Fuel Cell Update

Engineers Forum On Sustainability

Washington, DC

January 19, 2007

Bob Rose
US Fuel Cell Council
Breakthrough Technologies Institute, Inc.

Fuel Cells 2000 / BTI

- U.S. nonprofit organization
- Established in 1993
- Promotes fuel cells from public interest perspective.
- Supported by foundations, grants and contracts
- www.fuelcells.org

US Fuel Cell Council

- Trade Association of the Fuel Cell Industry
- Supports commercialization for all applications
- Eight Working Groups
- International membership
- 110+ Members

Our challenge

- Oil addiction*
  - US national security
  - Global Stability
  - Economic costs / energy competition
- Air, water and land pollution
- Global warming, climate instability

(Invert for Euro View)

Not a cafeteria plan!

Solution:
Stop Burning Carbon

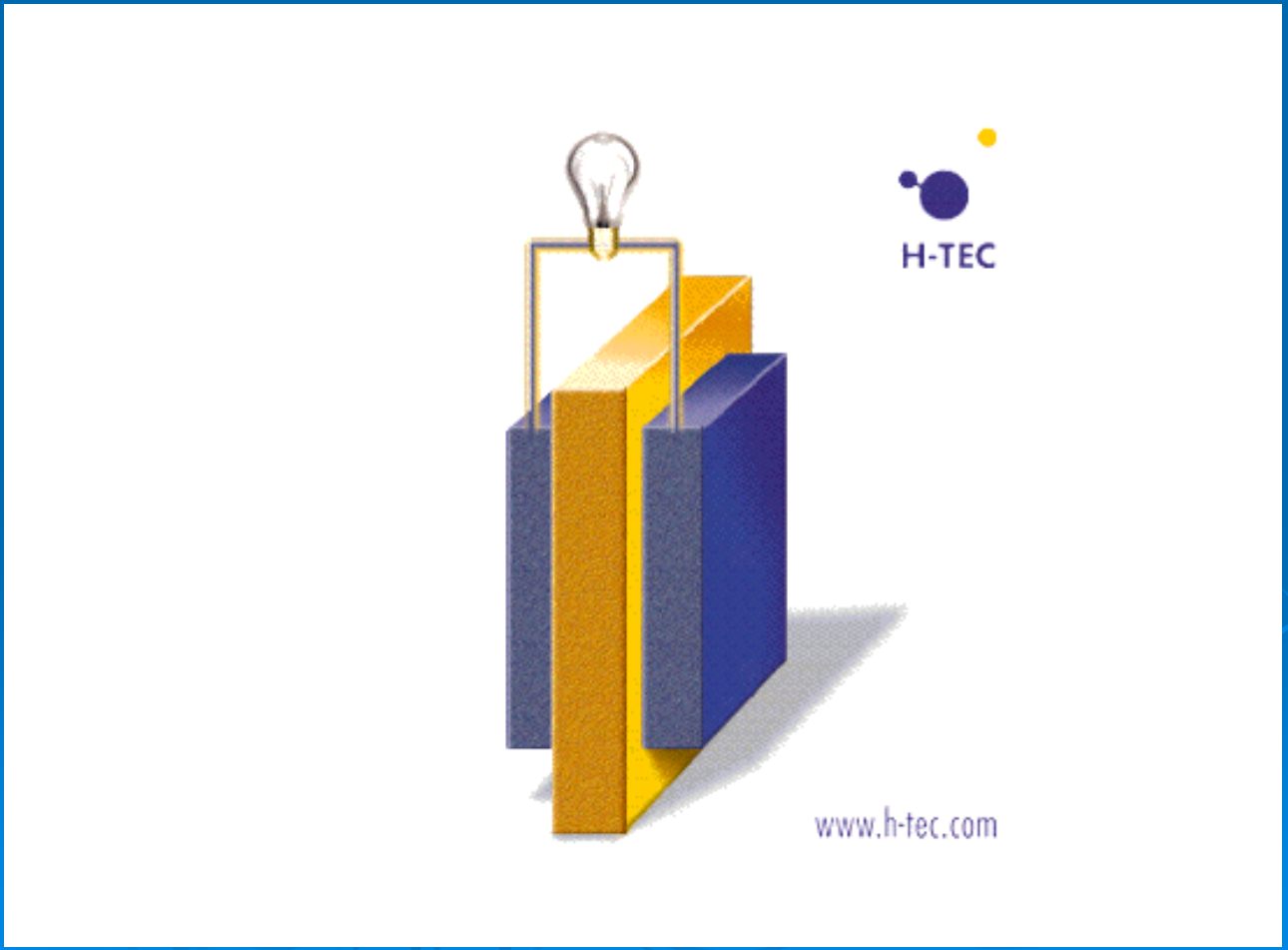
The Fuel Cell/Hydrogen Solution

Fuel Cell Basics

Fuel Cells - Defined

Fuel (H_2) + O_2 / Catalyst ⟹ (H_2)O + Heat

Fuel cells combine hydrogen and oxygen electrochemically to produce electricity. The only by-products are water and useful heat.



A Family of Technologies

Type	Efficiency	Operating Temp.
Solid Oxide	45-65%	800°C
Molten Carbonate	50%	650°C
Phosphoric Acid	40%	200°C
Alkaline	50-60%	80°C
Direct Methanol	40%	80°C
Polymer (PEM)	40%	50°C
Regenerative		

An unmatched combination of benefits

- Electrochemistry, not combustion
- Fuel Cells let us stop burning carbon
  - Low / Zero Emissions
  - High Efficiency → Low CO_2
  - Wide Range of Applications / Distributed Installation
  - High Quality, Reliable Power
  - Quiet
  - Fuel Flexible
  - Economic Benefits
  - Fuel Cells open the door to hydrogen energy

Past, Present and Future Applications for Fuel Cells

Pre-1995 | 1995 | 2000 | 2005 | 2010 | 2020+

- Space flight
- Breathalyzers
- Deep-sea submersibles

- Stationary Power (ONSI PC-25)

- Consumer electronics
- Military
- Portable power

- Small-scale stationary power
- Fleet Vehicles?
- Small and Off-road vehicles?

- Consumer vehicles?

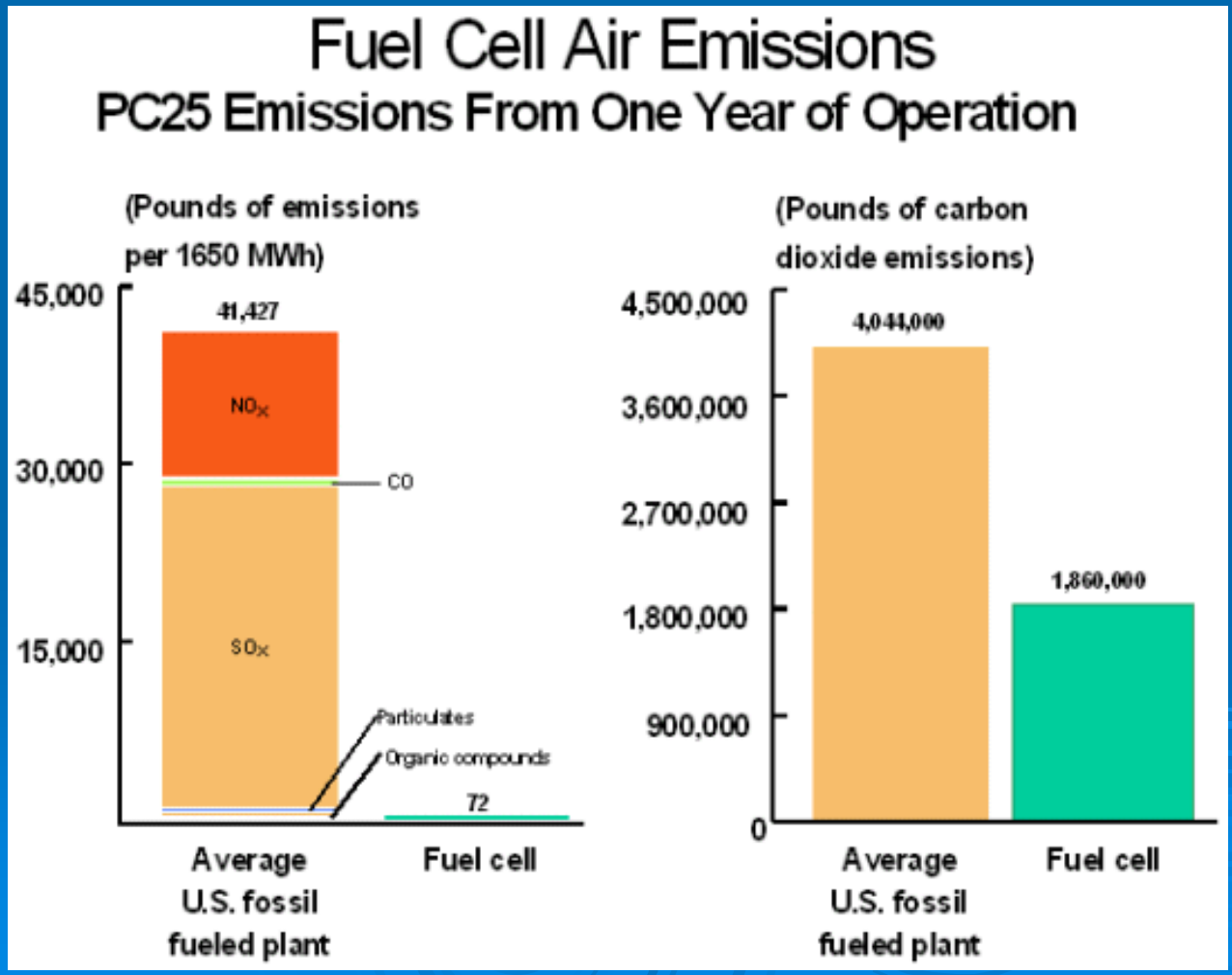
Source: Cambridge Energy Research Associates.

Fuel Cells in Power Generation

Big Payoff: Efficiency

- 80%+ in combined heat and power
- 35-60% electrical
  - Higher in hybrid configurations
- Validated by US EPA in 2005: 93.8%
  - PAFC, anaerobic digester gas

Big Payoff: Emissions (UTC)



Emissions

- Annual Emissions (1650 MWH)
  - UTC PC 25 = 75 pounds
  - Average U.S. fossil plant = 41,427 pounds
  - CO_2 reduction ~ 45%

Fuel Flexibility

- Hydrogen
- Natural Gas - CH_4
- Propane - C_3H_8
- Reformed Methanol
- Ammonia
- Diesel / Jet Fuel
  (Military Priority)

- Gasoline
  - Naphtha
  - Sulfur free distillate
- Syntroleum
  - Liquid Natural Gas
  - Direct Methanol
  - Ethanol

Recent Developments: Power Generation

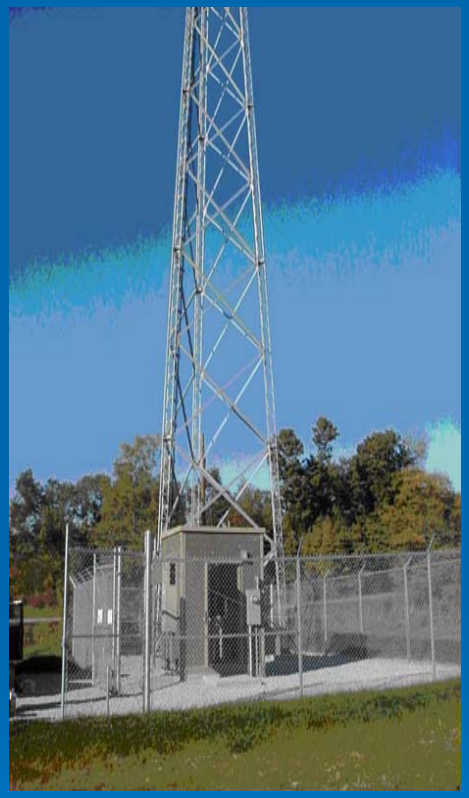
- Durability improving
  - PAFC 70,000 + (UTC to guarantee 80,000 hours)
  - PEM 10,000 +
    - Auto membrane 5000+
  - Small SOFC 9,000
  - MFCF more than 4 years (so far)
- Prices dropping
  - 20% + price reduction in some models
  - Plug Power: 9% reduction/year
  - Competitive with batteries for telecom backup (Citibank)

Waste to Energy

NYPA – 8 fuel cells at four sewage treatment plants (eliminates about 170 tons of regulated emissions annually and more than 9,000 tons of the greenhouse gas carbon dioxide)

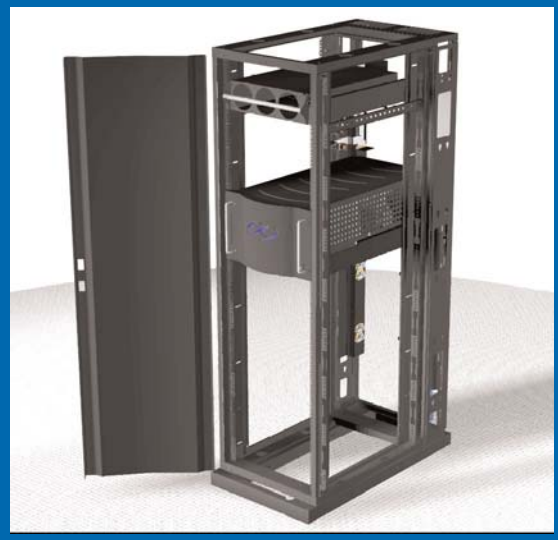
- Japanese breweries – Kirin, Asahi, Sapporo
- American brewery – Sierra Nevada
- LADWP – Terminal Island Treatment Plant
- Others – King County, Washington; Portland, Oregon; hog farm in China

Telecom Backup Systems



ReliOn unit in Ohio

Plug Power



Hydrogenics/ARC

Citigroup: Competitive on life cycle basis with battery backup – today

Fork Lifts

Advantages:

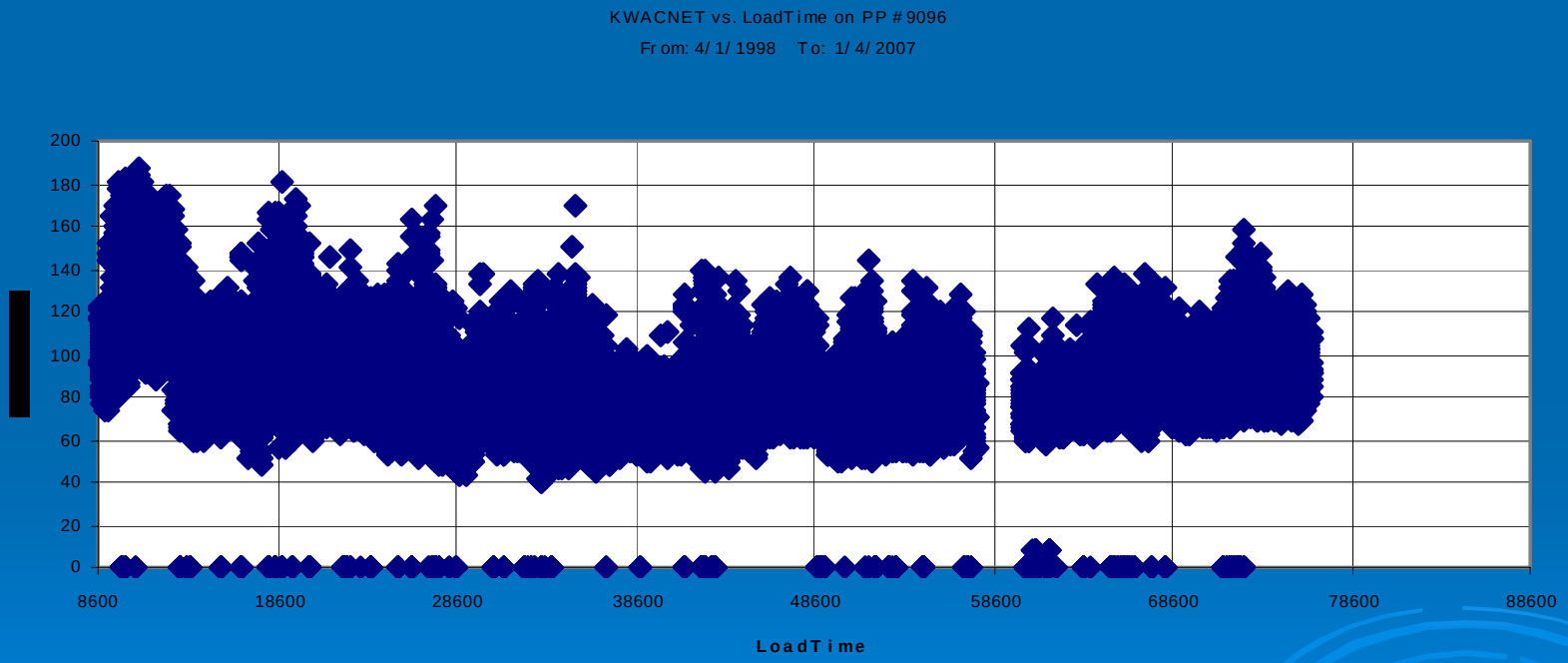
- minimal refilling
- less maintenance
- constant power delivery – lifting power
- eliminates reduction in voltage output
- zero emissions

The Defense Logistics Agency (DOD) has started a program to test forklifts and become an early adopter.

Successful trials at GM, WalMart, FedEx

School Admin. Building
(BOCES, Syracuse NY)

- Off grid, load following, 8 years operation



Micro Fuel Cells

Products

- Battery chargers
  - Caravans
- Battery replacements
  - Specialty applications
  - Military

Approval of fuel cells and their fuels on passenger aircraft is in process and well along for some fuels

Recent Announcements

- Samsung: fuel cell powered a notebook computer for ~40 hours, mass production by end of 2007.
- Hitachi has established facilities to make ~3000 direct-methanol fuel cells a month.
- Casio cell achieves 20 hours on single fuel canister – will offer sample quantities in 2007.
- Jadoo Power wins Electronic Products' Product of the Year Award for 2006.
- Quasar Business Solutions placed a 1 million unit order with Medis Technologies for 24/7 Power Pack.

Why Fuel Cells?

- Energy density requirements for powering portable electronic devices are not being met
  - Consumers want more features and longer operation time
  - Developers do too
    - Power requirements increase 15% per year
    - Battery capacity increases 5% per year
    - No battery breakthroughs yet
- Lithium Ion faces scale-up, cost safety challenges
- Note parallels with EV's

Early Markets

- Military
  - Soldiers are carrying more and more energy: 30-50 Watts > 50 pounds!
- Communications and Control
- Consumer electronics
- Recreation
- Remote power
- Battery Chargers
- Residential (non-US)
  - 1250+ units installed in Japan

Battery power is equivalent to
6% of US demand (2002)

More efficient systems yield a policy benefit

The Transportation Dilemma

Options: Policy

- Gas tax: 50 cents? $1? $2?
- Price Controls
- Market stimulus
  - Gas guzzler tax / gas sipper rebate
  - Increase credits for hybrids and other hi-tech cars
- Enforced conservation
  - No drive days
  - No trucks during rush hours
  - Staggered work hours – mandatory

Majority Support has been elusive

Options: Technology and Fuels

- Vehicles
  - Battery EV's
  - Gas-Electric Hybrids
  - "Plug In" Hybrids
- Fuels
  - "Traditional" Alt Fuels
  - Biofuels
    - Ethanol
    - Biodiesel
- Fuel Cells
  - Hydrogen fuel cells

Battery EV's

Still a Possibility, But . . .

- Cost
- Range
- Battery issues
  - Weight
  - Performance
  - Durability
  - Disposal
  - Resources
- Infrastructure
- Emissions depend on charging source
- Power required (16 Quads)
- Customer acceptance
- Industry resistance

Hybrids:
Not a Solution

Performance varies widely

- Optimistic Assumptions: 45%
- ANL: 10-20%
- New Lexus: 5%
- Savings depend on duty cycle

Plug-Ins:
Breakthroughs Needed

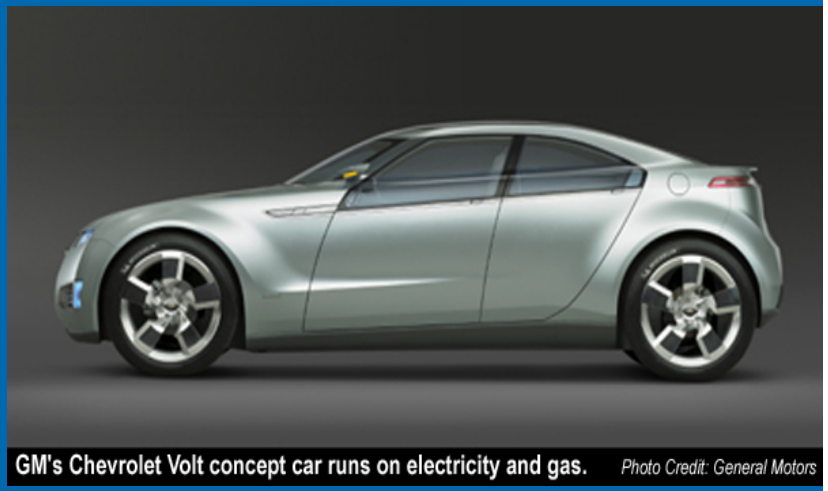
- Arguably not as far along as fuel cell vehicles (DCX promises 30 by 2008)
- NAS: Challenges “probably no greater than those facing hydrogen”
- Batteries not available yet
- Issues include cost, weight, cycle life, complexity, infrastructure
- Sprinter Van Example
  - EPA mileage: 22 city / 24 highway
  - Road test in Paris (100% city): 25.4 mpg

The Good News

- Better batteries mean better fuel cell vehicles
- Better hybrid technologies mean better fuel cell vehicles
- Best plug-in hybrids may be fuel cell hybrids

"While mechanical propulsion will be with us for many decades to come, GM sees a market for various forms of electric vehicles, including fuel cells and electric vehicles using gas and diesel engines to extend the range. With our new E-flex concept, we can produce electricity from gasoline, ethanol, bio-diesel or hydrogen."

GM VOLT concept car



GM's Chevrolet Volt concept car runs on electricity and gas. *Photo Credit: General Motors*

Ford Airstream

Ford's HySeries Drive powertrain delivers a combined city/highway equivalent fuel economy rating of 41 mpg.

A hydrogen-fueled, battery-powered plug-in

Alt Fuels

- Methanol, CNG, LPG may have niche markets
- Biofuels
  - Environmental Impact (production and emissions)
  - Net energy
  - Diversion of resources
  - Industry acceptance
  - Consumer acceptance
  - Performance
  - Range (CNG)
  - Infrastructure
  - NIMBY

The Good News

- Bio-fuels and bio-derived methanol are excellent hydrogen carriers
- Fuel cells help get renewable energy into the gas tank

Hydrogen Hybrids

- Honda solar-powered H2 station in Los Angeles

The Industry's Pursuit of Fuel Cells

If we accelerate hydrogen/fuel cell commercialization

We'll have a partner in the auto industry!

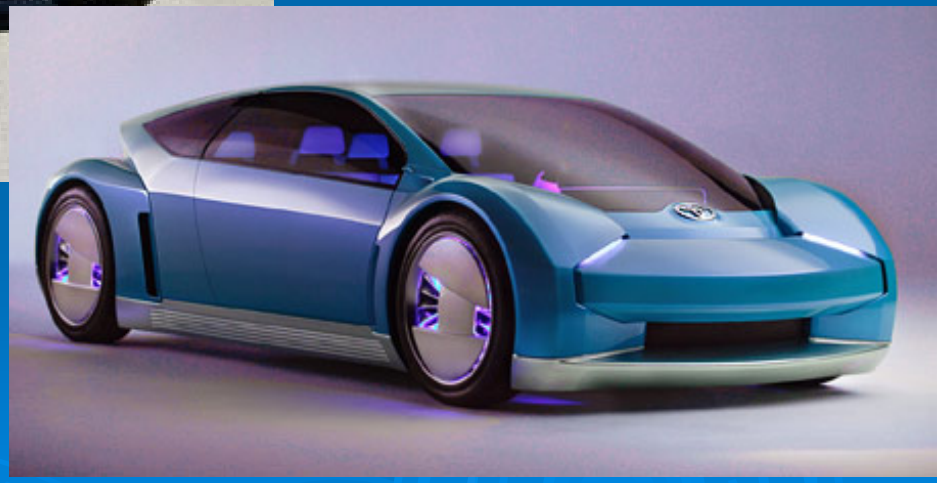
Why?

- Only Fuel Cells can enable the low impact vehicles that auto makers need to achieve their commercial goals
- 4x increase in total market by 2050
  - Fuel availability
  - Environmental impact

The Next Generation

GM Hy-wire

Honda FCX



Toyota FINE-S

2006 Honda FCX

Honda FCX

"... the ultimate green vehicle."

Takeo Fukui, President

- 350 mile range
- Home refueling
- Leasing in 2008
- Mass production by 2018

Other Manufacturers are promising again, too

- GM, Ballard: commercial ready by 2010
- DCX: 2012
- Honda: Production >12,000 annually by early 2010's

GM's Larry Burns: "A lot of people are skeptical about us pursuing a 2010 timeline. I'd like to think they'd celebrate that because this is something that the world really needs."

Ford

- Fuel cell Explorer Introduced in November 2006
- Fuel cell/battery hybrid
- 60 kW Ballard PEM stack
- 350 mile range
- Accumulated more than 17,000 miles in a year

Many Other Vehicles

Recent DOD Procurement RFP

Bus Demonstrations Worldwide

- CUTE: Europe
- Australia
- Iceland
- Tokyo
- CA, MI, FL

AC Transit reports 2x mileage, superb performance

Issues

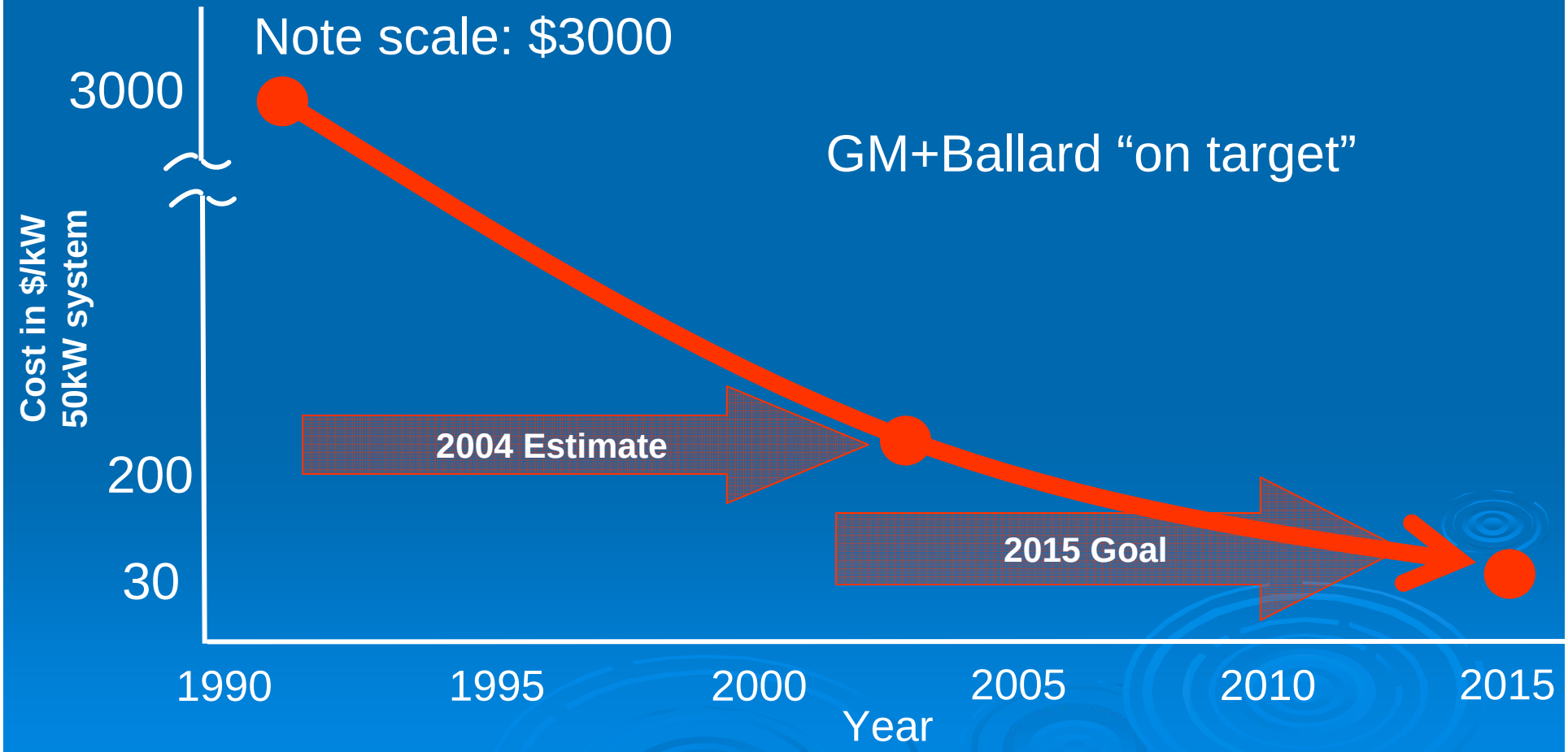
- Durability
- Cost
- Fuel

Durability

- Target is 5,000 hours (100K to 250K mi)
  - Two membrane suppliers
- Power generation systems > 13,000 hours
- Best reported in a vehicle is ~ 2,000 hours

Cost

Prototype cost remains high (~$3,000/kW), but the high volume[1] estimate of today's technology ~ below $120/kW



1. High volume production defined as 500,000 units per year
2. Cost estimated by A.D. Little (Sept. 2001) with enhanced hydrogen storage; independently confirmed.

Cost

- Toyota: $50,000 by 2015
- Honda: $84,000

Fuel:
The Hydrogen Factor

The hydrogen factor

- Auto industry “fuel neutral”
- Hydrogen may win out because of its flexibility and technical suitability
  - Fuel, energy carrier, storage medium
  - Many pathways
  - Source will depend on local resources, like e-
  - Carbon free promise

Infrastructure

- We'll need it eventually
- We won't need it all at once
- When we do need it, people will provide it in a safe, environmentally responsible manner – and make money selling hydrogen!

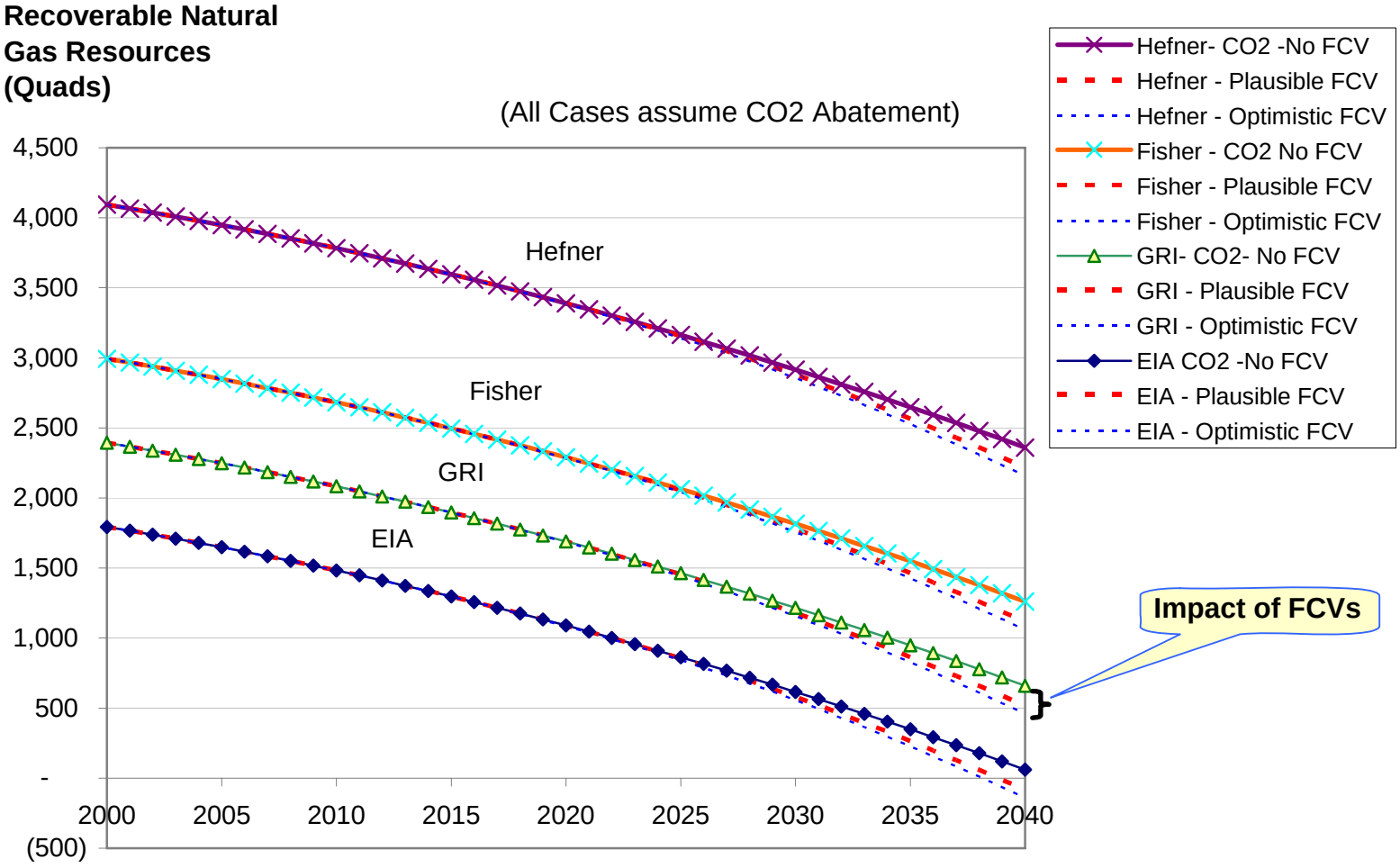
Infrastructure

- GM Estimates hydrogen for 70% of consumers would cost < $15 billion
  - ~ to cost of one year's gasoline infrastructure maintenance
- IEA analysis
  - Worldwide transition $1 trillion to $5 trillion over 30 years
  - ~0.3% of global product!
  - Compare to 5% - 10% transition costs to rail or cars
- The gasoline future is not free
  - ~ $3 trillion to meet new demand by 2030

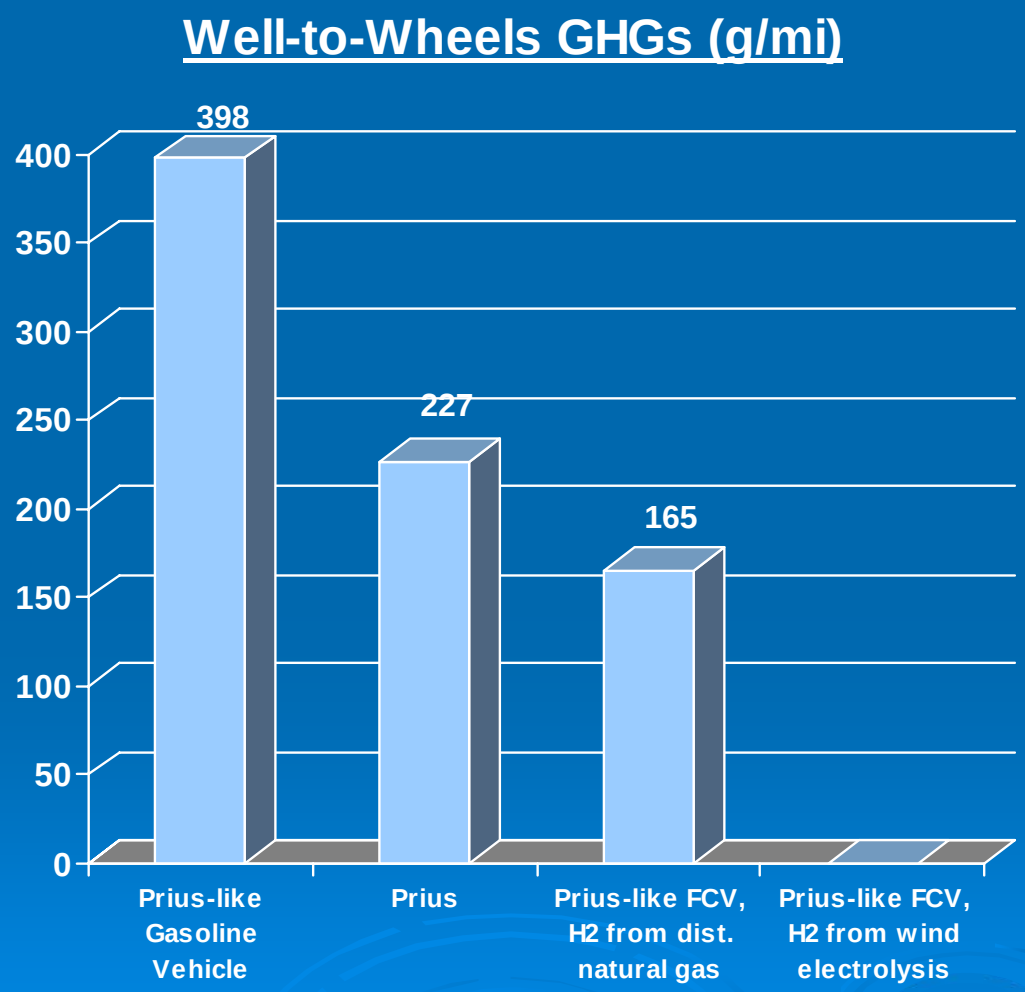
Natural gas is a good interim choice

- Low carbon fuel (not low enough!)
- Mixed with water today to produce hydrogen – 50% renewable fuel
- 2x times cheaper than gasoline on energy equivalent basis
- Efficiency and emissions benefits in a fuel cell vehicle

Impact of FCVs on NG Resources



Natural gas fuel cells offer a benefit



Source: ANL (GREET/PSAT) Models; 55/45 combined cycle

Cost competitive today!

	Hydrogen Cost ($/kg)			Hydrogen Fuel Cost per mile Traveled (untaxed)
	Production Cost	Compression & Storage Cost	Total Cost	($/gallon gasoline on range-equivalent basis)
Today (20 cars/day)	3.13	2.64	5.77	**$2.65/gallon**
3 Years (100 cars/day)	1.97	1.50	3.47	**$1.60/gallon**
6 Years (100 cars/day)	1.69	1.32	3.01	**$1.38/gallon**
~10 Years (250 cars/day)	1.28	1.32	2.60	**$1.20/gallon**

Assumptions: FCV has 2.2X fuel economy of an ICEV; hydrogen made on-site from natural gas @ $6.25/mmbtu; annual capital recovery factor = 213%; capacity factor = 80%;

Wind-to-Hydrogen Cost

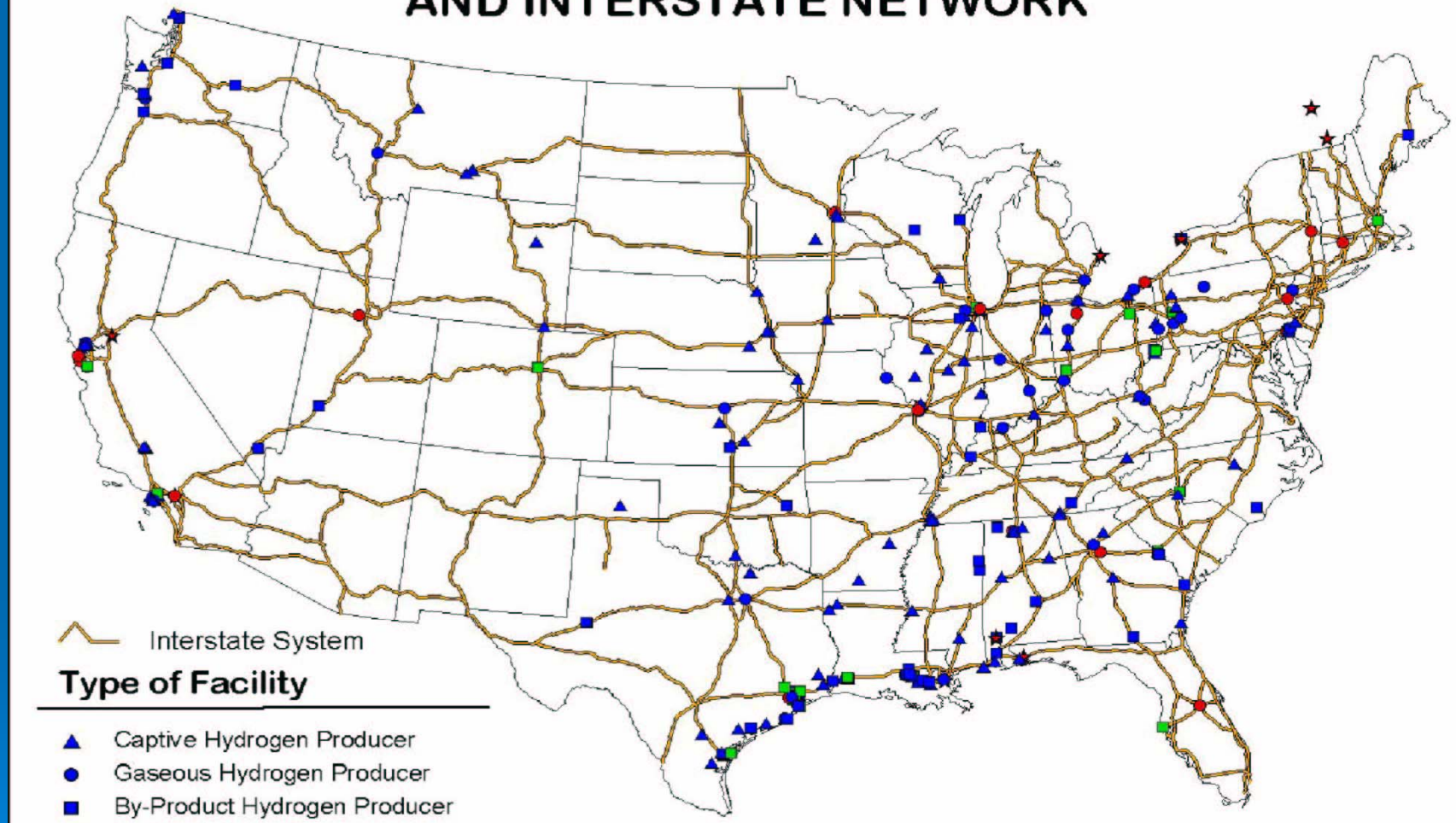
- Current: $2-3/kg to generate, $4-6 at the pump (Scott 2005)
- Stanford study (wind): $1.12 to $3.20
  - “unsubsidized near-term cost”

With 2x fuel cell efficiency,

these are competitive prices

(40 kWh/kg)

HYDROGEN FACILITIES AND INTERSTATE NETWORK



U.S. Hydrogen Stations

- California (16 in operation, 15 more planned)
- Michigan (3)
- Arizona (2)
- Illinois (‘00)
- Indiana
- Florida
- Nevada
- North Carolina
- Pennsylvania
- Washington DC
- New York
- Vermont
- Delaware

Benefit Estimates

An unmatched combination of benefits

1. Health, environmental, energy security, global warming benefits
2. Natural gas or wind powered fcv's:

- save 3,700 to 6,400 lives
- 1 to 3 million fewer asthma cases
- ~ 2x health benefit compared to hybrids
- Hybrids: "a rough tie for third" overall of five options
  - Assumes hybrid ~ 45% + efficiency

Jacobson (Stanford) et al. 2005

LCA Confirms the Benefit v. ICE

(comp. of two scenarios)

ICE/low sulfur diesel	-28%	+4%
ICE/CNG	-28%	-28%
ICE/Ethanol (corn)	+11%	+13%
ICE Ethanol (cellulose)	-62%	-57%
Battery EV (coal)	-12%	-22%
Battery EV (NG)	-62%	-64%
FCEV (NG)	-58%	-60%
FCEV (water)	-91%	-90%

DeLucchi 2005

Policy Priorities

- Federal Purchases
- Extension of installation tax credit
- Appropriations at EPACT Levels

Policy Priorities

- Federal Purchases: the number one priority of the fuel cell industry
  - EPACT 782
    - Vehicles
    - $105M 2008-2010
  - EPACT 783
    - Stationary, Portable, Micro
    - $345M 2006-2010

USFCC Product List

- Nearly 50 products with performance data, commercial terms
- Have products, need customers!

Barriers

- High first cost
- Purchasing Officer conservatism
- Imperfect mechanisms for evaluation (Energy Star)
- Lack of understanding
- Incomplete picture from the field

Contact

Bob Rose

USFCC

202-293-5500

brose@fuelcells.org

www.usfcc.com

www.fuelcells.org