A Bold New Approach is Required

The graph illustrates the projection of petroleum demand and supply in MMB/Day (Million Metric Barrel per Day) Oil Equivalent from 1970 to 2050. Key components include:

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

The graph shows actual and projected trends, with the projection labeled as 'EIA 2003 Base Case Extended.'
World Oil Reserves are Consolidating in OPEC Nations

U.S. 1998 Energy-Linked Emissions as Percentage of Total Emissions

- CO
- NOx
- VOC
- SOx
- PM10
- PM2.5
- CO2

- Electricity
- Buildings
- Industry
- Transport
Hybrids are a Bridge

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.
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

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**
  - 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

- **2010 target**
  - Chemical hydride: 1.5 kWh/l, 2.0 kWh/kg
  - Complex hydride: 0.8 kWh/l, 1.6 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
    - Chemical hydride: $8
    - Complex hydride: $16
    - Liq. H₂: $6
    - 10000 psi gas: $16
    - 5000 psi gas: $12
  - 2010 target
    - Chemical hydride: $4
    - Complex hydride: $8
    - Liq. H₂: $6
    - 10000 psi gas: $16
    - 5000 psi gas: $12
Cost of a fuel cell prototype remains high (~$3,000/kW), but the high volume 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 TIAX 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>
</thead>
<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>
<td>$30,000</td>
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<tr>
<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>
<td>$5,712</td>
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<tr>
<td><strong>EERE Hydrogen Technology Subtotal – (EWD)</strong></td>
<td><strong>$81,991</strong> (Net: $41,991)</td>
<td><strong>$95,325</strong></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>
<td>$4,900</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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</table>

* Includes $40M of Earmarked projects
** Includes $36.7M of earmarked projects. Eliminates education.
# DOE Hydrogen Budget

(EWD & Interior Appropriations in thousands of dollars)

<table>
<thead>
<tr>
<th>MAJOR LINE ITEMS</th>
<th>FY 05 Request</th>
<th>FY05 Plan*</th>
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<tbody>
<tr>
<td>Production &amp; Delivery R&amp;D (EE)</td>
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<td>Production</td>
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<td>Safety, Codes &amp; Standards, and Utilization (EE)</td>
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<td>Earmarks</td>
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<td><strong>EERE Hydrogen Technology</strong></td>
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<td><strong>$95,325</strong></td>
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<tr>
<td><strong>Subtotal– (EWD)</strong></td>
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</tbody>
</table>

* Tentative Plan
Delivery Budget

FY04 Actual $320k

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

- Delivery
  - Pipeline R&D $150k
  - Analysis $170k
- Delivery $1,150k
- Pipeline R&D $1,110k
- Storage $270k
- Carriers $600k
- Liquefaction $900k
- Delivery $1,110k
- Analysis $1,150k

FY04 Actual $320k
Back-Up Slides
HT Thermochemical Cycles

- Manganese Sulfate Cycle Example

\[
\text{MnSO}_4 \rightarrow \text{MnO} + \text{SO}_2(g) + \cdot5\text{O}_2(g) \quad 1150 \ C
\]

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

- Volatile Metal Cycle Example

  \[
  \text{ZnO} \rightarrow \text{Zn} + 0.5\text{O}_2 \quad \sim 2100 \, \text{K}
  \]
  \[
  \text{Zn} + \text{H}_2\text{O} \rightarrow \text{ZnO} + \text{H}_2 \quad 500 \, \text{K}
  \]
HT Thermochemical Cycles

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

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