## 2.2.3 HYDROGEN PRODUCTION AND DISTRIBUTION USING ELECTRICITY AND FOSSIL/ALTERNATIVE ENERGY

| Technology Description |
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Similar to electricity, hydrogen can be produced from many sources, including fossil fuels, renewable resources, and nuclear energy. Today, industrial hydrogen is produced primarily from natural gas using widely known commercial thermal processes. In the future, we can adapt current technologies through advanced development to produce hydrogen with significantly reduced overall $CO_2$ emissions, through carbon capture and sequestration – and by using renewable and nuclear electricity to produce hydrogen with no production-side $CO_2$ emissions.

**System Concepts and Representative Technologies**

- Natural gas can be delivered to refueling stations using existing pipelines and re-formed into hydrogen on-site. The infrastructure costs for small-scale, distributed production would be much lower than that required to pipe or truck mass-produced hydrogen from long distances. By making hydrogen from natural gas, we can also take advantage of existing natural gas infrastructure such as storage cylinders, pipelines, and compressors.
- Hydrogen made via electrolysis from nuclear or renewable power can be used as a sustainable transportation fuel or stored to meet peak-power demand. Hydrogen as a storage medium enables intermittent renewable power systems to provide reliable power, even when the wind is not blowing or the sun is not shining.
- Hydrogen produced from fossil fuels (followed by sequestration of the carbon) can enable the continued use of fossil fuels in a clean manner during the transition to the ultimate carbon-free hydrogen energy system.
- Biomass can be used to produce hydrogen, electricity, and other value-added coproducts such as activated carbon, fuel additives, and adhesives, when it is thermally treated under relatively mild conditions. This is part of the biorefinery concept, wherein fuels, power, and products are produced from biomass resources in an integrated process.
- Hydrogen separation- and purification-process improvements offer cost-reduction and efficiency improvement opportunities for current fossil-based systems.
- An ultimate hydrogen economy vision includes hydrogen production from several processes, including high-temperature thermochemical water splitting cycles, direct photoelectrochemical semiconductor-based systems, and biological systems.
- Transport and distribution concepts and technologies include evaluation of existing natural gas pipelines for use to transport hydrogen and natural gas mixtures or pure hydrogen, development of new pipeline materials to reduce costs and resolve hydrogen embrittlement issues, development of more reliable and lower-cost hydrogen-compression technologies, development of more energy-efficient and lower-cost hydrogen liquefaction technology,and the evaluation of novel solid or liquid carriers for hydrogen delivery.

**Technology Status/Applications**

- Nearly half of the worldwide production of hydrogen is via large-scale steam reforming of natural gas (a relatively low-carbon fuel/feedstock). In the United States, almost all of the hydrogen used as a chemical (i.e., for petroleum refining and upgrading, ammonia production) is produced from natural gas. Today, we produce and utilize 9 million metric tons of hydrogen annually in the United States. Although comparatively little hydrogen is currently used as fuel or as an energy carrier, there are emerging technologies such as fuel cells that will drive the future consumption of hydrogen into the transportation and electric-generation sectors.
- Hydrogen production from conventional fossil-fuel feedstocks is commercial (on a large scale), but results in significant $CO_2$ emissions.
- Current commercial electrolyzers are 60%-70% efficient, but the cost of hydrogen is strongly dependent on the cost of electricity.
- Biomass feedstocks (such as agricultural and forest residues, switchgrass and willow trees, and municipal waste) are being evaluated and tested for dedicated hydrogen production and multiproduct biorefineries.

**Current Research, Development, and Demonstration**

- Today, hydrogen is transported by cryogenic liquid truck and high-pressure tube trailers at a very high cost. Some is transported through a very limited hydrogen pipeline infrastructure. Research on lower-cost hydrogen distribution technologies is just now being initiated.

Hydrogen production by photovoltaic hydrolysis.

**RD&D Goals**

- By 2006: (1) completion of research of small-scale steam methane reformers with a projected cost of $3.00/kg hydrogen at the pump; (2) development of alternative reactors, including auto-thermal reactors; and (3) evaluation of whether renewable energy integrated hydrogen production by water electrolysis can achieve 64% net energy efficiency at a projected cost of $5.50/kg, delivered at 5,000 psi.
- By 2010: At the pilot-plant scale, demonstrate (1) membrane separation and reactive membrane separation technology for hydrogen production from coal, and (2) distributed hydrogen production from natural gas with a projected cost of $2.50/kg hydrogen at the pump.
- By 2015: At the laboratory-bench scale, demonstrate (1) a photo-electrochemical water-splitting system and (2) a biological system for water-splitting (or other substrates) that both show potential to achieve long-term costs that are competitive with conventional fuels and reduce the cost of hydrogen distribution to $1/kg.

**RD&D Challenges**

- Key challenges to commercializing small-scale distributed production technology are: (1) reducing the capital equipment costs; (2) reducing the cost of operating and maintaining these systems; and (3) using components that can withstand wide temperature ranges under which these systems operate.
- Electrolyzers operating at higher temperatures could provide more cost-effective hydrogen (higher efficiency/reduced electricity demand). Integration with intermittent renewable resources requires development of control strategies and/or design modifications.
- Improved heat and process integration as well as improved catalyst and membrane technology is needed to reduce the cost and improve the energy efficiency for the production of hydrogen from biomass.
- Hydrogen production via chemical cycles using high-temperature heat from nuclear power plants or solar collection facilities will need to be developed and then demonstrated.
- Photoconversion R&D efforts – including photoelectrochemical and photobiological processes – are presently in the exploratory research stage. Biological production of hydrogen from other substrates is also in the exploratory research stage. To continue advancing these technologies, research must be supported.
- Pipeline development to reduce pipeline capital and installation costs while resolving hydrogen embrittlement issues.

**RD&D Activities**

- The overall strategy of the HFCIT Program is to conduct a comprehensive and balanced program that includes mid- and long-term research and development of hydrogen production, storage, and utilization technologies; integrated systems and technology validation using close collaboration with industry that develops, demonstrates, and deploys critical technologies emerging from research and development; and an analysis element that helps determine the performance and cost targets that technologies must meet to achieve goals of the HFCIT Program – as well as specific project objectives determined by peer review.
- DOE's HFCIT Program is carried out by national laboratories, universities, and the private sector, including cost-shared industry-led efforts, and CRADA collaborations between industry and the labs.

**Recent Progress**

- Air Products and Chemicals Inc. achieved a three times reduction in hydrogen purification cost compared with commercially available units

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| • GE Global Research completed R&D for a highly efficient autothermal cyclic reformer for integration into the hydrogen generation system.<br>• Gas Technology Institute (GTI) developed a second-generation fuel processor and a hydrogen filling station with a fast-fill dispensing system.<br>• These three efforts indicate that the technology is approaching $3/gge for dispensed hydrogen from natural gas (690 kg/day, >100 units annually, $4/MMBTU NG, 90% utilization).<br>• An autothermal reformer was installed and operated at a transit agency in California to generate hydrogen for buses and other vehicles. Also at this facility, a PV-electrolysis system is operated to provide renewable hydrogen to the same vehicles.<br>• Increased photobiological efficiency of absorbed sunlight energy to ~15% (5% in 2003), found the first designer proton-channel gene, and designed the DNA sequence for the necessary proton channel to increase system efficiency<br>• Achieved 1,000 hours durability (100 hour in 2003) with new gallium nitride material for photoelectrochemical hydrogen production<br>• Oak Ridge National Laboratory (ORNL) developed a new proton transport membrane that – when used in a less capital intensive, single-step reactor – could cost about a quarter less than conventional hydrogen-purification technologies.<br>• Air Products and Chemicals Inc. fabricated a commercial-size ceramic membrane and operated a pilot scale prototype at 24 MSCFD of hydrogen.<br>• The National Renewable Energy Laboratory (NREL) developed a new catalyst for biomass gasification with reduced coking and improved attrition characteristics.<br>• More than 150 potential thermochemical cycles have been identified and have been screened for energy efficiency and practicality for use with solar concentrators to produce hydrogen from water and sunlight. Four families of cycles have been selected and are being researched. |
| **Commercialization and Deployment Activities** |
| • In an industry-university-national lab partnership, agricultural residues are being used to produce hydrogen and valuable coproducts. Peanut shells represent both a waste-disposal issue and a valuable resource. Pyrolysis of the densified shells results in a valuable vapor stream that can be used to produce chemicals and hydrogen, and in a solid stream that is used to make activated carbon. This concept is currently being tested in a pilot plant, in preparation for operation at an industrial site in Georgia.<br>• An industry-led project is installing a small-scale steam methane reformer to provide hydrogen for vehicles in the Las Vegas, Nevada, area. |