Hydrogen Program Response to GAO Comment on Targets

HTAC Meeting
February 18, 2009

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DOE Hydrogen Program

Hydrogen Fuel Initiative

DOE has made important progress and involved stakeholders but needs to update what it expects to achieve by its 2015 target.
OUTLINE

• Overview of GAO Review
• Findings
  – Program Management & Progress
  – Remaining Challenges & Gaps
• GAO Main Recommendation: Clarity on 2015 Technology Readiness
• Current Targets
• Reevaluation of Targets
Examined extent to which DOE:

- Made progress in meeting targets
- Worked with industry to set and meet targets
- Worked with other federal agencies to develop and demonstrate targets

Process:

- Reviewed documents
- Interviewed DOE program managers, national laboratory scientists, industry executives, independent experts, and federal/state government officials
- Assessed DOE’s process for soliciting industry input
- Attended technical meetings
- Toured industry facilities
- Attended 1st meeting of the Interagency Task Force (August 2007)
FINDINGS
Program Management & Progress

• DOE has made important progress in all R&D areas (fundamental and applied science):
  – Reduced cost of producing hydrogen from natural gas
  – Developed model to identify/optimize major elements of a H₂ delivery infrastructure
  – Increased storage capacity of H₂ by 50%
  – Reduced cost and improved durability of fuel cells

• DOE has generally managed its R&D resources well

• Managers at other federal agencies are generally satisfied with effort to coordinate activities among agencies

• DOE has involved experts at earliest planning stages and has continually focused on highest R&D priorities
FINDINGS
Remaining Challenges & Gaps

• Challenges requiring significant scientific advances lie ahead
  – Storing enough $H_2$ onboard to achieve >300 mi driving range
  – Reducing cost of delivering $H_2$ to consumers
  – Further reducing cost and improving durability of fuel cells

• Technical challenges and budget constraints has led DOE to push back some of its interim target dates

• DOE has not identified R&D funding needed to achieve its 2015 targets (Note: DOE does not publish out year budget profiles.)

• Emphasis on fuel cell for vehicles has left little funding for stationary/portable applications which potentially could be commercialized before vehicles
GAO MAIN RECOMMENDATION
Clarity on 2015 Technology Readiness

GAO Finding…

“DOE has not updated its 2006 Hydrogen Posture Plan to reflect what it reasonably expects to achieve by technology readiness date of 2015.”

DOE Response…

• Working toward cost and performance targets to enable technologies to be competitive in the market and industry to make commercialization decisions
• Identified critical path R&D/targets for automotive applications
• Also identified R&D activities/targets to further develop and sustain hydrogen infrastructure beyond 2015, as well as for fuel cells in stationary and portable applications
• Targets are currently being reevaluated and updated to reflect changes over the past several years
**Hydrogen Production - Cost**

- **Target (2015):** $2 - 3/gge (*delivered, untaxed*)
  - **Achieved:** $3/gge (*H₂ from distributed natural gas*)
  - **Status:** $4.5/gge – 5.0/gge (*distributed renewable H₂*)
  - **Status:** $5/gge - $9/gge (*central H₂*)

* Includes $3/gge for delivery.
### CURRENT TARGETS

#### Critical Path Technologies - H₂ Storage

#### H₂ Storage – System Gravimetric Capacity*
- Target (2010): 6%
- Target (2015): 9%

#### H₂ Storage – System Volumetric Capacity*
- Target (2010): 1.5 kWh/L (45 g/L)
- Target (2015): 2.7 kWh/L (81 g/L)

#### H₂ Storage System - Cost
- Target (2010): $4/kWh
- Target (2015): $2/kWh

#### H₂ Storage – 350 bar compressed H₂ - Status
- **Gravimetric Capacity**: 2.8% – 3.8%
- **Volumetric Capacity**: 17 – 18 g/L
- **Cost**: $17/kWh

#### H₂ Storage – 700 bar compressed H₂ - Status
- **Gravimetric Capacity**: 2.5% – 4.4%
- **Volumetric Capacity**: 18 – 25 g/L
- **Cost**: $27/kWh

#### H₂ Storage – Liquid H₂ - Status
- **Gravimetric Capacity**: 3%
- **Volumetric Capacity**: 14 – 19 g/L
- **Cost**: $15.6/kWh

#### H₂ Storage – Materials (adsorbent) - Status
- **Gravimetric Capacity**: 3%
### Fuel Cells (Auto) - Cost

- Target (2010): $45/kW
- Target (2015): $30/kW
  - Status (2008): $73/kW

### Fuel Cells (Auto) - Durability

- Target (2010 & 2015): 5,000 hrs
  - Status (2008):
    - 1,900 hrs (projected)
    - 1,700 hrs (observed)
CURRENT TARGETS
Other Targets

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- 2010: Distributed Bio-derived Liquids at $3.80/gge
- 2011: Distributed Electrolysis at $3.70/gge
- 2012: Central Wind Electrolysis at $3.10/gge (plant gate)
- 2013: Central Biomass Gasification at $1.60/gge (plant gate)
- 2014: Hydrogen Delivery 40% Efficiency
- 2015: Fuel Cells (Stationary) Cost $750/kW
- 2016: Durability 40,000 hrs
- 2018: Energy Density 1,000 W-h/L
- 2019: Hydrogen Delivery Efficiency 40%
- 2020: Fuel Cells (Stationary) Cost <$3/gge
The Program is Reevaluating Targets

• Milestones exist to reevaluate targets (e.g., H₂ storage targets evaluated every 5 years) to assure validity of assumptions

• Significant changes have occurred in past 5 years
  – Access to “real-world” data
  – Changes in cost of gasoline
  – Changes to vehicle architecture assumptions
  – Learning
    • Competing technologies
    • System requirements
    • Market requirements
BACK-UP SLIDES
Evolution of Technologies & Markets

RD&D continues beyond technology readiness milestone.

I. RESEARCH & TECHNOLOGY DEVELOPMENT
- Basic and applied research and technology development are conducted to meet technology performance and cost targets

II. INITIAL MARKET PENETRATION
- Portable power and stationary/transport systems are validated; infrastructure investment begins with governmental policies

III. EXPANSION OF MARKETS AND INFRASTRUCTURE
- Hydrogen power and transportation systems commercially available; infrastructure business case realized

IV. FULLY DEVELOPED MARKETS & INFRASTRUCTURE
- Hydrogen power and transport systems commercially available in all regions; national infrastructure developed

ONGOING RD&D
- Basic science research and applied RD&D continue, to develop and improve technologies to allow for widest possible commercialization of the technologies and full realization of benefits
• The Program has identified the critical path barriers and the targets that need to be met for fuel cell vehicle (FCV) technology readiness in 2015.
• Targets for stationary and portable power fuel cells have also been developed.

<table>
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<th>Challenges &amp; Barriers</th>
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<tr>
<td>Hydrogen Cost</td>
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<td>Target: $2 – 3 /gge</td>
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<td>H₂ Storage Capacity &amp; Cost</td>
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<td>Greater than 300-mile range, without compromising safety or performance</td>
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<td>Fuel Cell Cost &amp; Durability</td>
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<td>Targets:</td>
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<tr>
<td>Vehicles: $30 per kW, 5000-hr durability</td>
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<td>Stationary Systems: $750/kW, 40,000-hr durability</td>
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<td>Technology Validation:</td>
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<td>Technologies must be demonstrated under real-world conditions</td>
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<td>Economic &amp; Institutional Barriers</td>
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<td>H₂ Supply &amp; Delivery Infrastructure</td>
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<td>Domestic Manufacturing &amp; Supplier Base</td>
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<td>Public Awareness &amp; Acceptance</td>
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Critical Path Barriers for FCVs:

Market Transformation
Assisting the growth of early markets will help to overcome many barriers, including achieving significant cost reductions through economies of scale.
The Program is working to develop clean, diverse, pathways for the supply of hydrogen from domestic resources, including fossil, nuclear, and renewable sources.

**Key Production Objective:**
Reduce the cost of **delivered** hydrogen (untaxed) to $2.00 – $3.00/gge (gallon gasoline equivalent).

**Key Delivery Objective:**
Reduce total hydrogen delivery cost to < $1.00/gge.

**Current costs:**
- $3/gge to ~$5/gge
  - (includes $3/gge for delivery)
- ~$5/gge to ~$9/gge

### Production Pathways

- **Near-Term**
  - Natural Gas Reforming
  - Bio-Derived Liquid Reforming
  - Water Electrolysis

- **Mid-Term**
  - Coal with CO₂ Sequestration
  - Biomass Gasification
  - Renewable Water Electrolysis

- **Long-Term**
  - Solar or Nuclear High Temp Thermochem
  - Biological
  - Photoelectrochemical

Centralized production requires more delivery infrastructure.
KEY OBJECTIVE: Reduce the cost of hydrogen to $2 – $3/gge, delivered

The Program has established milestones for R&D efforts in all production pathways; cost of distributed production pathways has been reduced.
The Program has made progress in renewable hydrogen production, including advances in electrolyzers and biological production.

- The capital cost of electrolyzers is being reduced.
- The energy efficiency of electrolyzers is being improved.

### Electrolyzer Cost

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<th>Year</th>
<th>Status</th>
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<tr>
<td>2003</td>
<td>$700/kW</td>
<td>$400/kW</td>
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<td>2006</td>
<td>$665/kW</td>
<td>$125/kW</td>
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* Small-scale electrolyzers (for distributed production)

### Electrolyzer Efficiency

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<td>2006</td>
<td>62%</td>
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<td>2007</td>
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### Biological Production

**Light Utilization Efficiency**

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<th>Status</th>
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<td>2006</td>
<td>10%</td>
<td>15%</td>
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<td>2007</td>
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<td>2012</td>
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<td>2017</td>
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Hydrogen Delivery R&D

KEY OBJECTIVE: Reduce the total cost of delivering hydrogen to < $1.00/gge.

**CHALLENGES**

- High capital cost of pipelines, compression, liquefaction, off-board storage
- Improving energy efficiency of compression & liquefaction
- Embrittlement of pipelines
- Developing low-cost, efficient hydrogenation/dehydrogenation for liquid carriers
- Maintaining stringent quality requirements for H₂ used in PEM fuel cells

![Delivery Cost Reduced through Advances in Pipelines and Tube-trailers](image_url)

*Projected cost of delivery, using state-of-the-art technology*

**COST TARGET**: < $1/gge

- **2012 milestone**
- **2017 milestone**
**KEY OBJECTIVE:** > 300-mile driving range in all vehicle platforms, without compromising passenger/cargo space, performance, or cost

→ No current technology meets storage system weight and volume targets.

* System capacity estimates include materials, tanks, and balance of plant
• Projected system capacities based on modeling and material data.
• Subscale prototype developed for NaAlH₄
• Full scale prototype developed for cryo-compressed tank

• Preliminary designs developed and improvements made
• But no technology meets targets
• Need to focus on volumetric capacities
KEY OBJECTIVES: Reduce cost of automotive fuel cell systems to $30/kW and improve durability to 5,000 hours (~150,000 miles).

→ Significant progress is being made in reducing cost & improving durability.

Progress toward key targets is achieved through improvements in critical components.

Cost of Automotive Fuel Cell System
- Projected to high-volume manufacturing of 500,000 units/year -

Durability of Automotive Membrane Electrode Assembly (MEA) (in the lab)

* 5000 hours corresponds to roughly 150,000 miles of driving
KEY OBJECTIVES:
• Stationary Fuel Cell Systems—reduce cost to $750/kW and increase durability to 40,000 hours.
• Portable Fuel Cells—reduce cost to $3/W and increase energy density to 1,000 Watt-hours/Liter.
DOE Vehicle/Infrastructure Demonstration
(four teams in 50/50 cost-shared projects)

Verified performance in **122 fuel cell vehicles** and **16 hydrogen stations**:

- **EFFICIENCY**: 53 – 58% (>2x higher than gasoline internal combustion engines)
- **RANGE**: ~196 – 254 miles
- **FUEL CELL SYSTEM DURABILITY**:
  - 1,900 hours, projected (~57,000 miles)
  - 1,700 hours, observed (~51,000 miles)

Additional projects include:

- Demonstrating integration of renewable power and hydrogen production
- Data collection and analysis with other agencies
  - DOT’s Fuel Cell Bus Program
  - DOD’s fuel cell forklifts