



U.S. Department of Energy
Energy Efficiency and Renewable Energy

DOE Hydrogen Program EERE Hydrogen Production and Delivery

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Office of Hydrogen, Fuel Cells, & Infrastructure Technologies

U.S. Department of Energy

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Arlene Anderson - Distributed Reforming (Natural Gas, Liquid Fuels)

Roxanne Danz – Overall Feedstock/Production/Delivery Strategy and Analysis and Direct Water Splitting Using Photolytic Processes

Matt Kauffman - Electrolysis and Electricity Infrastructure Integration

Mark Paster - Hydrogen Production with Biomass and Hydrogen Delivery

Pete Devlin - Team Leader



Production Objectives

Research and develop low-cost, highly efficient hydrogen production technologies from diverse, domestic sources, including fossil and renewable sources.

By 2010 Complete Research to Achieve:

- \$1.50/kg hydrogen (delivered, untaxed) for distributed production from natural gas and/or liquid fuels.
- \$2.85/kg with distributed/central electrolysis.
- \$2.90/kg hydrogen at the plant gate from biomass pyrolysis.
- \$4/kg hydrogen at the plant gate for a solar-driven thermochemical water splitting cycle.

By 2015 Demonstrate:

- Engineering-scale biological system producing H₂ at a plant-gate cost of \$10/kg projected to commercial scale.
- Direct PEC water splitting with a plant-gate H₂ production cost of \$5/kg projected to commercial scale.



Delivery Objectives

Develop hydrogen fuel delivery technologies that enable the introduction and long-term viability of hydrogen as an energy carrier for transportation and stationary power.

1. By 2006, define a cost-effective and energy-efficient hydrogen fuel delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.
2. By 2015, reduce the total cost of hydrogen fuel delivery to $< \$1.00/\text{kg}$.





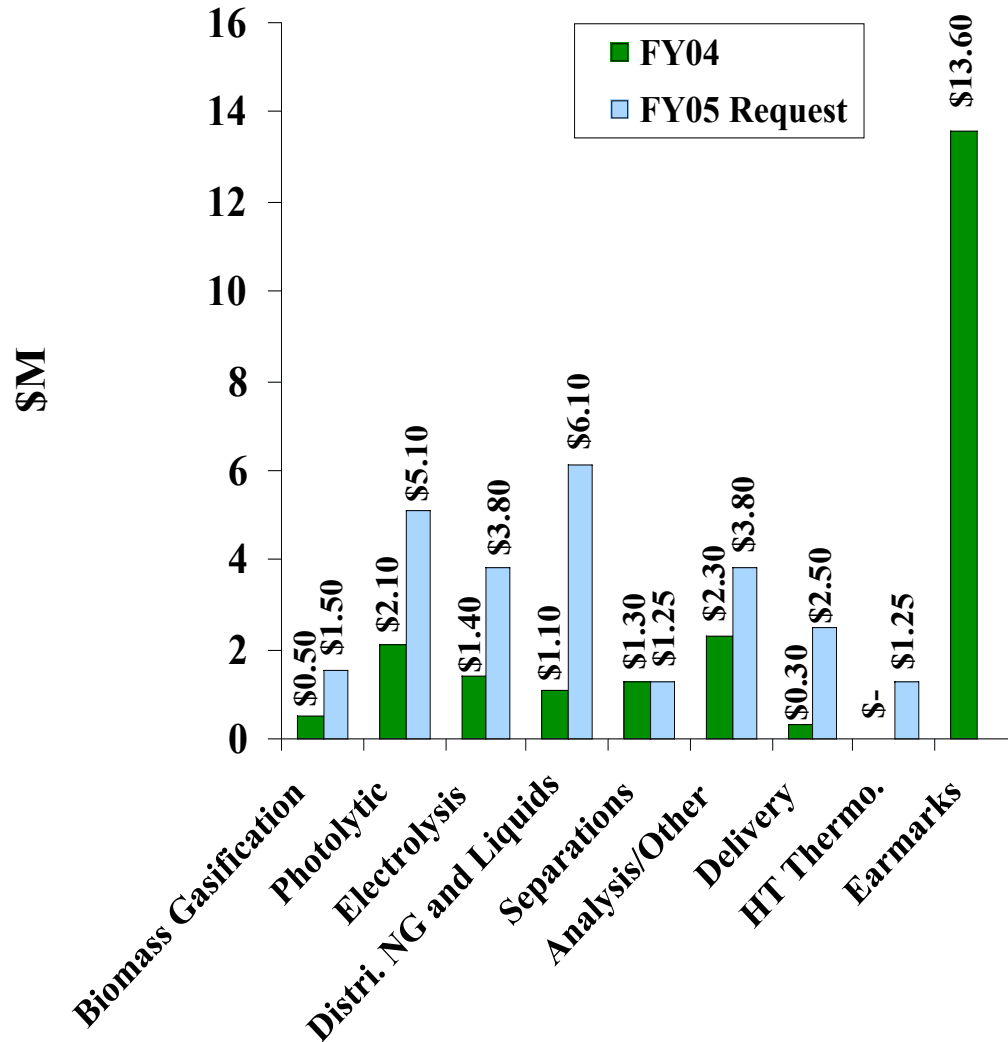
Production and Delivery R&D Approach

- Work with industry partners to identify technical issues, establish mutual goals, and evaluate progress
- Focus on high risk production and delivery R&D
 - Near and long term pathways
 - Central and distributed technologies
- Structure research to encompass diverse energy feedstocks and sources including natural gas, liquid fuels, solar, wind and biomass
- Execute projects under cost-shared agreements
- Measure progress regularly in a peer reviewed process



Budget

FY 2005 Budget Request = \$25.3M
FY 2004 Appropriation = \$22.6M



- **Emphasis:**

- Distributed natural gas and liquid reforming systems
- Renewable Technologies (photolytic, wind electrolysis)
- Initiate delivery R&D

- **Budget Obligations:**

Fulfill current contracts	\$2.5M
Maintain Laboratory R&D	\$9.0M
Solicitation new starts	\$13.8M
Total	\$25.3M



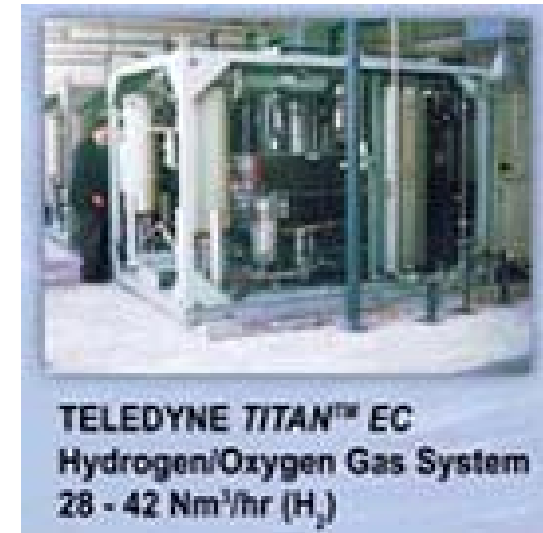
Key Barriers – Distributed Hydrogen Production

Reforming of Natural Gas and/or Liquid Fuels

- Capital costs
- Operation and maintenance

Water Electrolysis

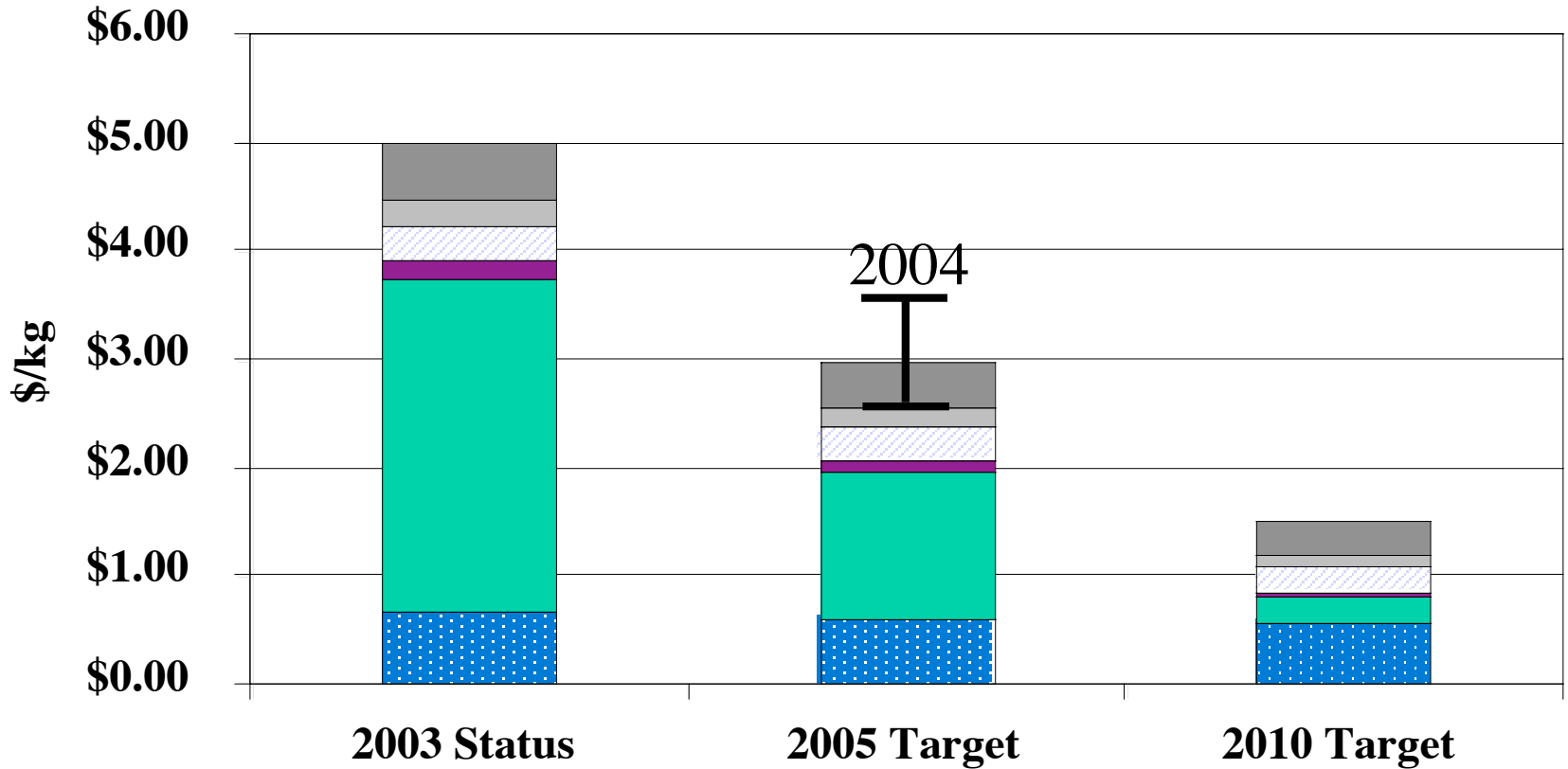
- Electrolyzer capital costs and efficiency
- Grid electricity emissions





Hydrogen Production Targets

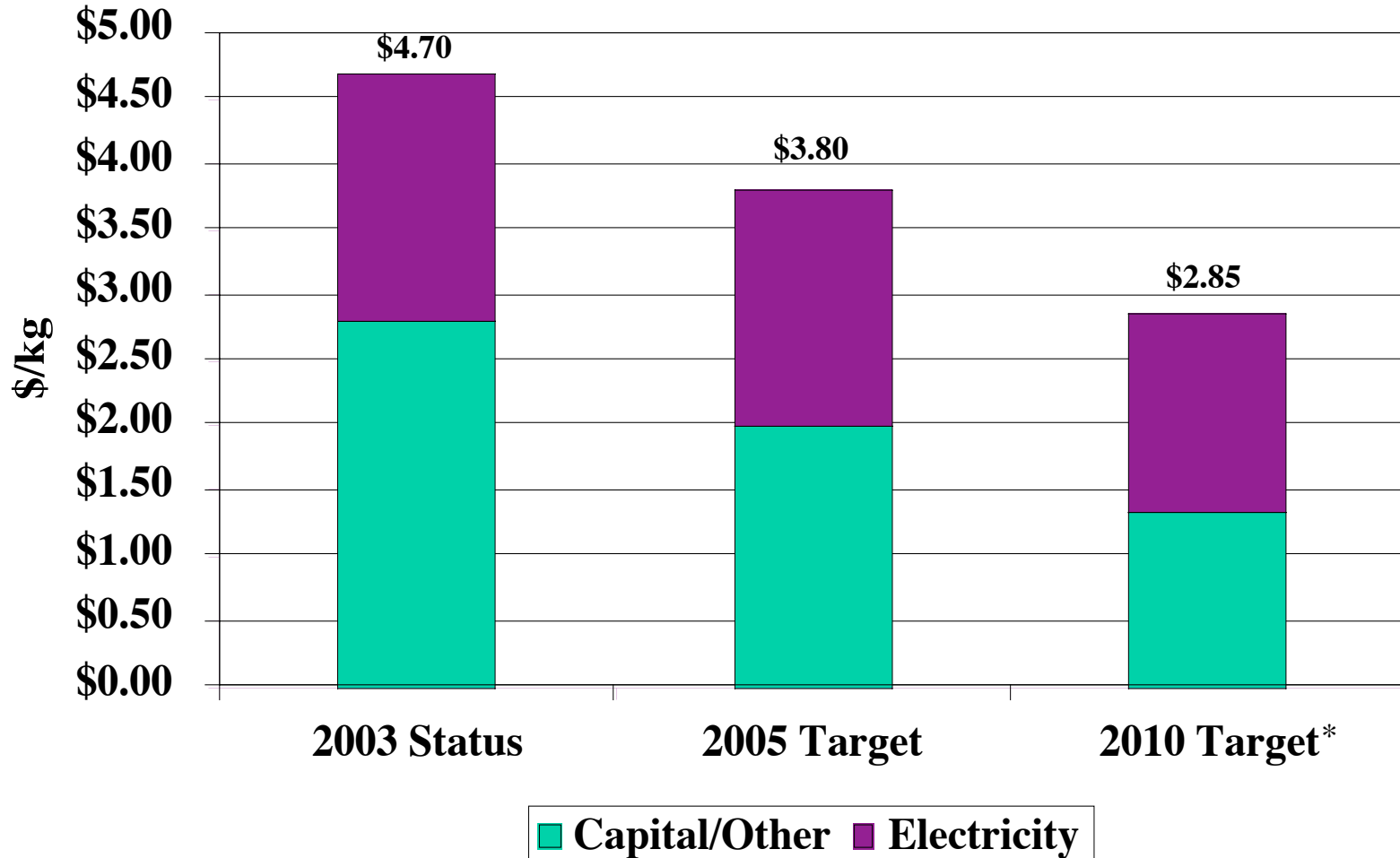
Distributed Production of Hydrogen from Natural Gas and Liquid Fuels





Hydrogen Production Targets

Production of Hydrogen from Water Electrolysis



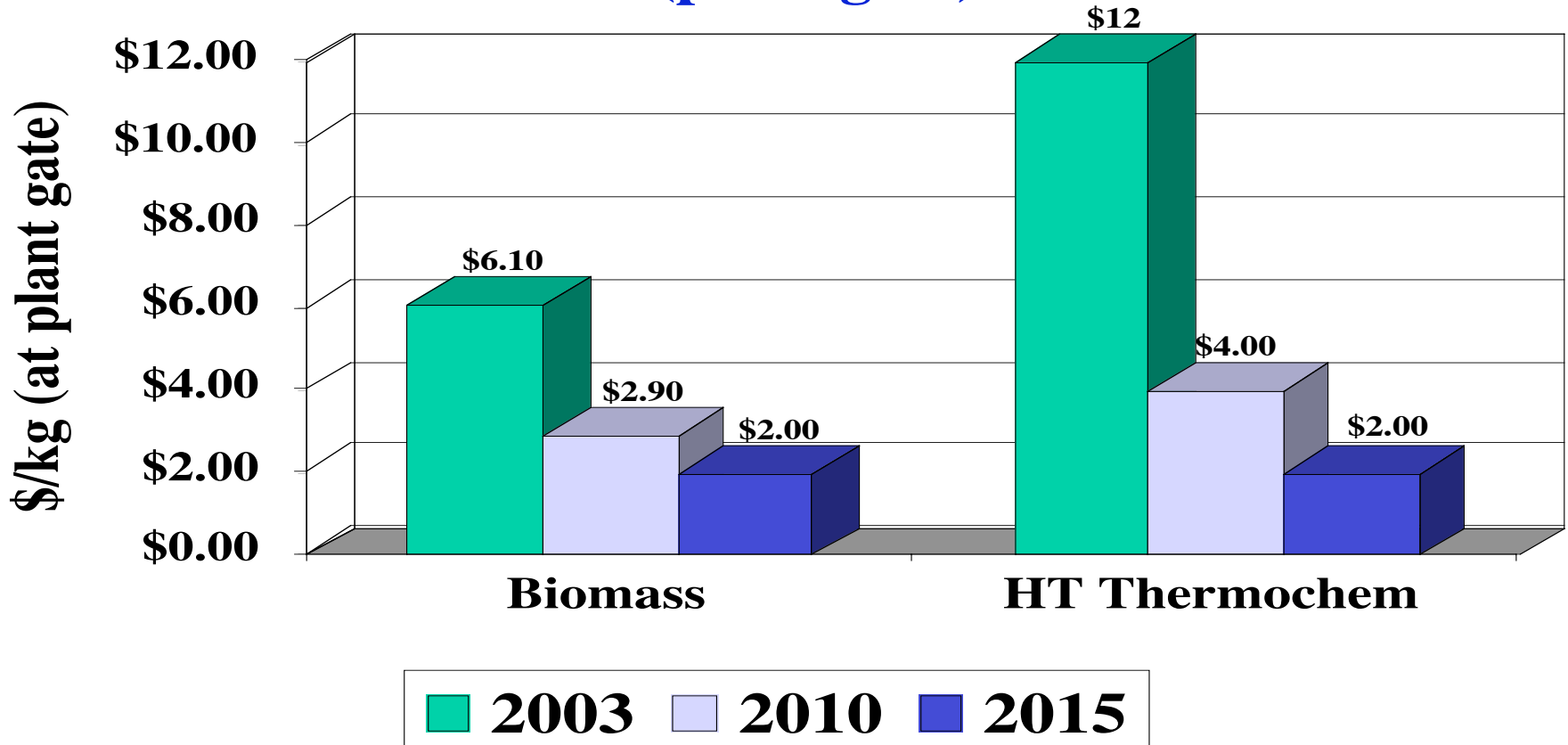
* Based on grid supplied electricity with a large percentage of wind and grid supported electrolysis at a refueling station



- Biomass Gasification/Pyrolysis
 - High capital cost of gasification/pyrolysis systems
- High-Temperature Thermochemical
 - Unproven thermochemical cycles
 - High-temperature (HT) materials



Central Hydrogen Production (plant gate)

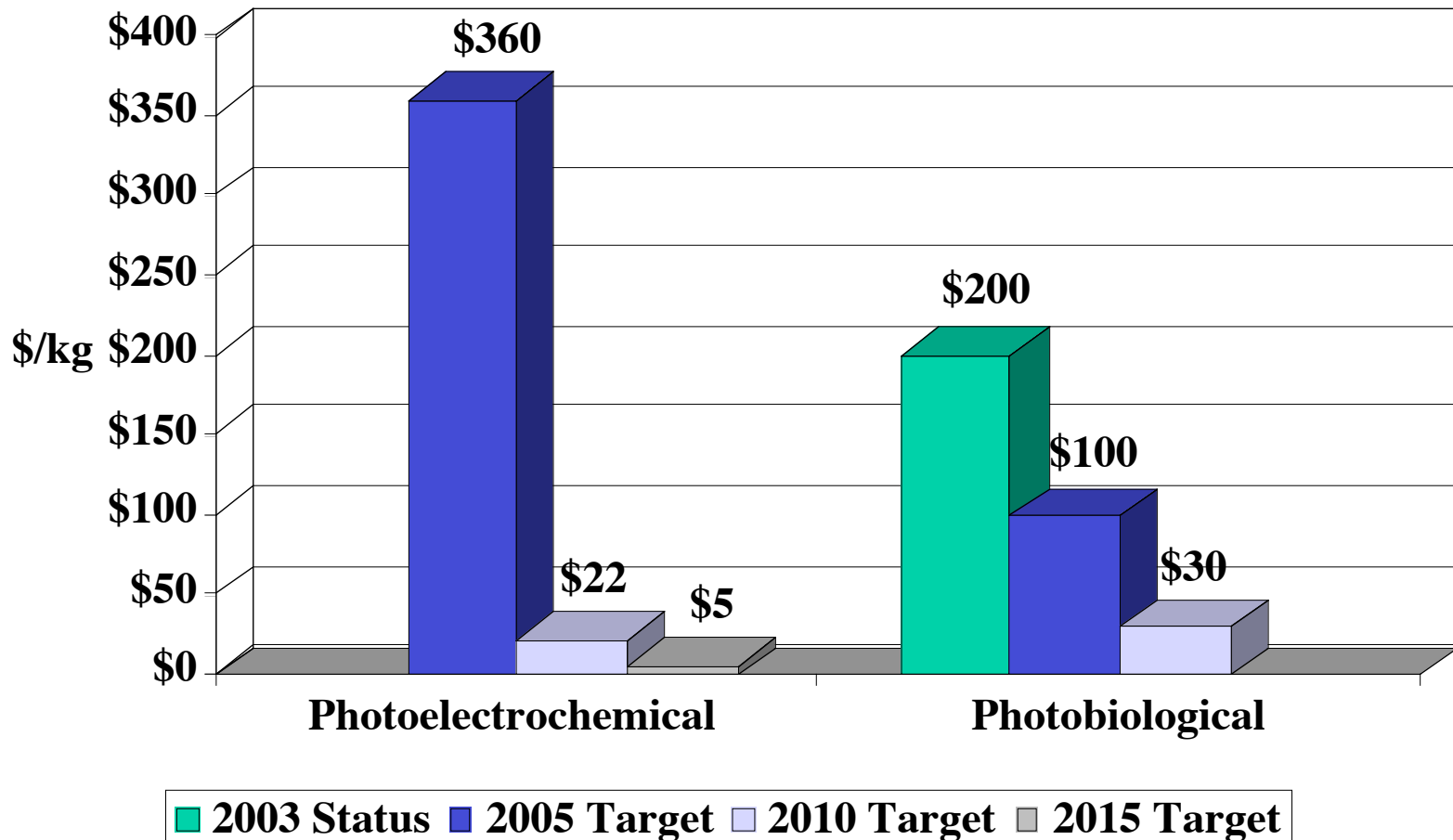




- Light utilization efficiency
- Rate of hydrogen production
- Continuity of photoproduction
- Materials
- Photoelectrochemical efficiency



Long-Term Hydrogen Production





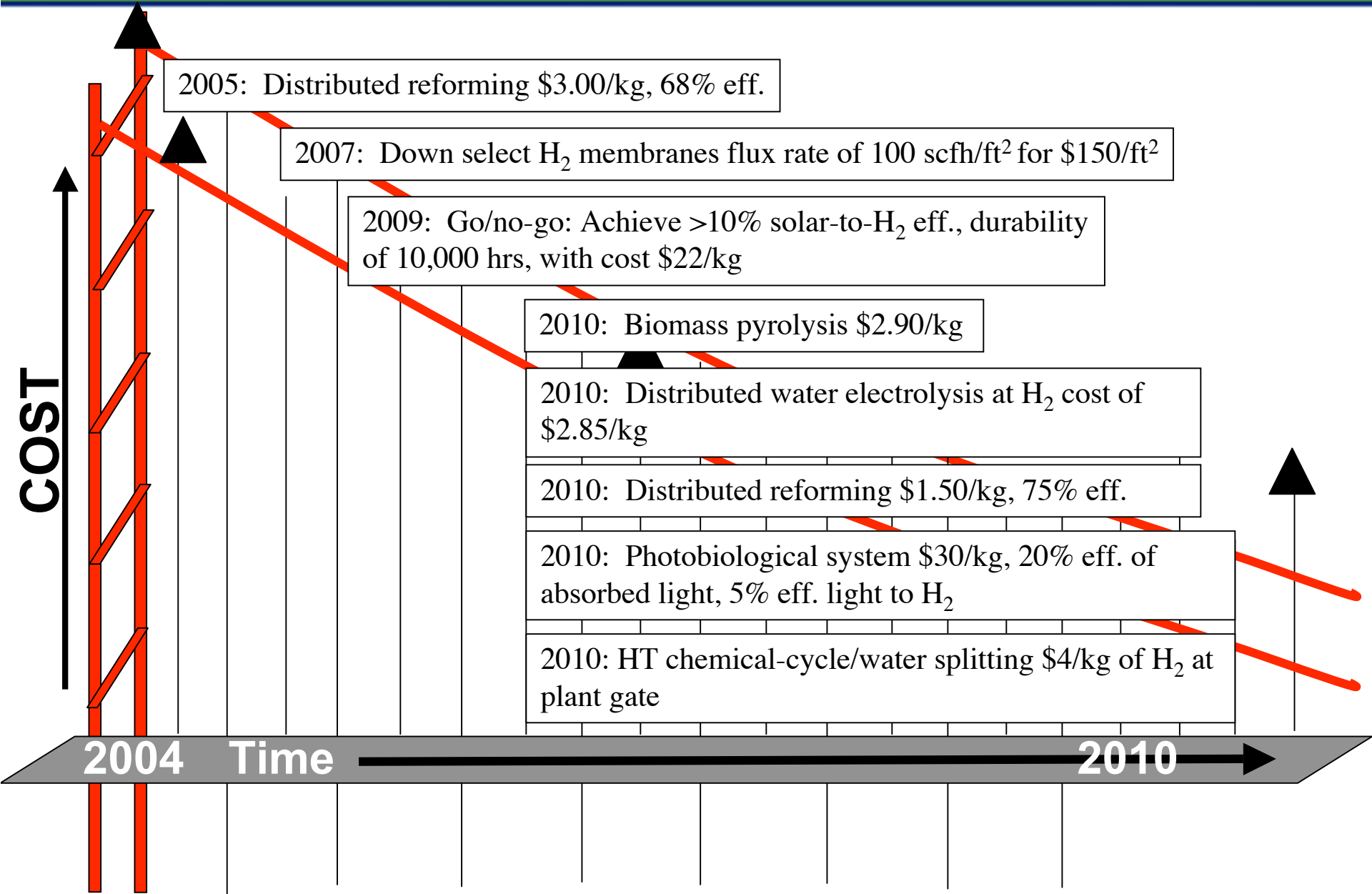
- Reforming Catalysts
- Process Simplification
- Hydrogen Separation and Purification
- High-Purity Water Availability



- High capital costs for pipelines and liquefaction
- Low energy efficiency of liquefaction
- Low compressor reliability/durability



Key Milestones





Distributed Natural Gas Reforming

- APCI: Turnkey refueling station
- Praxair: Low cost production platform (DFMA analysis)
- *FY04 Solicitation (1-3 new projects)*

Separations

- Praxair: Integrated ceramic membrane reactor system focused on hydrogen transport membrane and tube development
- APCI: Ceramic membrane development
- SNL: Inorganic thin film membrane development
- ORNL: Ion transport membrane development
- LANL: Photopolymerization/pyrolysis membrane microstructure development
- *FY04 Solicitation (1-3 new projects)*





Biomass Gasification/Pyrolysis

- Startech: Plasma gasification/membrane separations
- NREL: Pyrolysis
- *FY04 Solicitation (1-3 new projects)*

HT Thermochemical Cycles

- UNLV Consortium: Solar based cycles
- *FY04 Solicitation (1-3 new projects)*

Delivery

- Analysis: Part of H2A, Winds-H2 (NREL), HyTrans (ORNL, ANL)
- Ergenics: Hydride based compression and purification
- ORNL: Pipeline materials R&D
- *FY04 Solicitation: Analysis, Pipelines, Liquefaction, Compression, Novel Carriers (4-8 new projects)*



Photolytic

- UC Berkeley, ORNL, and NREL: Three projects to increase light absorption efficiency, reduce hydrogenase oxygen intolerance, and insert a polypeptide proton channel to increase hydrogen production efficiency in green algae.
- NREL, UC Santa Barbara, U of Hawaii, and SRI: Four material science projects to design/discover new materials with appropriate energetics to directly split water using sunlight.
- *FY04 Solicitation*

Electrolysis

- Teledyne, Proton, and Giner: Three new advanced high-pressure electrolysis projects started
- Sandia: Membrane, electrode, catalyst research
- NREL: Renewable power electronics integration
- *FY04 Solicitation (2-4 new projects)*





Technical Accomplishments/ Progress

Distributed Production from Natural Gas

- Target
 - On target for \$3.00/kg H₂ cost at dispenser (690 kg/day, 11% capital factor, >100 units annually, \$4/MMBTU(HHV) NG, 90% utilization)
- Reformer R & D
 - Optimizing desulphurization, reformer, and shift catalysts
 - Improving heat recovery system
- Purification R & D
 - Improved Pressure Swing Absorption (PSA) system to deliver 99.999% pure H₂ from a SMR stream at 120 psig
 - 3x reduction in cost of PSA when compared with commercially available units.
 - Advanced PSA unit much smaller than commercially available units
 - Efficiency Exceeds Program 2005 Target of 82% (from 75% in 2003)





Technical Accomplishments/ Progress

Delivery

- H2A Delivery analysis will set a benchmark
- Ergenics: Hydride based compression and purification demonstrated
- FreedomCAR and Fuel Partnership Delivery Tech Team initiated, draft roadmap expected by year end

Biomass Gasification/Pyrolysis

- NREL demonstrated improved reforming catalyst reducing attrition and coking

Electrolysis

- Analysis of wind technologies for hydrogen production (NREL)
- Industry meeting on hydrogen production from wind and hydropower
- Developing baselines using H2A analysis on forecourt and central electrolysis

HT Thermochemical Cycles

- UNLV Consortium: Completing database and ranking of cycles and solar concentrators



Technical Accomplishments/ Progress

Photobiological

- Reduced chlorophyll antenna size of green algae by 58% to increase utilization efficiency of absorbed sunlight energy to ~15%.
- 6 months continuous H₂ photoproduction

Photoelectrochemical

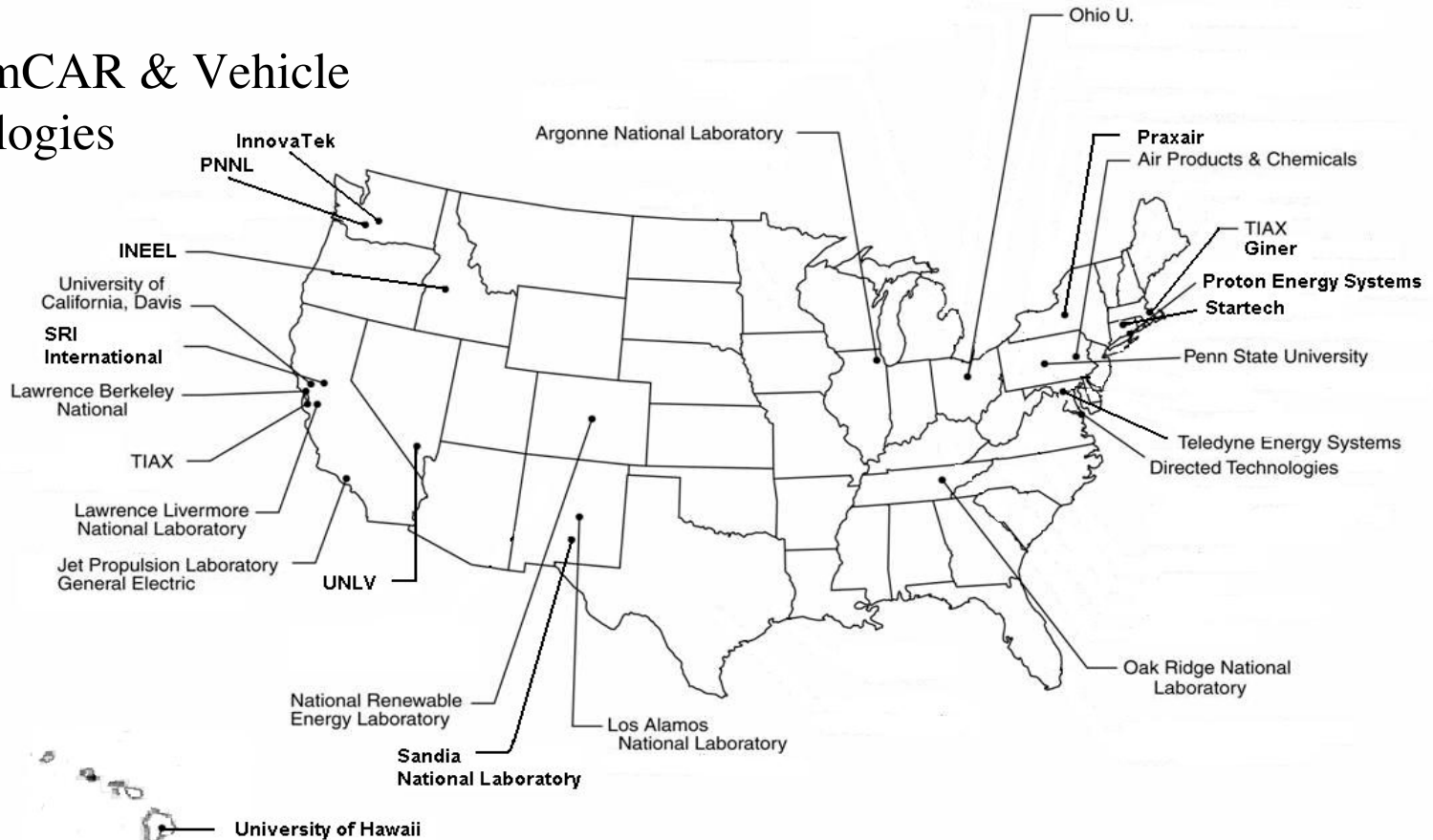
- Developed a new material, gallium phosphide nitride (GaPN), that should make the 2005 goal of 7% efficiency and 1000 hours lifetime.
- Identified cost-effective zinc based mixed metal oxides with 4 times solar-to-hydrogen production efficiencies improvement.
- Began developing models that will assist in the identification of materials that will meet the DOE targets for PEC hydrogen production.



Interactions & Collaborations

- Office of Fossil Energy
- Office of Science
- EERE
 - Wind and Hydropower
 - Solar
 - FreedomCAR & Vehicle Technologies

- FreedomCAR & Fuel Partnership
- IPHE
- IEA
- Interagency Task Force
- Universities
- Gov. Labs
- Industry





Summary of Planned H2 Production and Delivery R&D Funding*

<u>Topic</u>	<u>Total \$ (M)</u>	<u>Annual DOE \$ (M)</u>	<u>Industry Cost Share</u>
• Biomass to H2	\$15 M	\$4-6 M	20%
• Photolytic	\$11 M	\$3 M	20%
• Distributed Reforming	\$8 M	\$2 – 3 M	30%
• Separation	\$10 M**	\$3 - 4M	20%
• Electrolysis	\$8 M	\$2 – 3 M	20 - 25%
• High Temperature Thermochemical	\$10 M	\$2 – 4 M	20%
• Production Analysis	\$2 M	\$600 K – 1 M	N/A
• Delivery	\$15 M	\$3 – 6 M	20-30%
• Crosscutting Projects	\$10 M	\$2 – 4 M	20-30%
• University Projects	\$7.5 M	\$1 – 2 M	20%

* All funding is subject to availability of funds through the annual appropriations process.

** Includes Office of Fossil Energy commitment of \$1 Million per year.



- Revise draft RD&D to reflect new developments and analyses results
- Implement NAS recommendations with emphasis on:
 - Electrolyzer development to lower capital costs
 - Distributed reforming
- Leverage our long term research goals with expanded Office of Science fundamental work:
 - Materials – catalysts, membranes, pipelines
 - Photolysis – electrochemical, biological
- Select new projects from solicitation that achieve cost and efficiency targets