The U.S. Department of Energy
Hydrogen and Fuel Cells

Mark Paster
U.S. Department of Energy
Hydrogen, Fuel Cells and Infrastructure Program

January, 2005
A Bold New Approach is Required

- U.S. Refinery Capacity
- U.S. Transportation Oil Consumption
- Oil Consumption With Average Fuel Efficiency
- Automobile & Light Truck Oil Use
- U.S. Oil Production

Petroleum (MMB/Day Oil Equivalent)

Actual Projection

EIA 2003 Base Case Extended
World Oil Reserves are Consolidating in OPEC Nations

U.S. 1998 Energy-Linked Emissions as Percentage of Total Emissions
Hybrid vehicles are a bridge technology that can reduce pollution and our dependence on foreign oil until long-term technologies like hydrogen fuel cells are market-ready.
Why Hydrogen? It’s abundant, clean, efficient, and can be derived from diverse domestic resources.

- Biomass
- Water
- Hydro
- Wind
- Solar
- Geothermal

- Nuclear

- Coal

- Natural Gas

With Carbon Sequestration

- Distributed Generation

- Transportation

HIGH EFFICIENCY & RELIABILITY

ZERO/NEAR ZERO EMISSIONS
Tremendous Progress Made Since President Bush’s State of the Union Address

• Program Management of Departmental Hydrogen Activities Integrated
  - OSTP-Led Interagency Coordination

• Public/Private Partnerships Established

• NRC Evaluation of DOE Plans Aiding in Hydrogen Production Strategies

• Major Systems Integration/ Analysis Capability Being Implemented

• Significant Technology Progress

“Tonight I am proposing $1.2 billion in research funding so that America can lead the world in developing clean, hydrogen-powered automobiles.”

President George W. Bush
2003 State of the Union Address
January 28, 2003
FreedomCAR and Fuel Partnership
Established

New Energy Company/DOE Technical Teams
- Production
- Delivery
- Fuel Pathway Integration

New Joint Auto/Energy/DOE Technical Teams
- Codes and Standards
- Storage
International Partnership for the Hydrogen Economy

IPHE Partners’ Economy:
- Over $35 Trillion in GDP, 85% of world GDP
- Nearly 3.5 billion people
- Over 75% of electricity used worldwide
- > 2/3 of CO₂ emissions & energy consumption

An IPHE Vision:
“… consumers will have the practical option of purchasing a competitively priced hydrogen power vehicle, and be able to refuel it near their homes and places of work, by 2020.”
- Secretary Abraham, April 2003
DOE Intra-Agency Collaboration

DOE Posture Plan
- EERE
- Fossil Energy
- Nuclear Energy
- Office of Science

• EERE
  - Hydrogen, Fuel Cells, Infrastructure Program
  - Vehicle Technologies Program
  - Solar Program
  - Wind Program
  - Biomass Program
Positive commercialization decision in 2015 leads to beginning of mass-produced hydrogen fuel cell cars by 2020
Summary of U.S. Planning and Implementation

President’s Hydrogen Fuel Initiative

Jan'02  Nov'02  Jan'03  Feb'03  May'03  Nov'03  Feb'04

International Partnership for the Hydrogen Economy
Program Elements

- Hydrogen Production
- Hydrogen Delivery
- On-Board Vehicle Storage
- Fuel Cells
- Safety, Codes & Standards
- Systems Analysis
- Education
Barriers to a Hydrogen Economy

Critical Path Technology Barriers:
- Hydrogen Storage (>300 mile range)
- Hydrogen Production Cost ($1.50-2.00 per gge)
- Fuel Cell Cost (< $50 per kW)

Economic/Institutional Barriers:
- Codes and Standards (Safety, and Global Competitiveness)
- Hydrogen Delivery (Investment for new Distribution Infrastructure)
- Education

http://www.eere.energy.gov/hydrogenanfuelcells/mypp/

No current H₂ storage technology meets the targets

Volumetric & Gravimetric Energy Density

- **2015 target**: 2.7 kWh/l, 3.0 kWh/kg
- **2010 target**: 1.5 kWh/l, 2.0 kWh/kg
- **Chemical hydride**: 1.4 kWh/l, 1.6 kWh/kg
- **Complex hydride**: 0.6 kWh/l, 0.8 kWh/kg
- **Liq. H₂**: 1.6 kWh/l, 2.0 kWh/kg
- **10000 psi gas**: 1.3 kWh/l, 1.9 kWh/kg
- **5000 psi gas**: 0.8 kWh/l, 2.1 kWh/kg

Cost per kWh, $/kWh

- **2015 target**: $2
- **2010 target**: $4
- **Chemical hydride**: $8
- **Complex hydride**: $16
- **Liq. H₂**: $6
- **10000 psi gas**: $16
- **5000 psi gas**: $12

$kWh/l$ $kWh/kg$ $0 5 10 15 20$ $5000 psi gas$ $10000 psi gas$ $Liq. H₂$ $Complex hydride$ $Chemical hydride$ $2015 target$ $2010 target$
Cost of a fuel cell prototype remains high (~$3,000/kW), but the high volume\(^1\) production cost of today’s technology has been reduced to $225/kW.

Through 1990, PEM cost was dominated by platinum loading (~20g/kW). Today’s high volume estimate is $225/kW and is attributed to platinum and membrane cost.

Cost improved through Platinum reduction to 0.8 g/kW. Further platinum reduction to goal of 0.2g/kW, and reduced membrane cost.

Cost goal of $30/kW approximates the cost of conventional engine technology.

1. High volume production defined as 500,000 units per year
2. Cost estimated by TIAAX with enhanced hydrogen storage..
Hydrogen Production Technologies

- Distributed natural gas reforming
- Distributed bio-derived liquids reforming
- Electrolysis
- Reforming biomass producer gas from gasification/pyrolysis
- Biological hydrogen production
- Photoelectrochemical hydrogen production
- Coal gasification with sequestration (FE)
- Nuclear driven HT thermochemical cycles (NE)
- Solar driven HT thermochemical cycles
Analysis is Crucial to Success

- NRC Report: Strongly recommends an increased emphasis on analysis including systems integration analysis and all energy systems analysis
- The envisioned Hydrogen/Electric Economy and the Transition is complex, highly interactive, and has many dimensions
  - Technologies
  - Markets: transportation, power, all hydrogen markets, all energy markets, and interacts with chemicals, food and feed, etc. through feedstock use
  - Time frames: short term (2010-2030), mid term (2030-2050) and long term
  - Geography: local, regional, national, global
  - Costs and Benefits
  - Policy
Types of Analyses

- Resource Analysis
- Existing Infrastructure
- Technology Characterization (TEA & Enviro)
- Macro-System Models
- Integrated Baseline Analysis
- Market Analysis
- Infrastructure Transition Analysis
- Benefits Analysis
## DOE Hydrogen Budget

*(EWD & Interior Appropriations in thousands of dollars)*

<table>
<thead>
<tr>
<th>MAJOR LINE ITEMS</th>
<th>FY 04 Appropriations</th>
<th>FY 05 Request</th>
<th>Omnibus Appropriations</th>
</tr>
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<tbody>
<tr>
<td>Production &amp; Delivery R&amp;D (EE)</td>
<td>$22,564</td>
<td>$25,325</td>
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<tr>
<td>Storage R&amp;D (EE)</td>
<td>$29,432</td>
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<td>Safety, Codes &amp; Standards, and Utilization (EE)</td>
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<td>Infrastructure Validation (EE)</td>
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<td>Education and Cross-cutting Analysis (EE)</td>
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<td><strong>EERE Hydrogen Technology Subtotal– (EWD)</strong></td>
<td><strong>$81,991</strong> (Net: $41,991)</td>
<td><strong>$95,325</strong> (Net: $58,635)</td>
<td><strong>$95,325</strong> (Net: $58,635)</td>
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<td>NE Hydrogen Subtotal – (EWD)</td>
<td>$6,400</td>
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<td>FE Hydrogen Subtotal – (Interior)</td>
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<td>SC – (EWD)</td>
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<td><strong>Hydrogen Technology Total</strong></td>
<td><strong>$93,791</strong></td>
<td><strong>$149,525</strong></td>
<td><strong>$150,525</strong></td>
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* Includes $40M of Earmarked projects

** Includes $36.7M of earmarked projects. Eliminates education.
### DOE Hydrogen Budget

(EWD & Interior Appropriations in thousands of dollars)

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<th>FY05 Plan*</th>
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<td><strong>EERE Hydrogen Technology subtotal (EWD)</strong></td>
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* Tentative Plan
Delivery Budget

FY04 Actual $320k

Delivery Pipeline R&D $150k
Delivery Analysis $170k

FY05 (at Budget Request: $4.0M)
Plan: $2.7M plus CTC Earmarks (FY04:$2.9M, FY05:~$2M)

Liquefaction $900k
Carriers $600k
Storage $270k
Pipeline R&D $1,110k
Analysis $1,150k
Delivery

Delivery Budget

FY04 Actual $320k

Delivery Pipeline R&D $150k
Delivery Analysis $170k

FY05 (at Budget Request: $4.0M)
Plan: $2.7M plus CTC Earmarks (FY04:$2.9M, FY05:~$2M)

Liquefaction $900k
Carriers $600k
Storage $270k
Pipeline R&D $1,110k
Analysis $1,150k
Delivery
Back-Up Slides
HT Thermochemical Cycles

- Manganese Sulfate Cycle Example

\[ \text{MnSO}_4 \rightarrow \text{MnO} + \text{SO}_2(g) + 0.5\text{O}_2(g) \quad 1150 \degree C \]

\[ \text{MnO} + \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{MnSO}_4 + \text{H}_2(g) \quad 120 \degree C \]
HT Thermochemical Cycles

- Volatile Metal Cycle Example

ZnO -> Zn + 0.5O2 \quad \sim 2100 \text{ K}
Zn + H2O -> ZnO + H2 \quad 500 \text{ K}
HT Thermochemical Cycles

- Sulfuric Acid Based Cycles
  - Hybrid Sulfur
    \[ 2\text{H}_2\text{SO}_4(g) \rightarrow 2\text{SO}_2(g) + 2\text{H}_2\text{O}(g) + \text{O}_2(g) \quad 950 \text{ C} \]
    \[ \text{SO}_2(g) + 2\text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{SO}_4(l) + \text{H}_2(g) \quad (\text{elec}) \quad 77 \text{ C} \]

  - Sulfur Iodide
    \[ 2\text{H}_2\text{SO}_4(g) \rightarrow 2\text{SO}_2(g) + 2\text{H}_2\text{O}(g) + \text{O}_2(g) \quad 850 \text{ C} \]
    \[ 2\text{HI} \rightarrow \text{I}_2(g) + \text{H}_2(g) \quad 300 \text{ C} \]
    \[ \text{I}_2 + \text{SO}_2(a) + 2\text{H}_2\text{O} \rightarrow 2\text{HI}(a) + \text{H}_2\text{SO}_4(a) \quad 100 \text{ C} \]