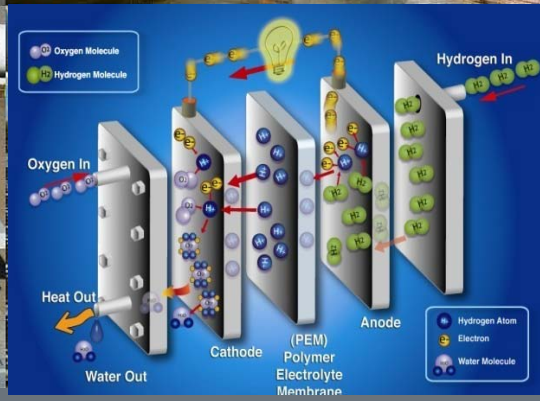
FUEL CELL TECHNOLOGIES PROGRAM

SMALL-SCALE DISTRIBUTED GENERATION WORKSHOP

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Fuel Cells for Distributed Generation

6/02/2011

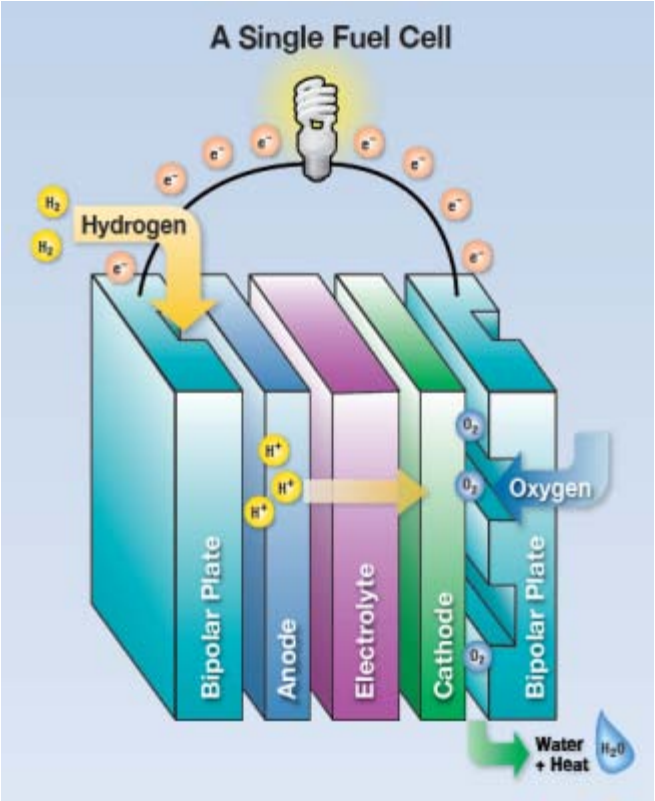
Sunita Satyapal
Dimitrios Papageorgopoulos
Jacob Spendelow

U.S. Department of Energy
Fuel Cell Technologies Program

Benefits of Fuel Cells

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Fuel cells use an efficient electrochemical process to generate electricity and heat, with low or zero emissions, offering benefits in a wide range of applications.



Types of Fuel Cells

- **Polymer Electrolyte Membrane (PEMFC)**
  - *Pros:* Low-temperature operation, quick start, and high power density
  - *Cons:* Expensive catalysts
  - *Applications:* Stationary generation, specialty vehicles, transportation, portable power
- **Phosphoric Acid Fuel Cell (PAFC)**
  - *Pros:* Low-temperature operation and high efficiency
  - *Cons:* Low current and power density
  - *Applications:* Distributed generation
- **Alkaline Fuel Cell (AFC)**
  - *Pros:* Low temperature operation and high efficiency
  - *Cons:* Expensive impurity removal
  - *Applications:* Military and space
- **Solid Oxide Fuel Cell (SOFC)**
  - *Pros:* High efficiency, multiple fuel feedstocks, usable waste heat, and inexpensive catalysts
  - *Cons:* Slow start-up and corrosion issues
  - *Applications:* Auxiliary Power Units (APUs) and distributed generation
- **Molten Carbonate Fuel Cell (MCFC)**
  - *Pros:* High efficiency, multiple fuel feedstocks, and usable waste heat
  - *Cons:* Slow start-up and corrosion issues
  - *Applications:* Electric utility

Fuel Cells vs. Combustion

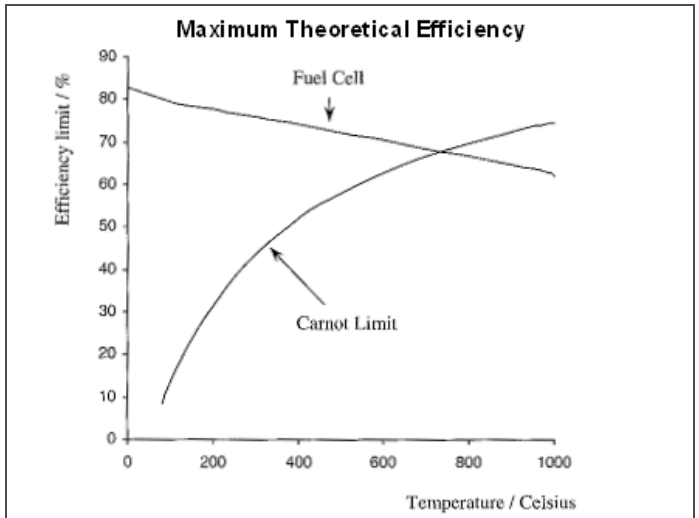
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Fuel cells are not heat engines, so their efficiency can exceed the Carnot efficiency

Conventional engines and turbines convert chemical energy into thermal energy prior to conversion to electrical energy. The efficiency of converting thermal energy to electrical energy is bounded by the Carnot efficiency.

$$\text{Carnot Efficiency} = \left(1 - \frac{T_C}{T_H}\right) \times 100\%$$

T_C = temperature at which waste heat is rejected
T_H = temperature of available heat



Adapted from Larminie and Dicks, Fuel Cell Systems Explained, 2000

Fuel cells convert chemical energy directly into electrical energy, bypassing inefficiencies associated with thermal energy conversion. The available energy is equal to the Gibbs free energy.

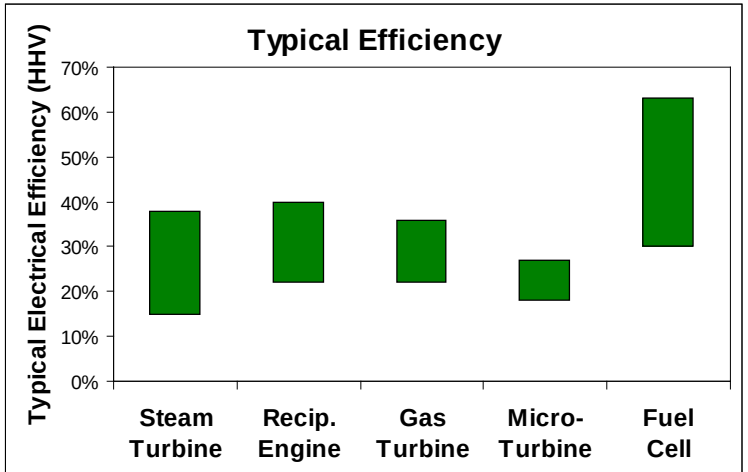
$$\text{Maximum Fuel Cell Efficiency} = \frac{\Delta G_f}{\Delta H_f} \times 100\%$$

ΔG_f = free energy of formation of H_2O from H_2 and O_2
ΔH_f = enthalpy of formation of H_2O from H_2 and O_2 (higher heating value)

Theoretical fuel cell voltage is directly proportional to ΔG_f.

$$V = \frac{\Delta G_f}{nF}$$

n = number of electrons transferred (2 for H_2)
F = Faraday constant



Source: EPA, Catalog of CHP Technologies, December 2008

Fuel Cells - *Where are we today?*

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Fuel Cells for Stationary Power, Auxiliary Power, and Specialty Vehicles

The largest markets for fuel cells today are in stationary power, portable power, auxiliary power units, and forklifts.

~75,000 ***fuel cells have been shipped worldwide.***

>15,000 ***fuel cells shipped in 2009***

Fuel cells can be a cost-competitive option for critical-load facilities, backup power, and forklifts.

Production & Delivery of Hydrogen

In the U.S., there are currently:

~9 million metric tons ***of H_2 produced annually***

> *1200 miles* ***of H_2 pipelines***

Source: US DOE 09/2010

Fuel Cells for Transportation

In the U.S., there are currently:

> 200 fuel cell vehicles

~ 20 active fuel cell buses

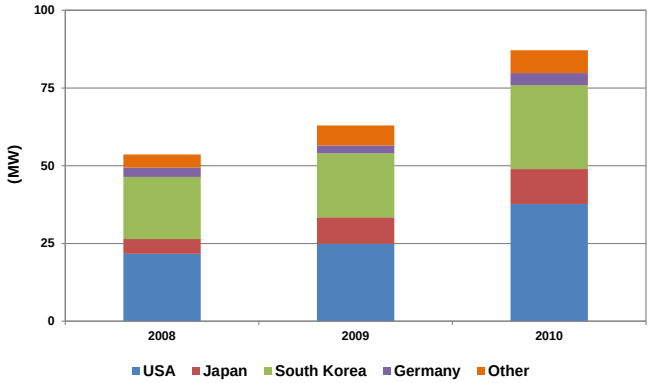
~ 60 fueling stations

Sept. 2009: Auto manufacturers from around the world signed a letter of understanding supporting fuel cell vehicles in anticipation of widespread commercialization, beginning in 2015.

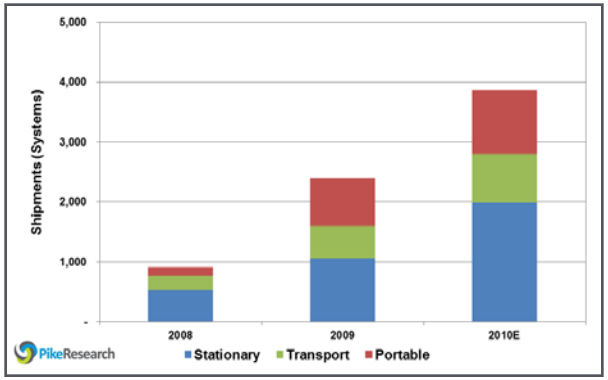
Fuel Cell Market Landscape

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Megawatts Shipped, Key Countries: 2008-2010



North American Shipments by Application



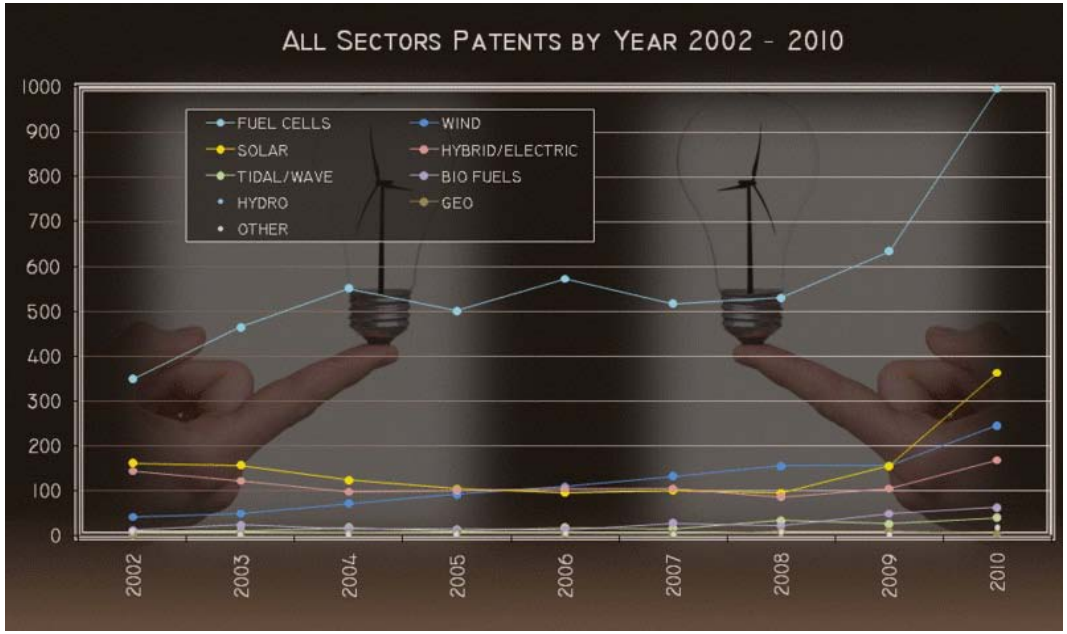
Global competition is increasing

- Germany & EC (>$1.2B each; 1,000 H_2 stations)
- Japan (2M vehicles, 1,000 H_2 stations by 2025)
- South Korea (plans to produce 20% of world shipments & create 560,000 jobs in Korea)

FuelCells2000, Pike Research, Fuel Cell Today, ANL

Fuel cell market continues to grow

- ~36% increase in global MWs shipped in 1 year
- ~50% increase in US MWs shipped



Clean Energy Patent Growth Index fuel cell patents lead in the clean energy field with nearly 1,000 fuel cell patents worldwide in 2010.

http://www.fuelcells.org/BusinessCaseforFuelCells.pdf
http://www.fuelcells.org/StateoftheStates.pdf

Examples of CHP Industry Deployments

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The Food Industry is an emerging market for stationary fuel cells

Announced Supermarket Deployments:

- **Whole Foods (CA,CT,MA)**
  - **3 sites, 400kW each**
- **Price Chopper (NY,CT)**
  - **3 sites, 400kW each**
- **SUPERVALU (MA,CA)**
  - **2 sites, 400kW each**
- **Ahold (CT, Stop & Shop)**
  - **1 site, 400kW**

Completed Food Producer Deployments:

- **Coca-Cola (NY, 800 kW) – another 800 kW under construction**
- **Gills Onions (CA, 600 kW)**
- **Pepperidge Farms (CT, 1.45 MW)**
- **Sierra Nevada Brewery (CA, 1 MW)**

MCFC, PAFC, and SOFC are used in most 100 kW – MW scale installations

PEMFC and SOFC are being commercialized in micro CHP (< 10 kW) installations

A 400-kW fuel cell (grey box) meets 85 percent of the energy needs of this Price Chopper supermarket in Albany. The installation reduces the building's carbon footprint by 71 tons, provides energy security for perishable items, and saves more than 4 million gallons of water each year. *(UTC Power. Photo taken from the Executive Summary of the New York State Climate Action Plan Interim Report)*

Progress – Fuel Cells

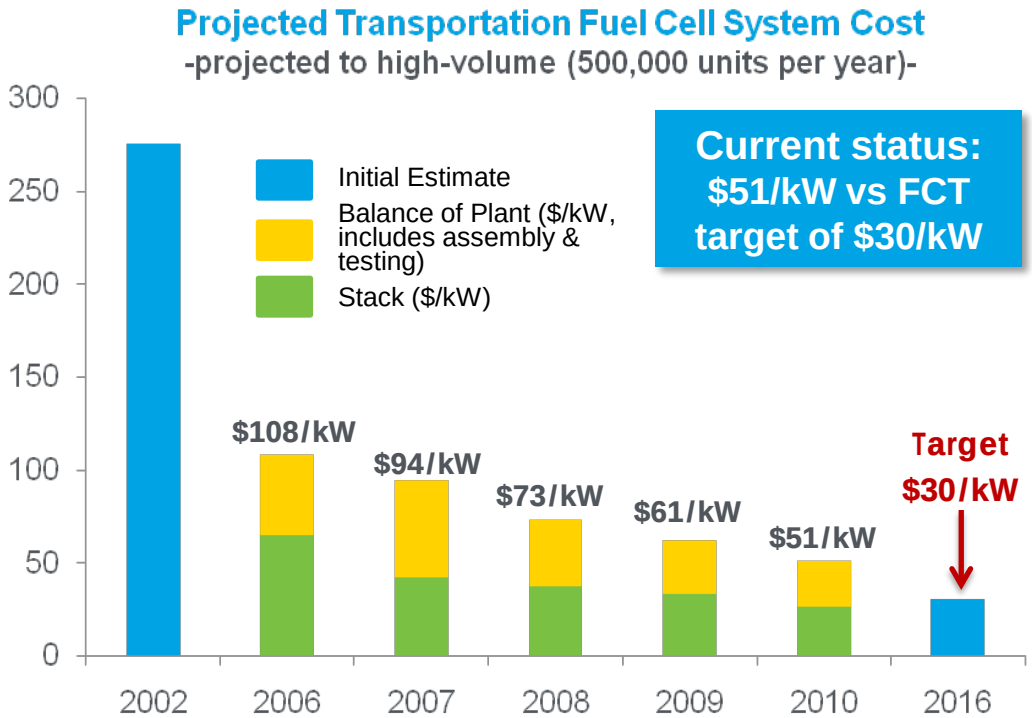
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

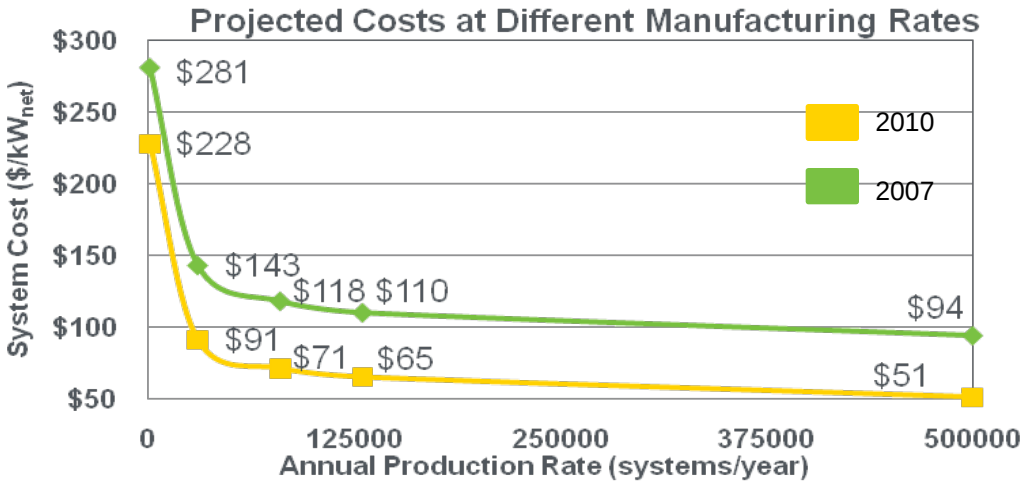
Fuel Cell Cost

	Rated Power	Volume (units/year)	Cost Status	FCT Cost Target
PEMFC, Trans-portation (hydrogen)	80 kWe	500,000	**$51/kW**	$30/kW (2016)
SOFC and PEMFC, µCHP (natural gas)	1 - 10 kW_e	50,000	**$750/$kW_e$** (stack + BOP required for stack operation), **$1500 - $2000/$kW_e$** (system)	$500/kWe (2020)
MCFC*, CHP (natural gas)	1.4 MW	20	**$4000/$kW_e$** (system installed cost)	$1500/kW installed (2020 target, preliminary)
MCFC*, CHP (biogas)	1.4 MW	20	**$7000/$kW_e$** (system installed cost)	$2000/kW installed (2020 target, preliminary)

*PAFC costs are similar

- **More than 80% reduction in projected cost of 80 kW transportation fuel cell systems since 2002**
- **Estimated 40% reduction in projected cost of 1 – 10 kW stationary fuel cell systems since 2004**





 Source: US DOE 6/8/2011

Micro-CHP Targets

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Targets developed with input from stakeholders and the research community

Cost and durability are the major challenges

Preliminary Technical Targets: 1 – 10 kW_e Residential Combined Heat and Power Fuel Cells Operating on Natural Gas[1]

	Units	Status	2020 FCT Targets
Electrical energy efficiency at rated power[2]	%	34	45
CHP energy efficiency at rated power[3]	%	80	90
Cost[4]	$ / kW_e	750	500
Transient response time (from 10 - 90% rated power)	min	5	2
Start-up time from 20 C ambient temperature	min	60	20
System availability	%	97	99
Operating lifetime[5]	hours	6,000	60,000
Degradation with cycling	% / hours	<2/1000	0.3/1000

[1] Standard utility natural gas delivered at typical residential distribution line pressures
[2] Regulated AC net/LHV of fuel.
[3] Only heat available at 80 °C or higher is included in CHP energy efficiency calculation.
[4] Cost includes materials and labor costs to produce stack, plus any BOP necessary for stack operation. Cost defined at 50,000 unit/year production (250 MW in 5-kW modules).
[5] Time until >20% net power degradation.

2010 Independent Assessment of CHP Fuel Cell Status & Targets

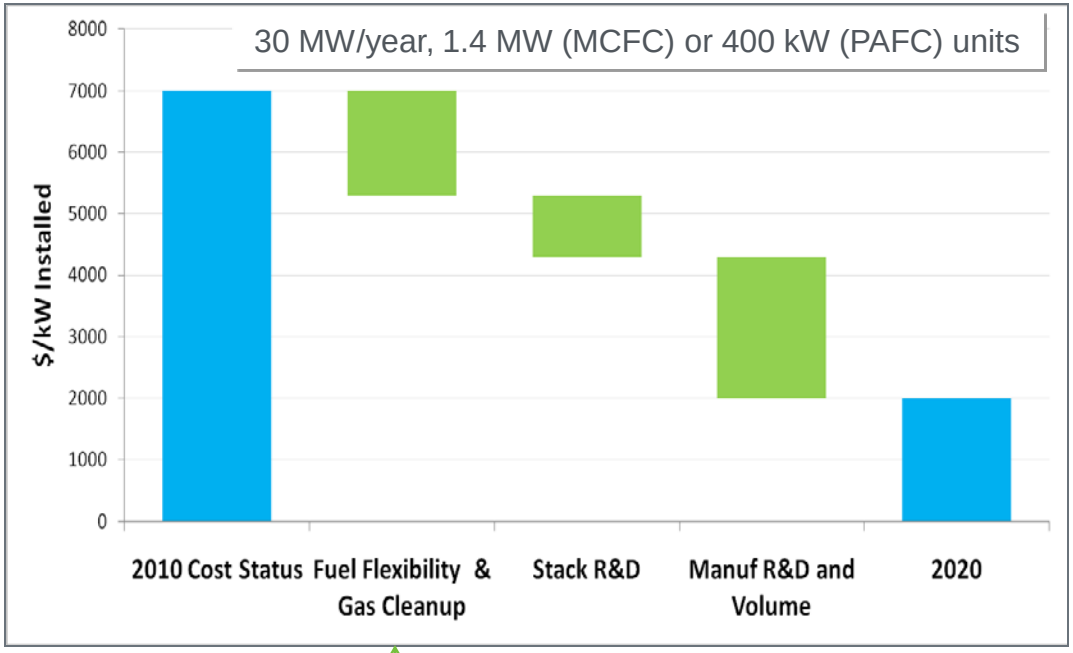
- **Confident that by 2015, LT-PEM & HT-PEM can achieve 40,000hr**
- **45% electrical efficiency (2020 target) for 1-10kW systems is feasible for HT-PEM, LT-PEM depends on improved catalysts & higher operating temps**
- **SOFC systems are likely to achieve DOE targets for electrical and CHP efficiencies. 90% CHP efficiency is likely to be attainable by SOFC systems**
- **Confident that by 2020, LT-PEM & HT-PEM can achieve $450-$750/kW, while SOFC can achieve $1000-2000/kW**

Challenges and Strategies: CHP

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Technical and cost gap analyses of molten carbonate fuel cell (MCFC) and phosphoric acid fuel cell (PAFC) stationary fuel cell power plants identify pathways for reducing costs

Medium-Scale Fuel Cell CHP with Biogas



Development of a cost-effective process for removing fuel contaminants, especially those found in renewable fuels, would have a positive impact and would allow for fuel flexibility.

Key areas identified:

➢For MCFC, power density and durability. The service life of the fuel cell stack needs to be extended to ten years by:

- reducing electrolyte losses
- reducing cathode dissolution
- increasing the stability of the electrolyte support material.

➢For PAFC, cost reductions could be achieved by:

- Reduction in platinum loading. A 50% reduction would result in a $200 to $250/kW reduction in first costs.
- Reduction in the impact of anion adsorption on the cathode catalyst. Potential for 20% increase in power density with no change in fuel consumption.

 Source: US DOE 6/8/2011

Challenges & Strategy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The Fuel Cells sub-program supports research and development of fuel cells and fuel cell systems with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications.

Barriers

Cost
Durability
Air/thermal/water management
Application Form Factor
Fuel flexibility for stationary applications

Strategy

Materials and systems R&D to achieve low-cost, high-performance fuel cell systems

Fuel Cell R&D

Testing and Cost/Technical Assessments

FOCUS AREAS

Stack Components
Catalysts
Membranes
GDL s and Seals
Bipolar Plates
MEAs and Integration
High-Temperature Fuel Cells

Operation and Performance
Mass transport
Durability
Impurities

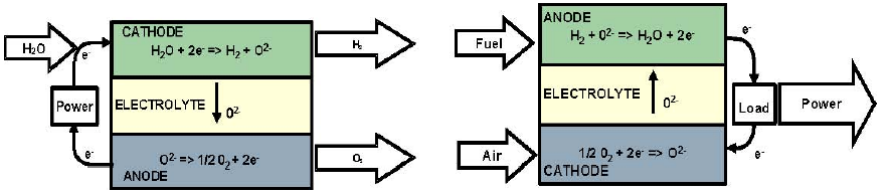
Systems and Balance of Plant (BOP)
BOP components
Stationary power
Fuel processor subsystems
Portable power
APUs and emerging markets

Examples of Progress: Stationary SOFCs

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

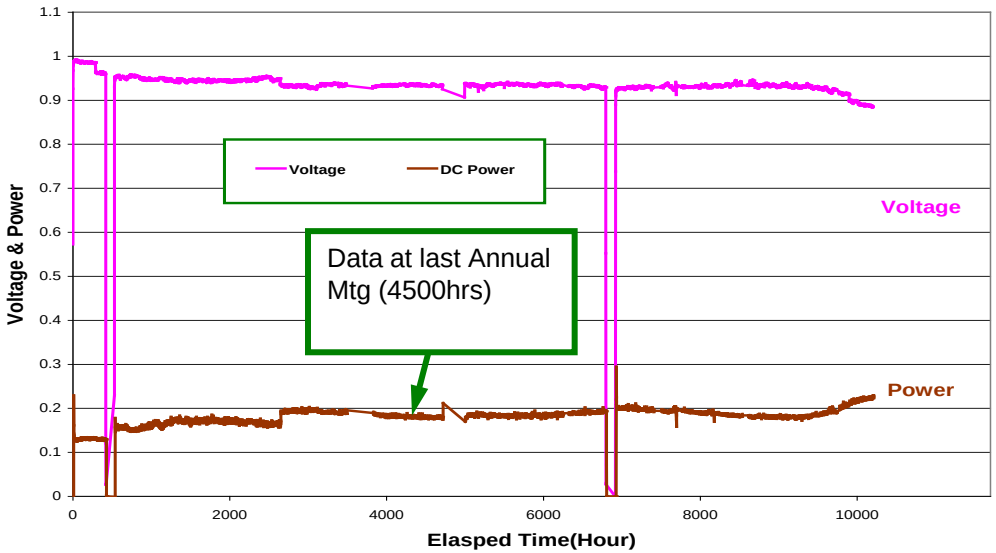
Improved performance and durability of SOFC systems

Reversible SOFCs under development at Versa Power Systems provide hydrogen generation and energy storage capability

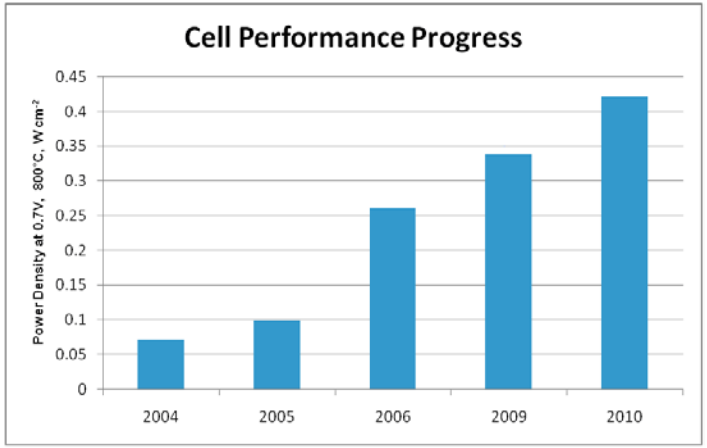


Metric	Target	Status
☑ **Performance** (Area specific resistance in both SOFC and SOEC operating modes)	< 0.3 Ω-cm²	0.223 Ω-cm² in SOEC 0.224 Ω-cm² in SOFC
☑ **Degradation** (Overall decay rate)	< 4% per 1000 hours	~1.5% per 1000 hours
☑ **Operating Duration**	> 1000 hours	1005 hours (as of Go/No-Go Decision)
☑ **Operating Current Density**	> 300 mA/cm²	500 mA/cm²

R. Petri et al., Versa Power Systems



Acumentrics achieved more than 10,000 hours operation of an SOFC in 2011 – more than double the 2010 durability



Cell power increased 6X from 2004 to 2010

Elec eff. 35%
CHP eff. 85%

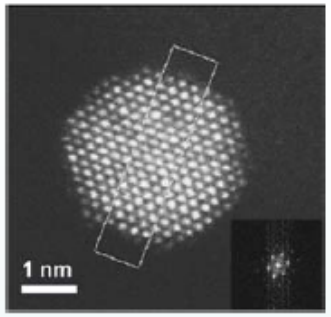
N. Bessette et al., Acumentrics

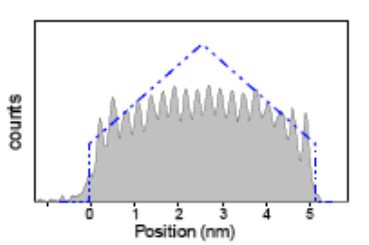
Examples of Progress: Catalysts

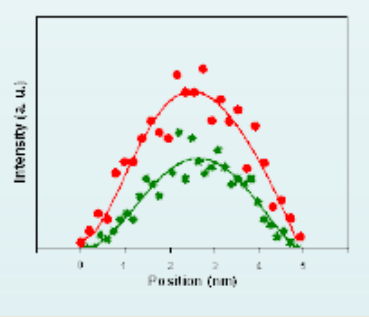
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Nano-segregated catalysts demonstrate performance more than 6X that of platinum

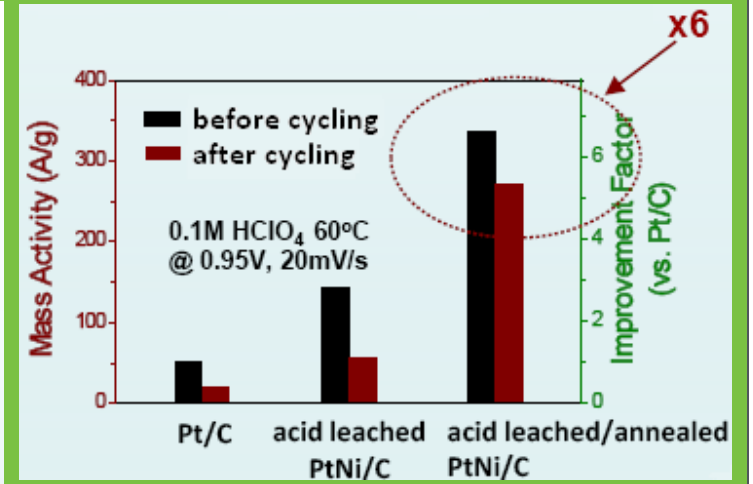
Nanosegregated Binary (PtNi)







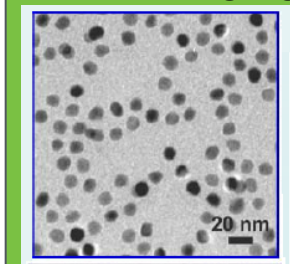
Multilayered Pt-skin surfaces confirmed for PtNi annealed NPs

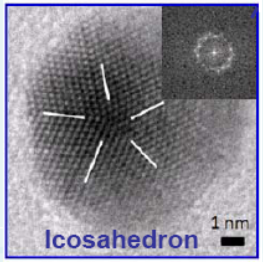


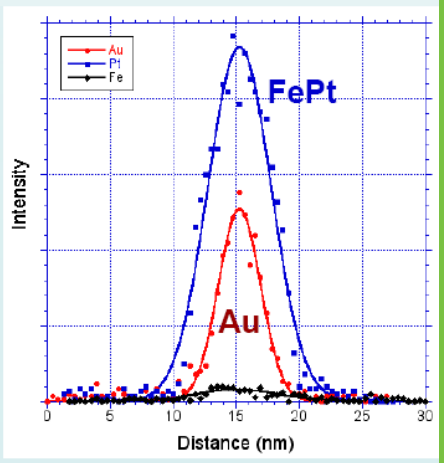
Performance: Nanosegregated PtNi/C catalysts have ORR mass activity ~0.35 A/mg in MEA testing – *approaching 0.44 A/mg target*

Durability: Loss in mass activity after 20,000 potential cycles is ~1/3 that of Pt/C

NanosegregatedTernary (PtFeAu)







Performance: FePt(shell)/Au(core) demonstrates ORR mass activity more than 3X that of Pt/C

Durability: Maintains 80% of initial activity after 80,000 potential cycles (cf. less than 20% for Pt/C)

N. Markovic et al., ANL

Summary

- Significant progress has been made in just the last few years
- More work is needed to reduce cost and improve durability
- Several opportunities for ARPA-E type game-changer projects

Thank You