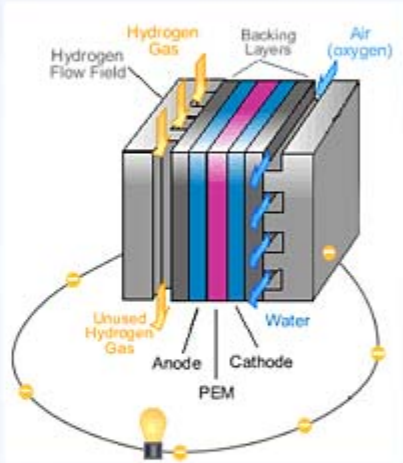
2005 Annual DOE Hydrogen Program Review

Fuel Cell R&D



Valri Lightner, Fuel Cell Team Leader
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Office of Hydrogen, Fuel Cells and Infrastructure Technologies

Outline

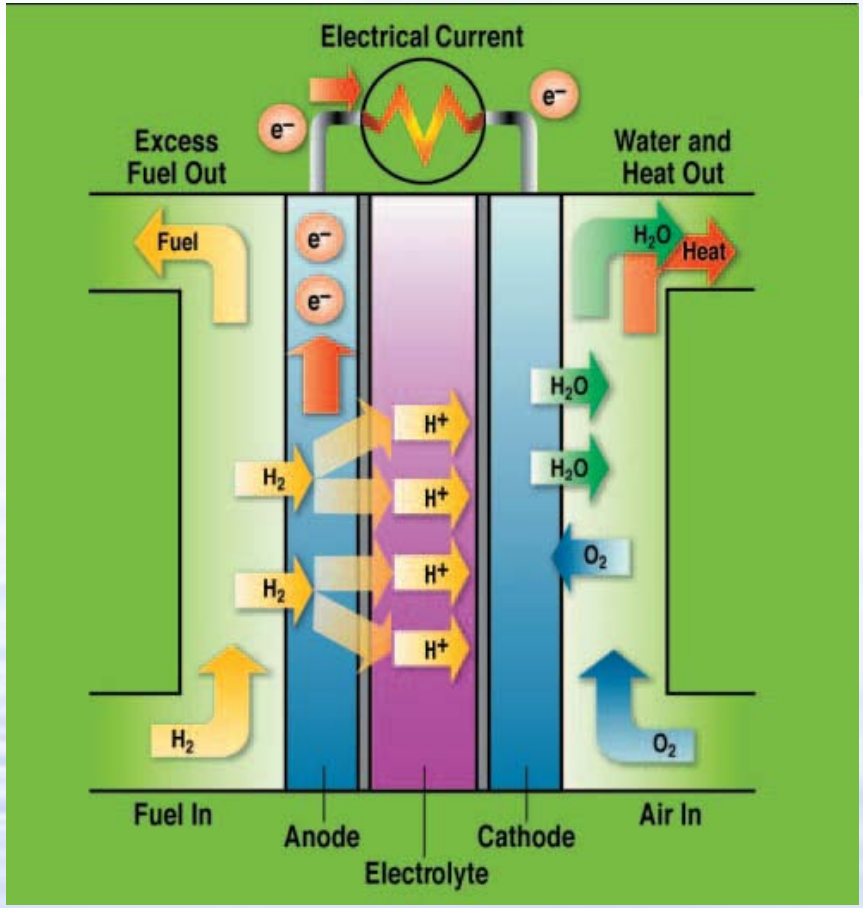
- Barriers
- Targets
- Planning and Implementation
- Coordination
- Research Partners
- Funding Distribution
- Areas of Research
- 2004 Accomplishments
- Future Plans

Fuel Cell Technical Barriers

Although many issues are discussed below, it should be noted that cost and durability present two of the more significant technical barriers to the achievement of clean, reliable, cost-effective systems.

BARRIERS

A. Durability
B. Cost
C. Electrode Performance
D. Thermal, Air, Water Management
E. Compressors/Expanders
F. Fuel Cell Power System Integration
G. Power Electronics
H. Sensors
I. Hydrogen Purification/CO Cleanup
J. Startup Time/Transient Operation



Key Targets

Transportation (PEMFC)

- $45/kW by 2010
- $30/kW by 2015
- 5,000 hours durability

Distributed Energy (PEMFC)

- $400-$750/kW by 2010
- 40,000 hours durability

Auxiliary Power Units (SOFC)

- specific power of 100 W/kg by 2010
- power density of 100 W/L by 2010

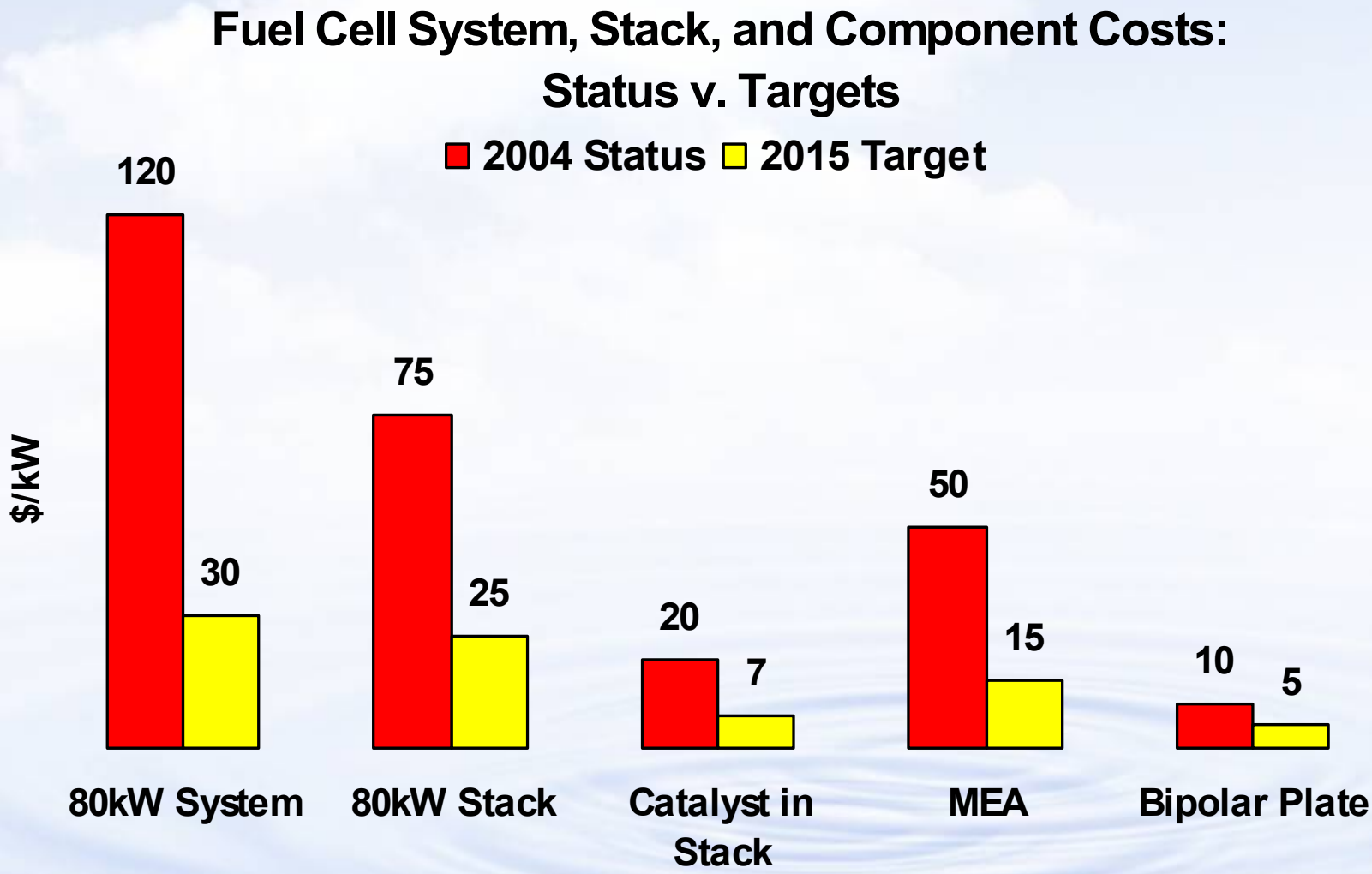
Consumer Electronics (DMFC)

- energy density of 1000 W/L by 2010

Changes to Technical Targets

- Targets focused on fuel cell system, excluding hydrogen storage
- Shift from 50kW fuel cell system for transportation to 80kW fuel cell system
- Shift to components:
  - Membranes
  - Electrocatalysts
  - Membrane Electrode Assemblies
  - Bipolar plates
- Hydrogen Quality

Gap Between Transportation PEMFC Status and Targets



Cost status and targets are based on production of 500,000 units per year.

Planning and Implementation

New Portable Power, APU and Off-Road Projects Begin

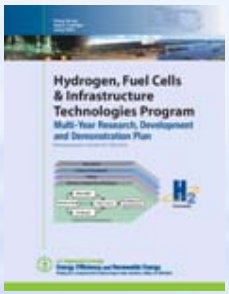
Fuel Cell Operation in Freezing Conditions Workshop

Portable Power Workshop

Funding Opportunity Announcement for New Fuel Cell Projects To Meet 2010 Targets

Sep '04 | **Feb '05** | **Mar '05** | **May '05** | **Aug '05** | **Aug '06**

MYRD&D Plan Published



Annual Peer Review

Pre-Solicitation Workshop

New Fuel Cell Projects Begin

Research Partners

Transportation Systems

System Modeling
ANL, NREL, LANL

Sensors
Honeywell, UTC Fuel Cells, LLNL, ORNL

Compressor
Honeywell, Mechanology

Humidifiers / Heat Exchangers
Honeywell, ORNL

APU's in Trucks (SOFC)
Delphi Automotive, Cummins, PNNL,ANL

Portable Power (DMFC)
PolyFuel, MTI Micro Fuel Cells, LANL

Off-Road (PEMFC)
IdaTech

Distributed Energy

Stationary Systems
IdaTech, UTC Fuel Cells, Plug Power

Modeling and Analysis
ANL, NREL, Battelle

Fuel Processor

Catalysts & FP Systems for Stationary
Nuvera, Texaco, Catalytica, U. Michigan, ANL, ORNL, PNNL

Stack Components

Membranes & MEA's
UTC Fuel Cells, 3M, DeNora, Arkema Chemicals, DuPont, Plug Power, LANL, ANL, NREL, SNL

Catalysts
Ballard, U. of South Carolina, 3M, Cabot-Superior Micropowders, OSRAM Sylvania, NRL, NASA, ANL, LBNL, BNL

Platinum Recycling
Englehard , Ion Power

Bipolar Plates
Porvair, ORNL, PNNL, NREL

Fuel Cell Characterization
NIST, ORNL, LANL, LBNL

Technology Validation (Vehicle Portion)

General Motors and Shell
Ford and BP
DaimlerChrysler and BP
ChevronTexaco and Hyundai

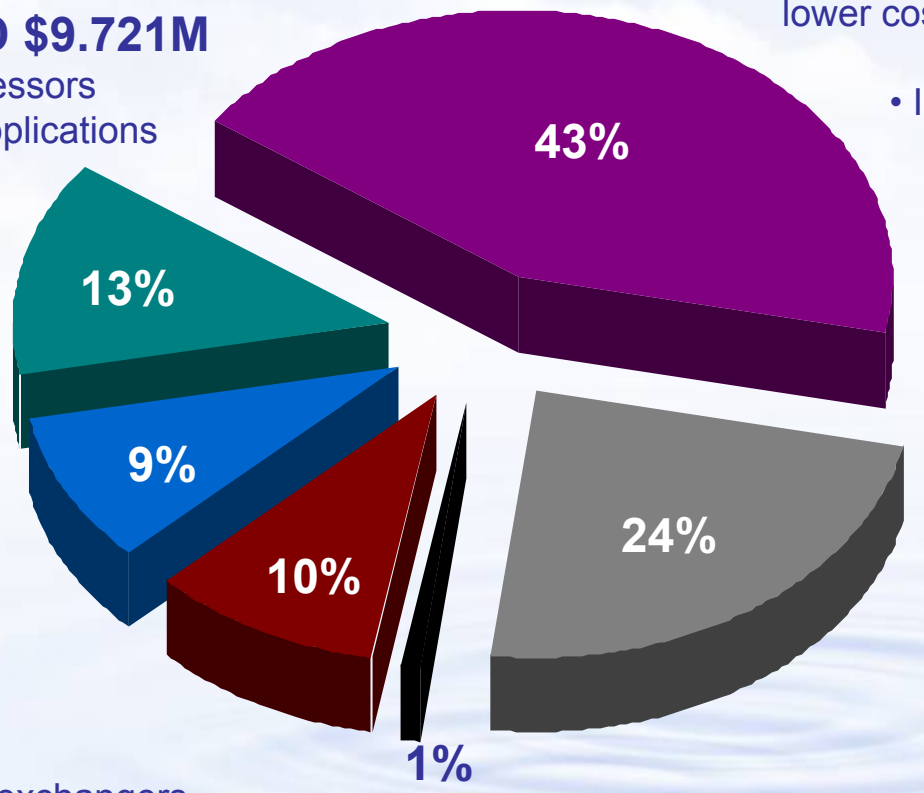
Funding Distribution

FY 2005 Fuel Cell Activities
$75 Million

Fuel Processor R&D $9.721M
- LPG or propane fuel processors technology for stationary applications
- Fuel processor catalysts

Distributed Energy Systems $6.902M
- High efficiency PEMFC power systems as an alternative to grid-based electricity for buildings

Transportation Systems $7.495M
- System analysis
- System sensors
- Compact humidifiers/heat exchangers
- APUs for trucks
- Portable power applications
- Full scale compressors



Stack Component R&D $32.541M
- High temperature, low RH membranes, with lower cost, improved durability and tolerance to impurities
- Improved understanding of proton conduction and membrane degradation
- Lower cost non-precious metal catalysts and ultra-low platinum loading
- Durable, lightweight, low-cost bipolar plates

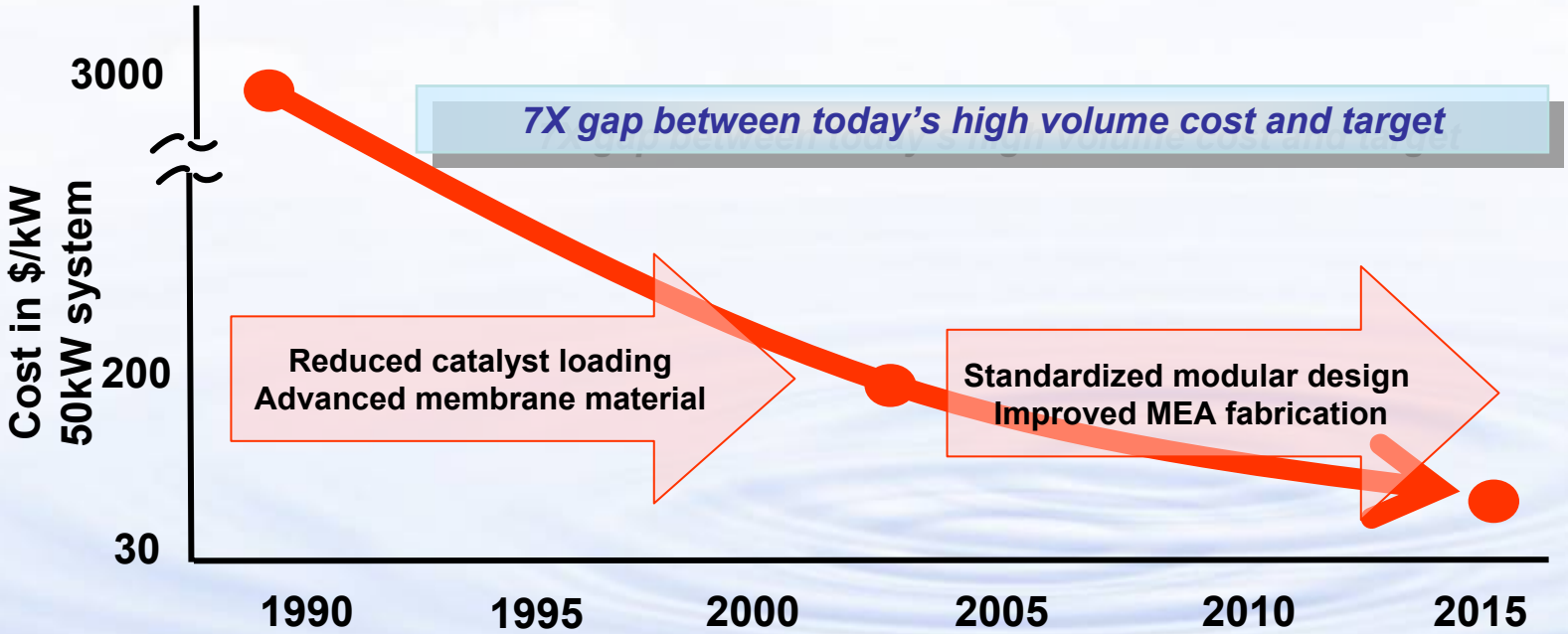
Technology Validation $17.750M
- 1st and 2nd generation fuel cell vehicles
- Validation of performance and durability of fuel cell systems

Technical/Program Management Support $0.535M
- Program, strategic & operating plans

2004 Technical Accomplishments

Overall Transportation Fuel Cell System Cost Goal:

- Reduced the high-volume cost of automotive fuel cells from $275/kW (2002) to $200/kW (2004) using innovative processes developed by national labs and fuel cell developers for depositing platinum catalyst. 2015 target is $30/kW.

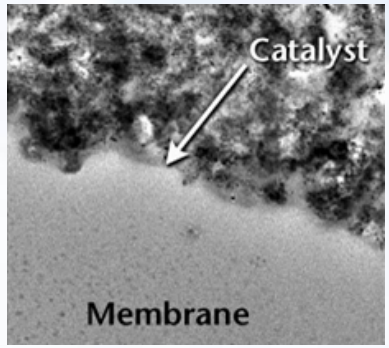


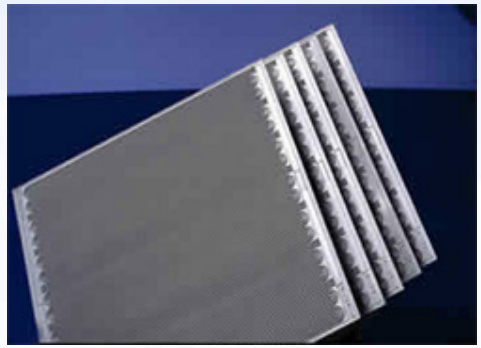
2004 Technical Accomplishments

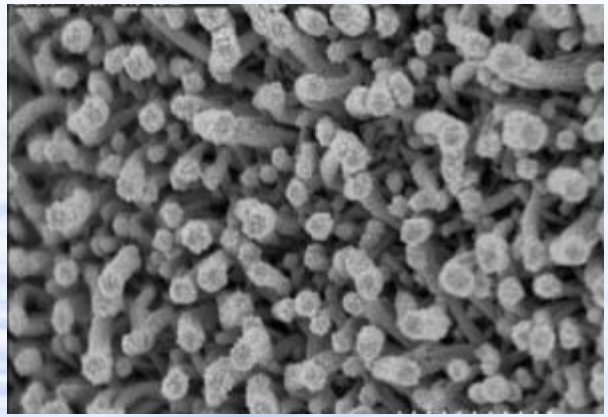
Overcoming critical technical barriers at the fuel cell component level

Demonstrated:

- long-term, 8X mass specific activity improvement of low Pt-content (Pt-Pd BNL) cathode catalysts.
- high-surface-area Pt-alloy/carbon catalysts achieve 2X activity gain and higher durability than pure Pt
- 5X gain in specific activity of Pt and Pt alloys on nano-structured thin film over catalysts on conventional high-area carbons
- electrolyte polymer with proton conductivity of 0.1 S/cm at < 25% RH and 120°C
- fluoride loss with chemically stabilized (CS) Nafion® reduced by ~90%
- bipolar plate manufacturing process (at 20 parts per hour) that produces plates with target properties and acceptable performance







Future Plans

Next Generation Fuel Cell R&D Projects

Pre-Solicitation Workshop to Discuss Potential Topics of Research
This Thursday, May 26, 1:00 – 5:00 pm, Here.

- **R & D focused on advancing PEM fuel cell technology toward 2010 performance targets**
- **Funding Opportunity Announcement ~ August 2005**
- **Anticipated DOE funding of $70 M over 3 years, with applicant cost share of 20-40% depending on stage of development**
- **Potential Topics of Research:**
  - ❑ **Improved Fuel Cell Membranes**
  - ❑ **Water Transport Within the Stack**
  - ❑ **Advanced Cathode Catalysts and Supports**
  - ❑ **Cell Hardware (Bipolar Plates, Seals)**
  - ❑ **Freeze-Capable Stacks**
  - ❑ **Balance of Plant (Compressors, Auxiliary Motor/Controllers)**
  - ❑ **Effects of Impurities on Fuel Cell Performance & Durability**

As announced in
April 19, 2005
Federal Register Notice
DE-PS36-05GO95018

Key Milestones

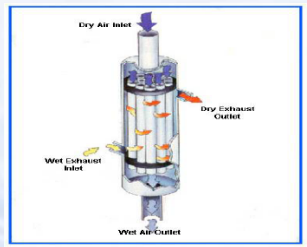
Go/NoGo Decision on Chemical and Physical Sensors

Go/NoGo Decision on Portable Power, APU and Off-Road

FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010

No Go Decision for On-Board Fuel Processing

Go/NoGo Decision on Air/Water/Thermal Management Systems



Go/NoGo Decision on Distributed Energy Systems

Coordination

Other DOE Offices - Science

- http://www.sc.doe.gov/bes/reports/abstracts.html#NHE

FreedomCAR & Fuel Partnership

- http://www.uscar.com/freedomcar/

International Partnership for the Hydrogen Economy

- IPHE.net

Interagency Hydrogen Research and Development Task Force (OSTP lead)

- hydrogen.gov

Federal/State/Local (Example)

- California Fuel Cell Partnership
- California Hydrogen Highway Network

For More Information

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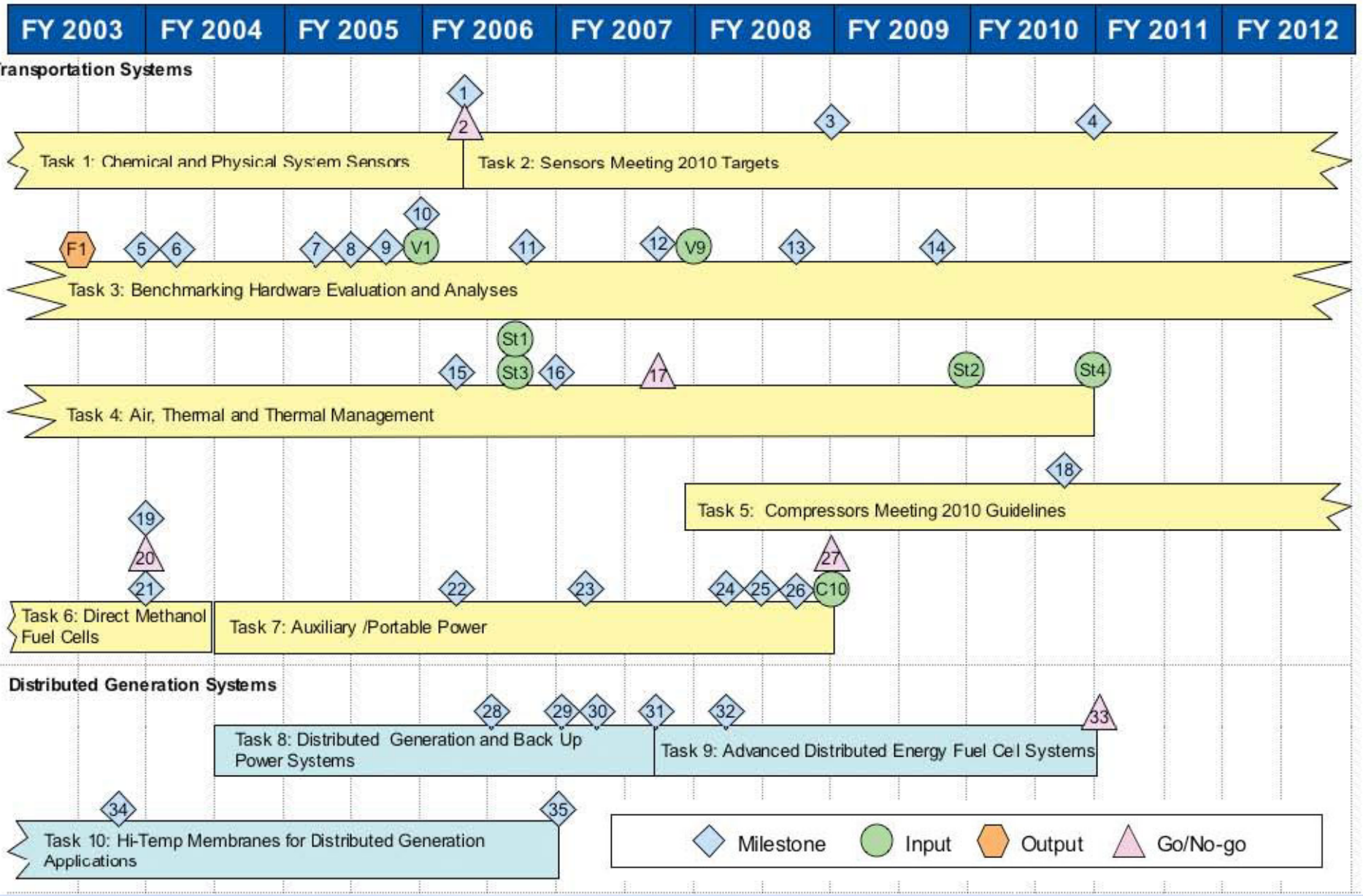
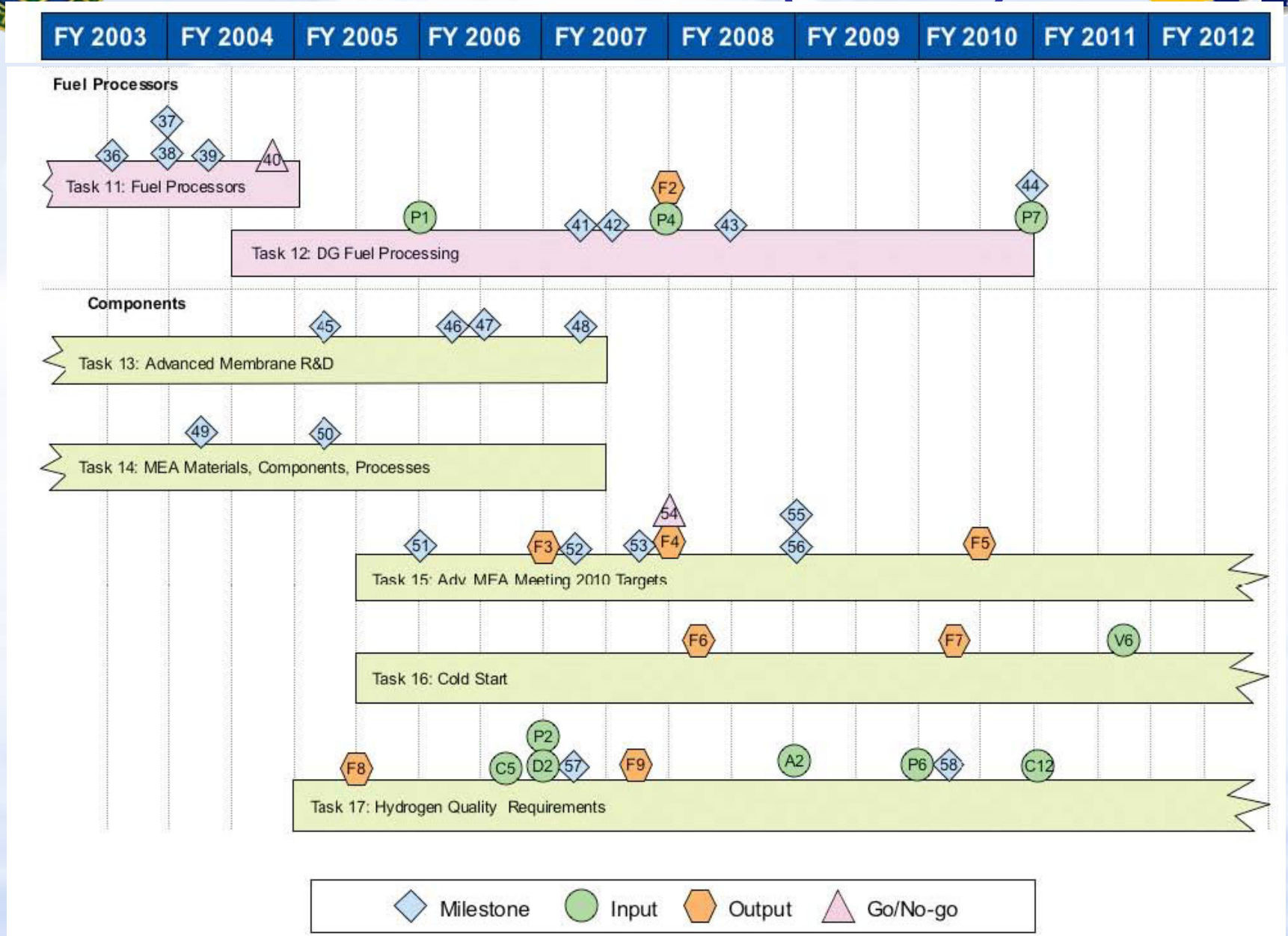
www.eere.energy.gov/hydrogenandfuelcells

Detailed R&D Timeline/Milestones

Hydrogen Fuel Cell R&D Milestone Chart



Hydrogen Fuel Cell R&D Milestone Chart (cont'd)



Milestones

Milestones

1	Complete development and testing of low-cost, high-sensitivity sensors.
2	Go/No-Go: The status of sensors and controls technologies will be assessed and compared with the established technical and cost targets. Based on the assessment and the degree of success, the technologies will be released for use, more development will be indicated, or effort will be terminated.
3	Develop laboratory-scale physical and chemical sensors with improved response time and lower cost.
4	Develop physical and chemical sensors meeting 2010 targets.
5	Deliver model of FCV system.
6	Complete modeling of the availability and economics of platinum group metals.
7	Complete initial evaluation of 25-50-kW advanced integration, atmospheric gasoline reformed system.
8	Quantify fuel cell power system emissions.
9	Evaluate progress towards meeting FY2005 fuel cell cost target.
10	Complete analysis of overall and specific component costs for transportation fuel cell systems.
11	Evaluate progress towards meeting FY2010 fuel cell cost target.
12	Evaluate progress towards meeting FY2010 fuel cell cost target.
13	Evaluate progress towards meeting FY2010 fuel cell cost target.
14	Evaluate progress towards meeting FY2010 fuel cell cost target.
15	Complete development of heat rejection technologies (compact humidifiers, heat exchangers, and radiators).
16	Complete development and testing of low-cost, high-efficiency, lubrication-free compressors, expanders, blowers, motors, and motor controllers.
17	Go/No-Go: The status of air management and thermal management technologies will be assessed and compared to the established technical and cost targets. Based on the assessment and the degree of success, the technologies will be released for use, more development will be indicated, or effort will be terminated.
18	Complete development of compressor, expander, motor blower and motor controller meeting 2010 targets.
19	Identify main routes of DMFC performance degradation.
20	Go/No-Go: Decision to discontinue DMFC R&D for transportation applications.
21	Down-select design scenarios for vehicular fuel cell APUs for further study.
22	Complete evaluation of fuel cell system designs for APUs.
23	Complete design of filtration unit for off-road applications.
24	Evaluate 3-10 kW APU system towards meeting 80 W/kg and 80 W/L targets.
25	Evaluate 20-50 W portable power fuel cell system towards meeting 2006 targets.
26	Portable power fuel cell technology available for industry evaluation.
27	Go/No-Go: Decision on whether to continue auxiliary power, portable power and off-road R&D based on the progress towards meeting 2010 targets.

Milestones (cont'd)

28	Complete testing on 50 kW stationary beta module system.
29	Complete economic analysis report.
30	Demonstrate prototype back up power system.
31	Complete 15,000 hour, stationary fuel cell system test.
32	Demonstrate the effective utilization of fuel cell thermal energy for heating to meet combined heat and power (CHP) efficiency targets.
33	Go/No-Go: Decision on whether to continue stationary fuel cell system based on progress towards meeting durability, cost and electrical efficiency simultaneously.
34	Demonstrate performance (600 mV at 400 mA/cm^2) of an ultra-thin membrane (< 75 µm) in an MEA under atmospheric conditions at 120°C in a 30-cm^2 cell.
35	Complete full-scale MEA evaluation in short stack.
36	Demonstrate fuel-flexible fuel processor meeting year 2005 targets for efficiency, power density and specific power. Measure startup capability.
37	Verify quick-start concept in brass-board prototype system demonstrating capability to meet 2010 startup technical target.
38	Verify small scale, microchannel reformer.
39	Fabricate prototype ion transport membrane module.
40	Go/No-Go: Decision to discontinue fuel processing R&D.
41	Verify fuel processing subsystem performance for distributed generation towards meeting system targets for 2010.
42	Absorption-enhanced natural gas reformer start-up/shut down cycle, transient and durability testing.
43	Develop base metal shift catalysts that enhance conversion to hydrogen and reduce conversion to methane (<1% methane).
44	Develop tolerance of reforming catalysts to fuel containing 1 ppm sulfur.
45	Evaluate 120°C membrane in MEA/single cell.
46	Evaluate 120°C MEA in <10 kW stack.
47	Demonstrate MEA in single cell meeting 2005 platinum loading and performance targets.
48	Evaluate first generation 150°C membrane in MEA/single cell.
49	Evaluate reproducibility (physical and performance) of full-size bipolar plates in high-rate manufacturing processes.
50	Evaluate reproducibility (physical and performance) of MEAs in high-rate manufacturing processes.
51	Initiate 2,000-hour test with advanced membrane & standard GDL.
52	Develop 120°C membrane for operation at < 25% RH.
53	Complete 2,000 hour durability test of advanced MEA for stationary fuel cell application.
54	Go/No-Go: Evaluate precious metal reclamation processes to determine whether to scale-up or terminate.
55	Develop technology for platinum group metal recycling.
56	Evaluate a MEA running on re-manufactured catalyst coated membranes.
57	Develop a method for cleaning sulfur-poisoned platinum catalyst layers in stacks, with minimum interruption of fuel cell operation.
58	Develop a method for cleaning sulfur- and nitrogen-oxide poisoned platinum catalyst layers in stacks, with minimum interruption of fuel cell operation.

Outputs and Inputs

Outputs

- F1 Output to Systems Analysis and Systems Integration: Develop a critical analysis of well-to-wheels studies of fuel cell system performance, efficiency, greenhouse gas emissions, and cost.
- F2 Output to Production: Research results of advanced reformer development.
- F3 Output to Technology Validation: Laboratory PEM technology with 2,000 hours durability.
- F4 Output to Technology Validation: Complete 4,000 hour testing of advanced MEA for stationary and transportation applications.
- F5 Output to Technology Validation: Laboratory PEM technology with 5,000 hours durability.
- F6 Output to Technology Validation: Verify cold-start in 60 s of short stack.
- F7 Output to Technology Validation: Technology short stack survivability at -40°C.
- F8 Output to Systems Analysis and Systems Integration: Develop preliminary hydrogen purity/impurity requirements.
- F9 Output to Systems Analysis and Systems Integration: Updated hydrogen purity/impurity requirements.

Inputs

- V1 Input from Technology Validation: Validate maximum fuel cell system efficiency.
- V9 Input from Technology Validation: Final report on safety and O&M of three refueling stations.
- St1 Input from Storage: Compressed and cryogenic liquid storage tanks achieving 1.5 kWh/kg and 1.2 kWh/L.
- St3 Input from Storage: Complex hydride integrated system achieving 1.5 kWh/kg and 1.2 kWh/L.
- St2 Input from Storage: Advanced compressed/cryogenic tank technologies.
- St4 Input from Storage: Full-cycle, integrated chemical hydride system meeting 2010 targets.
- C10 Input from Codes and Standards: Final draft standard (balloting) for portable fuel cells (UL).
- P1 Input from Production: Hydrogen production technology for distributed systems using natural gas with projected cost of $3.00/gge hydrogen at the pump, untaxed, no carbon sequestration assuming 100s of units of production per year.
- P4 Input from Production: Hydrogen production technology for distributed systems using natural gas with projected cost of $2.50/gge hydrogen at the pump, untaxed, no carbon sequestration assuming 100s of units of production per year.
- P7 Input from Production: Hydrogen production technologies for distributed systems using natural gas with projected cost of $1.50/gge hydrogen at the pump, untaxed, no carbon sequestration assuming 100s of units of production per year.
- V6 Input from Technology Validation: Validate cold start-up capability (in a vehicle with an 8-hour soak) meeting 2005 requirements (specific cold-start energy).
- C5 Input from Codes and Standards: Completed hydrogen fuel quality standard as ISO Technical Specification.
- P2 Input from Production: Assessment of fuel contaminant composition.
- D2 Input from Delivery: Hydrogen contaminant composition and issues.
- A2 Input from Systems Analysis: Initial recommended hydrogen quality at each point in the system.
- P6 Input from Production: Assessment of fuel contaminant composition.
- C12 Input from Codes and Standards: Final hydrogen fuel quality standard as ISO Standard.