2.2.3 HYDROGEN PRODUCTION

Technology Description

Similar to electricity, hydrogen can be produced from many sources, including fossil fuels, renewable resources, and nuclear energy. Today, hydrogen is produced primarily from natural gas using widely known commercial thermal processes. In the future, it could be produced directly from renewable resources. In the meantime, we can adapt current technologies to produce hydrogen with significantly reduced 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

- Feedstock flexibility is an essential and unique feature of hydrogen systems. With only minor modifications to existing and developing technologies, hydrogen can be produced efficiently and cleanly from nearly any resource.
- Hydrogen made via electrolysis from excess 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 by decarbonization of 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 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 chemicals, fuels, and materials 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 features hydrogen production from sunlight and water via photoconversion. Several processes, including semiconductor and biological, are under development to provide clean hydrogen for the hydrogen economy.

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 safely use about 90 billion m^3 (3.2 trillion ft^3) of hydrogen yearly. Although comparatively little hydrogen is currently used as fuel or as an energy carrier, there are emerging trends that will drive the future consumption of hydrogen.
- Hydrogen production from conventional fossil-fuel feedstocks is commercial (on a large scale), but results in significant CO_2 emissions.
- Current commercial electrolyzers are 70%-80% efficient, but the cost of hydrogen is strongly dependent on the cost of electricity.
- Small-scale reformers are under development for use as on-site hydrogen generators at refueling sites or in power parks.
- Biomass (dedicated feedstocks, agricultural and forest residues, and municipal waste) is being evaluated and tested as feeds for multiproduct biorefineries.
- Longer-term, direct hydrogen production processes – such as nuclear-based thermochemical cycles and high-temperature water-splitting, as well as photoconversion (photobiological, photoelectrochemical, and photochemical) water-splitting – are largely in the research stage. Significant progress is being made toward development of cost-effective, efficient, clean systems.

Current Research, Development, and Demonstration

RD&D Goals

Hydrogen production by photovoltaic hydrolysis.

- By 2005: (1) demonstrate small-scale steam methane reformers with a projected cost of $3.00/kg hydrogen at the pump; (2) develop alternative reactors, including autothermal, ceramic membrane, and microchannel reactors; (3) verify renewable integrated hydrogen production with water electrolysis at a projected capital cost of $300/kW for 236 kg/day capacity, delivered at 5,000 psi.
- By 2010: (1) demonstrate, at the pilot-scale, membrane separation and reactive/membrane separation technology for cost-effective hydrogen production from coal; (2) demonstrate hydrogen production from natural gas or liquid fuels that project to a cost equivalent to gasoline.
- By 2012: complete design of commercial-scale, nuclear-based hydrogen production system.
- By 2015: (1) demonstrate, at lab-scale, nuclear/thermochemical cycle hydrogen production; (2) demonstrate, at lab-scale, a photoelectrochemical water-splitting system; (3) demonstrate, at lab-scale, a biological system for water-splitting; (4) demonstrate a zero-emission coal plant for power and hydrogen production, with plant-gate hydrogen costs of $.79/kg.

RD&D Challenges

- Efficient and cost-effective small-scale reformers have not been demonstrated. New design concepts, including alternative catalysts, need to be fully developed and tested. Start-up and system cycling need to be addressed.
- Alternative reactor designs (autothermal, ceramic membrane, and microchannel) show promise for fossil-based production, but need to be tested and optimized before they can be considered for commercial development and operation.
- 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.
- Engineering challenges need to be addressed in the scale-up and operation of the integrated biorefinery concept at an industrial site, including process control during start-up, shutdown, and upset conditions; process optimization; and integration with existing facilities.
- Hydrogen production via chemical cycles using high-temperature waste heat from nuclear power plants will need to be developed and then demonstrated in alternative facilities before it can be considered for integration near nuclear facilities.
- Photoconversion R&D efforts – including photoelectrochemical, photobiological, and photochemical processes – are presently at the basic research stage. In order to continue advancing these technologies to the applied and engineering stages, research must be supported at universities and national labs.

RD&D Activities

- DOE's HFC&IT Program is carried out by national laboratories, universities, and the private sector, including CRADA collaborations between industry and the national labs, and cost-shared industry-led efforts.
- The overall strategy of the HFC&IT 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 with close industry collaboration that develops, demonstrates, and deploys critical technologies emerging from research and development; and an analysis element that helps to determine the performance and cost targets that technologies must meet to achieve the overall goals of the HFC&IT Program, as well as the specific project objectives determined by peer review.

Recent Progress
• A cooperative project between industry and an Arizona utility demonstrated a fully functional integrated renewable hydrogen utility system for the generation of hydrogen using concentrated solar power. • Intermittent renewable resources (wind and solar) were used to produce hydrogen via electrolysis in a renewable energy fuel cell system in Reno, Nevada. • An industry-led project has developed fueling appliances for small fleets and for home refueling of passenger vehicles. Both types of refueling appliance deliver gaseous hydrogen at up to 5,000 psi to the vehicle. • 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.
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. • An industry-led project is installing a small-scale steam methane reformer to provide hydrogen for vehicles in the Las Vegas, Nevada, area.