II.0 Hydrogen Production Sub-Program Overview

Introduction

Fiscal Year (FY) 2010 Hydrogen Production activities focus on developing technologies that enable the long-term viability of hydrogen as an energy carrier for a diverse range of end-use applications, including portable power, stationary power, backup power, specialty vehicles, and transportation. A variety of feedstocks and technologies are being pursued.

Four DOE offices have been engaged in research and development (R&D) relevant to hydrogen production:

- Energy Efficiency and Renewable Energy (EERE) is developing technologies for distributed production of hydrogen from bio-derived renewable liquids and by electrolysis of water, as well as centralized renewable production options that include water electrolysis integrated with renewable power (e.g., wind, solar, hydroelectric, and geothermal), biomass gasification, solar-driven high-temperature thermochemical water splitting cycles, direct photoelectrochemical (PEC) water splitting, and biological processes.
- Fossil Energy (FE) is advancing the technologies needed to produce hydrogen from coal-derived synthesis gas, including carbon sequestration and co-production of hydrogen and electricity.
- The Office of Basic Energy Sciences, within the Office of Science, conducts basic research to develop a fundamental understanding of biological and biomimetic hydrogen production, PEC water splitting, catalysis, and membranes for gas separation.
- In Nuclear Energy (NE), the Nuclear Hydrogen Initiative was discontinued as a separate program in FY 2009, after the selection of steam electrolysis as being the hydrogen production pathway most compatible with the Next Generation Nuclear Plant (NGNP). Limited development of high-temperature electrolysis is continuing under the NGNP project, which also includes evaluations of other end-user applications and energy transport systems.

Goal

The goal of the Program's hydrogen production portfolio is to research and develop low-cost, highly-efficient hydrogen production technologies from diverse, domestic sources, including coal (with sequestration), nuclear, and renewable resources.

Objective

The objective of the Program's hydrogen production portfolio is to reduce the cost of hydrogen dispensed at the pump to a cost that is competitive with gasoline, on a cents-per-mile basis. This goal applies to all production technology pathways. Specific targets–for *when* the various technologies will achieve this goal–are based on the technologies' current states of development.

FY 2010 Technology Status

Recent independent reviews of production pathway costs are summarized in Table 1. The report, *Distributed Hydrogen Production from Natural Gas* (National Renewable Energy Laboratory [NREL], 2006) provided the basis for DOE to discontinue R&D in steam methane reforming for hydrogen production–it verified that the cost target could be met from distributed reforming of natural gas. Other reports shown in Table 1 reflect the H2A cost projections and cost and performance targets for the Hydrogen Production sub-program's chapter of the Multi-Year Program Plan, which is currently being updated.

Interim and ultimate pathway-specific targets consistent with the overall targets established for the Program are being revised. These will include verification of the competitive feasibility of hydrogen production from non-ethanol bio-derived liquids by 2015, and of hydrogen production using advanced renewable technologies (including PEC and biological hydrogen generation, as well as high-temperature thermochemical cycles driven by concentrated solar energy) by 2020.

TABLE 1. Independent Reviews of Production Pathway Costs

Pathway	Report	Status[1]
Steam Methane Reforming (SMR)	*Distributed Hydrogen Production from Natural Gas,* NREL, October 2006[2]	\$2.75–\$3.50/gasoline gallon equivalent (gge)
Electrolysis Distributed Central (Wind)	*Current (2009) State-of-the-Art Hydrogen Production Cost Estimate Using Water Electrolysis,* NREL, September 2009[3]	Distributed: \$4.90–\$5.70/gge ~75% membrane efficiency (Proton Exchange Membrane) Central: \$2.70–\$3.50/gge ~75% membrane efficiency (Proton Exchange Membrane)
PEC	*Technoeconomic Analysis of Photoelectrochemical (PEC) Hydrogen Production,* Directed Technologies Inc., December 2009[4]	\$2.50–\$10/gge (projected cost based on technology readiness). R&D focus is on materials efficiency, durability and cost.
Biological	*Technoeconomic Boundary Analysis of Biological Pathways to Hydrogen Production,* Directed Technologies Inc., December 2009[5]	\$3–\$12/gge (projected cost based on technology readiness). R&D focus is on organism efficiency, durability, and cost.

[1] Costs for SMR and Electrolysis are projected high-volume costs. Cost projections for PEC and Biological are for technology readiness. Centralized pathway costs do not include delivery and dispensing costs.
[2] http://www.hydrogen.energy.gov/pdfs/40382.pdf
[3] http://www.hydrogen.energy.gov/pdfs/46676.pdf
[4] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/pec_technoeconomic_analysis.pdf
[5] http://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/46674.pdf

The goals and objectives of FE's efforts in hydrogen production are documented in the *Hydrogen from Coal Program Research, Development and Demonstration Plan* (September 2009). They include proving the feasibility of a near-zero emissions, high-efficiency plant that will produce both hydrogen and electricity from coal and reduce the cost of hydrogen from coal by 25 percent compared with current technology, by 2016.

FY 2010 Accomplishments

Biomass, Bio-Derived Liquids, Coal and Separations Processes

- NREL demonstrated hydrogen production by auto-thermal reforming of bio-oil using the bench-scale reactor system and achieved hydrogen production of 7.3 g/100 g bio-oil (potentially 9.6 g/100 g bio-oil after water-gas shift) with 93% bio-oil to gas conversion.
- Argonne National Laboratory (ANL) completed an analysis of the economic feasibility of hydrogen production from glycerol derived as a byproduct of the biodiesel industry. The cost of hydrogen for a base case set of conditions was estimated at \$4.86 per kg, where the price of glycerol was assumed to be \$1.07/gallon. The cost of feedstock (crude glycerol) represented 44% of the cost of hydrogen.
- United Technologies Research Center demonstrated nearly 100% conversion of wood, using an inexpensive base metal catalyst, and completed a study to better understand the impact of base concentration on hydrogen yield and selectivity.
- Eltron Research Inc., Southwest Research Institute®, and Worcester Polytechnic Institute have developed membrane separation technologies that achieve a hydrogen recovery rate of 90% with essentially 100% hydrogen purity, while simultaneously enabling 90–95% CO_2 capture at high pressure, minimizing CO_2 compression costs. (FE project)

Electrolysis

- Giner Electrochemical Systems reduced hydrogen embrittlement in titanium/carbon cell-separators, demonstrated enhanced dimensionally stable membrane (DSM™) performance, and projected a decrease in overall capital cost of their electrolyzer stack from >\$2,500/kW in 2001 to \$463/kW in 2010.

- NREL completed an independent review of wind electrolysis, estimating the levelized cost range for state-of-the-art electrolysis to be \$4.90–\$5.70/gge of hydrogen for forecourt refueling stations (including compression, storage and dispensing), and \$2.70–3.50/gge for central electrolysis operations (at the plant-gate, excluding all delivery and dispensing costs).

Solar Thermochemical Hydrogen Production

- The University of Colorado at Boulder optimized formulations for hercynite materials, which are more stable and generate hydrogen at lower temperature than the traditional ferrites; they also completed a techno-economic analysis indicating that atomic-layer-deposition of ferrite materials on 100 m^2/g supports with an oxidation/reduction cycle every five minutes will meet the 2015 DOE cost targets.
- ANL initiated a development and testing project for new membrane materials for the CuCl electrolyzer in the hybrid copper chloride cycle, and demonstrated that a decrease in the reactor pressure reduces the amount of steam required ($H_2O/CuCl_2$ ratios reduced by more than 30%, from 20–23 to 11–15) for >90% yield of the desired Cu_2OCl_2 product.

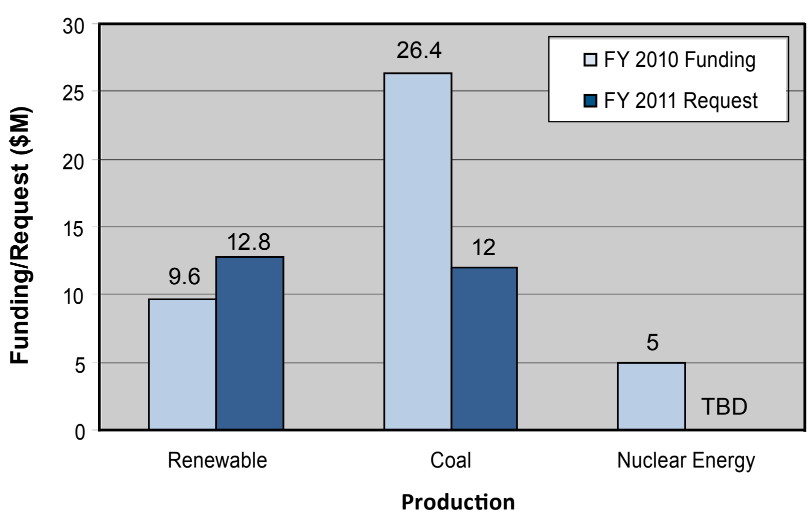
PEC and Biological Production

- Stanford University achieved the first-ever demonstration of bandgap tailoring in photoactive MoS_2 nanoparticles. The bulk MoS_2 bandgap of 1.2 eV was increased to 1.8 eV, a more optimal value for PEC water splitting, by quantum confinement effects in 5-nm diameter nanoparticles.
- Directed Technologies Inc. completed separate techno-economic boundary analyses of PEC solar hydrogen production and biological hydrogen production, projecting cost ranges of \$2.50–\$10/gge H_2 for PEC and \$3–\$12/gge H_2 for biological production, based on the assumption of technology readiness for the PEC materials and biological organisms being developed.
- University of California, Berkeley, developed methods to minimize the size of chlorophyll antennae used in photosynthesis by decreasing the expression of the Truncated-Light-Antenna genes, thereby substantially improving solar light energy utilization efficiencies in plants and microalgal cultures from the 2000 baseline of 3% up to 25%.
- NREL, in collaboration with Pennsylvania State University, designed, constructed, and tested a 2.5-L bench-scale prototype microbial electrolysis cell that produced hydrogen gas at a rate up to 1,250 mL/d, demonstrating the usefulness of this design.

Budget

The FY 2010 appropriation for hydrogen production provided \$41 million for continued hydrogen production research. FE received \$26.4 million, NE \$5 million, and EERE \$9.6 million to continue research efforts in FY 2010.

The President's FY 2011 budget request for EERE includes \$40 million for hydrogen fuel R&D, of which \$12.8 million is planned for hydrogen production, with an emphasis on materials and processes for hydrogen from renewable resources. The request for FE is \$12 million.



FY 2011 Plans

- Continued emphasis on addressing major challenges in hydrogen production. In particular, the sub-program will focus on cost reduction, including the cost of materials and capital equipment. Performance enhancement will remain a priority as cost reductions are expected to result through process optimizations for all production pathways and technologies.
- Completion of an Independent Panel Review of costs for hydrogen production from biomass gasification and an analysis of near-term markets for hydrogen from biomass gasification.
- Update H2A cost projections for hydrogen production pathways.
- Update the Hydrogen Production chapter of EERE's Multi-Year Program Plan.
- Continue EERE coordination with the Office of Science, which plans up to $50 million in basic research related to hydrogen and fuel cell technologies. Through basic science activities, a fundamental understanding of issues related to hydrogen production, particularly in the longer term R&D areas of PEC and biological processes, can help address the challenges of hydrogen production.
- Deployment projects funded by the American Recovery and Reinvestment Act will provide lessons-learned related to hydrogen production technologies.
- The National Energy Technology Laboratory will continue to support implementation of the membrane separation test protocols.
- Eltron Research Inc. plans to perform slipstream tests of a 12 lb/day hydrogen separation membrane at Eastman Chemicals' coal gasification facility.
- Projects will complete 150 hours of laboratory-scale testing of non-precious-metal hydrogen separation membranes to show potential toward cost goals.

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