II.0 Hydrogen Production Sub-Program Overview

Introduction

The Hydrogen Production activity is focused on developing hydrogen production technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power. A variety of feedstocks and technologies are being pursued.

Four DOE offices are engaged in R&D relevant to hydrogen production. The Office of Energy Efficiency and Renewable Energy (EERE) is developing technologies for producing hydrogen in a distributed manner from natural gas, bio-derived renewable liquids, and by electrolysis of water, and is developing centralized renewable production options that include water electrolysis integrated with renewable power (e.g., wind, solar, hydroelectric, geothermal), biomass gasification, solar-driven high-temperature thermochemical water splitting cycles, direct photoelectrochemical water splitting, and biological processes. The Office of Fossil Energy (FE) is focused on advancing the technologies needed to produce hydrogen from coal-derived synthesis gas, including co-production of hydrogen and electricity as well as carbon sequestration. The Office of Nuclear Energy, Science and Technology (NE) is developing commercial-scale production of hydrogen using heat from an advanced nuclear reactor through high-temperature steam electrolysis and thermochemical water splitting cycles. The Office of Science's basic research program is emphasizing fundamental understandings of biological hydrogen production, photoelectrochemical water splitting, catalysis, and membranes for gas separation.

In 2007, EERE completed a significant revision of the Production section of the Program Multi-Year Research, Development and Demonstration Plan. The revision included significant changes to both Program Objectives and individual Technical Targets (see Objectives, below).

Goal

Research and develop low-cost, highly efficient hydrogen production technologies from diverse, domestic sources, including renewable sources.

Objectives

Reduce the cost of hydrogen to $2.00-$3.00/gasoline gallon equivalent (gge) delivered at the pump. This goal is independent of the production technology pathway. Technologies are being researched to achieve this goal in timeframes relative to their current states of development.

- By 2010 reduce the cost of distributed production of hydrogen from natural gas to $2.50/gge (delivered) at the pump. By 2015 to reduce the cost of distributed hydrogen production from natural gas to $2.00/gge (delivered) at the pump.
- By 2012 reduce the cost of distributed production of hydrogen from biomass-derived renewable liquids to $3.80/gge (delivered) at the pump. By 2017, reduce the cost of distributed production of hydrogen from biomass-derived renewable liquids to <$3.00/gge (delivered) at the pump.
- By 2012, reduce the cost of distributed production of hydrogen from distributed water electrolysis to $3.70/gge (delivered) at the pump. By 2017, reduce the cost of distributed production of hydrogen from distributed water electrolysis to <$3.00/gge (delivered) at the pump. By 2012, reduce the cost of central production of hydrogen from wind water electrolysis to $3.10/gge at the plant gate ($4.80/gge delivered). By 2017, reduce the cost of central production of hydrogen from wind water electrolysis to <$2.00/gge at the plant gate (<$3.00/gge delivered).
- By 2012, reduce the cost of hydrogen produced from biomass gasification to $1.60/gge at the plant gate (<$3.30/gge delivered). By 2017, reduce the cost of hydrogen produced from biomass gasification to $1.10/gge at the plant gate ($2.10/gge delivered).
- By 2017, develop high-temperature thermochemical cycles driven by concentrated solar energy to produce hydrogen with a projected cost of $3.00/gge at the plant gate ($4.00/gge delivered) and verify the potential for this technology to be competitive in the long term.

- Develop advanced renewable photoelectrochemical and biological hydrogen generation technologies. By 2018, verify the feasibility of these technologies to be competitive in the long term.
- By 2015, prove the feasibility of a zero emissions, high-efficiency co-production power plant that will produce hydrogen from coal along with electricity.
- Demonstrate the commercial-scale, economically feasible production of hydrogen using nuclear energy by 2017.

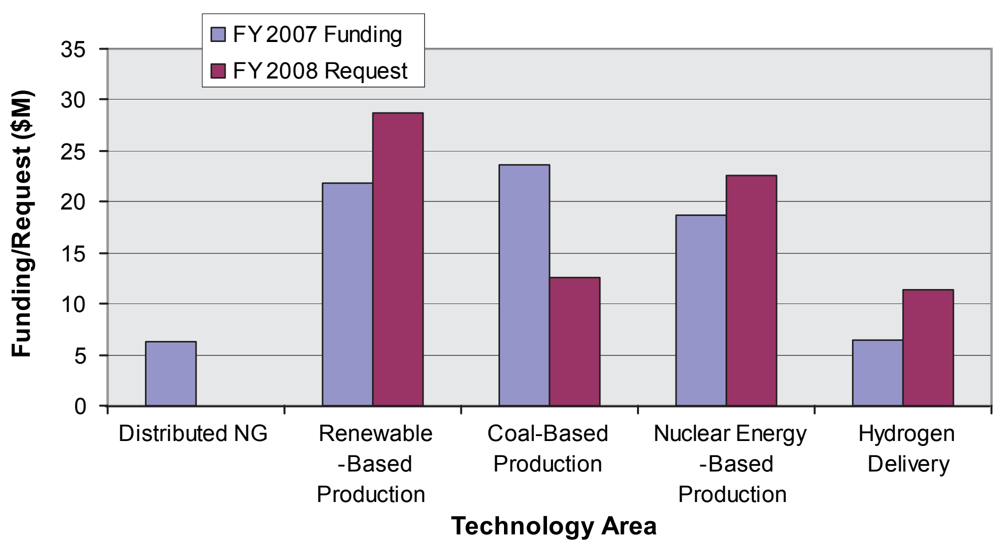
FY 2007 Accomplishments

- H2Gen completed the fabrication of their first distributed 565 kg/day hydrogen generator. The new system will produce five times the capacity of their smaller unit. The generator burner significantly reduces the power required increasing the overall electrical efficiency of the H2Gen small-scale steam methane reforming system. The projected cost of hydrogen from this system at a refueling site at large system production volumes (500 units/yr) approaches the 2010 target of $2.50/gge of hydrogen. In addition, GE's Short Contact Partial Oxidation Reactor and other small-scale hydrogen production technologies made progress towards further reducing the cost of hydrogen produced on-site from natural gas.
- Achieved high hydrogen yields from initial bio-ethanol reforming tests using low-temperature (350-550°C) non-precious metal catalysts.
- Developed a new reactor system to enable aqueous phase reforming of bio-sugar in high concentrations and under conditions that minimize side reactions and eliminates the need for subsequent water-gas shift of the reformer products.
- Giner Electrochemical Systems, LLC demonstrated electrolysis cell efficiency of 72% (lower heating value basis) using an advanced high-strength membrane. This membrane would enable the electrolyzer system to exceed the DOE 2012 efficiency target of 69%. The electrolysis stack capital cost was reduced by greater than 40% through development of low cost components and fabrication methods, including a 60% reduction in stack parts count.
- The National Renewable Energy Laboratory (NREL) Renewable Electrolysis Project completed installation and initial testing of the Wind2H2 Project between NREL and Xcel Energy which integrates wind turbines with both proton exchange membrane and alkaline electrolyzers. Furthermore, NREL completed testing and evaluation of the second generation power electronics interface for connecting a 10 kW wind turbine to a 5 kW electrolyzer.
- Considerable progress was made in the area of solar-driven high temperature thermochemical water splitting for hydrogen production. This effort is on track for a down-select to two to four cycles in FY 2008 for further development and initial on-sun integrated verification in 2012.
- At the University of Nevada, Las Vegas a collaborative research team was established that combines materials theory, synthesis, and characterizations. Focus materials classes for photoelectrochemical pathways were established and the following progress was made in recent focus materials experiments: 1) photocurrents in excess of 6.5 mA/cm^2 in Si- and chalcopyrite-based films and; 2) solar to hydrogen device efficiencies in excess of 3% in WO_3-based multi-junction structures (under 1-sun).
- In biological pathways, O_2-tolerant hydrogenase genes in *E. Coli* were developed by NREL for increasing continuity of H_2 production using cyanobacteria.
- The University of California at Berkeley isolated a gene (*Tla1*) which regulates antenna size in light-harvesting chlorophyll during photosynthesis, opening the way for improved solar conversion efficiency in hydrogen producing microalgae.
- Eltron Research, Inc. developed a dense cermet membrane that demonstrated the ability to meet FE's 2010 hydrogen membrane targets at laboratory-scale and plans to scale-up from 1.3 lbs/day to 220 lbs/day and eventually to 4 tons/day.
- Southwest Research Institute has also demonstrated the ability to meet FE's 2010 hydrogen separation technical targets and has produced self-supported Pd-Cu alloy membranes that have reduced membrane thickness to 5 microns.

- Two separate research teams, led by Aspen Products group and United Technologies Research Corporation, have developed and successfully tested several tri-metallic water-gas shift hydrogen separation membranes and reactors.
- The team consisting of Sandia National Laboratories, General Atomics, and the Commissariat à l'Energie Atomique of France completed assembly of an integrated laboratory-scale Sulfur-Iodine thermochemical system and performed pre-operational testing consisting of system operation using water as a surrogate fluid.
- Idaho National Laboratory completed assembly and pre-operational testing of an integrated laboratory-scale high temperature steam electrolysis system consisting of verification of individual component performance.
- Savannah River National Laboratory completed a 100-hour longevity test of a single-cell SO_2 depolarized electrolyzer for use in the Hybrid sulfur cycle, and constructed and began testing of a multi-cell electrolyzer.

Budget

The President's FY 2008 budget request includes increased funding for R&D on hydrogen production from nuclear and renewables resources. There will be no additional funding for R&D on distributed natural gas reforming in FY 2008. (Current funding already in place is targeted to further reduce the cost of hydrogen from the current $3.00/gge towards $2.50/gge.) A reduction in coal-based hydrogen production technologies is also indicated.

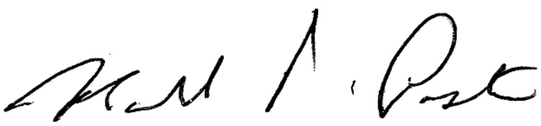


2008 Plans

- The interim target for natural gas distributed reforming has been met and the R&D emphasis for distributed reforming will be shifted from natural gas to bio-derived liquids (<$3.00/gge delivered in 2017).
- Establish a Hydrogen Separations and Purification Working Group.
- Continue to work with the Hydrogen Utility Working group to increase collaboration with electric utilities on development of high-efficiency, low-cost electrolysis systems, and increase focus on the integration of electrolysis technologies with renewable electricity sources ($3.00/gge delivered by 2017). Establish new projects to reach this goal.
- Support biomass gasification R&D by funding verification of conventional technology integrated for hydrogen production at a bench/pilot scale, and breakthrough approaches utilizing a membrane

in the gasifier for process intensification and biomass hydrolysate aqueous phase reforming while continuing to leverage the DOE EERE Biomass Program efforts.

- Continue the development of solar-driven high temperature thermochemical water splitting technology. Down-select to two to four cycles based on laboratory research results and H2A cost analyses.
- After several years of low funding in the longer-term renewable technologies of photobiological and photoelectrochemical, establish a more robust R&D effort in these technologies.
- Continue research efforts on hydrogen from coal production technologies and advance hydrogen separation membrane technologies to the next scale of development. Conduct laboratory-scale efforts on combined water-gas shift hydrogen separation systems (i.e., process intensification).
- Conduct integrated laboratory-scale experiments on the Sulfur-Iodine thermochemical cycle and high temperature steam electrolysis to confirm the technical viability of the integrated system.
- Conduct key technology experiments to determine feasibility of the Copper-Chlorine and Calcium-Bromine thermochemical cycles as alternatives to sulfur-based cycles.



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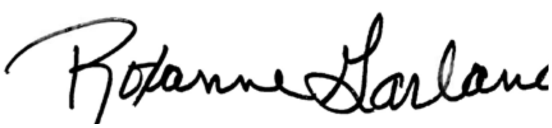

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