Fuel Cells for Transportation Program

Energy Efficiency and Renewable Energy
Office of Advanced Automotive Technologies

Fuel Cell Codes and Standards Summit III

April 5-7, 1999

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OFFICE OF TRANSPORTATION TECHNOLOGIES

PNGV

UNITED STATES OF AMERICA DEPARTMENT OF ENERGY

Fuel Cell Benefits

Fuel Cells

» ***Energy Security***

- ✓ reduce dependence on oil
- ✓ reduce trade deficits
- ✓ increases economic, political & military security

» ***Emissions***

- ✓ reduce air pollution
- ✓ reduce “Climate Change” (via CO_2 reduction)

» ***Economy***

- ✓ increase jobs & international competitiveness in automotive, utility, construction, industrial sectors
- ✓ reduced expenditures on fuel

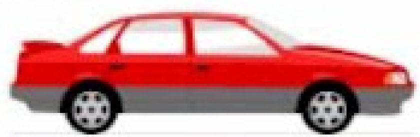
Projected Fuel Cell Vehicle Performance (PNGV-Class Series Hybrid)

Fuel Cells

Projected Mileage, MPG

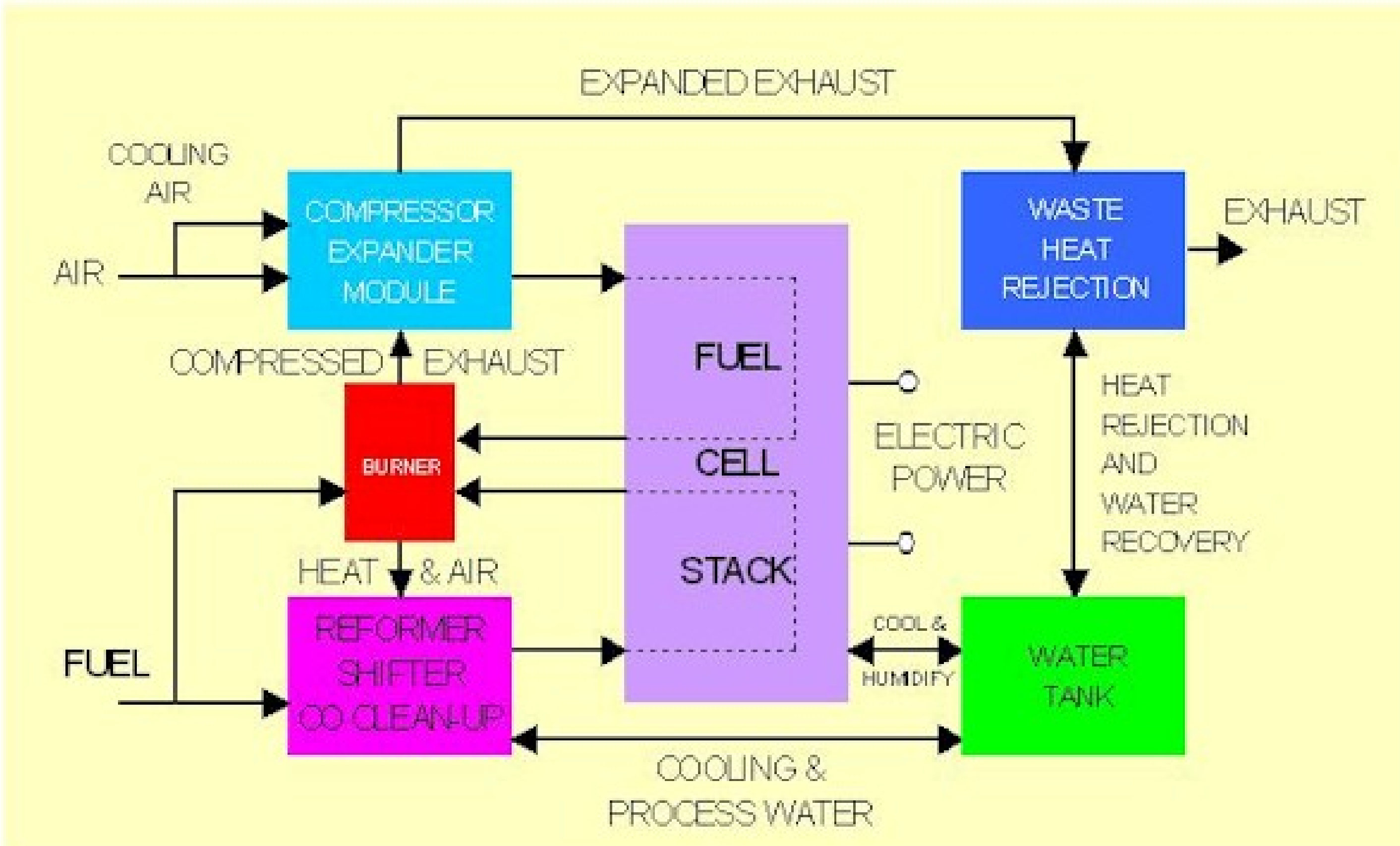
	Gasoline Fueled	Hydrogen Fueled
Urban Fuel Economy	79	101
Highway Fuel Economy	97	128
Combined	**86**	**111**

Note: Based on NREL/ADVISOR system modeling using target fuel cell efficiencies.



Reformer-based, Pressurized PEM Fuel Cell System

Fuel Cells



Modeling Has Identified Design Improvements Needed to Meet PNGV Roadmap Targets

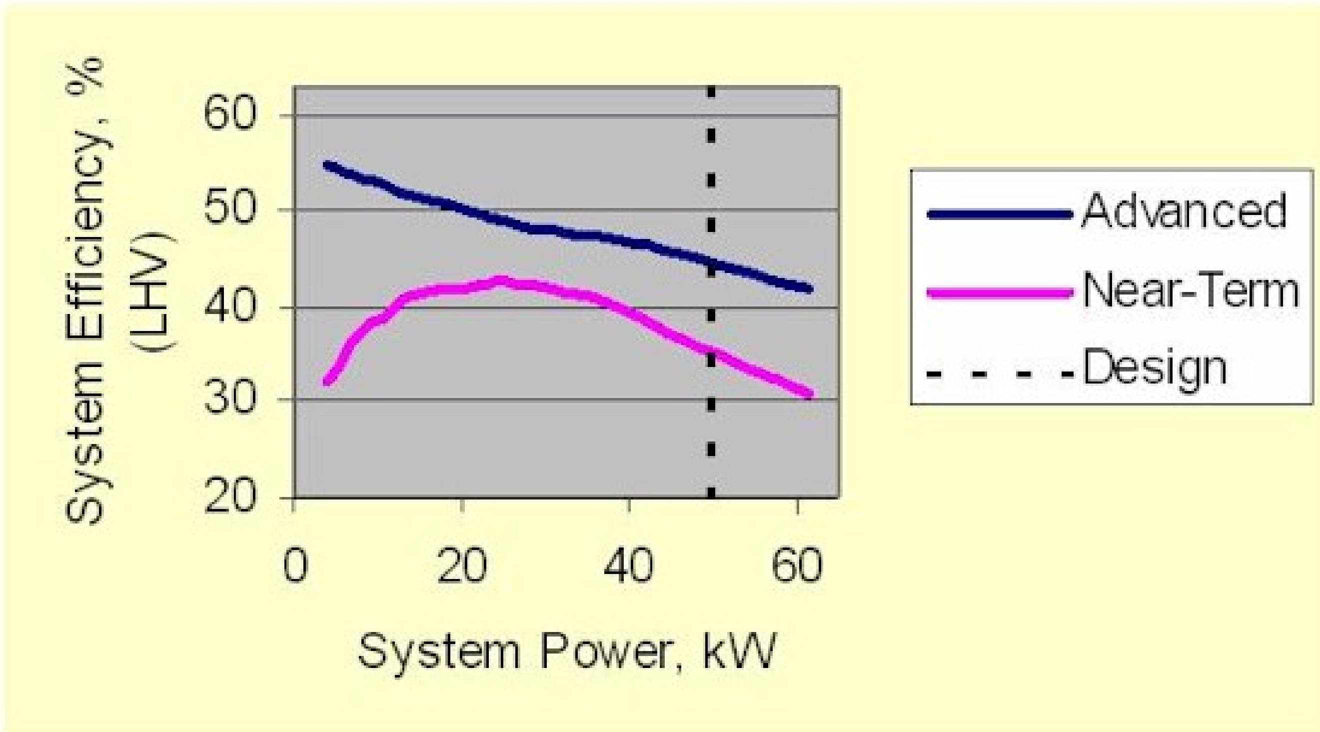
Fuel Cells

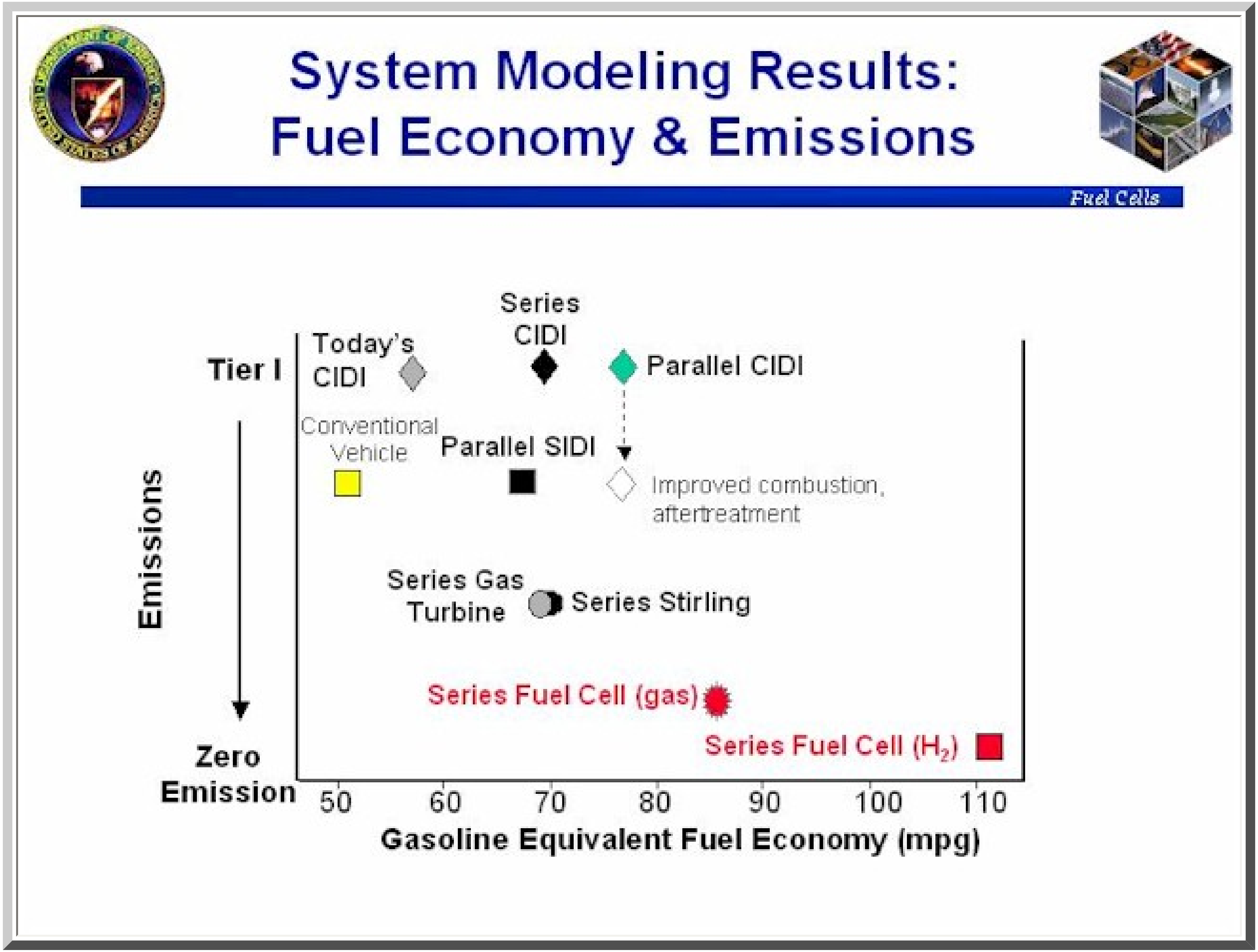
At Full Load:	Near-Term Performance	Target Performance
Cell voltage, V:	0.685	0.8
Fuel utilization, %:	85	90
Oxygen utilization, %:	40	50
Reforming temperature, K:	1300	1000
Efficiency, % (DC Energy Out/LHV Fuel In)		
Fuel cell stack:	54.6	63.7
Fuel cell system:	**35.1**	**46.9**
	(not optimized)	

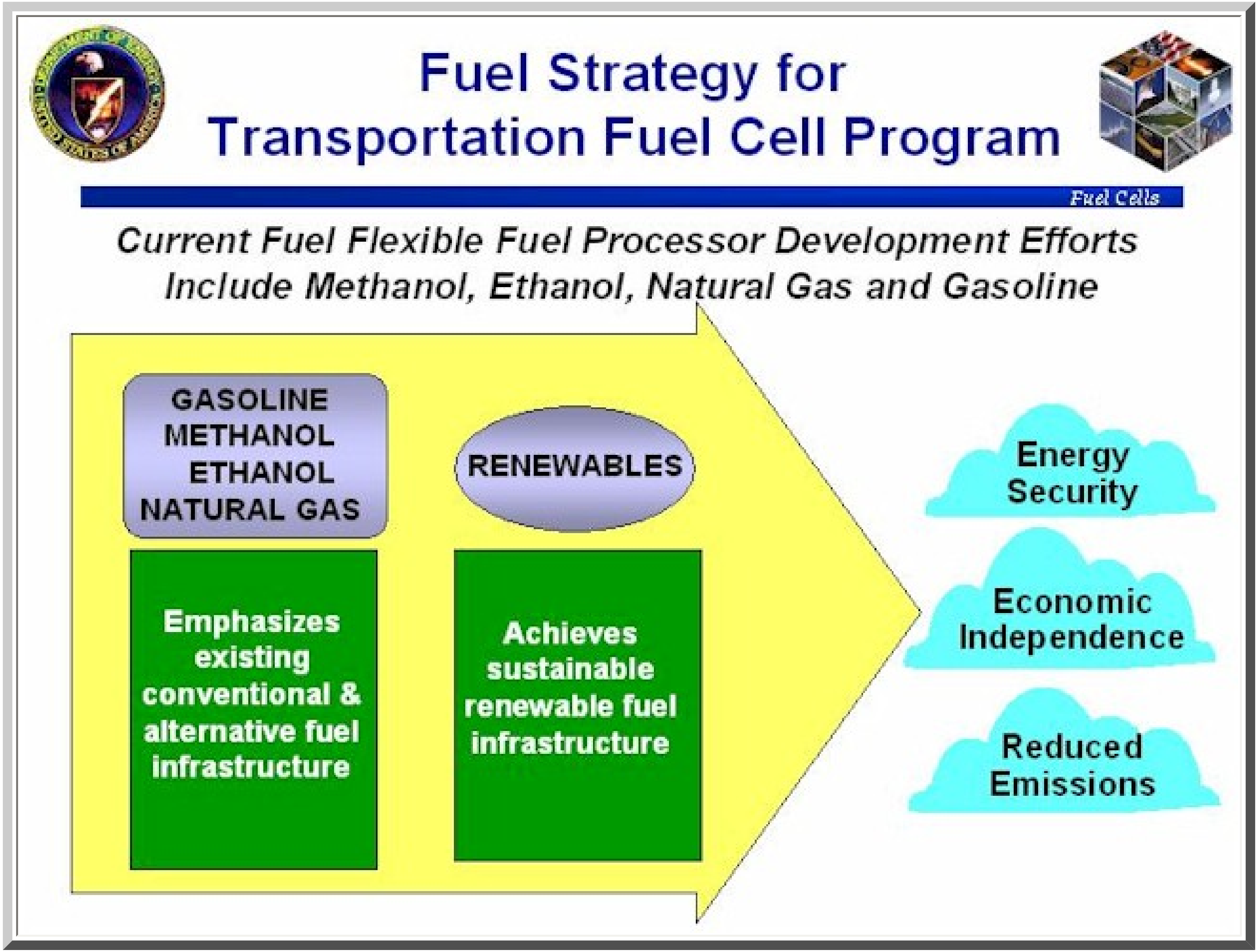
Efficiency increases at part load.

Near-Term and Advanced System Efficiencies Over the Load Curve

Fuel Cells




System Modeling Results:
Fuel Economy & Emissions
Fuel Cells
Series CIDI
Today's CIDI
Tier I
Parallel CIDI
Conventional Vehicle
Parallel SIDI
Improved combustion, aftertreatment
Emissions
Series Gas Turbine
Series Stirling
Series Fuel Cell (gas)
Series Fuel Cell (H_2)
Zero Emission
50
60
70
80
90
100
110
Gasoline Equivalent Fuel Economy (mpg)


Fuel Strategy for
Transportation Fuel Cell Program
Fuel Cells
Current Fuel Flexible Fuel Processor Development Efforts
Include Methanol, Ethanol, Natural Gas and Gasoline
GASOLINE
METHANOL
ETHANOL
NATURAL GAS
RENEWABLES
Emphasizes existing conventional & alternative fuel infrastructure
Achieves sustainable renewable fuel infrastructure
Energy Security
Economic Independence
Reduced Emissions

Technical Barriers

Fuel Cells

Systems

- System Integration
  - Volume/Weight
  - Thermal Management
  - Water Management
  - Cost Trade-offs
- Balance of Plant Components

Fuel Processor

- CO Clean-Up
- Fuel Processor System Integration & Efficiency
- Fuel Processor Start-up & Transient Operation
- Catalyst Cost

Stack Subsystem Components

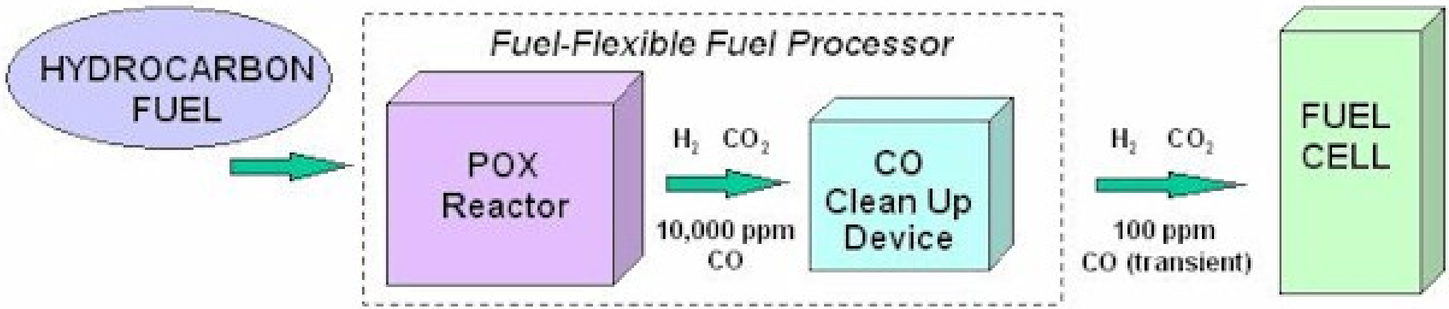
- Air Systems
- Stack Material Cost/Performance
- CO Tolerance

Cost-Weight-Volume

Technical Barrier : *CO Poisoning*

Fuel Cells

- Challenge: Fuel cell catalysts poisoned by CO causing power degradation.

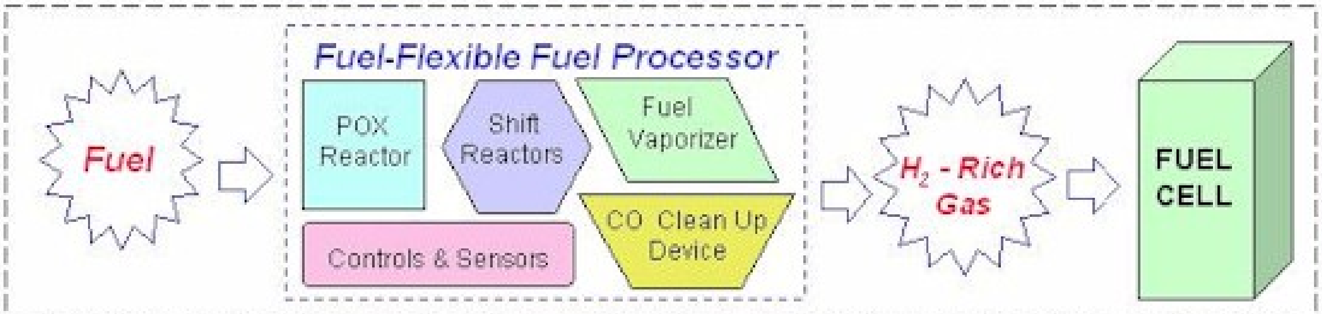


- Approach:
  - Improve CO tolerance of the stack
  - Reduce CO levels from fuel processor

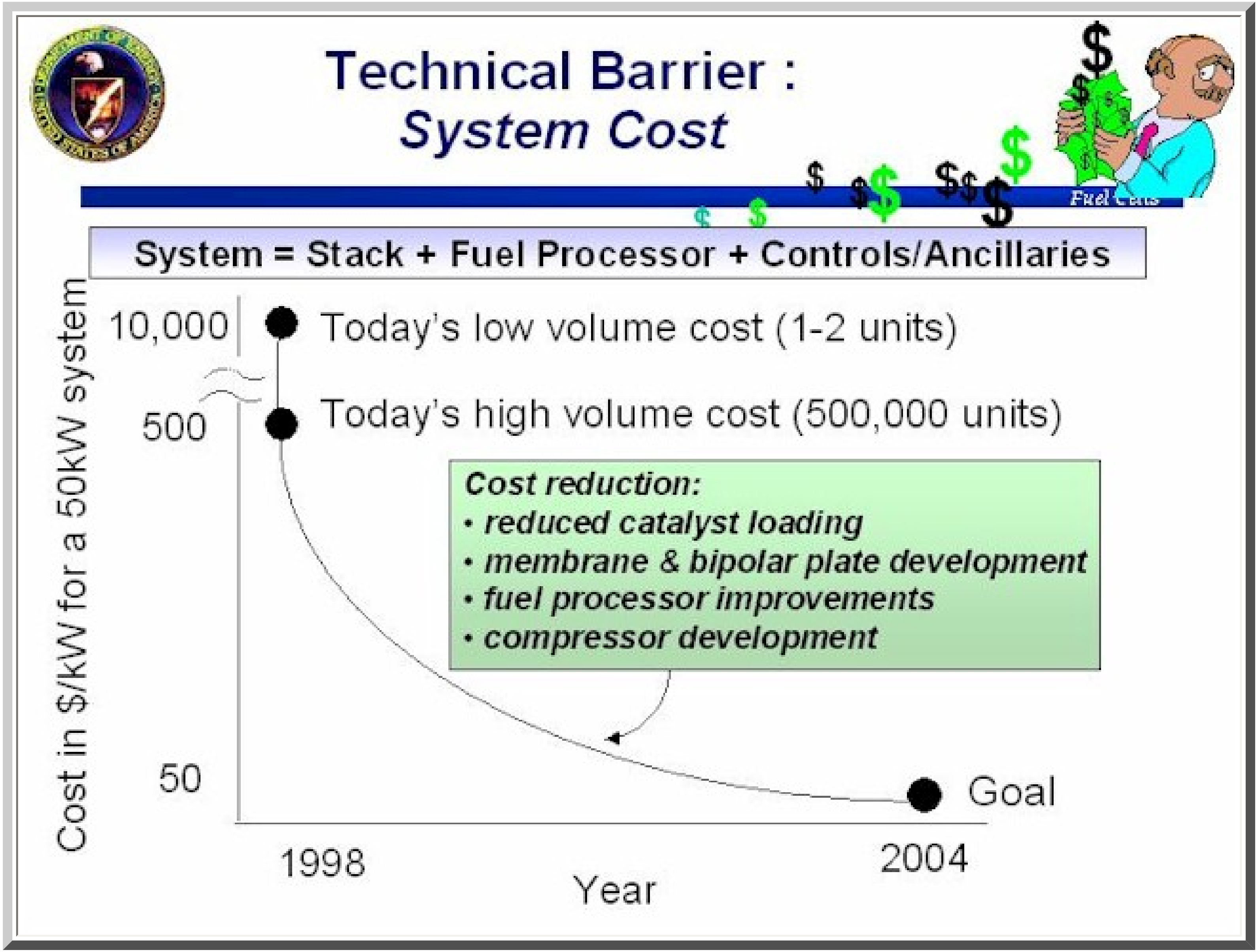
Technical Barrier : *Fuel Processor Efficiency*

Fuel Cells

- Challenge:
  - Low fuel processor efficiency lowers system efficiency



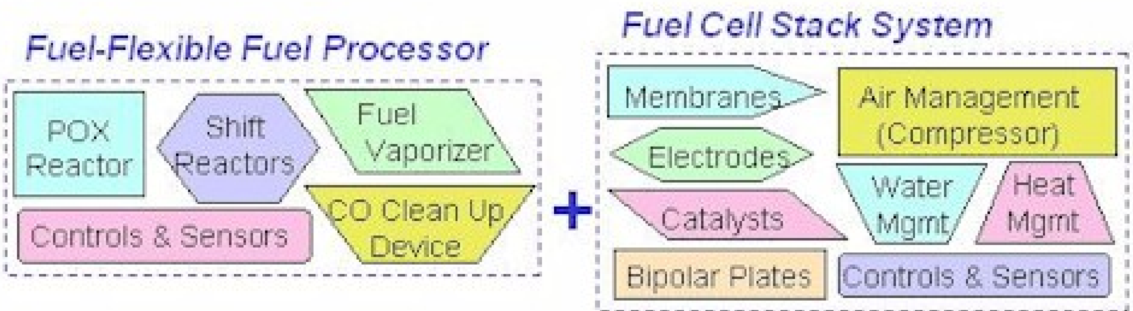
- Approach:
  - integrate processor components into highly efficient automotive-scale systems, evaluate & optimize


Technical Barrier :
System Cost
Fuel Cells
System = Stack + Fuel Processor + Controls/Ancillaries
Cost in $/kW for a 50kW system
10,000
Today's low volume cost (1-2 units)
500
Today's high volume cost (500,000 units)
Cost reduction:
• reduced catalyst loading
• membrane & bipolar plate development
• fuel processor improvements
• compressor development
50
Goal
1998
2004
Year

Technical Barrier : *Power System Integration*

Fuel Cells

- Challenge: Integrated fuel-flexible fuel cell power system has not been fabricated yet.



- Approach:
  - integrate into an automotive-scale system
  - test & evaluate under driving cycle profiles & update system analyses

Goal and Objectives

Fuel Cells

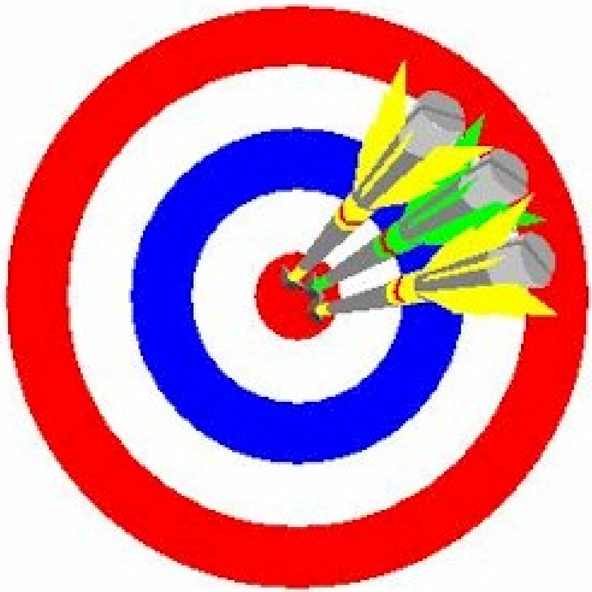
Goal

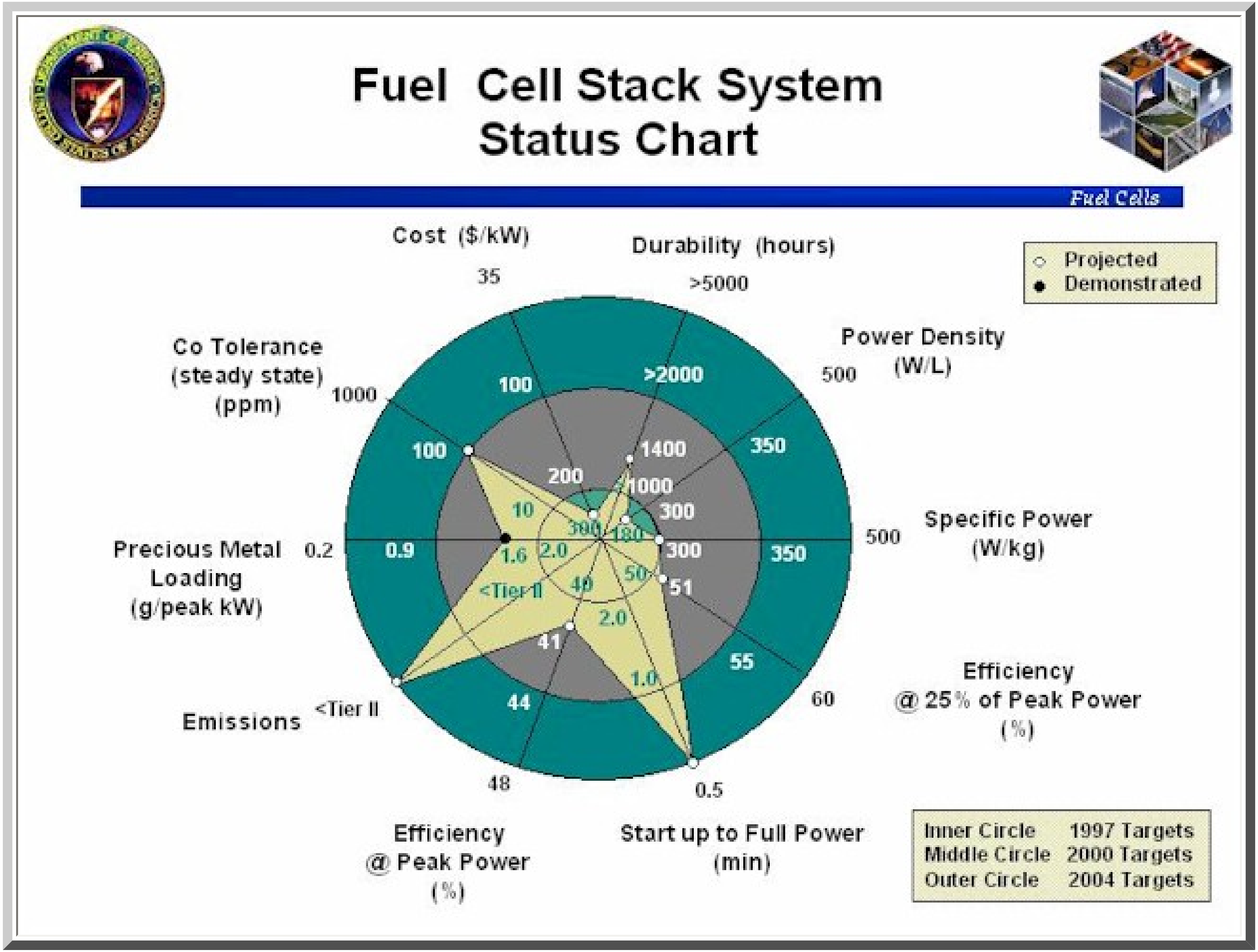
Develop highly efficient, low- or zero-emission, cost-competitive automotive fuel cell power system technologies that operate on conventional & alternative fuels

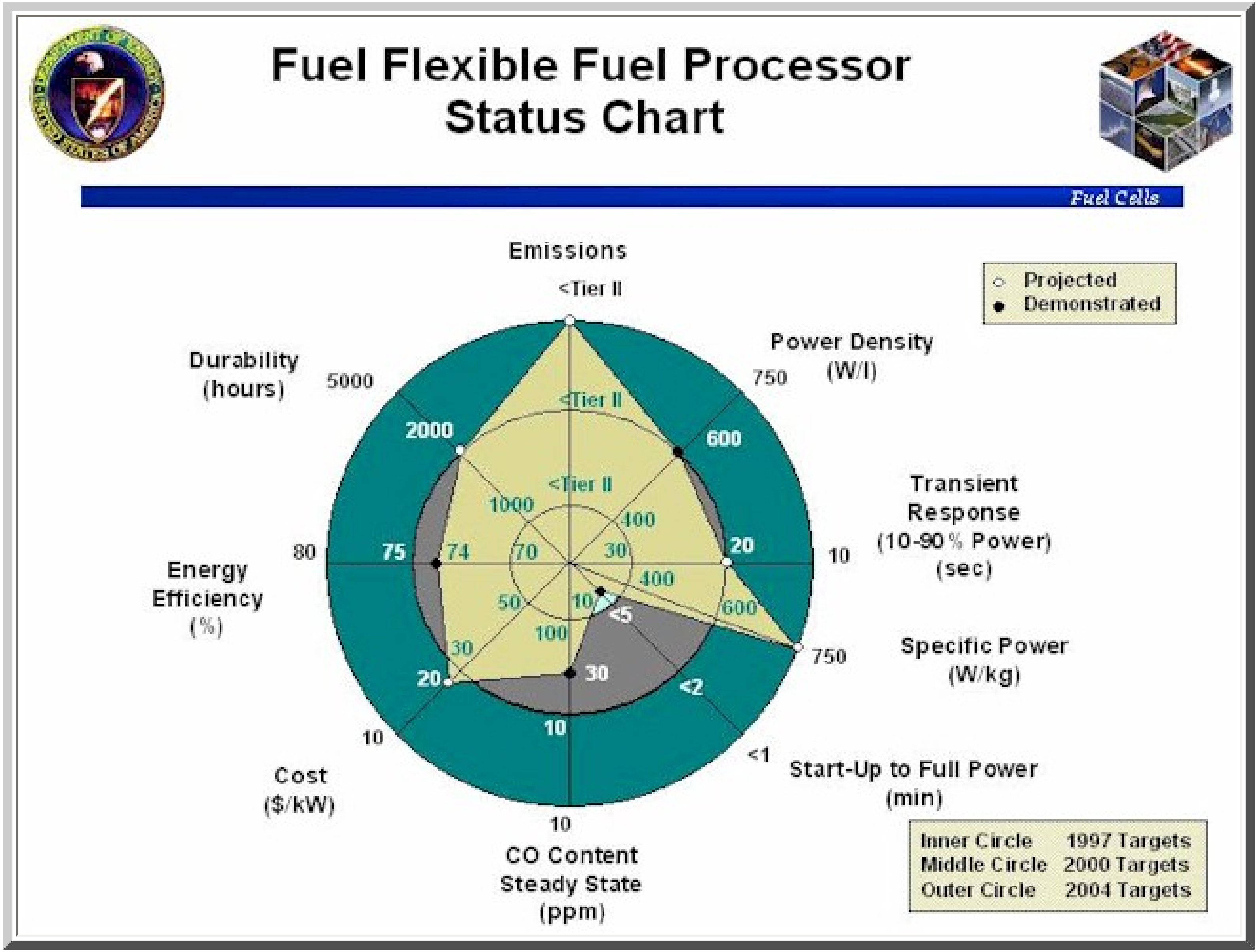
Objectives

- By 2000, develop and validate fuel cell stack system technologies that are:
  - Greater than 55% energy efficient at 25% peak power
  - >100 times cleaner than EPA Tier 2 emissions
  - Capable of operating on Hydrogen rich fuel produced from gasoline, methanol, ethanol, and natural gas
- By 2004, develop and validate fuel cell power system technologies that meet vehicle requirements in terms of:
  - Cost-competitive with internal combustion engines
  - Performance, range, safety and reliability

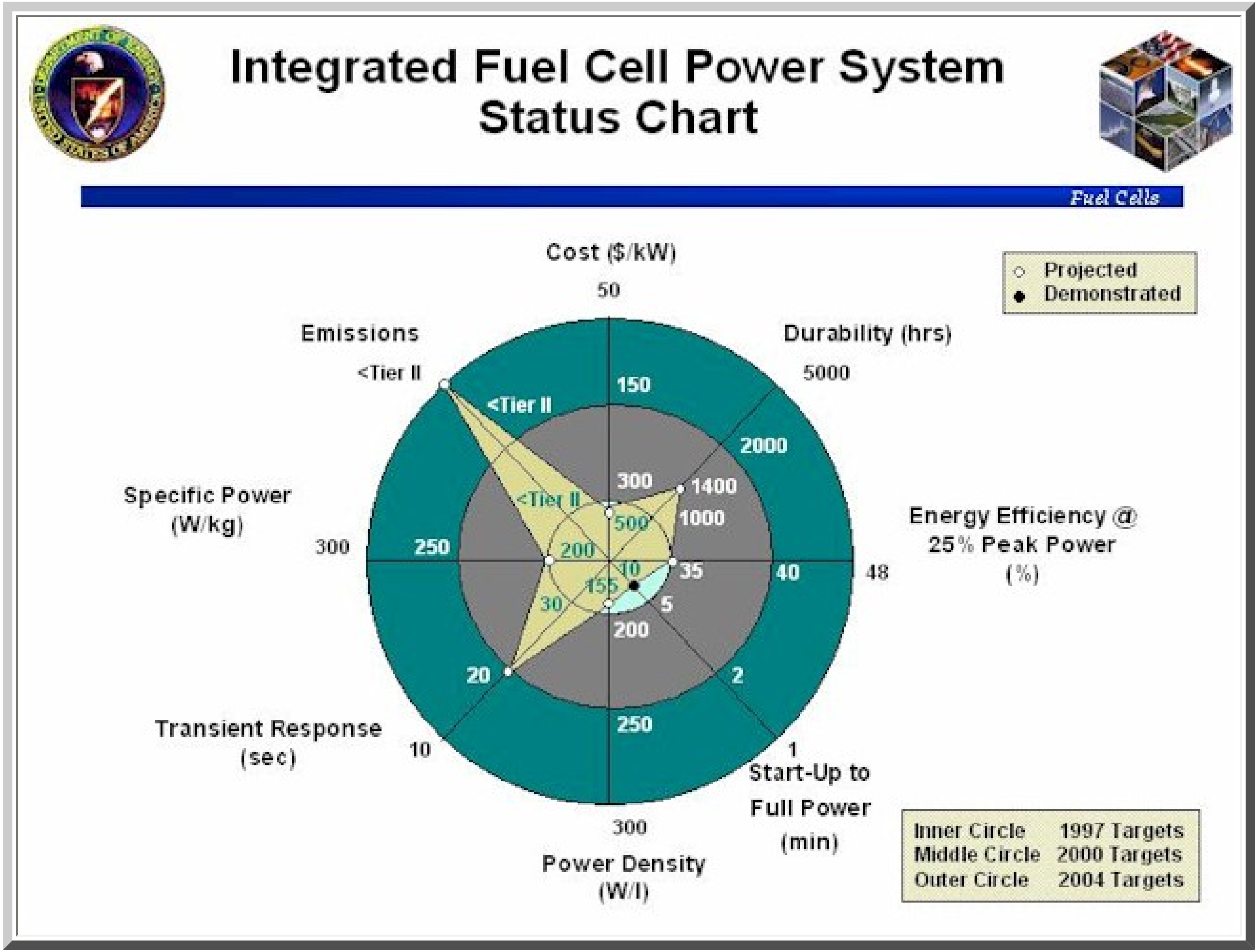
Technical Targets and Status

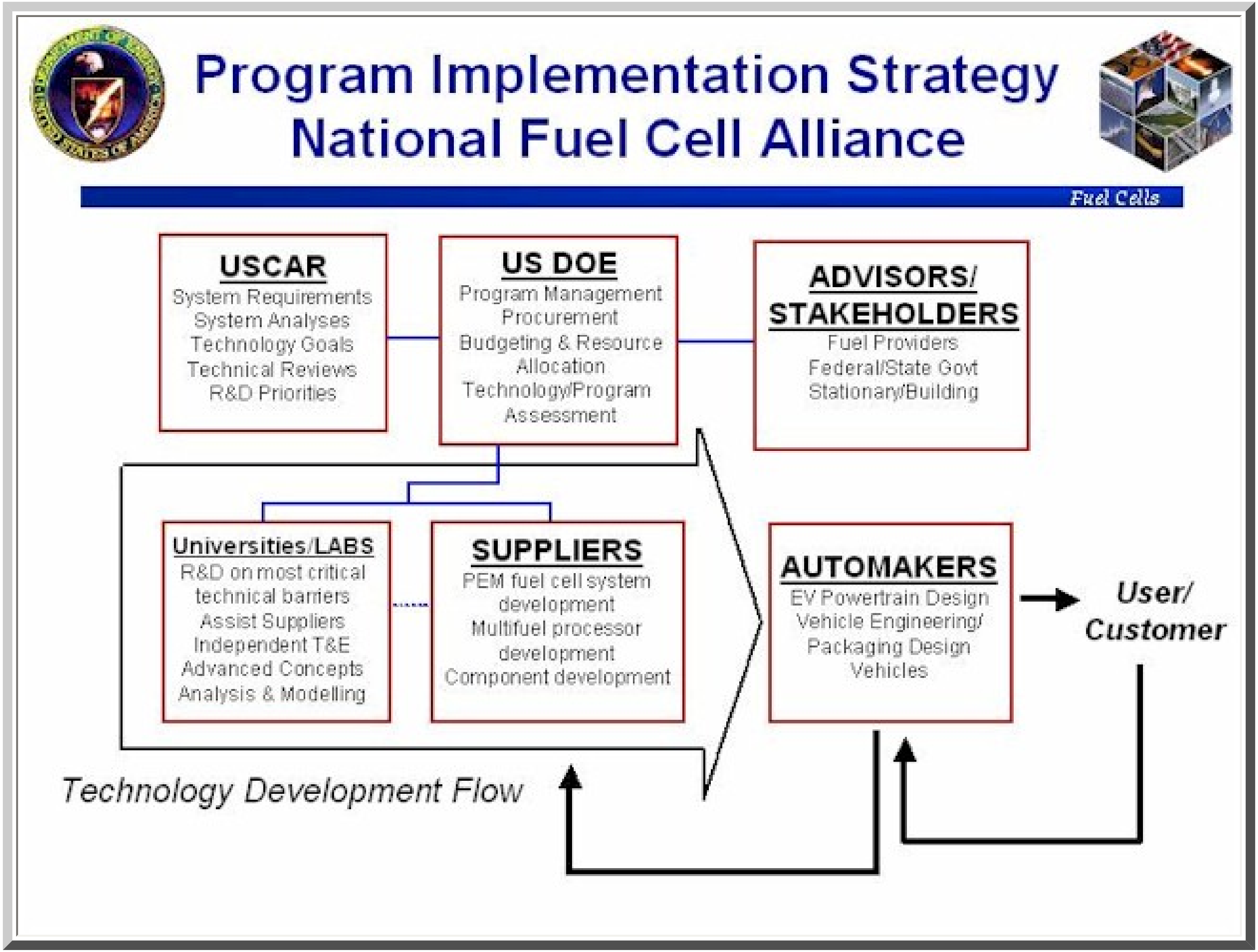



Fuel Cell Stack System
Status Chart
Fuel Cells
Projected
Demonstrated
Cost ($/kW)
35
100
200
10
Durability (hours)
>5000
>2000
1400
1000
Power Density (W/L)
500
350
300
Specific Power (W/kg)
500
350
300
180
Efficiency @ 25% of Peak Power (%)
60
55
51
50
Start up to Full Power (min)
0.5
1.0
2.0
Efficiency @ Peak Power (%)
48
44
41
40
Emissions
<Tier II
<Tier II
Precious Metal Loading (g/peak kW)
0.2
0.9
1.6
2.0
Co Tolerance (steady state) (ppm)
1000
100
300
Inner Circle 1997 Targets
Middle Circle 2000 Targets
Outer Circle 2004 Targets



Fuel Flexible Fuel Processor
Status Chart
Fuel Cells
Emissions
<Tier II
Projected
Demonstrated
Power Density
(W/l)
750
600
400
Durability
(hours)
5000
2000
1000
<Tier II
<Tier II
Transient
Response
(10-90% Power)
(sec)
10
20
30
Energy
Efficiency
(%)
80
75
74
70
50
30
20
400
600
750
Specific Power
(W/kg)
10
<5
<2
<1
Start-Up to Full Power
(min)
100
30
10
Cost
($/kW)
10
CO Content
Steady State
(ppm)
Inner Circle 1997 Targets
Middle Circle 2000 Targets
Outer Circle 2004 Targets


Integrated Fuel Cell Power System
Status Chart
Fuel Cells
Projected
Demonstrated
Cost ($/kW)
50
150
300
500
Durability (hrs)
5000
2000
1400
1000
Energy Efficiency @ 25% Peak Power (%)
48
40
35
Start-Up to Full Power (min)
1
2
5
10
Power Density (W/l)
300
250
200
155
Transient Response (sec)
10
20
30
Specific Power (W/kg)
300
250
200
Emissions
<Tier II
<Tier II
<Tier II
Inner Circle 1997 Targets
Middle Circle 2000 Targets
Outer Circle 2004 Targets


Program Implementation Strategy
National Fuel Cell Alliance
Fuel Cells
USCAR
System Requirements
System Analyses
Technology Goals
Technical Reviews
R&D Priorities
US DOE
Program Management
Procurement
Budgeting & Resource Allocation
Technology/Program Assessment
ADVISORS/ STAKEHOLDERS
Fuel Providers
Federal/State Govt
Stationary/Building
Universities/LABS
R&D on most critical technical barriers
Assist Suppliers
Independent T&E
Advanced Concepts
Analysis & Modelling
SUPPLIERS
PEM fuel cell system development
Multifuel processor development
Component development
AUTOMAKERS
EV Powertrain Design
Vehicle Engineering/
Packaging Design
Vehicles
User/ Customer
Technology Development Flow

Projects and Funding by Budget Category

Systems

- Plug Power
- IFC
- Energy Partners
- AlliedSignal
- Argonne

FY99: $5.75M

Fuel Processing

- Epyx
- Hydrogen Burner
- Argonne
- Los Alamos
- Pacific Northwest

FY99: $13.0M

Stack Subsystem Components

- Energy Partners, AlliedSignal, IFC, Plug Power
- IGT, Electrochem
- 3M, Foster-Miller
- Vairex, A.D. Little, AlliedSignal, Meruit
- Spectracorp
- Argonne, Los Alamos, NREL, LBNL

FY99: $14.9M

Fuel Cell Project Highlights

Fuel Cells

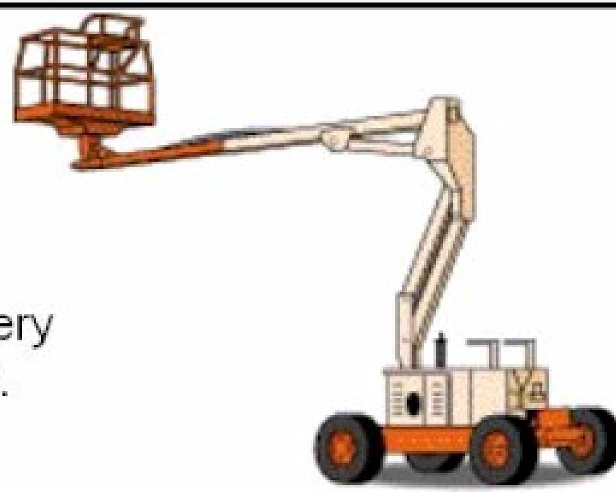
Systems
Fuel Processing
Components

Technical Accomplishment: AlliedSignal Demonstrates Large Scale Stack

Fuel Cells

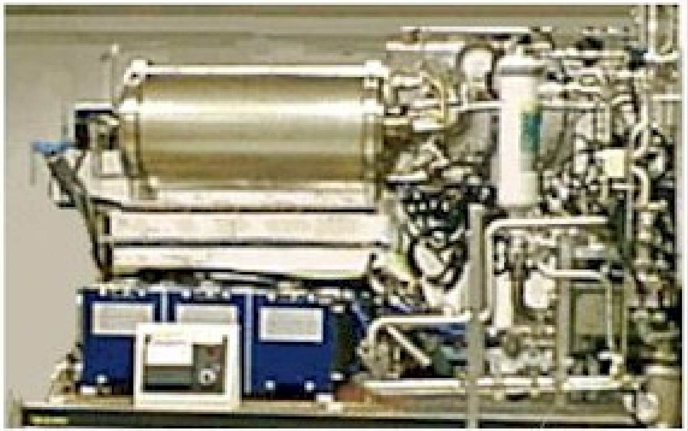
- **Description:** Demonstrated 17.8 kW stack (hydrogen), 15.1 kW (synthetic reformate, 39% H2, 10ppm CO). Stack consisted of 130 cells, weighed 24.9kg, and is 13 liters in volume.
- ***580W/cm², .7V/cell@.6A/cm²***

- **Demonstration:** Stack was incorporated into a JLG Industries Boom Lift and demonstrated at the CONEXPO '99 Heavy Equipment Show in Las Vegas, March 23-27. System was run as a fuel cell / battery hybrid and was fueled by Hydrogen.



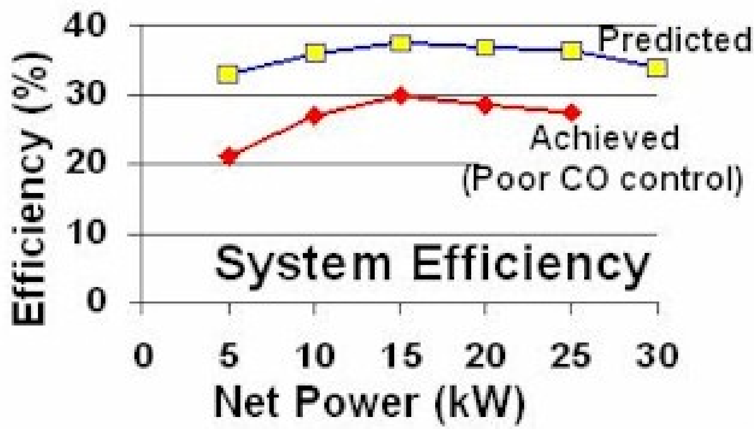
Technical Accomplishments
General Motors 30kW Methanol Fueled System

Fuel Cells



- 30kW net brassboard system:
  - GM MeOH steam reformer
  - Ballard Stack
- Sensors and controls
- Extremely low emissions capability on reformed fuel
- Automotive components

GM Zafira Concept Minivan



Accomplishment
Institute of Gas Technology

Fuel Cells

Development of $10/kW Bipolar Separator Plate

- Electrical, chemical, & physical property targets met or exceeded
- $10/kW cost target within reach with separator plate materials cost at $4/kW
- Performance comparable to state-of-art machined graphite

Bipolar Plate Properties

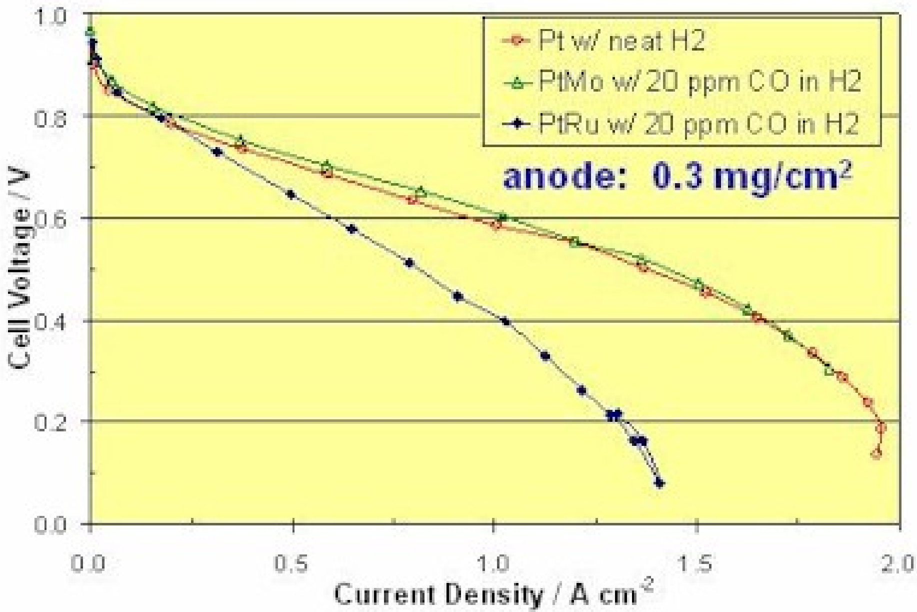
PROPERTY	DOE TARGET	IGT MEASURED VALUE
Conductivity (S/cm)	100	250 to 350
Corrosion ($\mu A/cm^2$)	16	< 5
H_2 Permeability (cm^3/cm^2-sec)	16×10^{-6}	$< 2 \times 10^{-6}$

Future Direction

- Design & build pilot production molding line
- Transfer technology to commercial fuel cell stack developers

Technical Achievement: Improved CO-Tolerant Catalyst - LANL

Fuel Cells

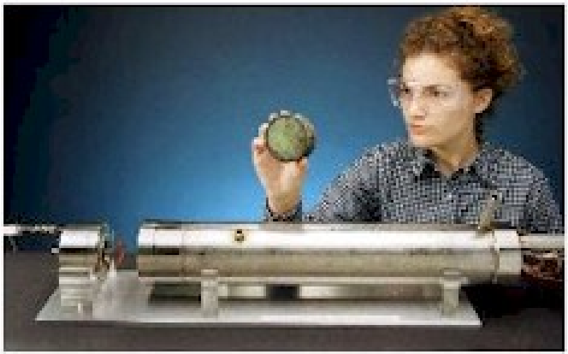


Pt/Mo is completely tolerant to 20 ppm CO in hydrogen

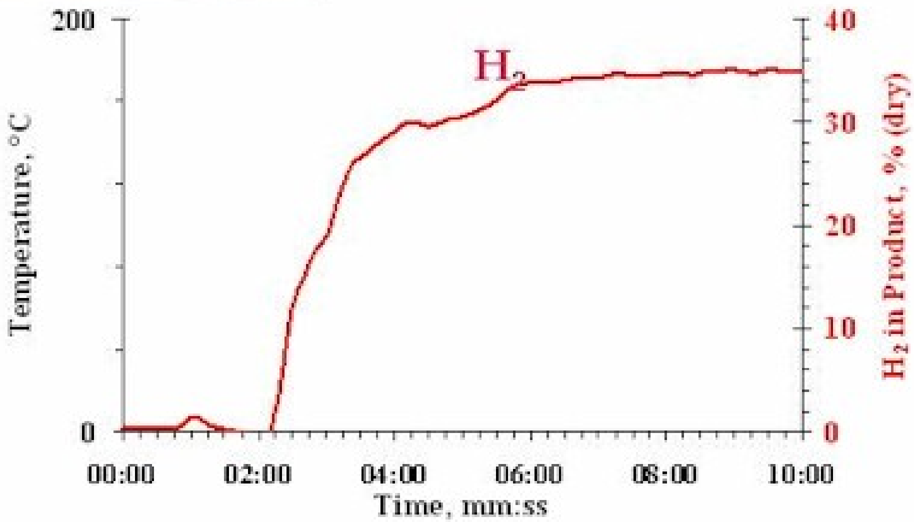
Tolerance to 100 ppm CO in reformate has been demonstrated for PtMo with less anode Pt (0.2 vs 0.5 mg/cm^2) and less air bleed (2.5 vs 4%) than PtRu

Accomplishment
ANL Catalyzed POX Reformer

Fuel Cells



- High H2 concentration: 38%
- Compact/Lightweight:
  1.7 L (2.2 kg) ---> 3kWe
- Low temperature: 750C (vs 1000C)
- Rapid start-up: 30% H2 in < 4 min
- Fuel-Flexible



1998 PNGV Award for the Development of Fuel-Flexible Fuel Processing

Fuel Cells

Vice-President's PNGV Medal Presented March 17, 1999

Arthur D. Little, LANL, Plug Power

Demonstrated technical feasibility of gasoline-powered fuel cell systems (gasoline, ethanol, methanol & nat. gas)

ANL, GM R&D

Developed new catalyst for fuel-flexible fuel processing

Recognizes key contributors on a government/industry team who have collaboratively made outstanding and cooperative contributions to advancing the state-of-the-art of automotive technology and to the success of the PNGV

Recent Solicitation Results

Fuel Cells

R&D of Fuel Cells, Direct Injection Engines and Fuels

Topic Areas:

- Fuel Cells
  - → Transportation (fuel processing, durability, cost reduction, etc.)
  - → Buildings (NG reformer, high temperature membranes)
- CIDI (NOx and PM aftertreatment subsystem)
- SIDI (fuel delivery and mixing technology)
- Fueling Infrastructure (small-scale natural gas reformer)

The Fuel Cell Program Made 9 Selections - Contracts are Currently Under Negotiation
Total of $70M w/cost share

New Awards
Cost Issues

Fuel Cells

Membrane-Electrode Assembly Cost Reduction/ High Volume Process Development

- 3M
- SwRI/Gore
- U. Wisconsin

MEA

	Status	2004 Target
Pt loading g/kW	1.6	0.2
Cost $/kW	$1500 (low vol.)	10 (high vol.)

Manufacturing Cost Analysis

- Arthur D. Little

Integrated Fuel Cell Power System

	Status	2000 Target	2004 Target
Cost ($/kW)	500 (high vol.)	150 (high vol.)	50 (high vol.)

New Awards

Fuel Processing/System Issues

Fuel Cells

Autothermal Reforming

- Plug Power/UOP
- McDermott

Fuel Processor Meeting 2004 Targets

- Epyx/Energy Partners

Novel CO Reduction Technology

- Allied Signal

Independent Emissions Testing

- Arcadis

Fuel Processor

	Status	2000 Target	2004 Target
Efficiency	74% projected	75%	80%
Start-Up	10 min	<60s	<30s
Durability (Hours)	1000	2000	5000
CO Content (Steady State)	30 ppm	10 ppm	10 ppm
Emissions	<Tier II (estimate)	<Tier II	<Tier II

New Awards

Compressor Downselection

Fuel Cells

Turbocompressor

- AlliedSignal

	Status	DOE Spec.
Cost	$650	$200
Weight	8.6 kg	3 kg
Power @ Max	6 kW	4 kW

Summary

Fuel Cells

- The DOE Fuel Cells for Transportation Program focuses on R&D to remove technical barriers for PEM systems
- Major technical barriers are CO management, fuel processor efficiency, cost, and system integration
- Utilizing the existing fuel infrastructure will allow early introduction of fuel cell vehicles & facilitate transition to hydrogen fuel cell vehicles
- The DOE Fuel Cells for Transportation Program has made tremendous technical progress

Fuel Cell Vehicle Demonstrations Have Been Numerous

Fuel Cells

General Motors Zafira, 1998

DaimlerChrysler NECAR 4, 1999

Toyota RAV4 FCEV, 1996

Ford P-2000, 1999