon-based raw materials ranging from natural gas to heavy oils are heated in a high temperature reactor. A plasma burner, utilizing recycled hydrogen from the process, splits the hydrocarbons. The products then go through a cooling and filtering system to separate the carbon black from the hydrogen. The first commercial CB&H plant went online in 1999.[10]

Pros - No emissions result from this process; one hundred percent of the raw materials are used, and two valuable products, carbon black and hydrogen, are produced. CB&H replaces the traditional process for producing carbon black, (used primarily in tire production) which is extremely polluting.

Cons – The CB&H process uses carbon-rich fossil fuels, whose extraction despoils the land and pollutes water. The process requires large amounts of electric power, which, if generated from dirty sources, will be a significant source of greenhouse gas emissions.

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Where Does Hydrogen Fuel Come From? [continued]

Other Production Pathways

Hydrogen production methods that are still being researched and developed, but could someday become commercially viable include photoelectrolysis, thermal decomposition of water, photobiologial production, and the plasmatron.

1 "Report to Congress on the Status and Progress of the DOE Hydrogen Program," by DOE, February 4,1999.

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4 "Clean Hydrogen Transportation: A market Opportunity for Renewable Energy," by James S. Cannon, REPP Issue Brief No.7, April 1997.

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6 "Gasification Technologies," Fossil Energy.gov, http://www.fe.doe.gov/coal_power/gasification/index.shtml

7 "Hydrogen production from coal and coal bed methane, using byproduct CO2 for enhanced methane recovery, with CO2 sequestration in the coal bed," by Robert Williams, Center for Energy and Environmental Studies, Princeton University, PU/CEES Report No. 309, August 1998.

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9 "Hydrogen-Status and possibilities," Russia, England, and Norways combined report 2: 2002: Hydrogen Bellona Report. www.bellona.no : Energy : Hydrogen.

10 "Carbon Black and Hydrogen with No Emissions," SINTEF Materialteknologi, http://www.sintef.no/units/matek/annual99/12-99.html

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