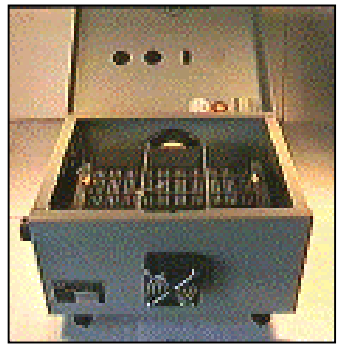
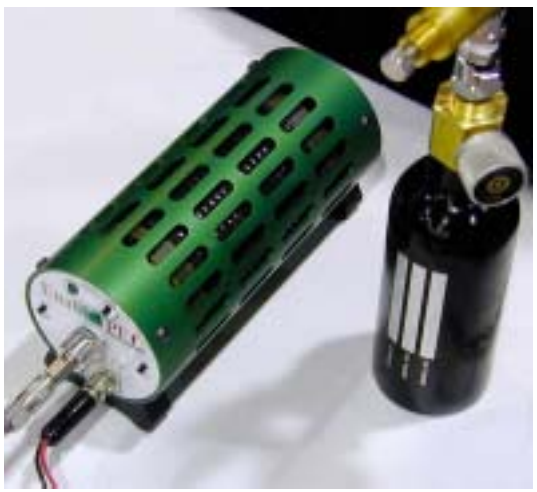
Peer Review of the Hydrogen Program

Hydrogen Briefing



May 5, 2002



Assistant Secretary Garman's

9 Priorities

EERE's Priorities: Hydrogen

1. Dramatically reduce or even end dependence on foreign oil
3. Increase viability and deployment of renewable energy.
4. Increase reliability and efficiency of electricity generation.
9. Lead by example through government's own actions.

Milestones and Deliverables

Install distributed refueling stations that can produce hydrogen untaxed at $1.25 per gallon equivalent.

Hydrogen storage system that can provide 6% by weight hydrogen and 250 – 400 miles of range.

Validate integrated systems into Power Parks that co-produce electricity (<$0.06/kW) and hydrogen.

Priority/Support

1. Balanced research, development and validation program to produce hydrogen from indigenous fossil and non-fossil sources.
3. Initiated a number of collaborations with Wind, CSP and DER programs using energy storage.
4. Collaborated with other EERE and FE programs on integrating fuel cells with hydrogen production
9. Last three years have developed collaborations with FE,OIT,OTT, DOT to foster major hydrogen initiatives.

Major Accomplishments

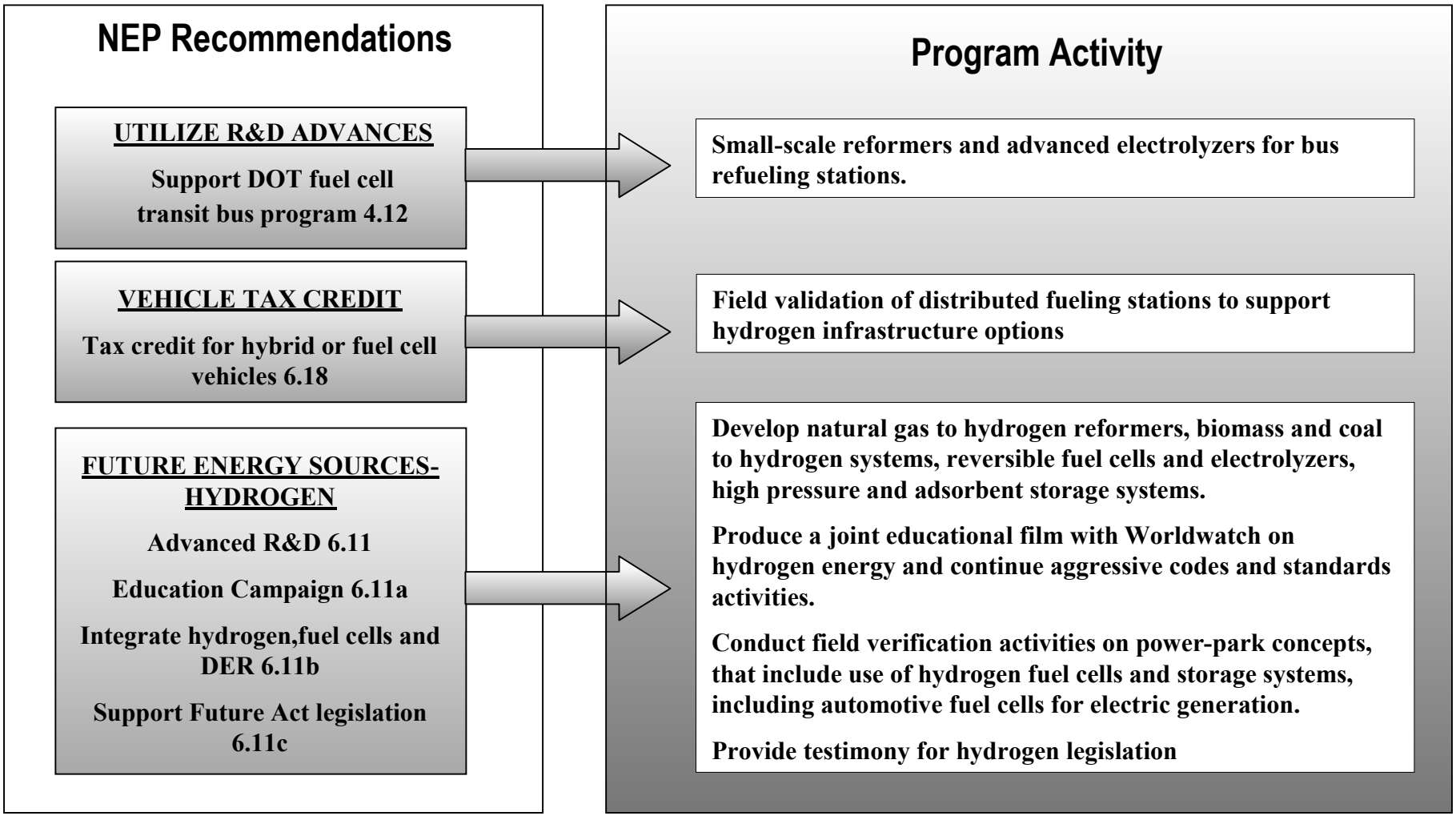
Awarded three cooperative agreements with industry teams for hydrogen refueling stations.

Completed certification of a 6% by weight, 5000 psi cyrogas hydrogen storage tank.

Completed 100 cycles of a 5.2 % by weight hydride tank.

Completed testing of hydrogen production and 50kWe hydrogen fuel cell.

Hydrogen Program- Relevance to NEP



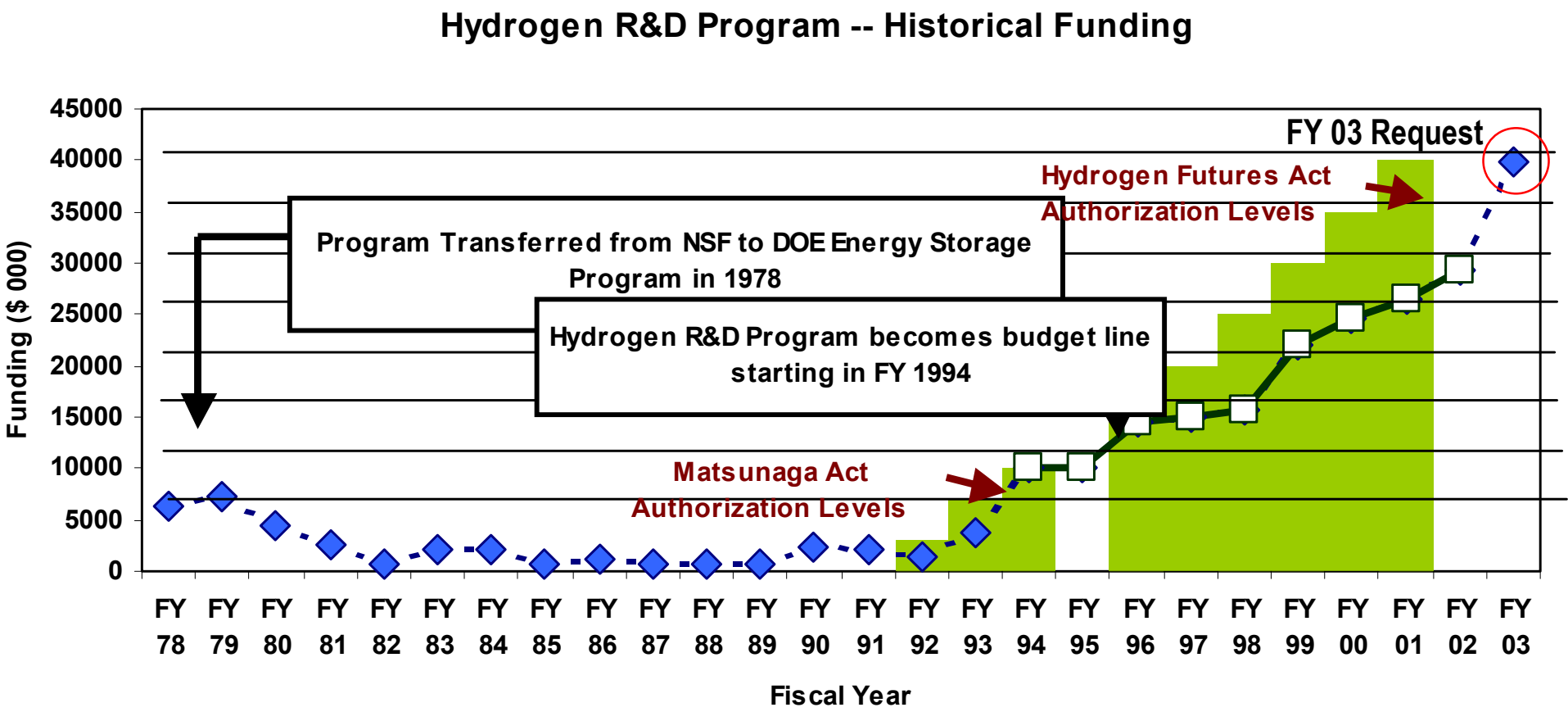
Congressional Language

Conference Committee:

Hydrogen. --The Committee recommendation is $31,000,000 for hydrogen activities. The Conference Agreement includes:

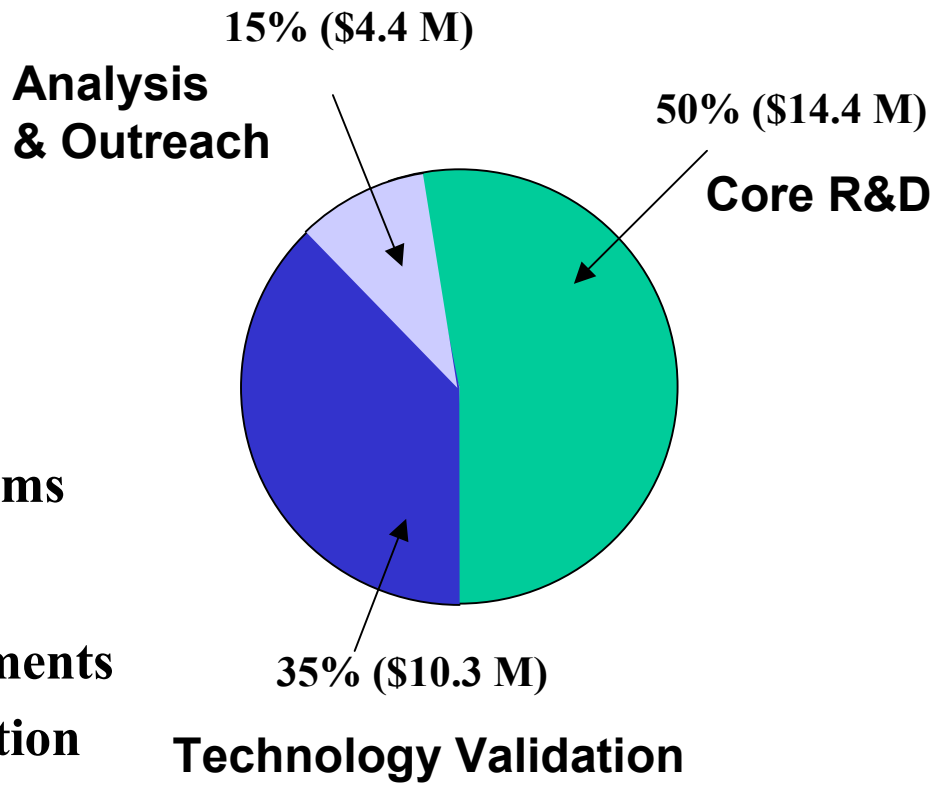
- $1,000,000 for the Fuel Cell Technology Assessment and Demonstration at the University of Alabama at Birmingham
- $350,000 for the Big Sky Economic Development Authority Demonstration Fuel Cell Technologies, Montana
- $500,000 for the gasification of Iowa switch grass and its use in fuel cells, Iowa State
- $1,500,000 for the ITM Syngas project, Air Products Pennsylvania
- $1,500,000 for the fuel cell installation project at Gallatin County, Montana
- $1,000,000 for continued demonstration of the hydrogen locomotive and front-end loader projects, Nevada.

Hydrogen Program Funding Summary



Hydrogen Program Structure

- **Core R&D**
  - Production
  - Storage
  - Utilization
- **Technology Validation**
  - Renewable Hydrogen Systems
  - Hydrogen Infrastructure
  - Distributed/Remote Power Systems
- **Analysis and Outreach**
  - Economic and Technical Assessments
  - Operational Database on Validation
  - Projects for Codes & Standards

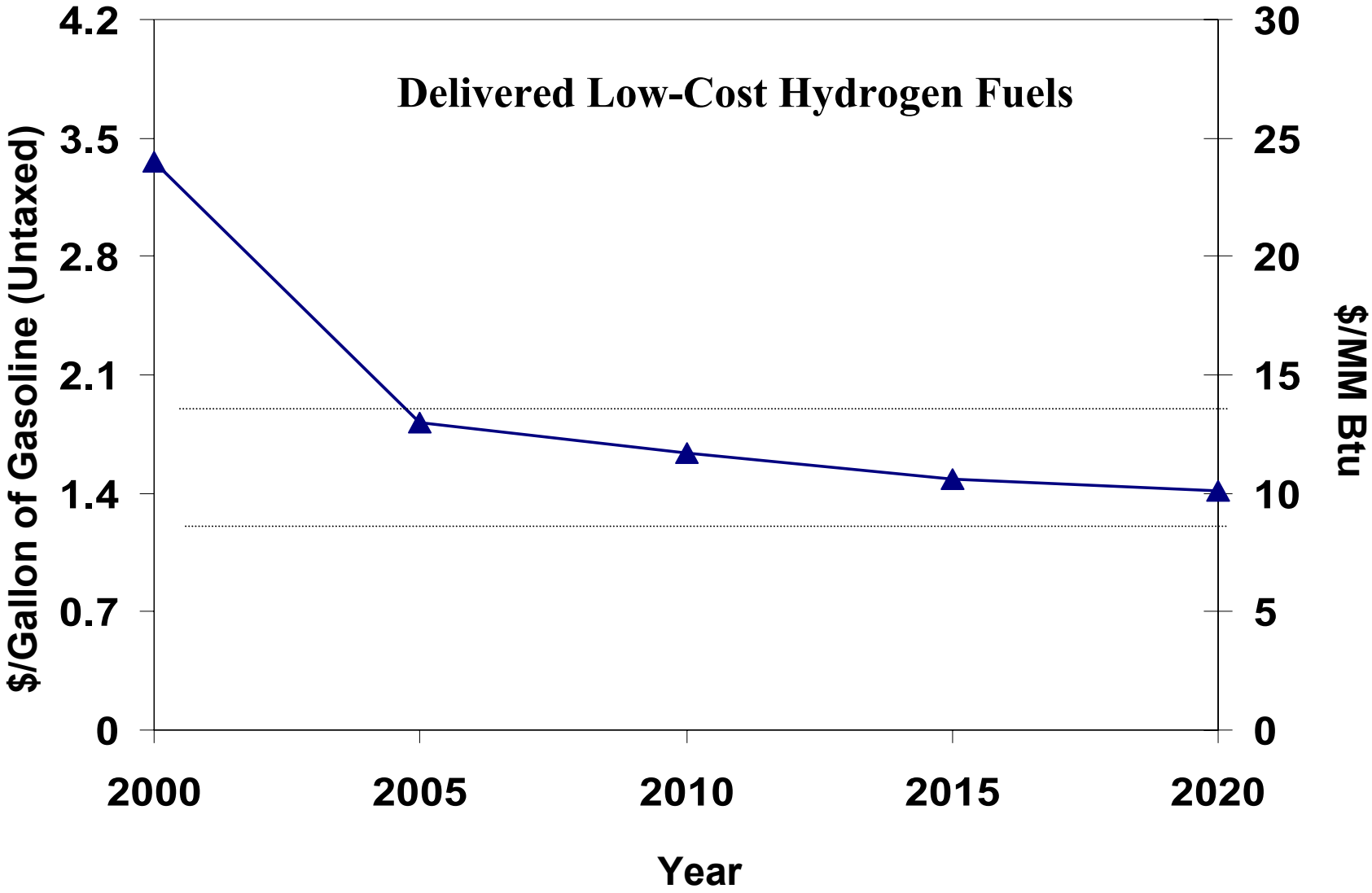


Technology-Specific 2010 Goals FreedomCAR

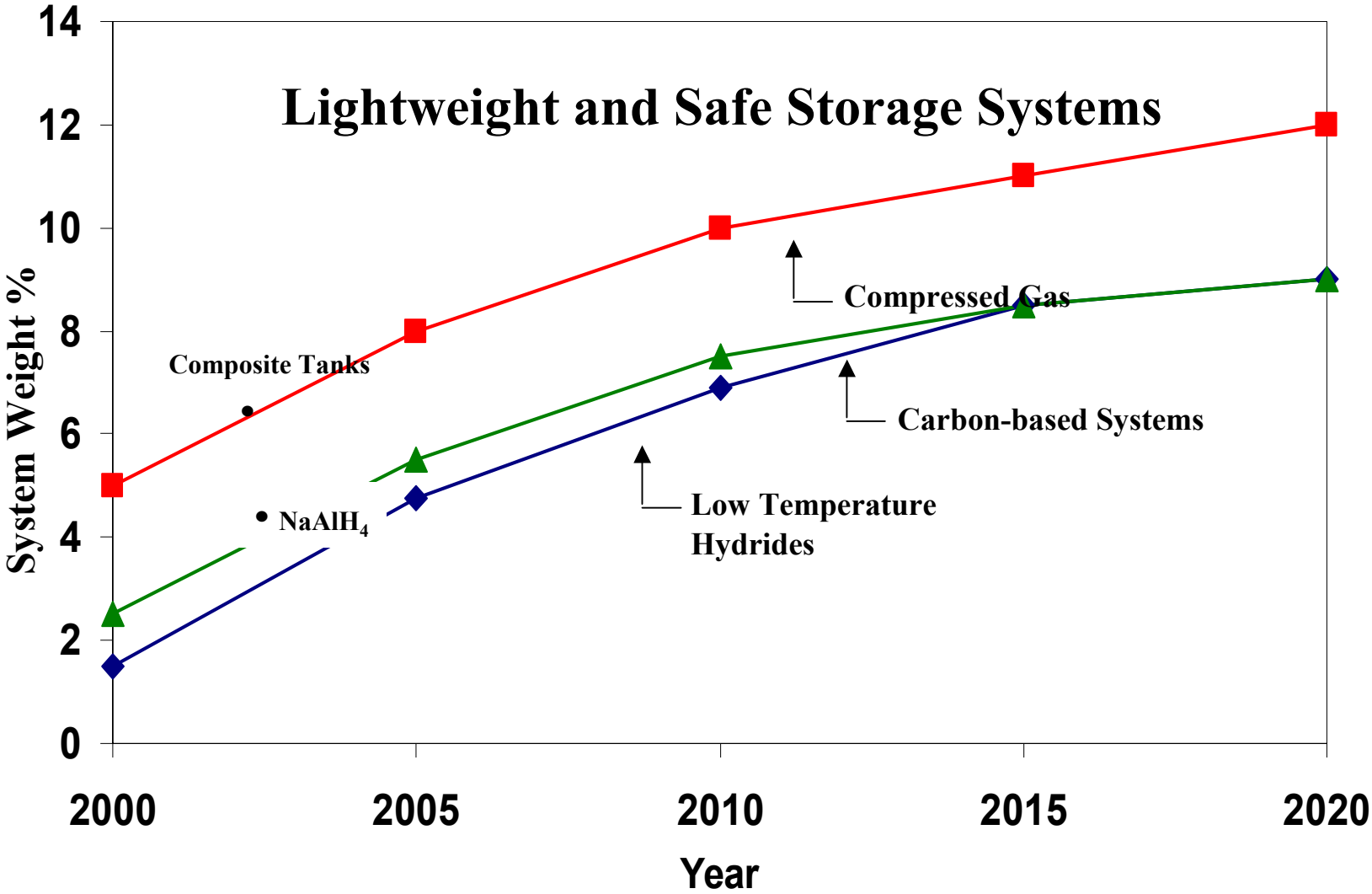
Enabling the transition to a hydrogen economy:

- Demonstrated hydrogen refueling with developed commercial codes and standards and diverse renewable and non-renewable energy sources. Targets: 70% energy efficiency well-to-pump; cost of energy from hydrogen equivalent to gasoline at market price, assumed to be $1.25 per gallon (2001 dollars).
- Hydrogen storage systems demonstrating an available capacity of 6 wt% hydrogen, specific energy of 2000 W-h/kg, and energy density of 1100 W-h/L at a cost of $5/kWh.
- Internal combustion systems operating on hydrogen that meet cost targets of $45/kW by 2010 and $30/kW in 2015, have a peak brake engine efficiency of 45%, and meet or exceed emissions standards.

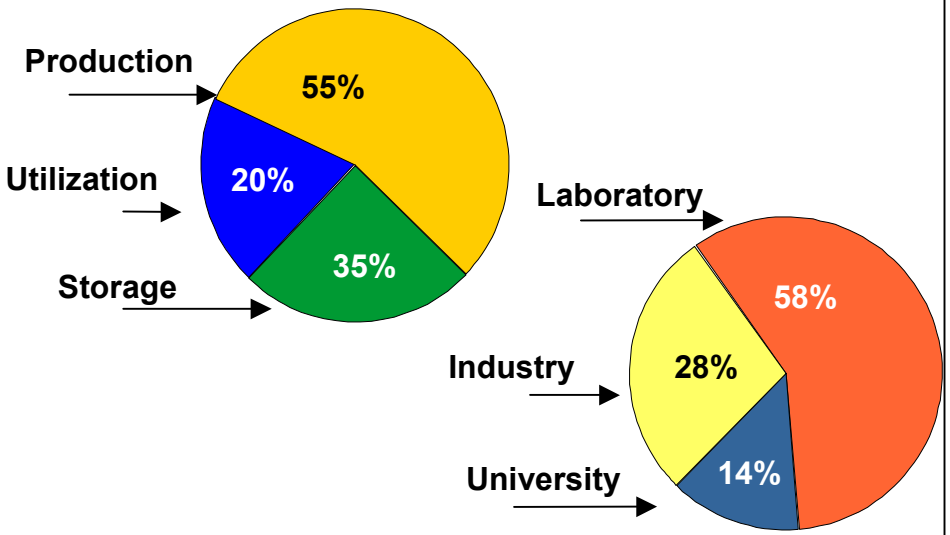
Hydrogen Program Performance Measures



Hydrogen Program Performance Measures



Core R&D Thrust FY02



Storage: $ 7.84 M

FY 01 Milestones

Developed new method to synthesize catalyzed alanate.

Demonstrated thermal compressor at 6000 psig.

FY 02 Milestones

Validate 5.2% by weight storage on catalyzed alanate with over 1000 cycles.

Scale up thermal compressor to 15 liters/min

Production : $ 7.76 M

FY 01 Milestones

Completed construction of ITM PDU

Operated a 5 liter bioshift reactor on a slipstream of syngas.

FY02 Milestones

Operate PDU continuously at 24,000 SCFD of syngas to verify performance.

Operate the 5 liter bioshift reactor at 10 psi on a slipstream of syngas

Utilization : $ 3.74 M

FY 01 Milestones

Supported CaFCP by modeling maintenance building ventilation.

Hydrogen additions to natural gas extended the lean flammability limits cutting NO_x by 25%.

FY 02 Milestones

Demonstrate 200 W advanced PEM fuel cell for personal mobility devices.

Quantify the effect of adding up to 100% hydrogen to combustion turbine emissions.

Hydrogen Production: Ion Transport Membrane

Title: Ion Transport Membrane SynGas/Hydrogen Project

Organization: Air Products and Chemicals

Funding: **EE:** $4.6 million

FE: $12.1 million

Air Products: $15.6 million

Project Period: 96 months

Milestones and Deliverables

Completed fabrication of 24,000 PDU (go decision)

Complete fabrication of 500 MSCFD (go/no go)

Complete test runs of SEP

Complete economic evaluation

Objectives and Background

APC will lead multi-company effort to develop and demonstrate a novel ceramic membrane reactor for the low-cost conversion of natural gas to hydrogen.

Technical Success: Demonstrate SEP at up to 500,000 SCFD syngas and verify hydrogen production cost.

Prime Contractor: Air Products and Chemicals

Subcontractors:

Chevron	Eltron Research
McDermott	Penn State
Norsk Hydro	Ceramatec
University of Alaska	ANL

Hydrogen Production:
High Efficiency Steam Electrolyzer

Title: Solid Oxide Steam Electrolysis

Organization: Lawrence Livermore National Lab

Funding: **EE:** $4.0 million

Project Period: **60** months

Milestones and Deliverables

Demonstrate long term stability of seal
Tested at target pressure of 150 psi and survived multiple rapid cycles

Demonstrate 200 W stack

Demonstrate 1 kW stack prototype

Demonstrate 5 kW prototype

Objectives and Background

LLNL will develop and demonstrate a novel low-cost high temperature solid oxide electrolyzer for distributed hydrogen production.

Technical Success: Demonstrate 5 kW prototype in 2005 to verify hydrogen production cost.

Technical Lead: Lawrence Livermore

Industry Partner: American Fuel Cells

Hydrogen Production: Catalytic Fuel Reforming

Title: Novel Catalytic Fuel Reforming

Organization: InnovaTek, Inc.

Funding: **EE:** $1.2 million

InnovaTek: $0.3 million

Project Period: **48** months

Milestones and Deliverables

Final decision on hydrogen purification process

Membranes have demonstrated pure hydrogen

Finalize design for thermal management

Micro-heat exchanger will help reformation

Complete 1000 hour continuous reforming run

Complete test runs of integrated system

Objectives and Background

InnovaTek will develop and demonstrate a novel microchannel catalytic reactor for the low-cost conversion of natural gas to hydrogen.

Technical Success: Demonstrate hydrogen production with the reformer attached to a PEM fuel cell.

Prime Contractor: InnovaTek

Subcontractors:

Colorado School of Mines

University of Washington

Hydrogen Storage:

Title: High Density Storage

Funding: DOE: $3.3 million

Cost Share**:** $0.8 million

Project Period: 36 months

Milestones and Deliverables

Validate tank systems

Certified 5000 psi composite tank 3600 psi cryogas

Validate NaAlH4 material study

Processing upgrade to provide 5.2% material

Engineer tank system for NaAlH4

Complete test runs of integrated system

Expand carbon R&D

Demonstrate chemical means of cutting

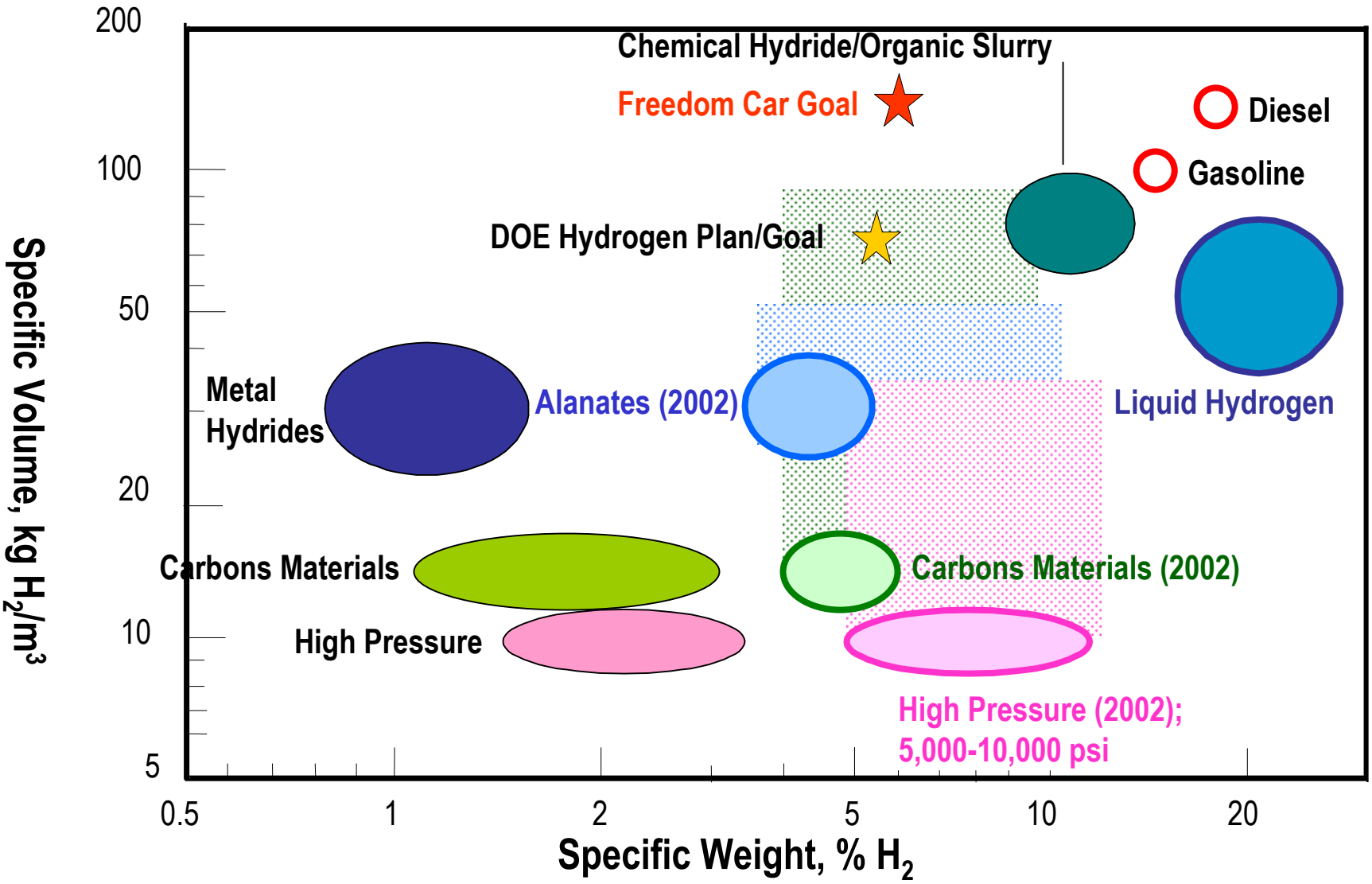
Objectives and Background

Develop and demonstrate novel materials and processes to store 5 kilograms of hydrogen in a tank with a total volume less than 180 liters.

Technical Success: Demonstrate hydrogen storage system that when installed on a vehicle with a PEM fuel cell will achieve 350 400 miles of range.

Sandia National Laboratory
Quantum
J Hopkins/Lincoln
INEEL
University of Hawaii
FSEC
NREL
UTRC
SRTC
CIT
Ergenics
LLNL
SunaTech

Hydrogen Storage Developments
Reference Data From the R&D Roadmap 1998



Hydrogen Utilization:

Title: Applications

Funding: DOE: $1.5 million

Cost Share**:** $0.5 million

Project Period: 36 months

Milestones and Deliverables

Validate adiabatic FC system

Demonstrate PMV at 1 kW

Validate hydrogen ICE with <45% efficiency

Demonstrate FPE

Validate sensors

Complete test of fiber optic sensor

Combustion Turbine

Demonstrate zero emissions

Objectives and Background

Develop and demonstrate small fuel cells for battery replacements, free piston hydrogen fueled ICE's for hybrids and stationary generation, and gas turbines using hydrogen natural gas blends.

Technical Success: Demonstrate near-term infrastructure for PMD (medical) using PEM fuel cells, establish training program, and collect operational data for C&S.

Sandia National Laboratory

DCH

LANL

ORNL

TMI

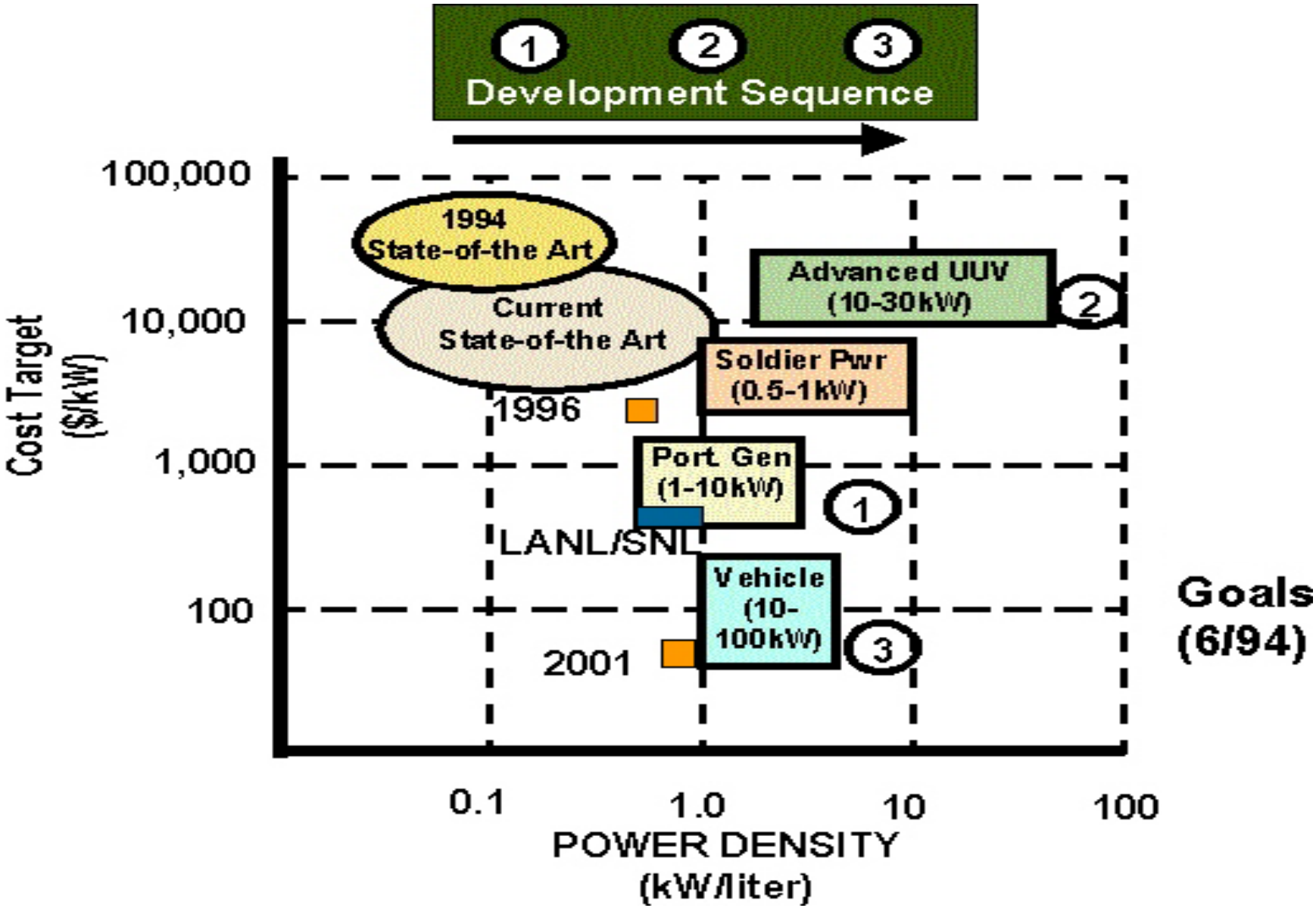
Peterson Ridge

NREL

ATMI

HTAP PEM Fuel Cell Requirements

From June 1994



Hydrogen Program: Timeline

	1990-1995	1996	1997	1998
Changes of Direction	Program moved from an earmarked activity to projects funded through competitive solicitations. Created HTAP charter and appointed members	Created and industry outreach project to inform industry about the program, its goals and longer-term objectives.	Created Technology Validation project Initiated cluster concept for refueling stations	Published strategic plan to replace five-year management plan. Decision made to develop natural gas to hydrogen reformers for refueling stations
Key Accomplishments	Published five year management plan Created Hydrogen Interagency Panel Created Peer Review Process	Produced industry roadmap on hydrogen. Initiated codes and standards activities	Demonstrated first PEM fuel cell vehicle at Palm Desert. Published report that hydrogen fueled internal combustion engines could achieve significant efficiency and emissions improvements.	Published technology roadmap for R&D Two researchers received awards, Christopher Columbus and SAE Top Research Paper Achieved 12.4% solar-to-hydrogen efficiency
Down Selects	Four universities earmarked in prior years were required to compete for awards. Four storage contracts were awarded.	Discontinued all activated carbon storage work, and high temperature metal hydrides. Moved glass microsphere storage work to industry	Eliminated R&D on carbon foam and other engineered carbon forms for hydrogen adsorbents.	Discontinued coal gasification Discontinued all conventional hydride development Refocused carbon nanotube research

Hydrogen Program: Timeline

	1999	2000	2001	2002
Changes of Direction	Initiated joint program with State Energy Program to validate technology. Established collaboration with DOT on fuel cell buses	Signed an MOU with FE to co-fund and co-manage coal to hydrogen projects. Instituted powerpark program	Initiated joint program with OTT to co-fund and co-mange research on hydrogen storage and validate refueling technology.	Expanded joint program with OTT to co-fund and co-mange research on hydrogen storage, production and validate refueling technology. Co-fund separation technology development with FE
Key Accomplishments	First electrolyzer delivered to BC Transit to fill three fuel cell buses. Operated reversible fuel cell at 1000 amps/ft^2 @ 0.6 V Created Dr. Bob show to teach middle and high school students.	Second generation electrolyzer delivered to SunLine Transit to fill vehicles. Demonstrated 7.5% by weight hydrogen storage in high pressure tanks.	Third electrolyzer delivered to Nevada to fill buses. Operated lab scale PDU for Ion Transport Membrane Reactor. Created hydrogen curriculum and implemented it in CA.	Demonstrated hydride storage system for mine vehicle Completed milestone for Ion Transport Membrane Reactor. Nevada refueling station Mining Locomotive
Down Selects	Discontinued Sorbent Enhanced Reaction project due to poor performance on scale-up.	Discontinued work on organic catalysts for metal hydride adsorbents. Discontinued work on diesel reforming.	Discontinued project with ECD, commercialization partnerships could not be finalized.	Discontinued projects with FSEC, ORNL, NETC, SNL, UTRC, MER Carbon storage was expanded