2005 Annual DOE Hydrogen Program Review
Hydrogen Production & Delivery

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Hydrogen Program
Hydrogen Production Team Leader
May 23, 2005
State of the Art
Near-term technologies

- **Distributed Natural Gas Steam Methane Reforming:** $4-5/gasoline gallon equivalent (gge) delivered

- **Electrolysis:** $4.75 – 5.15/gge delivered

  [Image of Sunline HyRadix Reformer]

  [Image of Giner PEM Electrolyzer]
EERE
- Distributed natural gas and bio-derived liquid reforming
- Electrolysis
- Reforming biomass gas from gasification/pyrolysis
- Biological hydrogen production
- Photoelectrochemical hydrogen production
- Solar HT thermochemical cycles
- Separations

Office of Fossil Energy
- Coal gasification with sequestration

Office of Nuclear Energy
- Nuclear driven HT thermochemical cycles
- HT electrolysis

Office of Science
- Basic research on materials and catalysts
Hydrogen Production Barriers
Cost and Energy Efficiency

Distributed Reforming
Using Natural Gas and Renewable Liquids
• Intensified, lower capital cost, more efficient NG reformer technology
• Improved catalysts and technology for renewable liquid reforming
  • Ethanol, sugar alcohols, bio-oil

Electrolysis
• Low cost materials and high efficiency system designs
• Integrated compression
• Integrated wind power/electrolysis systems

Biomass Gasification
• Integrated gasification, reforming, shift and separations technology to reduce capital cost and improve efficiency.

Solar/Photolytic
• Durable and efficient materials for direct photo-electrochemical solid state water splitting using sunlight
• Microorganisms that split water using sunlight or produce H2 through fermentation
• Thermochemical cycles, solar concentrators, receivers/reactors to split water (600 – 2000 C)
  • Effective and efficient thermochemical cycles
  • Reduced capital cost of the solar concentrator
New Hydrogen Cost Goal for 2015

- Pathway independent

- Consumer fueling costs are equivalent on a cents per mile basis

- Gasoline ICE and gasoline-electric hybrids are benchmarks

- Provide a "yardstick" for assessing technology performance
Hydrogen Cost
Goal for 2015

Mechanics

\[
\text{H2 Cost (} \$/\text{gge} \text{)} = \frac{(\text{EIA Projected Gasoline Price in 2015})}{\text{Fuel Economy H2FCV \over \text{Fuel Economy Competitive Vehicle}}} \]

<table>
<thead>
<tr>
<th>Input</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline price projection for 2015</td>
<td>$1.26 / gal (untaxed, 2005 $)</td>
<td>EIA Annual Energy Outlook, 2005</td>
</tr>
<tr>
<td>Ratio of FCV fuel economy to evolved gasoline ICE</td>
<td>2.40</td>
<td>NRC H2 Economy Report</td>
</tr>
<tr>
<td>Ratio of FCV fuel economy to gasoline hybrid</td>
<td>1.66</td>
<td>NRC H2 Economy Report</td>
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Results

• $2.00 - $3.00 / gge*

1 Ratio of FCV fuel economy to competitive vehicle

* Actual calculated values are $2.09 and $3.02 / gge
Hydrogen Production Targets Compared to 2015 Cost Goal

- Dist. NG
- Dist. Renewable Liquids
- Water Electrolysis

* Pending final approval by DOE Change Control Board
Hydrogen Production & Delivery Funding Distribution

FY 04 = $10.3 M*

- Distributed Reforming: 27%
- Electrolysis: 9%
- Reformer: 17%
- Delivery: 25%
- Analysis: 15%
- Bio & PEC: 4%
- Central Biomass Reforming: 4%
- Solar HT: 3%
- Thermochemical Separations: 4%

FY 05 = $14.2 M**

- Distributed Reforming: 20%
- Electrolysis: 18%
- Delivery: 27%
- Analysis: 4%
- Bio & PEC: 4%
- Central Biomass Reforming: 4%
- Solar HT: 3%
- Thermochemical Separations: 3%

Total FY 06 Request = $32.0 M

*FY 04 Appropriation including earmarks = $22.6 M
**FY 05 Appropriation including earmarks = $25.3 M
R & D Plan

New goals and targets
• Distributed renewable liquid reforming
• Water electrolysis from central renewables
• Separations technologies: dense metallic and microporous
• Biomass (gasification/pyrolysis) reforming
• Photosynthetic bacteria and dark fermentation

Detailed target guidance
• Capital equipment targets separate from operations and maintenance
• Total system energy efficiency
• Specific capacity utilization factors

Developed R & D targets based on common set of economic parameters
• 10% IRR after taxes, 100% equity financing, 1.9% inflation, 38.9% tax rate, 7 year depreciation

http://www.eere.energy.gov/hydrogenandfuelcells/mypyp/
Key Milestones

**FY 2008**

- Go/No-go: Determine if membrane separation technology can be applied to natural gas distributed reforming during the transition to a hydrogen economy.
- Down-select to a primary technology and configuration for central biomass gasification/pyrolysis clean-up, reforming, shift, separations and purification.

**FY 2009**

- Complete development of integrated “appliance” type distributed reforming system applying DFMA principles.

**FY 2010**

- Go/No-Go: Identify cost-effective transparent H2-impermeable materials for use in photobiological and photoelectrochemical systems.
- Go/No-Go: Verify the feasibility of an effective integrated high-temperature solar-driven thermochemical cycle for hydrogen projected to meet the 2010 cost goal of $6/gge ($4/gge delivered by 2015).
2004 & 2005 DOE Hydrogen Production & Delivery Projects

Distributed Production
- MSRI
- GE Energy
- Air Products
- GTI
- PNNL
- Virent Energy Systems
- BOC Group, Inc.
- H2Gen Inno. Inc.
- GE Global Res.

Separations
- Eltorn Res. Inc.
- ORNL
- GTI

Photobiological
- U.C. Berkeley
- NREL
- ORNL
- J. Craig Venture Institute

Biomass Reforming

H.T. Thermochemical
- Univ. of Nevada

Photoelectrochemical
- U. of Hawaii
- NREL
- U. of Cal. Santa Barbara
- Midwest Optoelectronics
- GE Global Research
- SRI

Electrolysis
- Giner
- INEEL
- NREL
- Teledyne

Delivery
- ANL
- ORNL
- Air Products
- Secat, Inc.
Hydrogen Production R&D – Planning and Implementing

- **May ‘04**: Production & Delivery Selections Announced
- **Jun ‘04**: Annual Program Review

**Workshops**
- **May ‘04**: Fermentation Workshop
- **Sep ‘04**: Separations Workshop
- **Oct ‘04**: Utility Electrolysis Workshop
- **Nov ‘04**: Solar Electrolysis Workshop
- **Feb ‘05**: R&D Plan Published

**Development Solicitations**
- **May ‘05**: Opening Solid oxide Materials & Systems Development Solicitation

**Tools**
- **H2A Tool**
Recent Technical Accomplishments

Natural Gas Distributed Reforming
• Approaching R & D target of $3/gge for distributed natural gas reforming at 5000 psi.

Electrolysis
• Achieved 2000 psi H2 production in planar electrolysis stack
• Developed new system designs with 40-50% part count reduction
• Novel stack design for alkaline system on track for achieving a hydrogen production cost of $2.85/gge by 2010.
Recent Technical Accomplishments

Biological

- Increased photobiological efficiency of absorbed sunlight energy to ~15% (5% in 2003)
- 40-50% increase in oxygen tolerance achieved

Photoelectrochemical

- Projected 1000 hours durability with new gallium phosphide nitride material for photoelectrochemical based on accelerated testing
- Integrated photovoltaic electrolysis panel ready for prototype testing
Recent Technical Accomplishments

**Biomass Gasification/Pyrolysis**
- Developed biomass reforming catalyst to reduce coking and attrition

**Solar HT Thermochemical**
- Demonstrated lab feasibility of zinc and manganese cycles
- Selected 4 groups of cycles
  - Volatile metal
  - Metal oxide
  - Sulfate
  - Sulfuric acid
Delivery State of the Art

- Today hydrogen is transported by cryogenic liquid trucks and gaseous tube trailers. There is also a very limited transmission pipeline infrastructure (630 miles; Gulf Coast, California, Chicago)
- Cost $4-9/gge of H2 or more depending on distance for truck transport. Pipeline transport can be <$1/gge.
Delivery Pathways and Components

- **Pathways**
  - Gaseous Hydrogen Delivery
  - Liquid Hydrogen Delivery
  - Carriers

- **Components**
  - Pipelines
  - Compression
  - Liquefaction
  - Liquid and Gaseous
    - Storage Tanks
  - Carriers & Transformations
  - GH2 Tube Trailers
  - Terminals
  - Separations/Purification
  - Dispensers
  - Mobile Fuelers
  - Other Forecourt Issues
  - Cryogenic Liquid Trucks
  - Rail, Barge, Ships

Including mixed pathways
Delivery Barriers

Analysis Needs
• Infrastructure options and trade-offs for the transition and long term

Compression
Transmission and Forecourt Applications
• Reliability
• Lower capital costs
• Energy efficiency

Pipelines
• Hydrogen embrittlement and permeability
• Lower capital costs – new materials to reduce pipeline installation costs
• Coating – to allow usage of existing NG or other pipeline infrastructure or for new pipelines
• ROW
• Can we use existing NG infrastructure for mixtures if H2 and NG?

Liquefaction
• Higher energy efficiency – current technology consume >30% of H2 energy
• Lower cost – current technology >$/gge of H2

Off-Board Storage
Forecourt, Terminals, Other
• Lower cost (lower capital cost)
• Smaller footprint (Forecourt)

Novel Carriers
• Discovery of novel solid or liquid carriers with sufficient H2 density
• System energy efficiency and cost
Delivery Objectives

• By 2007, define the criteria for a cost-effective and energy-efficient hydrogen delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.

• By 2010, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to < $0.90/gge of hydrogen.

• By 2010, develop technologies to reduce the cost of compression, storage, and dispensing at refueling stations and stationary power sites to less than < $0.80/gge of hydrogen.

• By 2015, develop technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to < $1.00/gge of hydrogen in total.
## Delivery Key Targets

<table>
<thead>
<tr>
<th>Targets</th>
<th>2003 Status</th>
<th>2015 Target</th>
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<tbody>
<tr>
<td>Transmission Pipeline Capital ($/mile)</td>
<td>$1.20</td>
<td>$0.80</td>
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<tr>
<td>Forecourt Compression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost Contribution ($/gge of H2)</td>
<td>$0.60</td>
<td>$0.25</td>
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<tr>
<td>Reliability</td>
<td>Unknown</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>Forecourt Storage Cost Contribution ($/gge of H2)</td>
<td>$0.70</td>
<td>$0.20</td>
</tr>
<tr>
<td>Carrier (weight % H2)</td>
<td>3%</td>
<td>13%</td>
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Delivery Planning and Implementation

- Delivery Workshop
- H2A Delivery Analysis Initiated
- Pipeline WG Formed
- Solicitation Project Awards Announced
- Carrier Feasibility
- Compression Technology Down-Select
- R&D Plan Published
- Comprehensive Delivery Analysis
- Pipeline Materials Down-Select
Delivery Funding

FY04 Actual

Delivery Pipeline R&D $150k
Delivery Analysis $170k
Total = $0.32M

FY05

Delivery Pipeline R&D
Delivery Analysis
Liquefaction
Carriers
Storage
Total = $2.7M
Delivery

Key Accomplishments

• Delivery Tech Team and Draft Roadmap

• R&D Multi-Year Plan

• H2A Delivery Analysis Tools
  – Components and Scenarios

• Initial Portfolio of Research Projects

• Pipeline Working Group
## DOE Hydrogen Production Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Contact Information</th>
<th>Responsibilities</th>
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<tbody>
<tr>
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