



# A Hydrogen Economy

An Online Continuing Education Course for Engineers

**Course Number: R-3020**

**Credit: 3 Hours / 3 PDH / 3 CPD**

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## Introduction

There is a possibility that hydrogen may be the fuel of the future to revolutionize the way energy is produced and used. Hydrogen is widely held to be one of the most promising technologies that can be deployed on a large scale in the foreseeable future. Replacing fossil fuels with hydrogen could bring major environmental benefits – provided the technical, environmental, and cost challenges in the way hydrogen is produced, transported, stored, and used are overcome.

Hydrogen, as an energy carrier, has the potential to replace all forms of final energy in use today and provide energy services to all sectors of the economy. The fundamental attraction of hydrogen is its potential environmental advantages over fossil fuels. At the point of use, hydrogen can be burned in such a way as to produce no harmful emissions. If hydrogen is produced without emitting any carbon dioxide or other climate-destabilizing greenhouse gases, it could form the basis of a sustainable energy system – the hydrogen economy.

Hydrogen is **an energy carrier**  
not an energy source.

Numerous technical challenges prevent the creation of a large-scale hydrogen economy. These include,

- Difficulty in developing long-term storage, pipelines, and engine equipment,
- Lack of off-the-shelf engine technology that can run safely on hydrogen,
- Safety concerns about the high reactivity of hydrogen fuel with oxygen in ambient air,
- The expense of producing it by electrolysis, and
- Lack of efficient photochemical water splitting technology.

Hydrogen does not occur naturally except in very limited quantities, so it must be manufactured. The carbon footprint of hydrogen depends on how it is produced. The main advantage of hydrogen as a fuel carrier is that it does not produce carbon dioxide emissions (CO<sub>2</sub>) when combusted or used in fuel cells. However, depending on the production process used, hydrogen may not yield any net reduction in CO<sub>2</sub> emissions.

The world's energy system is becoming less carbon intensive as it has moved from coal to oil and then natural gas, and a transition to a hydrogen-energy system will present another step on the path away from carbon-based fossil energy.

Technology exists today to produce, store, transport, and convert hydrogen to usable energy in end-use applications, such as fuel cells. Technologies to capture carbon dioxide and other gases released during

the process of producing hydrogen from fossil fuels and storing them have also been demonstrated. In many cases, these processes are not fully commercialized.

The cost of supplying hydrogen energy is expensive compared to conventional energy technologies. Major technological and cost breakthroughs are needed before the hydrogen economy can become a reality. And hydrogen may never become cost-competitive with existing energy sources.

The Earth's resources of oil, natural gas and coal are large enough to meet our energy needs for several centuries. Advances in *carbon capture and storage (CCS)* technologies could enable the continuing use of fossil fuels to generate electricity in an environmentally acceptable manner and at an acceptable cost.

Currently hydrogen is primarily used as an industrial feedstock, primarily for the production of ammonia and methanol, and in petroleum refining. Worldwide, about 95% of the world's hydrogen is consumed yearly in industrial processing. Fertilizer production accounts for 45% of the hydrogen used. Hydrogen can be used to decarbonize other industrial sectors that are hard to electrify, essentially, the hard-to-abate sectors such as cement, steel, long-haul transport, etc. In order to phase out fossil fuels and limit climate change, hydrogen can be created from water using nuclear power and renewable sources, and its combustion only releases water vapor into the atmosphere.

Because both the world population and the intensive agriculture used to support it are growing, ammonia demand is growing. Ammonia can be used as a safer and easier indirect method of transporting hydrogen. Transported ammonia can then be converted back to hydrogen by membrane technology.

The remainder of current hydrogen production is used to convert heavy petroleum sources into lighter fractions suitable for use as fuels. This latter process is known as *hydrocracking*. Hydrocracking represents an even larger growth area since rising oil prices encourage oil companies to extract poorer source material, such as oil sands and oil shale. The scale economies inherent in large-scale oil refining and fertilizer manufacture make possible onsite production use. Smaller quantities of hydrogen are manufactured and delivered to end users as well.

Growth projections for the hydrogen economy vary greatly based on goals for worldwide reductions in carbon dioxide emissions and corresponding targets for reductions in global warming. For instance, if aggressive global warming targets are addressed (less than 1.8C rise), hydrogen production may increase to over 600 megatons (Mt) per year by 2050. With a more realistic target of 2.3C, the hydrogen market will likely be around 450 Mt. per year. In any scenario, it appears that hydrogen will be a growth market. Figure 1 shows the potential increase in hydrogen production, and the blue line represents the most likely scenario.

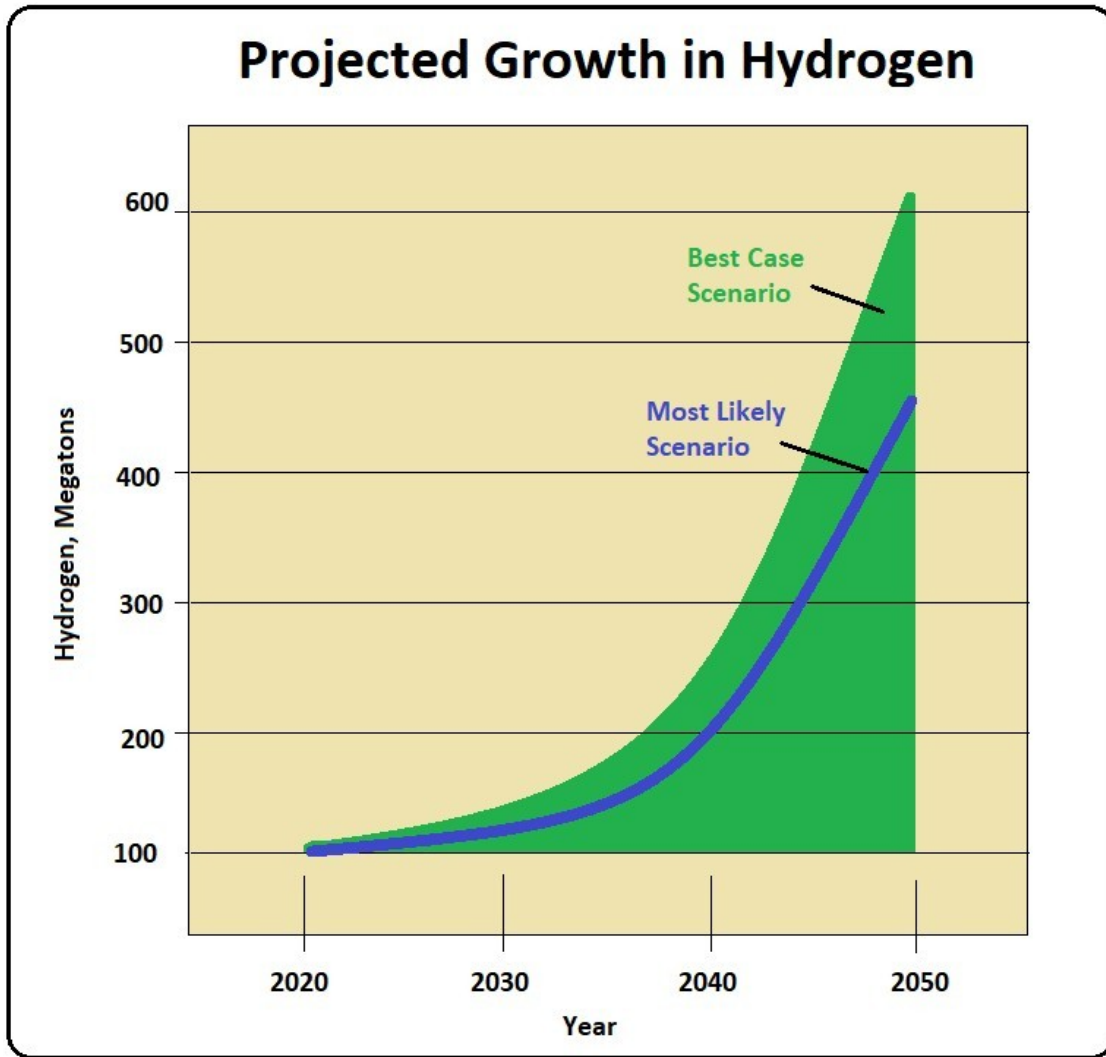


Figure 1

Since hydrogen is present but diffuses in the Earth and does not exist in convenient reservoirs, it must be produced from chemical feedstocks or water. The predominant methods currently employed to extract hydrogen include fossil fuels and occur at large-scale industrial facilities.

Hydrogen is produced using a multi-step process starting with *steam methane reforming* (SMR) of desulfurized natural gas, followed by the production of additional hydrogen using the non-hydrogen products of the SMR step. A final step in the process is to recover hydrogen produced in the earlier steps to a higher level of purity. Other methods employ water as a feedstock and use an electrolysis process to decompose water into hydrogen and oxygen.

Hydrogen produced from non-emitting resources (hydropower, wind, solar) is called *green hydrogen*. *Pink hydrogen* is produced from nuclear power, and *grey hydrogen* is produced from fossil fuels. Chapter two provides more information about the 'colors' of hydrogen.

Some refineries and chemical manufacturers produce their hydrogen, utilized at the same site where it is made. The *merchant hydrogen* sector manufactures hydrogen and sells it to various concerns, including refineries and chemical manufacturers. Complementing this on-purpose use of hydrogen is by-product hydrogen, referring to the hydrogen produced in a mixture with other chemicals during industrial processes where hydrogen is not the primary commodity.

The term *high carbon* hydrogen is used to refer to traditional methods of producing hydrogen with high CO<sub>2</sub> emissions, such as steam methane reforming or coal gasification. *Low-carbon* hydrogen is used to refer to all forms of hydrogen with low CO<sub>2</sub> emissions. These can include:

- Steam methane reforming (SMR) of natural gas with Carbon Capture and Storage (CCS),
- Coal gasification with CCS,
- Electrolysis using low emissions electricity such as nuclear power and renewables,
- Methane pyrolysis, which does not produce CO<sub>2</sub> emissions.

The most common method of extracting hydrogen is through *steam methane reforming* (SMR) which releases significant quantities of carbon dioxide. However, newer technologies, such as *methane pyrolysis*, could greatly reduce carbon emissions.

*Polymer electrolyte membrane* (PEM) fuel cells are currently being evaluated as a power source for automobiles. Fuel cells use hydrogen and atmospheric oxygen to create electric power and water vapor. While some devices, such as the PEM fuel cell, require the use of pure hydrogen fuel, others can use hydrogen blended with methane in a combustion turbine, a type of engine found in electric power stations. Hydrogen is also being investigated for distribution in existing natural gas pipelines, blended with methane. A hydrogen economy could thus be a combination of the old with the new.

Hydrogen could become part of the energy infrastructure by storing energy, or it could provide an alternative fuel to meet the demand for thermal comfort in buildings or high-temperature heat in industry. Hydrogen can also be used in industrial applications such as steelmaking.

Heating homes and businesses is primarily fueled by electricity and natural gas, and transportation is fueled by petroleum. Most of these fuel sources burn hydrocarbon fuels, which emit carbon dioxide and other pollutants. Hydrogen can be an environmentally cleaner source of energy to end-users without the release of pollutants such as particulates or carbon dioxide.

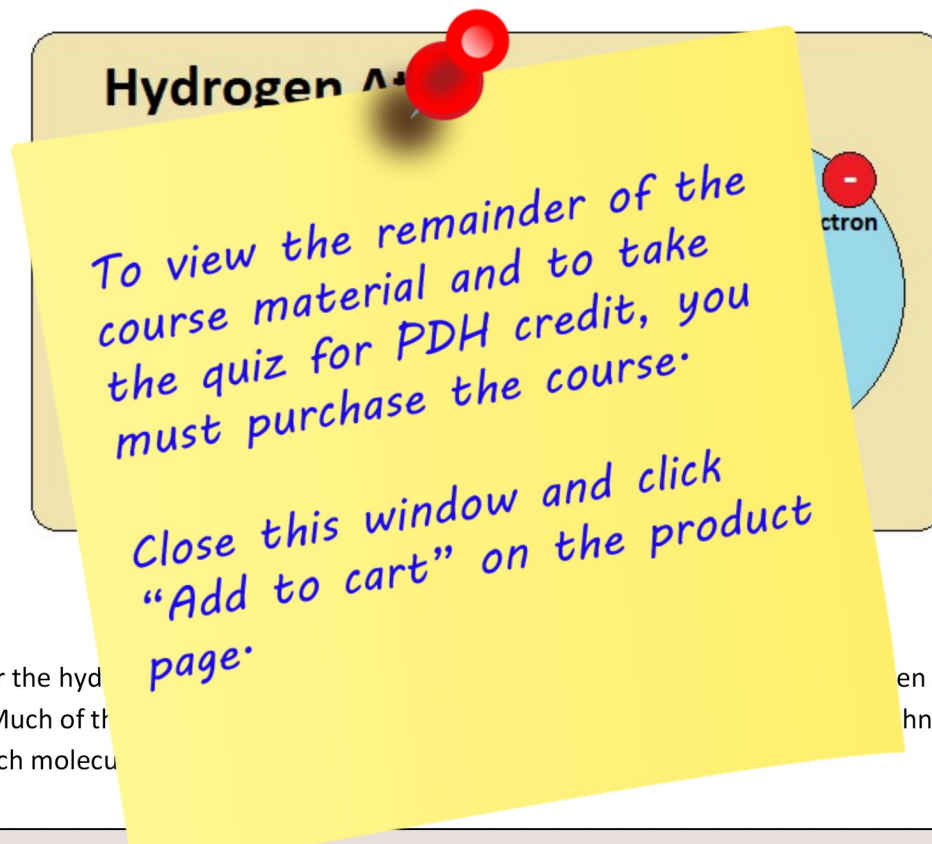
This course is divided into six chapters. The first chapter explains the basics of hydrogen and how it may be used. Chapter two describes the production methodologies to extract hydrogen and convert it to a

usable fuel source. Chapter three provides insight into the infrastructure required to transport and store hydrogen for end use. Chapter four discusses the potential applications of hydrogen as a fuel source. Chapter five describes the challenges facing a hydrogen economy. The final chapter ends with several application examples of hydrogen use.

## Chapter 1: Hydrogen Basics

Hydrogen is the most abundant element in the Universe, representing an estimated 70 to 75 percent of all known matter. On the Earth, hydrogen does not exist as a "free" gas—it is present only in combination with other elements, notably oxygen, carbon, and nitrogen. Thus, to capture hydrogen for use in multiple applications, it must be separated from the paired substances, most commonly water (H<sub>2</sub>O) and natural gas (CH<sub>4</sub>).

In its normal gaseous state, hydrogen is odorless, tasteless, colorless, and non-toxic. It is made up of just one electron and one proton and is, therefore, the first element in the periodic table. See Figure 2.



The fuel for the hyd...  
together. Much of th...  
manage such molecu...

en atoms bound  
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Hydrogen does not occur naturally and therefore some other form of energy is needed to produce or extract hydrogen. Once it is extracted, hydrogen can function as an energy carrier to transport energy from one place to another. In contrast, an energy source is a fuel that can be used directly. Like hydrogen, electricity is also an energy carrier. Coal, natural gas, wood, and petroleum oil are sources of energy.