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 research and development (R&D) relevant to hydrogen production. The Office of Energy Efficiency and Renewable Energy (EERE) has developed the technology for producing hydrogen in a distributed manner from natural gas and is developing technologies for producing hydrogen from bio-derived renewable liquids and by electrolysis of water. Further, EERE is developing 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 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 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 and biomimetic 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 fossil, nuclear and renewable sources.

Objectives

Reduce the cost of hydrogen to $2.00-$3.00/gasoline gallon equivalent (gge) delivered at the pump. This goal applies to all production technology pathways. Technologies are being researched to achieve this goal in timeframes relative to their current states of development. The delivered cost target of the hydrogen production pathways are summarized in the following table:

Production Pathway	Production Site	Near-Term Hydrogen Cost Target		Long-Term Hydrogen Cost Target	
		Year	$/gge	Year	$/gge
Bio-Derived Liquids	Distributed	2014	3.80	2019	3.00
Electrolysis	Distributed	2014	3.70	2019	3.00
Biomass Gasification	Central	2014	3.30	2019	2.10
Electrolysis	Central	2014	4.80	2019	3.00
Solar Thermochemical	Central	N/A	N/A	2019	4.00
Nuclear – Electrochemical and Thermochemical	Central	2014	5.00	2020	4.50
Coal with Sequestration	Central	N/A	N/A	2016	3.00

N/A - not applicable

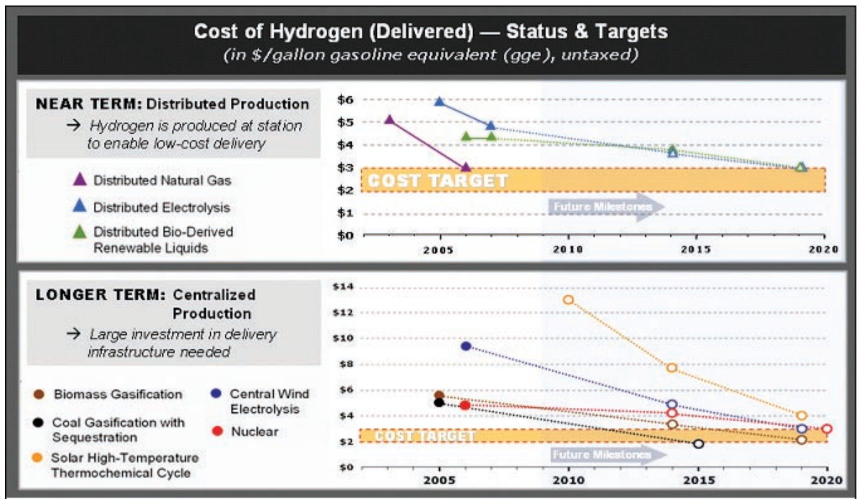
In addition to the objectives listed in the table above:

- By 2019, verify the potential for high-temperature thermochemical cycles driven by concentrated solar energy to be competitive in the long-term.
- Develop advanced renewable photoelectrochemical (PEC) and biological hydrogen generation technologies. By 2020, verify the feasibility of these technologies to be competitive in the long-term.

- By 2016, prove the feasibility of a near-zero emissions, high-efficiency co-production power plant that will produce hydrogen from coal along with electricity.
- Demonstrate commercial-scale, economically feasible production of hydrogen using nuclear energy by 2020.

FY 2008 Status

The hydrogen production pathways include distributed (produced where the hydrogen is used) and central production technologies. The distributed production technologies include reforming of bio-derived liquids and water electrolysis. (Distributed steam methane reforming R&D is no longer funded by the DOE.) The centralized production technologies include biomass gasification, coal gasification with sequestration, water electrolysis using wind, solar or geothermal energy to generate the electricity, thermochemical technologies using nuclear or solar energy, biological and photoelectrochemical technologies. Milestones for these production technologies are based primarily upon achieving the target cost of $2.00 to $3.00/gge. The current status of the projected cost of the various pathways and the future milestones are shown in the figure below.



In 2008, the research and development efforts in the technologies have continued to make progress toward the long-term target costs and toward commercialization. For example, the distributed bio-derived liquid reforming processes using bio-oil and ethanol have projected production costs that approach or are below the 2014 cost target of $3.80/gge. The membrane separation research and development in Fossil Energy is advancing toward a demonstration at a commercial facility. In Nuclear Energy, the lab-scale demonstration of high-temperature electrolysis was expanded to 720 cells with an initial hydrogen production of 5,000 l/hr, and the thermochemical Sulfur-Iodine cycle integrated laboratory demonstration unit began operation. For the longer-term pathways of biological and photoelectrochemical technologies, work has begun to provide a baseline, modeled cost of each pathway, which will be used to identify areas in which R&D should be focused in future solicitations.

The EERE sub-program also awarded two new competitively selected projects in FY 2008 for $3.9 million over three years, totaling $4.9 million with cost sharing. These two projects, which were awarded to Avalence and to Giner Electrochemcal Systems, will develop improved water electrolyzer technology to help achieve the objectives that are listed above.

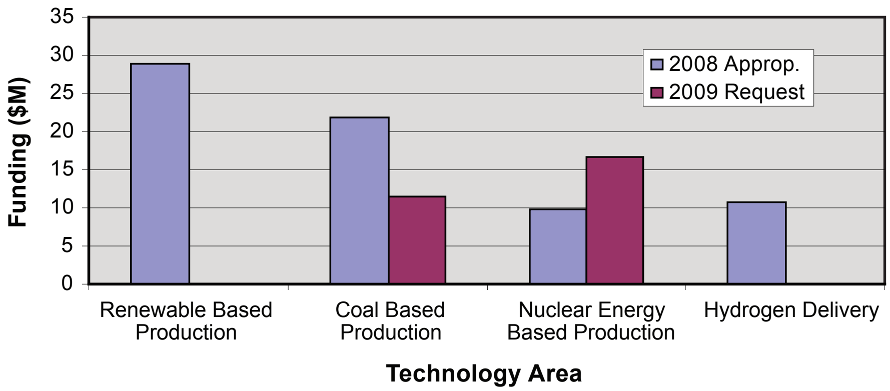
FY 2008 Accomplishments

- H2Gen Innovations, Inc. has completed the design, construction and demonstration of a steam methane reformer and pressure swing adsorption system for on-site distributed hydrogen generation. The field test of the prototype Model HGM 10000 was terminated in May, 2008 after achieving 3,963 operating hours in the field (at greater than 67.5% lower heating value efficiency), exceeding the goal of 2,500 field-test hours. Based on results to date and projected cost estimates, it is expected that the HGM 10000 (565 kg H_2/day) technology scaled to 1,500 kg H_2/day will meet or exceed the DOE 2015 cost targets for distributed hydrogen production from natural gas at a fueling station. Completion of this contract brings to a close DOE funded R&D on distributed steam methane reforming.
- Analysis shows that, with improvements made by the National Renewable Energy Laboratory (NREL) in bio-oil reforming and by Ohio State University (OSU) in ethanol steam reforming, the NREL and OSU processes have the potential to meet the 2019 hydrogen production cost target of $3.00/gge (including delivery).

- Ohio State University has demonstrated H_2 yields over 90% during bio-ethanol steam reforming over non-precious metal catalysts at temperatures below 500°C under neat reaction conditions. Initial H2A economic analysis indicates a hydrogen production cost of $3.17/gge without delivery costs.
- Virent Inc., and Pacific Northwest National Laboratory (PNNL) researchers continued to improve aqueous phase reforming (APR) of bio-derived liquids. This technology, which can produce hydrogen from inexpensive, renewable feedstock, such as glucose and other sugars, through low-temperature processing without steam, is expected to be more cost-effective than conventional gas phase reforming. Specific achievements include:
  - Catalyst lifetimes now exceed 1 year, a reduction of the cost of H_2 by 10X since 2005, and a 700X scale-up in reactor size to 10 kg H_2/day by Virent, Inc. for APR of sugars and sugar alcohols.
  - 50% improvement in hydrogen productivity by APR of bio-derived carbohydrates demonstrated by PNNL through chemical control of feedstock and catalyst improvement.
- Pall Corporation has demonstrated the potential of Pd membranes to achieve very high levels of H_2 purity (99.999%) in mixed gas tests, exceeding the 2010 hydrogen permeate quality goal and their preliminary analysis projects that the 2010 goal of $1,000/ft^2 module is achievable.
- Giner Electrochemical Systems, LLC has improved stack efficiency from 61% (400 psi) to 67% at 1,200 psi and tested a new membrane in a single cell which shows an efficiency of 74% and is about 1/10 the cost of the current Nafion® membrane.
- Cycle cost projections for the active solar thermochemical cycles have been reduced from about $10.00/gge to below $5.00/gge and are showing the potential to meet the 2019 cost target of $3.00/gge.
- The University of Nevada, Las Vegas and the University of Hawaii accomplished the first all-experimental determination of the electronic surface structure of a candidate PEC material (WO_3), enabling in situ, real-time material characterization.
- The Photoelectrochemical Working Group developed a draft standardized test protocol for material characterization, which is needed to develop and implement material selection criteria in 2009.
- The J. Craig Venter Institute cloned a novel hydrogenase, along with its structural and accessory genes, using environmental DNA, providing the capability to greatly expand the library of hydrogen producing enzymes.
- NREL developed a bio-degradable matrix for immobilizing biological cells that increases light-conversion efficiency and protects the hydrogen producing system from oxygen inactivation for up to 6 days.
- Eltron Research, Inc. and Southwest Research Institute® have demonstrated, in bench-scale tests, membranes that have the ability to meet nearly all of FE's 2010 hydrogen separation targets. Preliminary cost estimates of the Eltron membrane show that it could be competitive with conventional technology. Southwest Research Institute® has also produced self-supported Pd-Cu alloy membranes that have reduced membrane thickness to 5 microns.
- The National Energy Technology Laboratory Office of Research and Development (ORD) has completed independent verification testing of several membranes to validate performance. ORD has also conducted studies on the impact of sulfur on palladium membranes that have shown that two degradation mechanisms typically occur and that gas species concentrations throughout the membrane can impact degradation.
- The team consisting of Sandia National Laboratories, General Atomics, and the Commissariat à l'Energie Atomique of France began integrated operations of a laboratory-scale Sulfur-Iodine thermochemical system and produced hydrogen at initial rates of 30-40 liters per hour.
- Idaho National Laboratory upgraded their integrated laboratory-scale high-temperature steam electrolysis system to the full 720-cell configuration and began operations with an initial output of over 5,000 liters per hour.
- Savannah River National Laboratory successfully tested a multi-cell SO_2 depolarized electrolyzer for use in the hybrid sulfur cycle, and continued development of improved membranes for use in the system.

Budget

As shown in the bar chart below, the President's FY 2009 budget request includes increased funding for R&D on hydrogen production from nuclear resources compared to the 2008 Congressional appropriation, and the funding request for coal-based hydrogen production technologies is lower than the FY 2008 appropriation. The EERE 2009 hydrogen production budget request is $0 to allow for focused effort on the critical path technologies of on-board storage and fuel cells.



2009 Plans

- Fund EERE projects into 2009 to allow for the projects to reach a logical stopping point in the experimentation while R&D efforts are shifted to on-board hydrogen storage and fuel cells.
- Continue laboratory-scale research efforts on coal-based hydrogen production technologies, hydrogen separation membrane technologies, and combined water-gas shift hydrogen separation systems (i.e., process intensification).
- Implement the testing protocol for separation and purification systems for hydrogen from coal.
- Complete integrated laboratory-scale experiments on the Sulfur-Iodine thermochemical cycle and high-temperature steam electrolysis to confirm the technical viability of the integrated system.
- Construct, test, and analyze short stacks of solid oxide electrolysis cells to improve longevity and to determine and mitigate the causes of cell degradation.
- Intensify efforts to find solutions for sulfur crossover in SO_2 depolarized electrolysis cells.
- Conduct key technology experiments to determine feasibility of the copper-chlorine thermochemical cycle as an alternative to sulfur-based cycles.

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