Chapter IV. Hydrogen R&D

Hydrogen research and development (R&D) is focused in several major categories: production, use, delivery and storage. In all areas, research includes some focus on basic science as well as practical application. Hydrogen production from natural gas and less commonly through electrolysis already occurs in a number of industrial settings, where it is quickly transformed into other products. Its production is costly and is not efficient enough to justify its use over direct use of the fossil feedstock. Hydrogen also cannot yet be practically stored in a way that makes distribution possible.

Hydrogen production R&D is being pursued in several parallel pathways. It has not yet been determined what method of production is the most efficient and sustainable. In the renewable arena several methods are under evaluation: reforming bio-gas, water electrolysis from electricity generated from renewable resources, biological production from algae, and several types of early-stage direct solar applications including photoelectrochemical and thermochemical production. Research on other methods of separating hydrogen from fossil fuels include natural gas reforming, coal gasification and nuclearchemical cycles as well as other basic materials research is also underway.

Production of hydrogen from renewable energy resources is most likely to come from electricity produced from those resources. Electrolysis, a process whereby electricity is used to separate hydrogen and oxygen in water, produces hydrogen with water as a by-product. Alkaline electrolysis systems are mature and commercial, although quite expensive and only used in niche processes. Proton exchange membrane systems are even more costly and need improved durability. Both types need greater efficiency. Other barriers are of course, the cost of renewable electricity itself and the intermittency of that power. Electrolysis also requires constant supply of clean power.

Hydrogen storage research is pursuing several potential storage mediums including high-pressure compressed storage, chemical storage and materials-based storage such as carbon, boron and metal hydrides. Storage, both for distribution and on-board vehicles, is a key component of a hydrogen-based economy.

Hydrogen use is likely to achieve the highest potential efficiency via fuel cells. Separate research on this energy conversion device is also underway, but is not discussed here. Fuel cells are also quite expensive to produce and do not yet have the durability and efficiency necessary for widespread use.

At least 15 hydrogen research projects are underway in the Appalachian region. The most concentrated research effort takes place at Oak Ridge National Laboratory in Tennessee. Research also takes place in several of the major universities in the region, with much of that work conducted at the Pennsylvania State University and the University of Alabama. A portion of this research is described below, with research on renewable hydrogen production discussed first.

1. Solar Hydrogen Production[16]

Several types of early stage research are underway on the potential production of hydrogen using solar heat to induce water electrolysis to separate hydrogen and oxygen. These include photoelectrochemical production, whereby water is split directly upon illumination using semiconductor materials and thermochemical production, whereby water is split as chemical or metal compounds such as sulfuric acid, metal sulfate, or metal oxides interact with water to produce hydrogen. Solar concentrating systems could provide heat for these processes. Another very early-stage research area is photobiological production, whereby hydrogen is produced from unicellular green algae or cyanobacteria that live on solar energy.

Hydrogen research in the Appalachian region based on production from renewable energy is concentrated in solar applications and includes:

- Pennsylvania State University –
  - observation of the efficiency of solar electrolysis by isolating single crystal silicon photovoltaic cells.
  - development of novel silicon and cadmium selenide nanowire for water splitting
  - development of "A Hybrid Biological/Organic Half-Cell for Generating Hydrogen"
- Virginia Polytechnic Institute and State University –
  - studies of trinuclear, rhodium-centered mixed-chemical complexes for water splitting.
- Oak Ridge National Laboratory –
  - Research to increase the rate of algal hydrogen production by designing a proton channel to stabilize proton activity during production, thus removing a physiological obstacle to efficient conversion of light energy.
- Marshall University (Huntington, WV) –
  - Adaption of photosynthesis to the production of hydrogen from algae.[17]

2. Non-Renewable Hydrogen Production R&D[18]

Much hydrogen research is also focused in production from fossil fuels.

- Oak Ridge National Laboratory –
  - Fossil Hydrogen Production: Use of microporous inorganic membranes to separate hydrogen from a synthesis gas (possibly coal derived) at certain pressures and temperatures.

[16] U.S. Department of Energy (2005). "Solar and Wind Technologies for Hydrogen Production," Report to Congress. http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/solar_wind_for_hydrogen_dec2005.pdf
[17] The lead researcher on this project, Dr. Sergei Markov, is no longer with Marshall University.
[18] http://www.hydrogen.energy.gov/annual_review06_delivery.html#electro

    - Nuclear Hydrogen Production: This method attempts to extract hydrogen from water at a low-temperature reaction – between 650C and 750C – through the use of a sulfur dioxide reaction and use of microporous membranes.
- Media and Process Technology, Inc. (Pittsburgh, PA) –
    - Use of a carbon molecular sieve membrane as reactor for water gas shift reaction. This method takes carbon monoxide and water through high temperatures into a ceramic membrane that facilitates the creation of carbon dioxide and hydrogen.
- Ohio University –
    - This project tries to tackle the problems of hydrogen sulfide in syngas derived from coal into the creation of solid oxide fuel cells through the use of specialized anodes.

3. Hydrogen Storage R&D[19]

- Pennsylvania State University's Carbon Center of Excellence –
    - Use of boron in metal loaded high porosity carbon materials for the reversible storage of hydrogen.
- University of Pittsburgh's Metal Hydride Center of Excellence –
    - Computational work on finding workable alloys in metal hydride systems.
- Oak Ridge National Laboratory –
    - Research on the use of carbon for the storage of hydrogen, including of carbon-based solutions and compounds.
- University of Alabama's Chemical Hydrogen Center of Excellence –
    - Evaluation of the chemical storage of hydrogen using carbenes and cyanocarbons, both types of electron deficient molecular compounds.
    - Evaluation of the use of boron in the storage of hydrogen.

[19] http://www.hydrogen.energy.gov/annual_review06_storage.html