DOE Hydrogen Program
EERE
Hydrogen Production and Delivery

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U.S. Department of Energy
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Hydrogen Production Team

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 H_2 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.

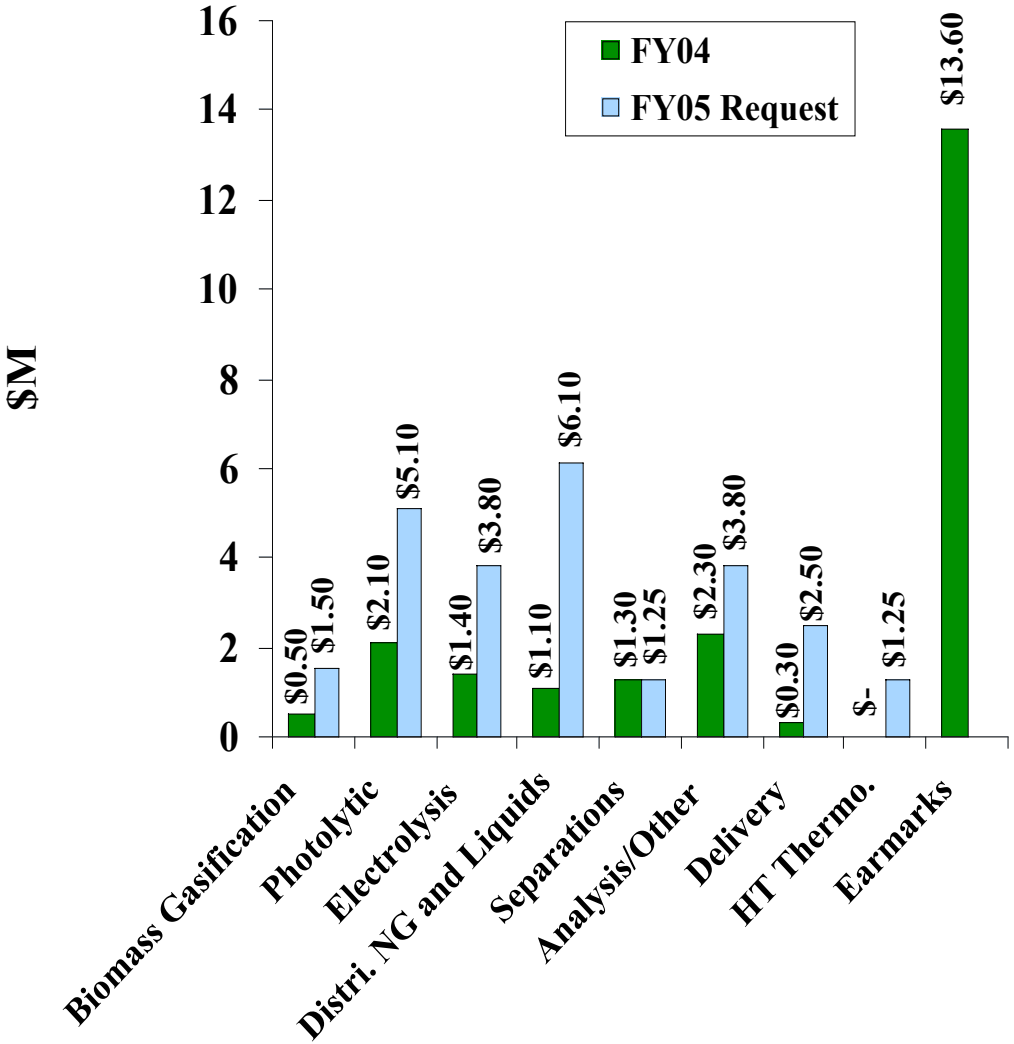
1. By 2006, define a cost-effective and energy-efficient hydrogen fuel delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.
2. By 2015, reduce the total cost of hydrogen fuel delivery to <$1.00/kg.

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

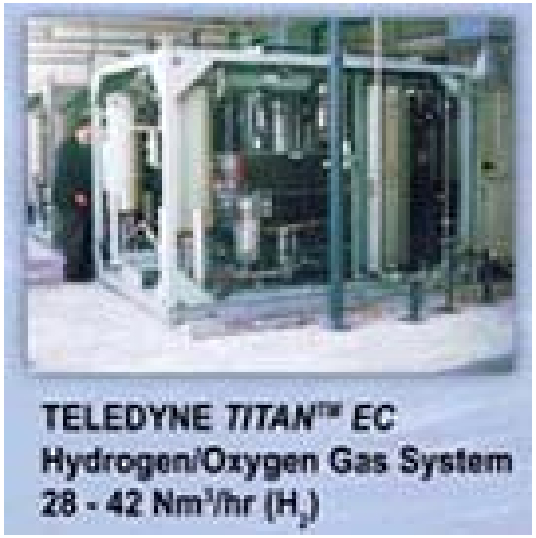
Key Barriers – Distributed Hydrogen Production

Reforming of Natural Gas and/or Liquid Fuels

- Capital costs
- Operation and maintenance

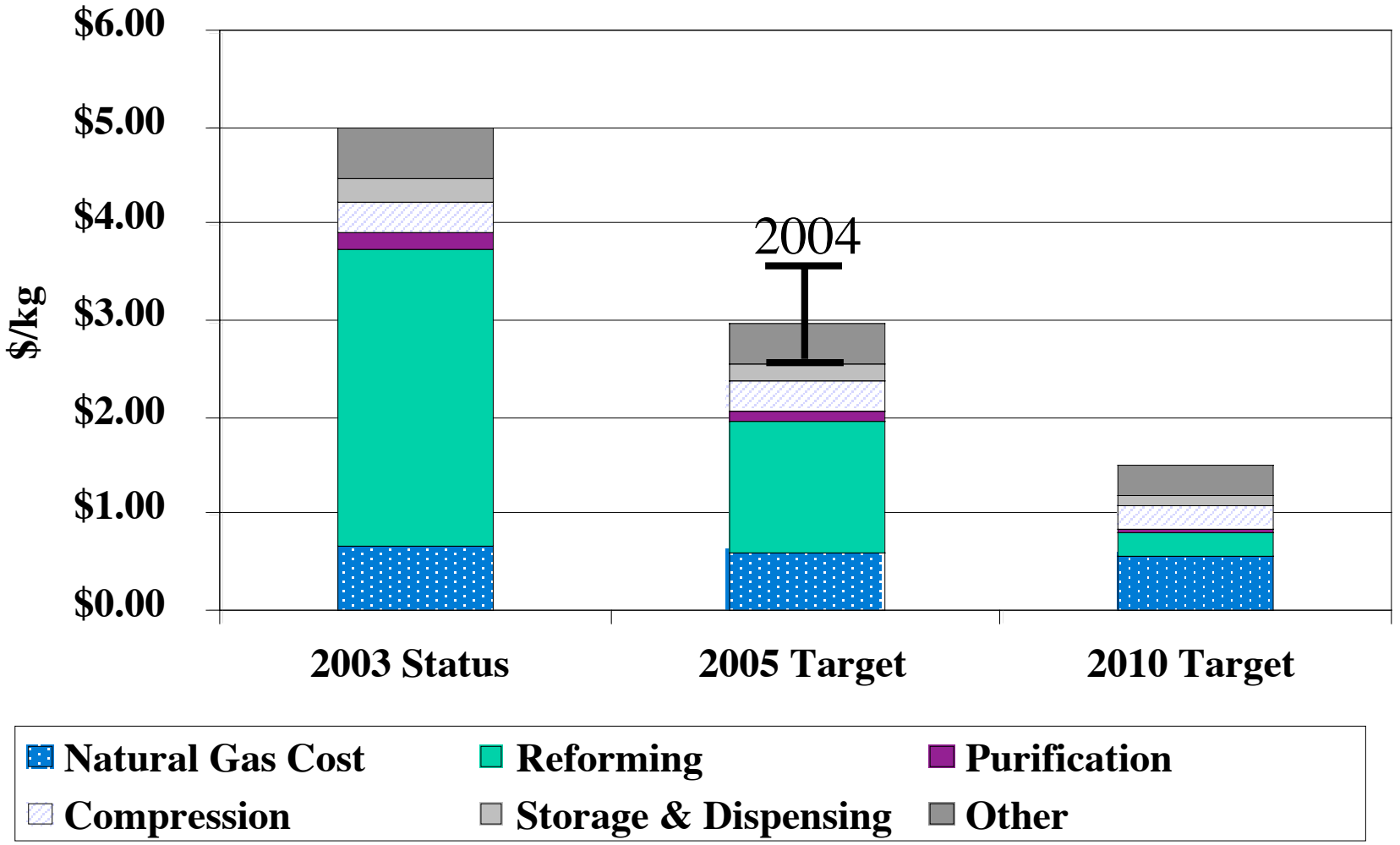
Water Electrolysis

- Electrolyzer capital costs and efficiency
- Grid electricity emissions



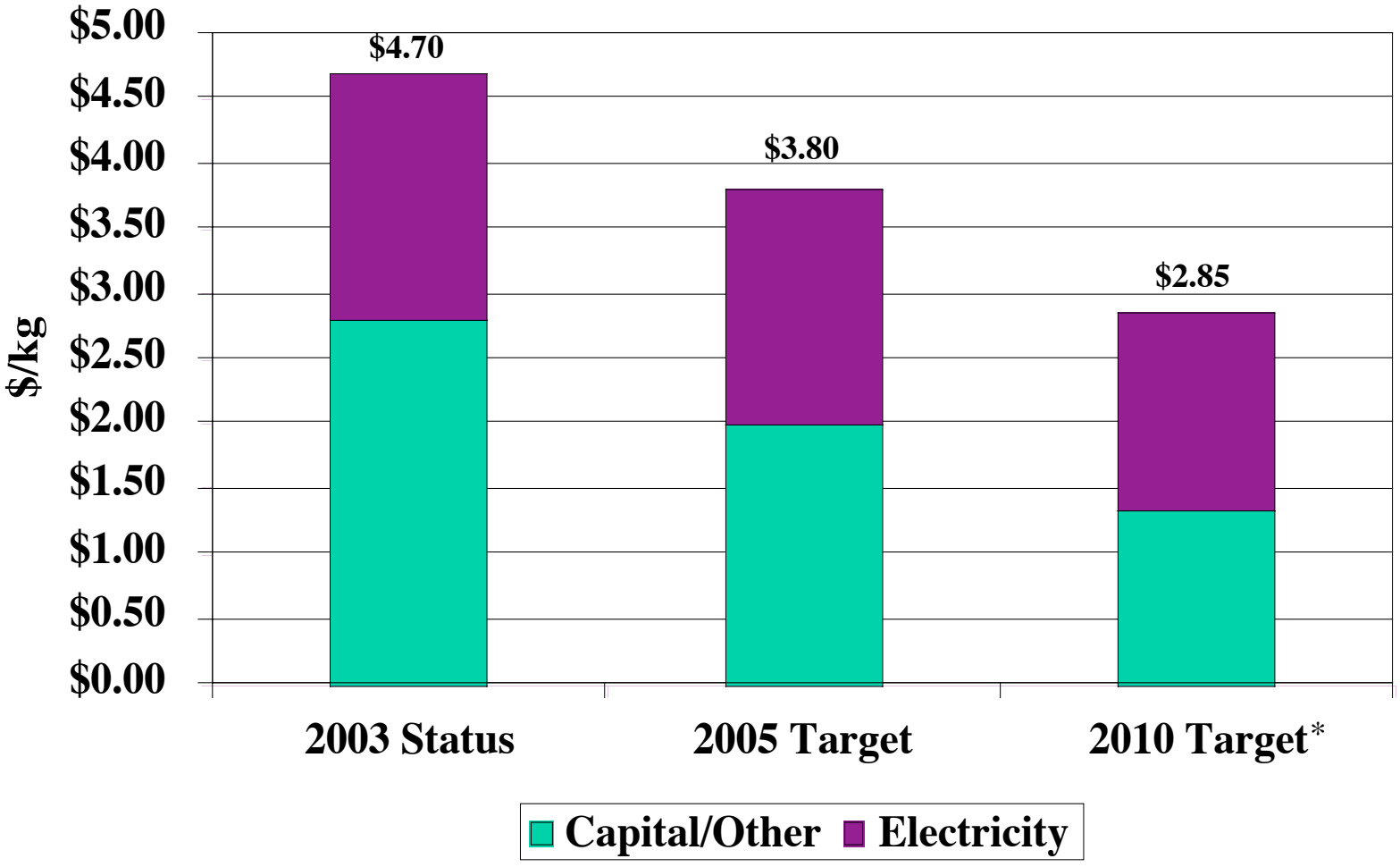
Hydrogen Production Targets

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

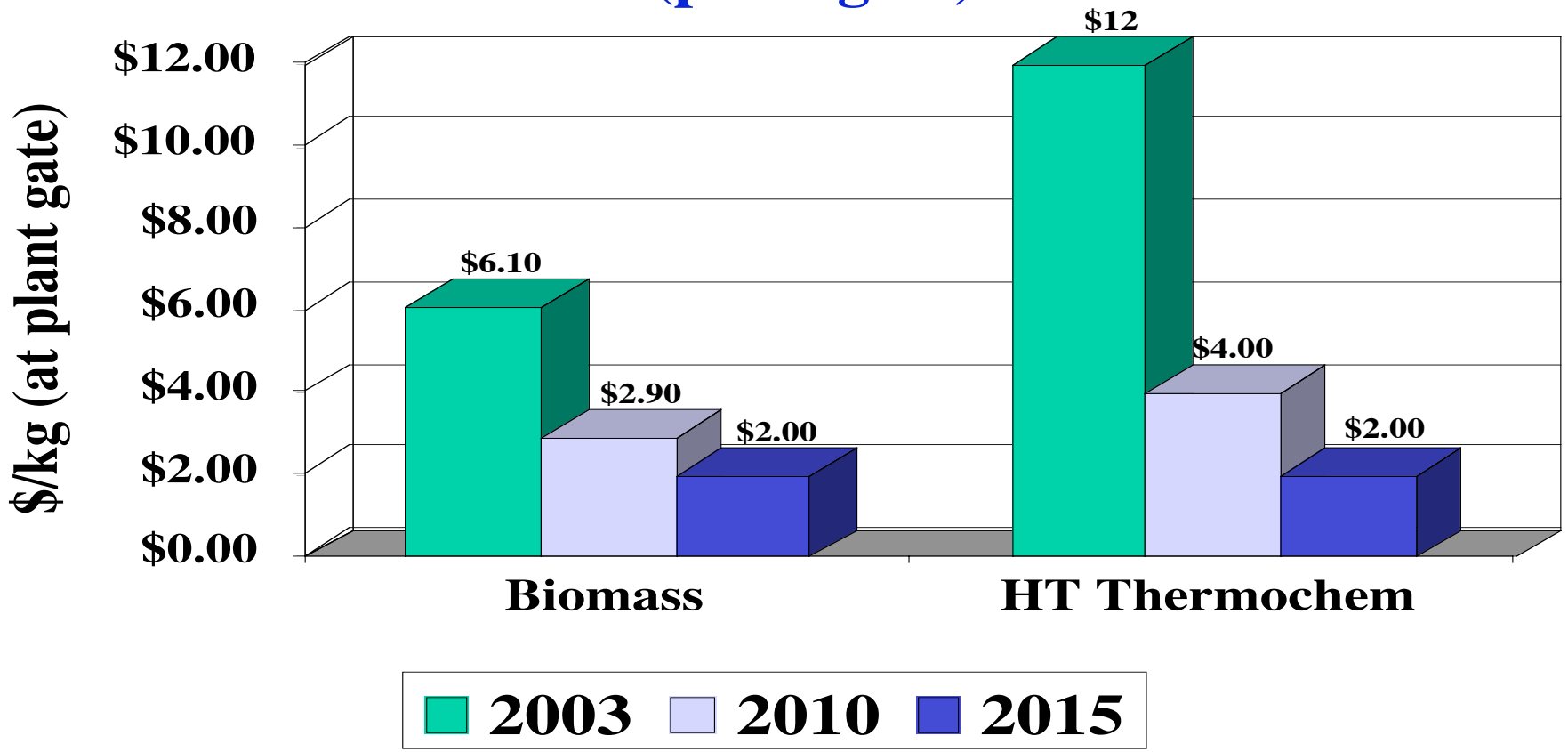
Barriers – Central Production

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

Hydrogen Production Targets

Central Hydrogen Production

(plant gate)

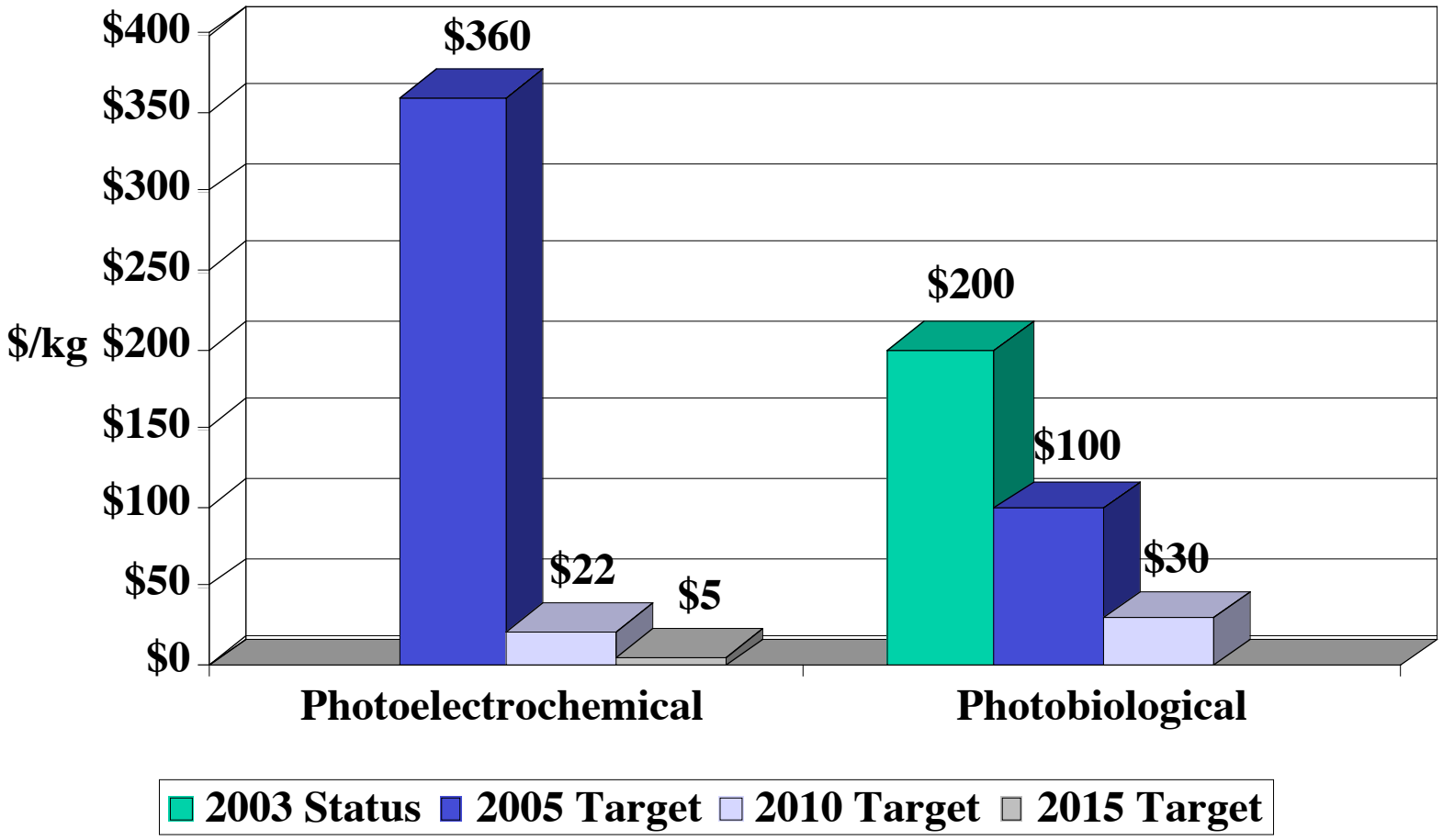


Barriers – Photolytic

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

Hydrogen Production Targets

Long-Term Hydrogen Production



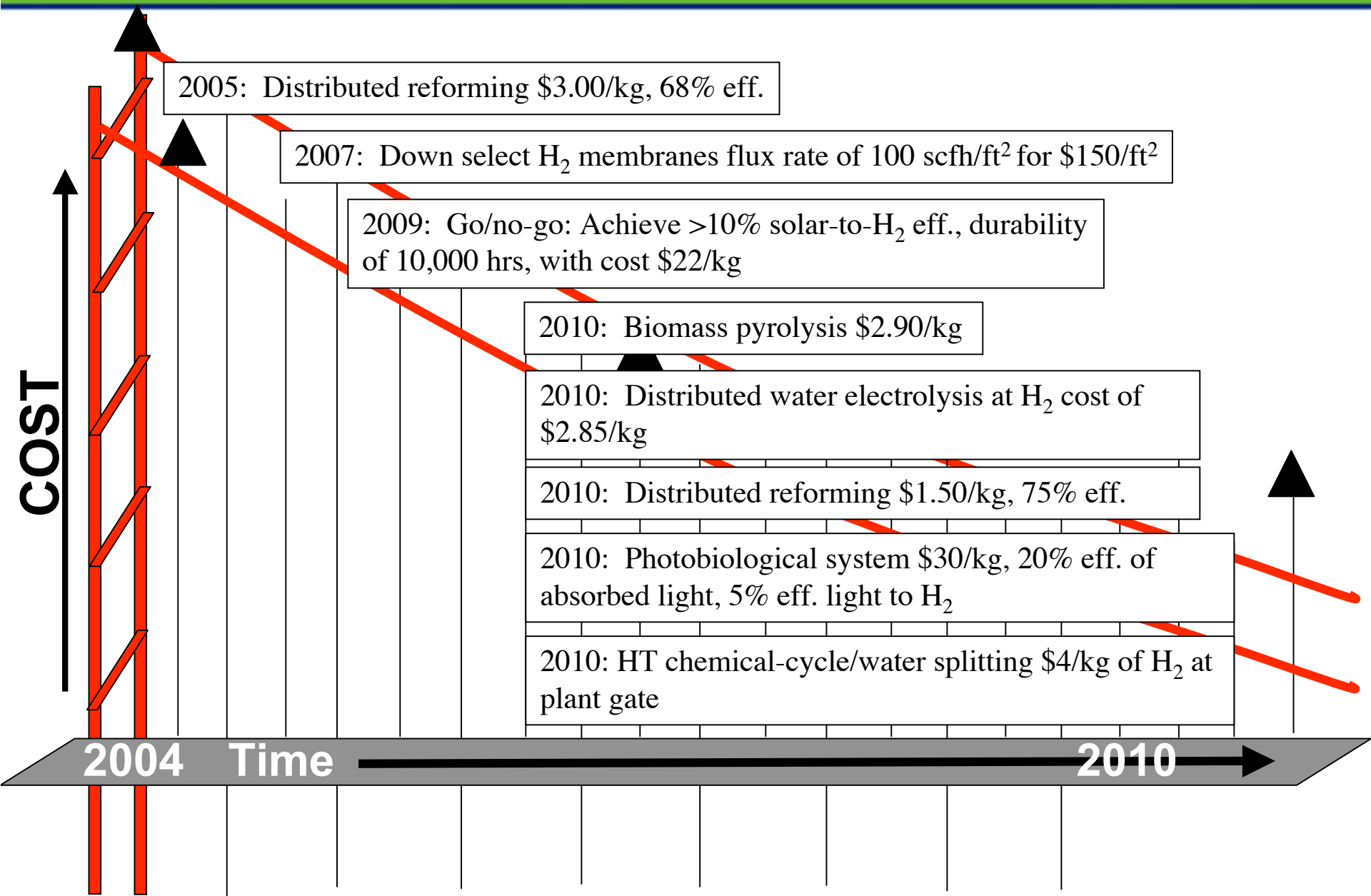
Barriers – Cross Cutting

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

Barriers – Hydrogen Delivery

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

Key Milestones



R&D Portfolio

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)*

R&D Portfolio

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)*

R&D Portfolio

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 H_2 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

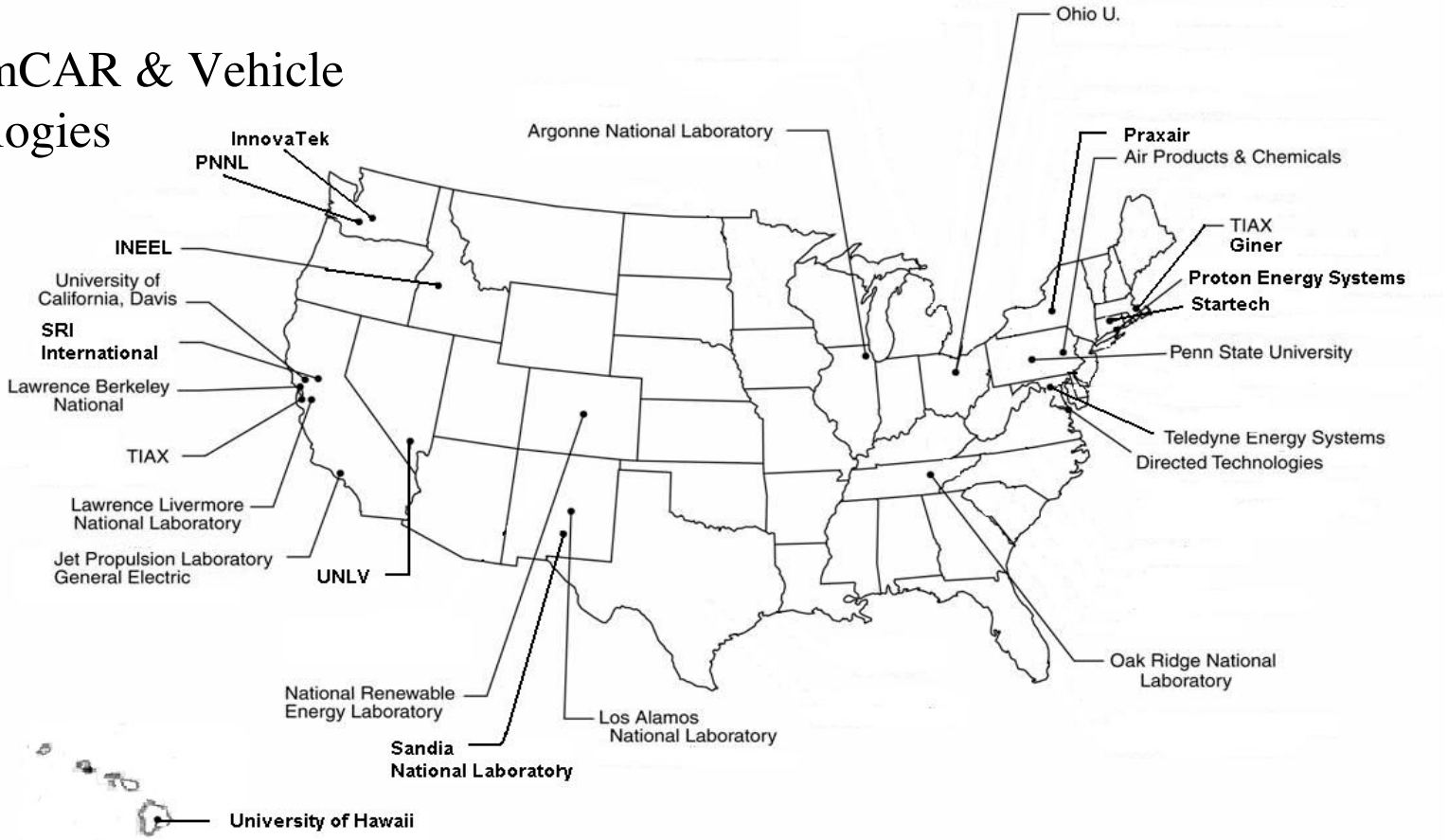
- Reduced chlorophyll antenna size of green algae by 58% to increase utilization efficiency of absorbed sunlight energy to ~15%.
- 6 months continuous H_2 photoproduction

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



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

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

Topic	Total $ (M)	Annual DOE $ (M)	Industry Cost Share
• **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.*

Future Directions

- 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