

Ford Technology & Iceland as a Proving Ground



**North Atlantic Hydrogen
Association Conference
Reykjavik, Iceland**

**Dr. Scott M. Staley, P.E.
Chief Engineer**



Outline

- **Ford Technology – EV, H2ICE, FCEV**
- **Ford Focus FCEV – Experience to date**
- **Iceland as a Proving Ground**
- **Prospects for a Hydrogen Future**



Ford EV Technology



1992 - 1993 Ford Econstar

1998 - 2000 Ford Ranger
and Postal Program



2001 Th!nk city

2002 Th!nk neighbor



Ford H2ICE Technology

2.0L I4



2001 - P2000

2.3L Supercharged I4



2003 - NAIAS Model U



2003 - H2ICE Focus

6.8L Boosted V10



2006 - H2ICE Demo/Fleet



2004 - H2ICE Generator (Generac)



2004 - H2ICE C-Max



2003 - Centennial H2RV



2004 - H2ICE Hybrid Bus (ISE)



2005 - H2ICE Hybrid Bus (Designline)



2004 - H2ICE Rotary (Mazda)



2006 - 4.2L V-6





Ford Model U - Hydrogen ICE

Bob Natkin, Group Leader Hydrogen Internal Combustion Engine



H₂ ICE-HEV Powertrain Generation II

2.3L 4 cylinder
engine

HEV
Controller

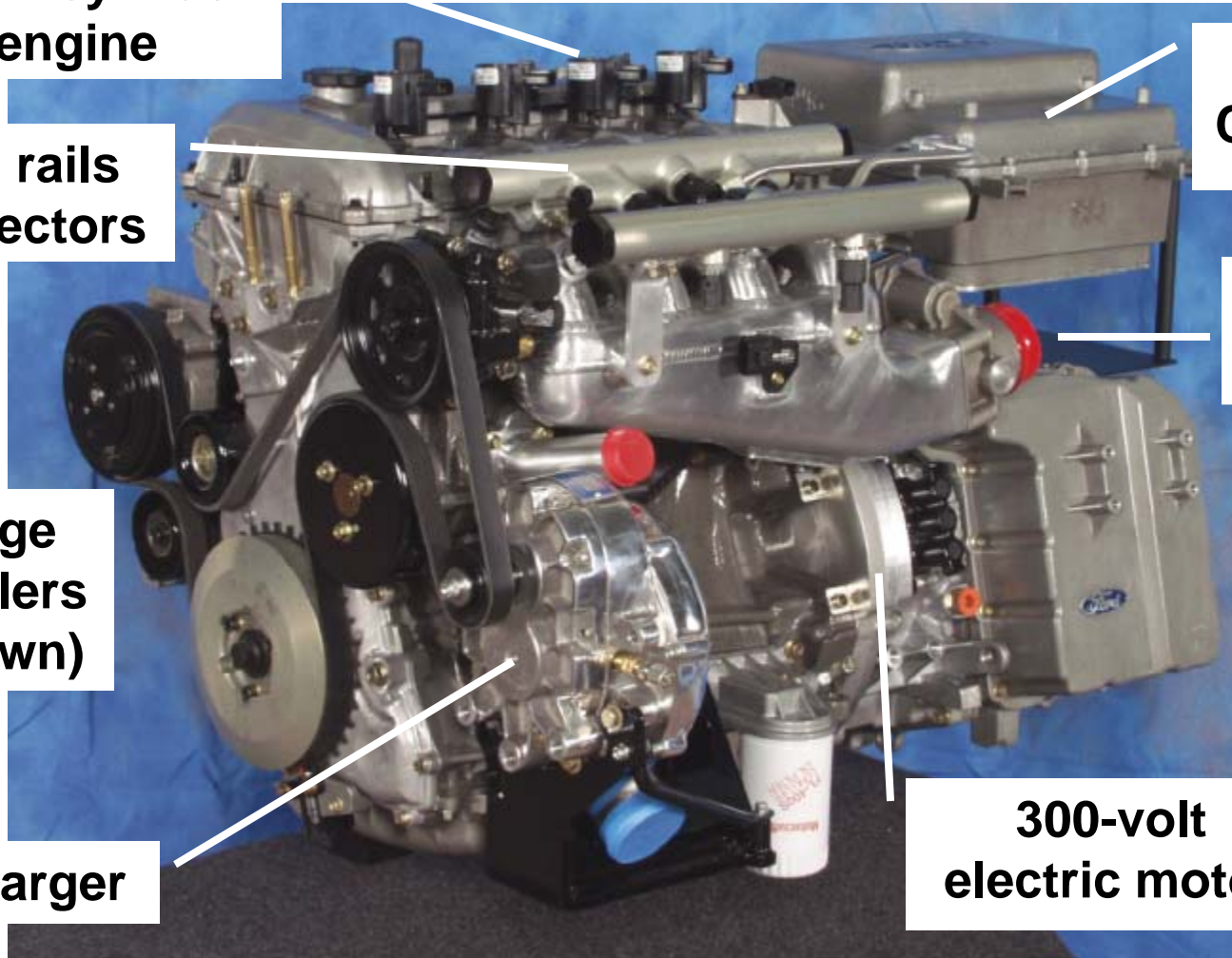
Dual fuel rails
and H₂ injectors

Throttle-
by-wire

Dual-stage
intercoolers
(not shown)

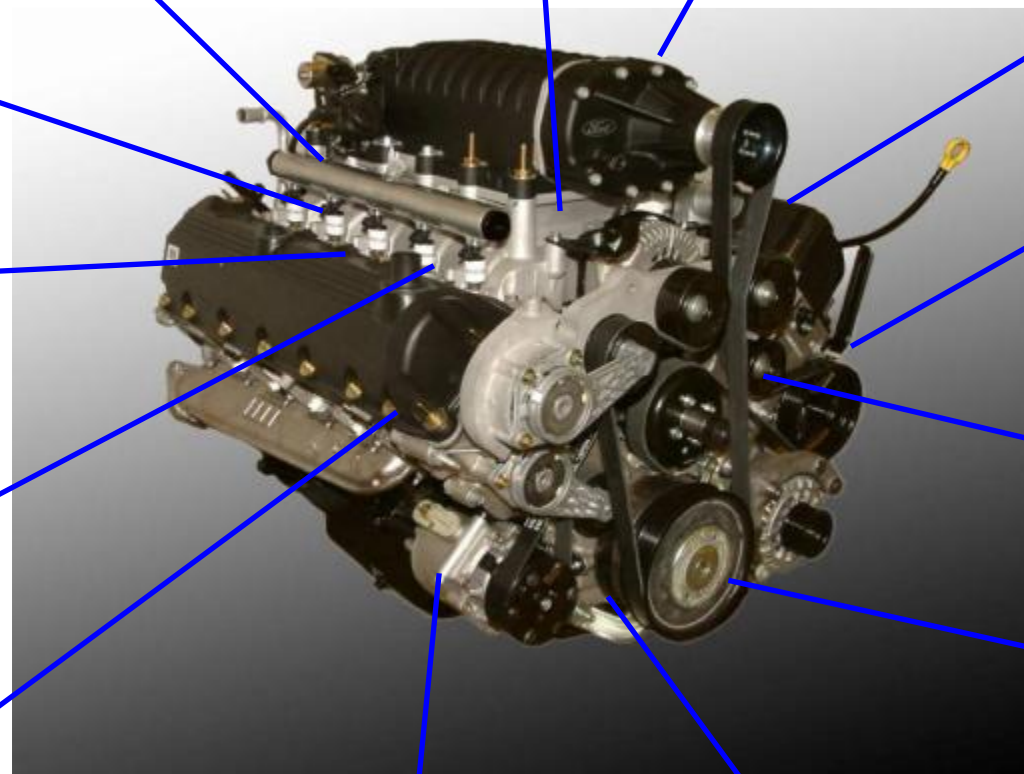
Supercharger

300-volt
electric motor





Unique H2ICE Hardware



Fuel Rail Assemblies

-Greater Volume

Intake Manifold

-Purpose Designed

Supercharger/Intercooler

-3300cc Twin Screw
-Water-to-air intercooler

Fuel Injectors

-Designed for H2

Spark Plug

-Iridium tipped

Ignition Coil

-High energy

Valves/Seats

-Premium material

PCV System

-External oil separator

FEAD

-Supercharger
-2nd alternator

Head Gasket

-Rated for 100 bar

Damper

-Tuned for H2 combustion

Piston/Rod/Rings

-Forged Eutectic piston
-Forged steel rods

New oil formulation

-Low ash content
-Extra corrosion inhibitors



Ford FCEV – Experience to date



Ford Fuel Cell Vehicle Technology

P-2000 FCEV



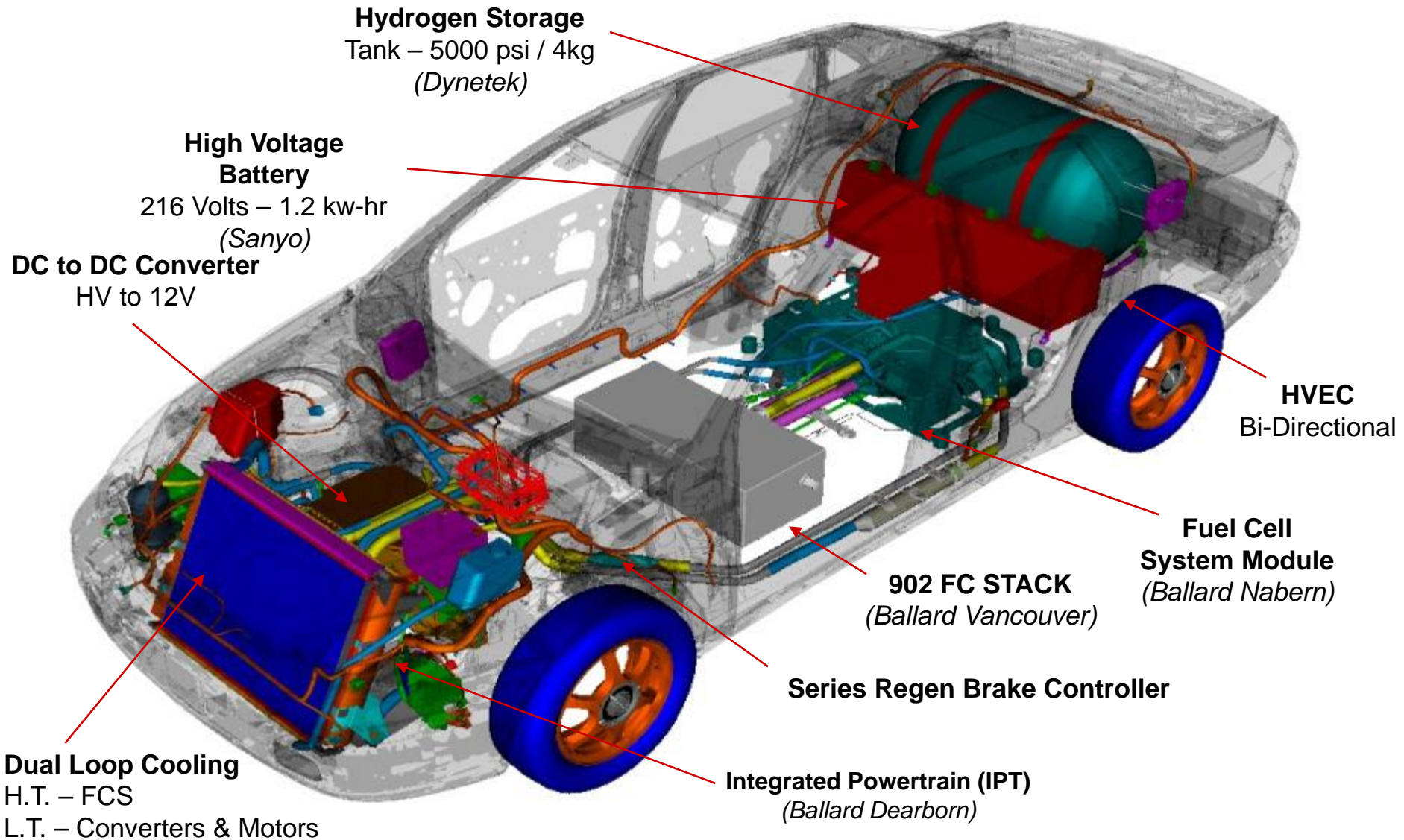
2005 Focus Fuel Cell Vehicle



- Ford Focus 4 Door
- Curb Mass: 1600 kg (3520 lbs)
- Fuel Cell: Ballard Mark 902 FC STACK
- Power: 68kW (87hp)
- Powertrain: Integrated AC Induction
- Hybridized – 216 volt Battery Pack
- Series Regenerative Braking
- City = 48 Mi/Kg H₂ (49 MPG gas equivalent)
- Hwy = 53 Mi/Kg H₂ (54 MPG gas equivalent)
- Range: 200 mi/320 km
- Max speed: 80+ mph/128+ kph
- Fuel: 5000 psi Compressed Hydrogen
- Emissions: Zero
- Cold Start Capability > 2 C
- Operational Capability: –15 C up to 50 C



FCV Architecture - Key Subsystems



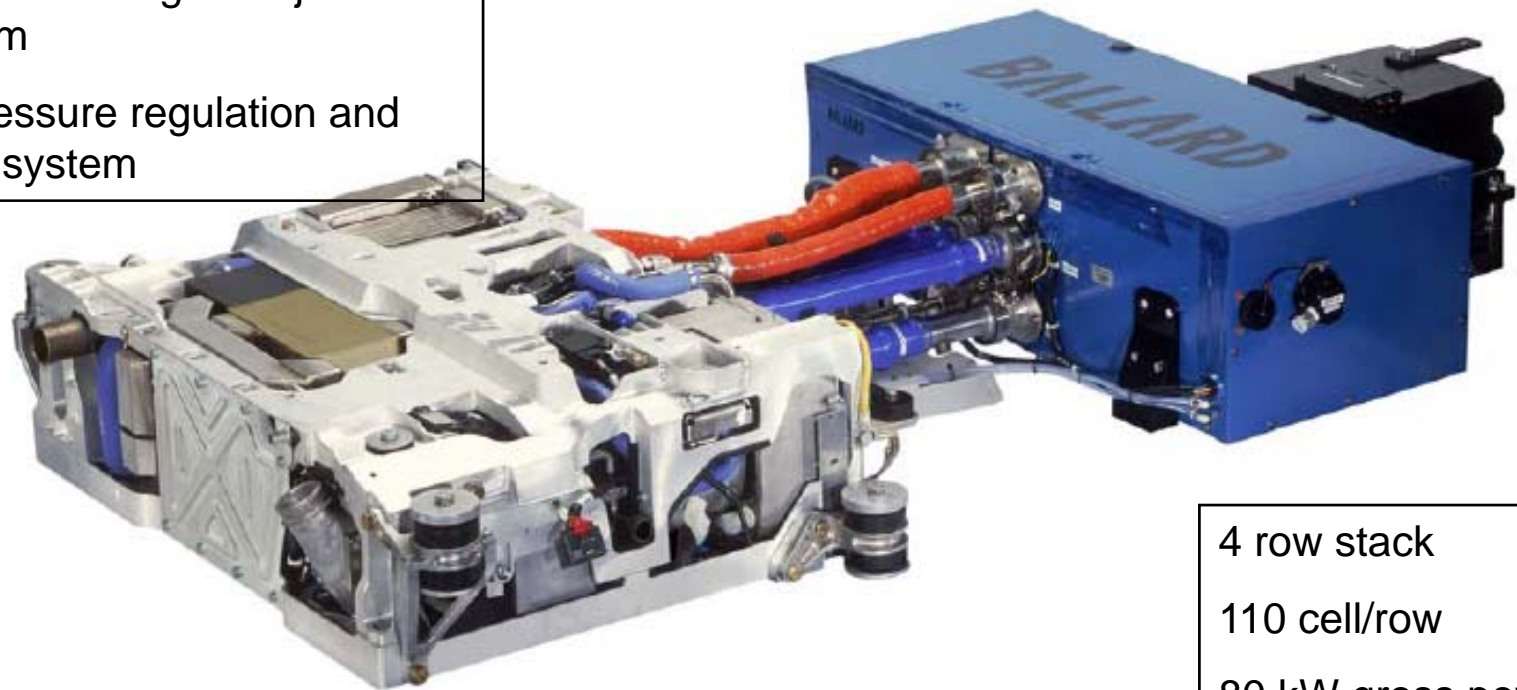
Ballard Fuel Cell Engine

Air Compressor/expander & e-motor drive system

Air/H₂ Humidifiers

DI Water storage & Injection System

H₂ pressure regulation and recirc system



4 row stack

110 cell/row

80 kW gross power

Cell Voltage Monitor

TDV2 in LA Auto Show



2006 L.A. Auto Show: Ford Explorer Fuel Cell



Ford is debuting what looks like a standard Explorer SUV in L.A. this week, but it actually packs a hydrogen powertrain; a tank of the alternative fuel can take the Explorer 350 miles on a single fill-up.

The fuel cell prototype is partially funded by the U.S. Department of Energy in order to show a viable alternative to petroleum. We'd have to assume the government wouldn't want to invest in any hydrogen infrastructure without seeing some real working samples on the road.

The fuel cell Explorer has been tested over more than 17,000 miles, and traveled 1,556 miles in a 24-hour period. Ford will also launch its next-generation Escape and Escape Hybrid compact SUVs tonight at midnight.





TDV7 – Ford Edge with HySERIES Drive



207 mph (330 kph)



Iceland as a Proving Ground



Ford Corporate Testing Procedures

Vehicles Robustness and Durability Testing



14,000 Ft Altitude Testing



Mud Bath / Salt Water Fording



90° Fixed Barrier Impact



Sault Ste Marie Brake Testing -18 C



Cobblestone Roads

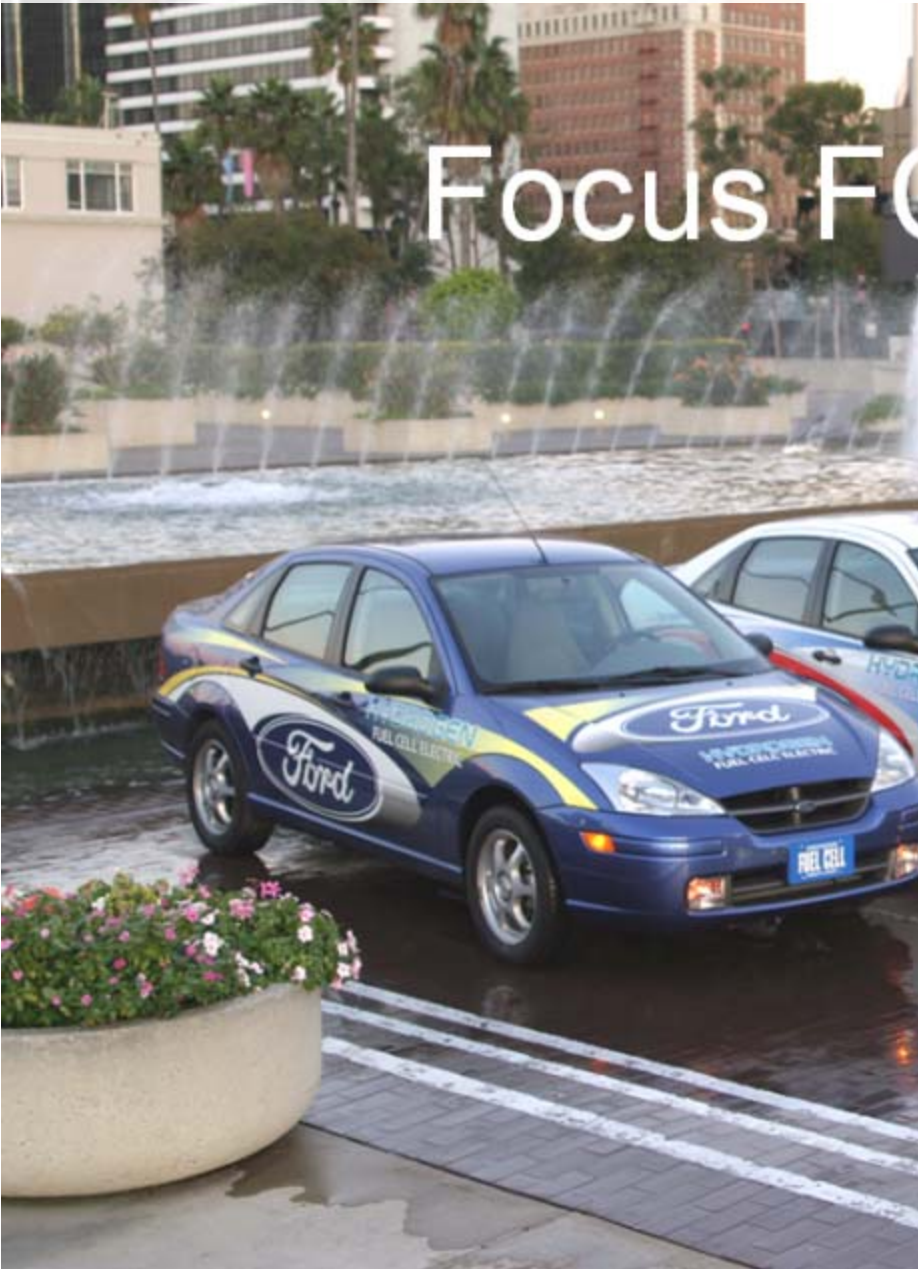


90° Moving Barrier Impact



Focus FCV Demonstration

- 3 years
- 30 vehicles (18 in DOE)
- 750,000 miles
- 150 participants
- 9 fueling locations
- 95% up time



Ford Focus FCEV Vehicle Locations



- 32 FCV in operation worldwide (US, Canada & Germany)
- 27 Vehicles Delivered to 7 Customer locations
- 18 Vehicles in the DOE-funded Demonstration Fleet
- 5 Engineering vehicles used between Dearborn and Sacramento



Driving innovation

THE VANCOUVER FUEL CELL VEHICLE PROGRAM



**NHA Annual Hydrogen Conference 2006
Long Beach, California**

Canada 



Berlin CEP



And Now, Iceland



Iceland has a Plan

1. Hydrogen fuel cell bus demonstration: ECTOS



Demonstration
Programme

Gradual introduction
into bus fleet

2. Hydrogen passenger vehicles



Demonstration
Programme

Gradual introduction
into passenger car fleet

3. Hydrogen fishing vessel demonstration



Demonstration
Programme

Gradual introduction
into fishing fleet

2000

2003

Time

Iceland has Hydrogen Infrastructure

April 2003



Iceland has Experience



Iceland has Technical and Scientific Contributions



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Implementing the hydrogen economy

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Abstract

In the Icelandic community the use of renewable energy and the tests with a clean domestic fuel that most people refer to as the fuel of the future have become the points of focus. In Reykjavík this future has arrived. Hydrogen is used currently as the energy carrier within the public transportation system and is electrolyzed from water with hydroelectric power and leaves the system as water again.

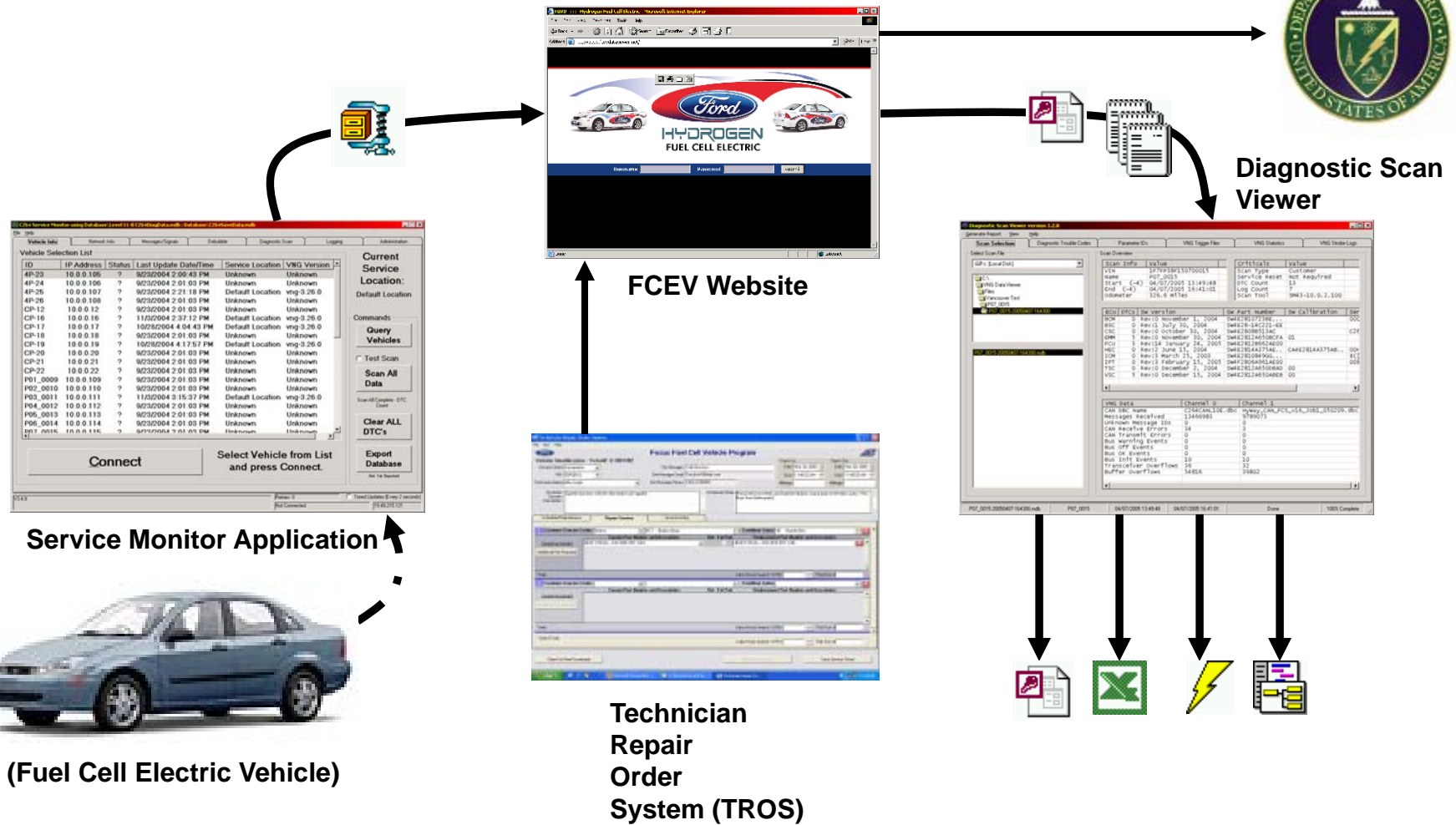


Figure 1. The fuel cell bus at the filling station.

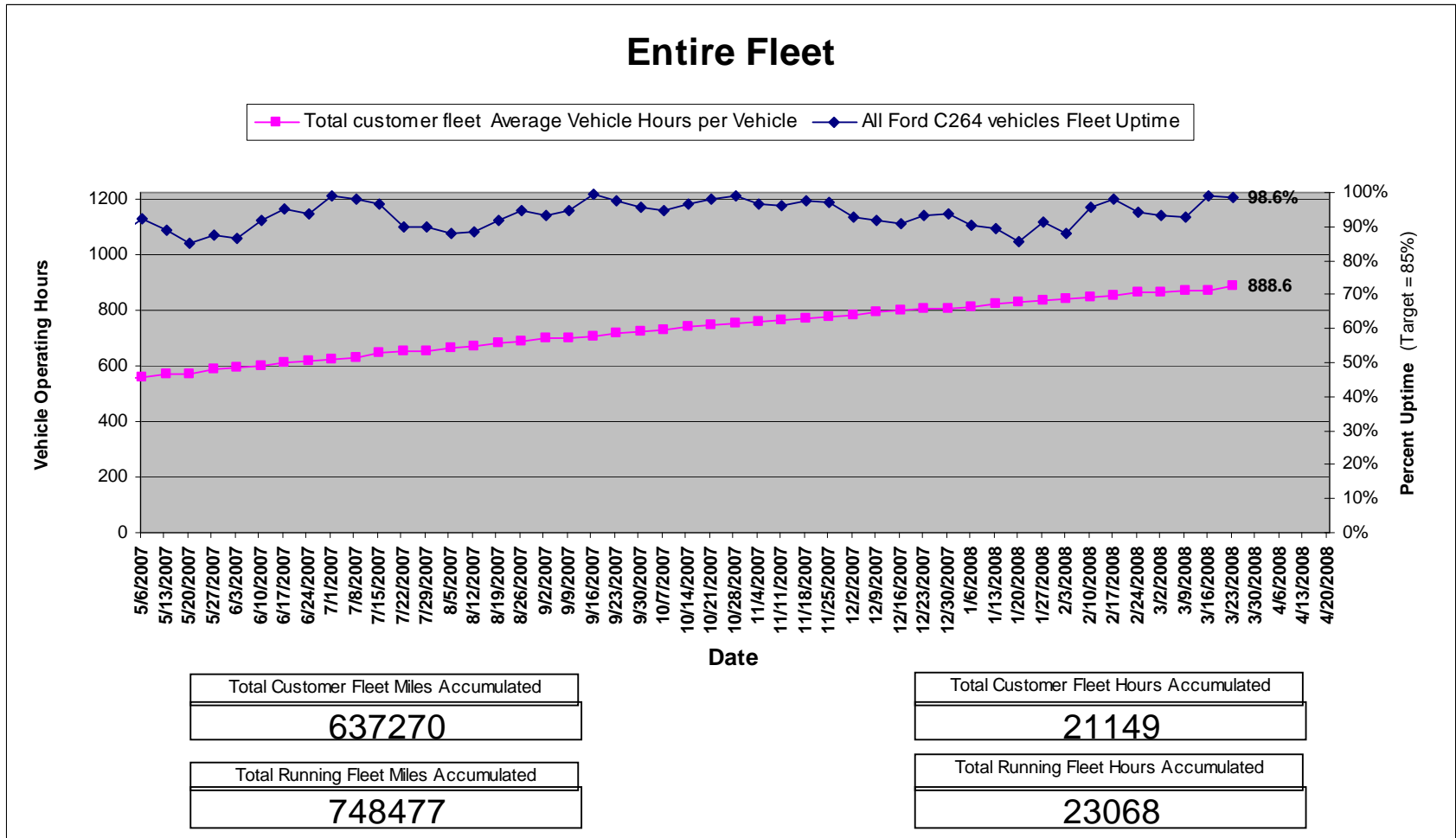
The US DOE, Ford and INE add another FCV to the Iceland Fleet



Fleet Data Collection & Reporting

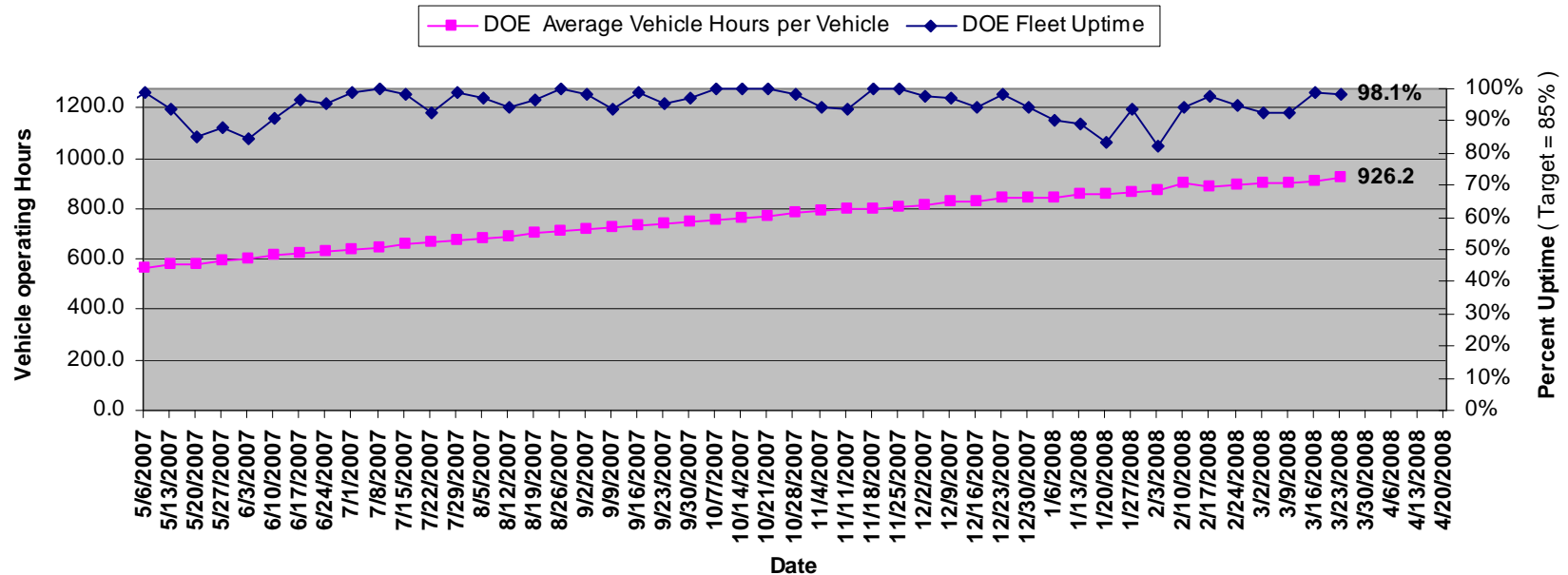


Entire Fleet



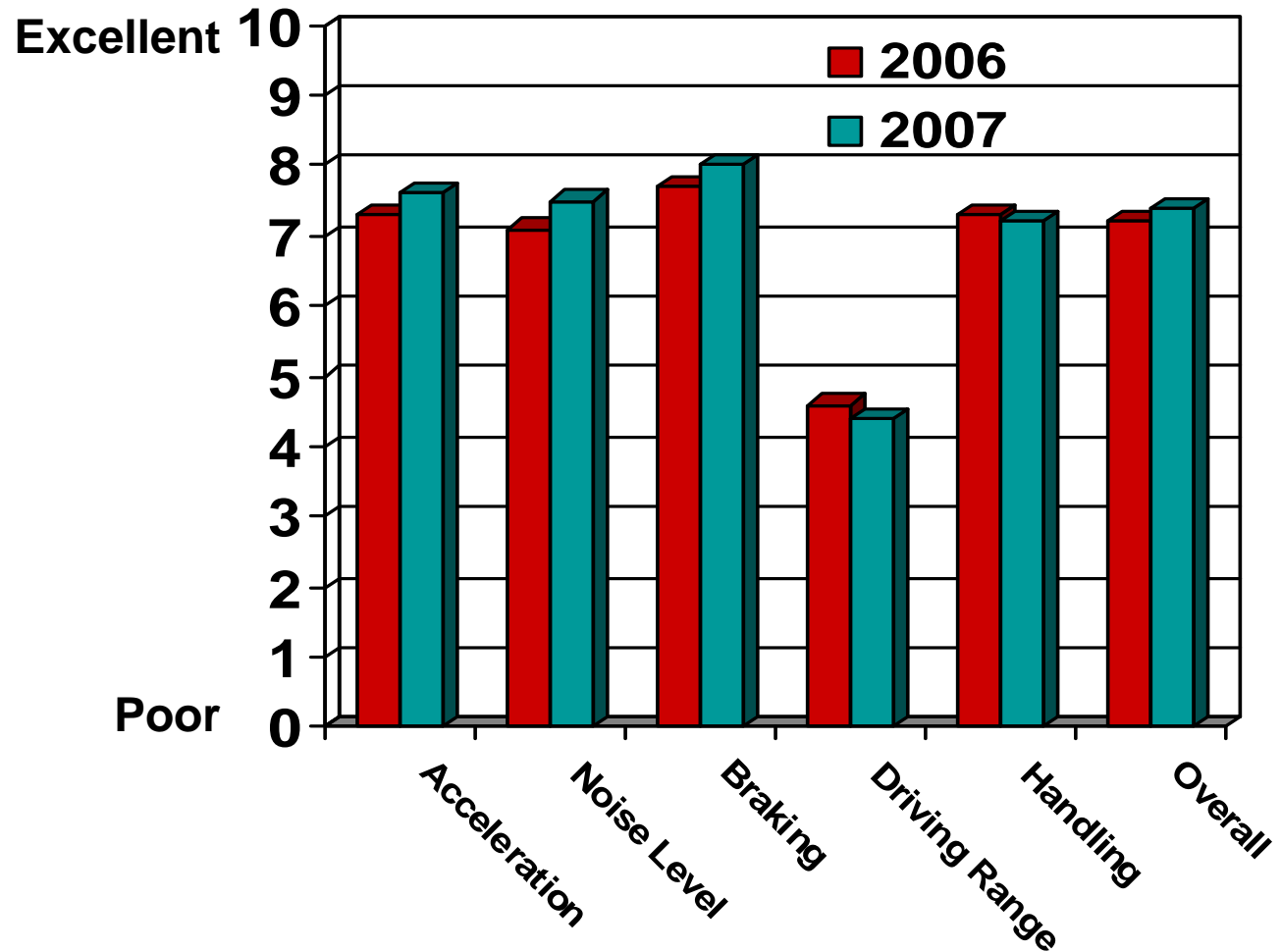
DOE Vehicles

DOE Fleet

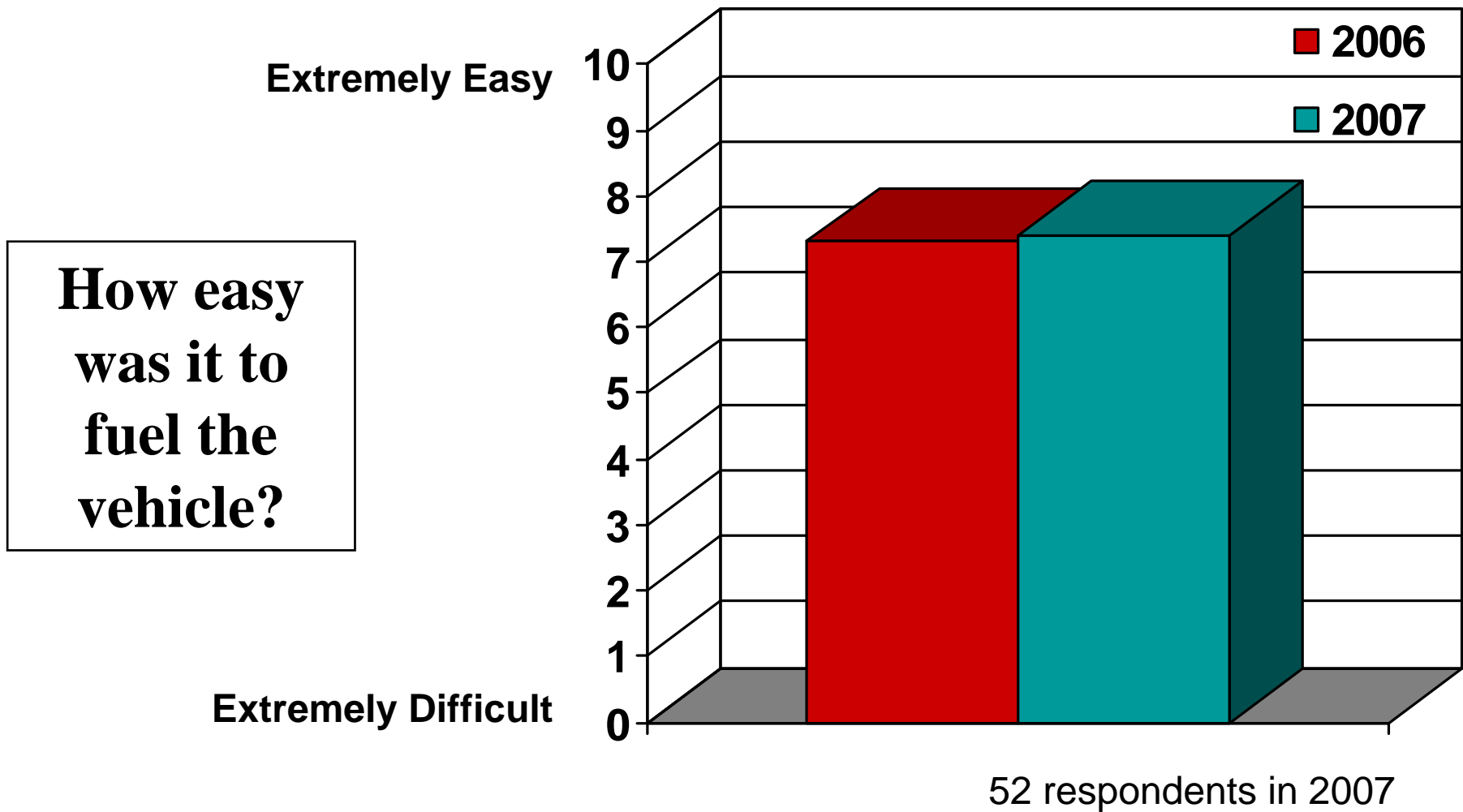


Highlights from Fleet Customer Survey

How would you rate the vehicle's performance?



Highlights from Fleet Customer Survey



The Hydrogen Future Bookends



Conclusions with Respect to a Sustainable Energy Future

A sustainable energy future must be based on energy from renewable sources and energy efficiency

Hydrogen must be fabricated from renewable electricity

By laws of physics much energy is needed (and lost) for producing, packaging, distributing, storing and using hydrogen:
(Losses about 50% for gaseous hydrogen and 75% for electricity from fuel cells)

Hydrogen cannot compete with its own energy source:
RENEWABLE ELECTRICITY

Therefore, a global “**Hydrogen Economy**” has no future!

In fact, the hasty implementation of a Hydrogen Economy may block the establishment of a sustainable energy future based on electricity from renewable sources

35

Ulf Bossel, Ph.D., October 2004



Wind energy and the hydrogen economy—review of the technology

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Abstract

The hydrogen economy is an inevitable energy system of the future where the available energy sources (preferably the renewable ones) will be used to generate hydrogen and electricity as energy carriers, which are capable of satisfying all the energy needs of human civilization. The transition to a hydrogen economy may have already begun. This paper presents a review of hydrogen energy technologies, namely technologies for hydrogen production, storage, distribution, and utilization. Possibilities for utilization of wind energy to generate hydrogen are discussed in parallel with possibilities to use hydrogen to enhance wind power competitiveness.

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Keywords: Hydrogen energy; Wind energy; Fuel cells; Solar energy; Hydrogen production; Hydrogen storage

Periodic Table

Periodic Table

| | | | | | | | | | | | | | | | | | | |
|---------------------------------|----------------------------------|-----------------------------------|---------------------------------|-------------------------------------|----------------------------------|------------------------------------|---------------------------------|----------------------------------|----------------------------------|------------------------------------|-----------------------------------|-----------------------------------|----------------------------------|------------------------------------|------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|
| | | | | | | | | | | | | | | | | | | 18 VIII A |
| 1 H Hydrogen 1.00794 | | | | | | | | | | | | | | | | | | 2 He Helium 4.002602 |
| 3 Li Lithium 6.941 | 4 Be Beryllium 9.012182 | | | | | | | | | | | 5 B Boron 10.811 | 6 C Carbon 12.0107 | 7 N Nitrogen 14.00643 | 8 O Oxygen 15.999 | 9 F Fluorine 18.9984032 | 10 Ne Neon 20.1797 | |
| 11 Na Sodium 22.989770 | 12 Mg Magnesium 24.3050 | | | | | | | | | | | 13 Al Aluminum 26.981538 | 14 Si Silicon 28.0855 | 15 P Phosphorus 30.973761 | 16 S Sulfur 32.059 | 17 Cl Chlorine 35.453 | 18 Ar Argon 39.948 | |
| 19 K Potassium 39.0983 | 20 Ca Calcium 40.078 | 21 Sc Scandium 44.955910 | 22 Ti Titanium 47.887 | 23 V Vanadium 50.9415 | 24 Cr Chromium 51.9961 | 25 Mn Manganese 54.938049 | 26 Fe Iron 55.845 | 27 Co Cobalt 58.933200 | 28 Ni Nickel 58.6934 | 29 Cu Copper 63.546 | 30 Zn Zinc 65.409 | 31 Ga Gallium 69.723 | 32 Ge Germanium 72.64 | 33 As Arsenic 74.92160 | 34 Se Selenium 78.96 | 35 Br Bromine 79.904 | 36 Kr Krypton 83.798 | |
| 37 Rb Rubidium 85.4678 | 38 Sr Strontium 87.62 | 39 Y Yttrium 88.90585 | 40 Zr Zirconium 91.224 | 41 Nb Niobium 92.90638 | 42 Mo Molybdenum 95.94 | 43 Tc Technetium (98) | 44 Ru Ruthenium 101.07 | 45 Rh Rhodium 102.90550 | 46 Pd Palladium 106.42 | 47 Ag Silver 107.8682 | 48 Cd Cadmium 112.411 | 49 In Indium 114.818 | 50 Sn Tin 118.710 | 51 Sb Antimony 121.760 | 52 Te Tellurium 127.60 | 53 I Iodine 126.90447 | 54 Xe Xenon 131.29 | |
| 55 Cs Cesium 132.90545 | 56 Ba Barium 137.327 | 57 to 71 | | 72 Hf Hafnium 178.49 | 73 Ta Tantalum 180.9479 | 74 W Tungsten 183.84 | 75 Re Rhenium 186.207 | 76 Os Osmium 190.23 | 77 Ir Iridium 192.222 | 78 Pt Platinum 195.078 | 79 Au Gold 196.96655 | 80 Hg Mercury 200.59 | 81 Tl Thallium 204.3833 | 82 Pb Lead 207.2 | 83 Bi Bismuth 208.98039 | 84 Po Polonium (209) | 85 At Astatine (210) | 86 Rn Radon (222) |
| 87 Fr Francium (223) | 88 Ra Radium (226) | 89 to 103 | | 104 Rf Rutherfordium (261) | 105 Db Dubnium (262) | 106 Sg Seaborgium (266) | 107 Bh Bohrium (264) | 108 Hs Hassium (277) | 109 Mt Meitnerium (268) | 110 Ds Darmstadtium (271) | 111 Rg Roentgenium (272) | 112 Uub Ununbium (285) | 113 Uut Ununtrium (284) | 114 Uuq Ununquadium (289) | 115 Uup Ununpentium (288) | 116 Uuh Ununhexium (292) | 117 Uus Ununseptium (294) | 118 Uuo Ununoctium (294) |

Atomic masses in parentheses are those of the most stable or common isotope.

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| | | | | | | | | | | | | | | |
|-----------------------------------|---------------------------------|---------------------------------------|---------------------------------|---------------------------------|--------------------------------|---------------------------------|----------------------------------|----------------------------------|-----------------------------------|----------------------------------|-------------------------------|-----------------------------------|---------------------------------|----------------------------------|
| 57 La Lanthanum 138.9055 | 58 Ce Cerium 140.116 | 59 Pr Praseodymium 140.90765 | 60 Nd Neodymium 144.24 | 61 Pm Promethium (145) | 62 Sm Samarium 150.36 | 63 Eu Europium 151.964 | 64 Gd Gadolinium 157.25 | 65 Tb Terbium 158.92534 | 66 Dy Dysprosium 162.500 | 67 Ho Holmium 164.93032 | 68 Er Erbium 167.259 | 69 Tm Thulium 168.93421 | 70 Yb Ytterbium 173.04 | 71 Lu Lutetium 174.967 |
| 89 Ac Actinium (227) | 90 Th Thorium 232.0377 | 91 Pa Protactinium 231.03688 | 92 U Uranium 238.02891 | 93 Np Neptunium (237) | 94 Pu Plutonium (244) | 95 Am Americium (243) | 96 Cm Curium (247) | 97 Bk Berkelium (247) | 98 Cf Californium (251) | 99 Es Einsteinium (252) | 100 Fm Fermium (257) | 101 Md Mendelevium (258) | 102 No Nobelium (259) | 103 Lr Lawrencium (260) |

Conclusion: hydrogen and carbon are the only important elements in transportation fuels.



Wheel-to-Wells Findings

- **Electricity would be the ideal transportation fuel.**
 - **Lowest CO₂ impact with today's generation mix.**
 - **Distribution infrastructure is already in place.**
 - **But ... on-board storage – meaning range - and recharge time are unacceptable**
- **Hydrogen (for fuel cells) from natural gas is the best chemical fuel.**
 - **But ... Depends on limited fossil fuel resource**
 - **On-board storage remains a major challenge**
 - **No existing retail infrastructure**
 - **Fuel cell systems are much more expensive than ICE**
- **Hydrocarbon from fossil petroleum is the poorest fuel on a CO₂ basis.**
 - **But ... is the most practical in the vehicle**
 - **Retail distribution and infrastructure are in place**
 - **Efficiency improvements continue to be made (HEV, PI-HEV, S-HEV)**





U.S. DoE Hydrogen Activities

Hydrogen, Fuel Cells and Infrastructure Technologies Program

Toward a More Secure
and Cleaner Energy
Future for America

A NATIONAL VISION OF AMERICA'S TRANSITION TO A HYDROGEN ECONOMY — TO 2030 AND BEYOND

Based on the results of the
National Hydrogen Vision Meeting
Washington, DC
November 15-16, 2001

February 2002



United States Department of Energy

Toward a More Secure and
Cleaner Energy Future for America

NATIONAL HYDROGEN ENERGY ROADMAP

PRODUCTION • DELIVERY • STORAGE • CONVERSION
• APPLICATIONS • PUBLIC EDUCATION AND OUTREACH

Based on the results of the
National Hydrogen Energy Roadmap Workshop
Washington, DC
April 2-3, 2002

November 2002



United States Department of Energy

DRAFT (June 3, 2003)

Plotting the way
toward a hydrogen
energy future

Hydrogen, Fuel Cells & Infrastructure Technologies Program

Multi-Year Research, Development
and Demonstration Plan
Planned program activities for 2003-2010



U.S. Department of Energy
Energy Efficiency and Renewable Energy
The long-term program to develop energy to clean,
domestic, reliable, and affordable

HYDROGEN POSTURE PLAN

AN INTEGRATED RESEARCH, DEVELOPMENT,
AND DEMONSTRATION PLAN

February 2004



United States Department of Energy



Research & Advanced Engineering

April 25, 2003

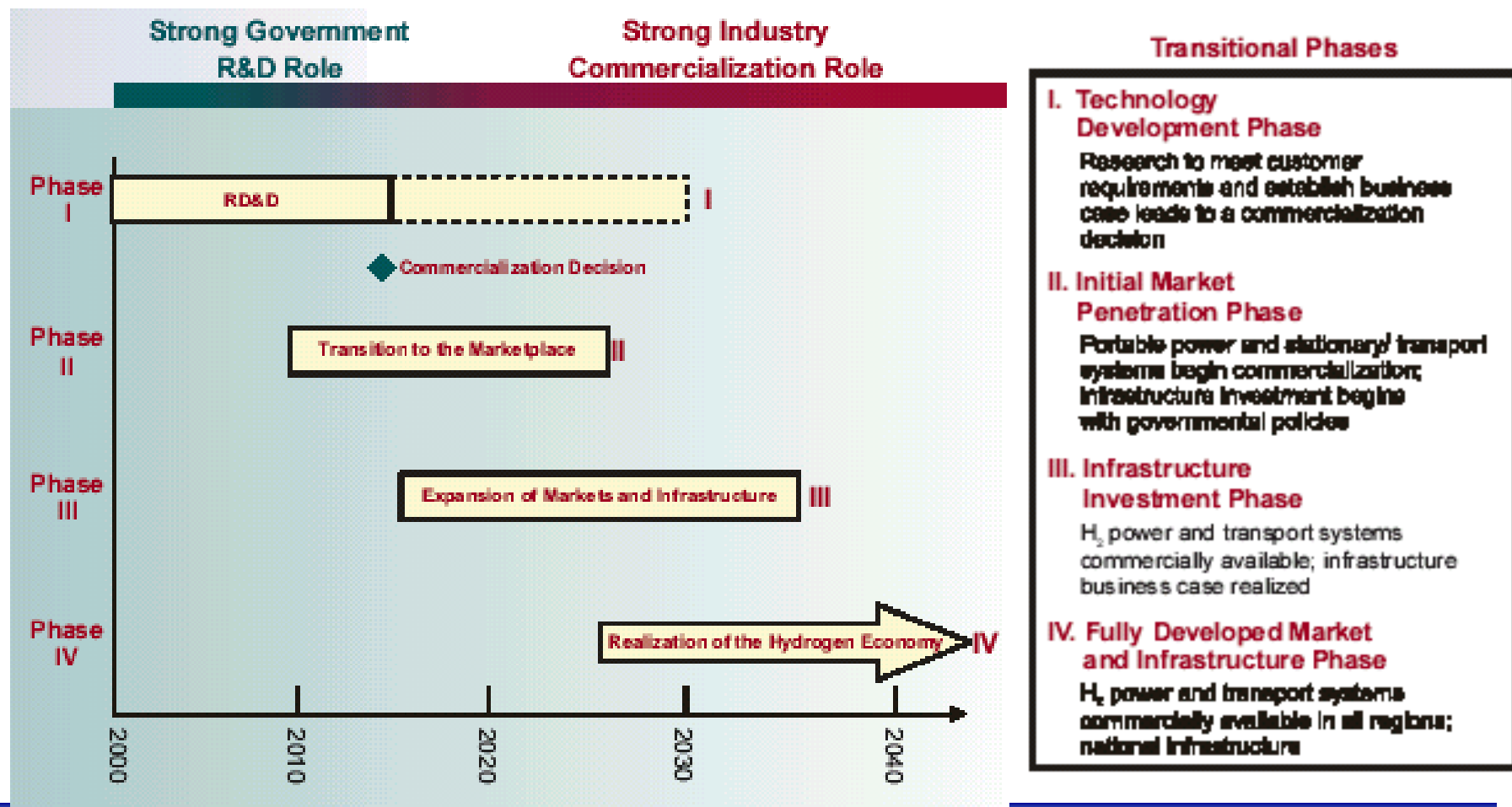


United States

Department of Energy

Science, Technology and Energy for our Future

DOE Hydrogen Plan



Can it be done?



Should it be done?

With the following clear trends:

- **\$117/barrel Oil**
- **Emerging world economies (China, India, etc.)**
- **Global environmental concerns**
- **Energy security concerns**

Something must be done!



Will it be done?

- **Can Durability, Freeze-start, and other technical performance attributes be achieved?**
- **Can On-Board Hydrogen Storage be achieved?**
- **Can Hydrogen Fuel Supply & Infrastructure be installed?**
- **Can Codes and Standards be agreed?**
- **Can Affordability be achieved?**
 - simplified system design
 - reduced material cost
 - mass production

The World is NOT Running Out of Energy



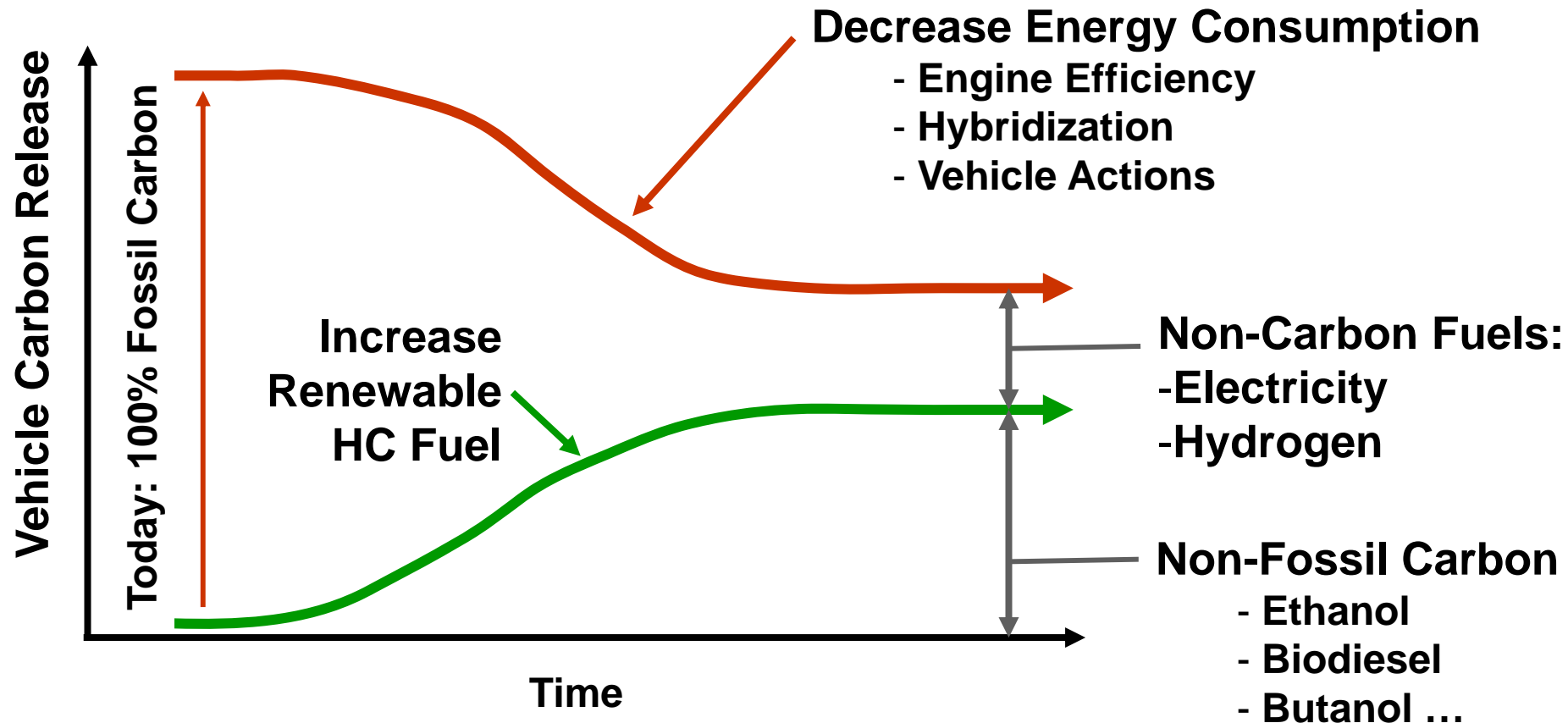
But it *is* running out of...

- Cheap oil
- Environmental capacity
- Tolerance for inequity
- Money for better options
- Time for a smooth transition
- Leadership to do what is required

Ford's Portfolio Approach

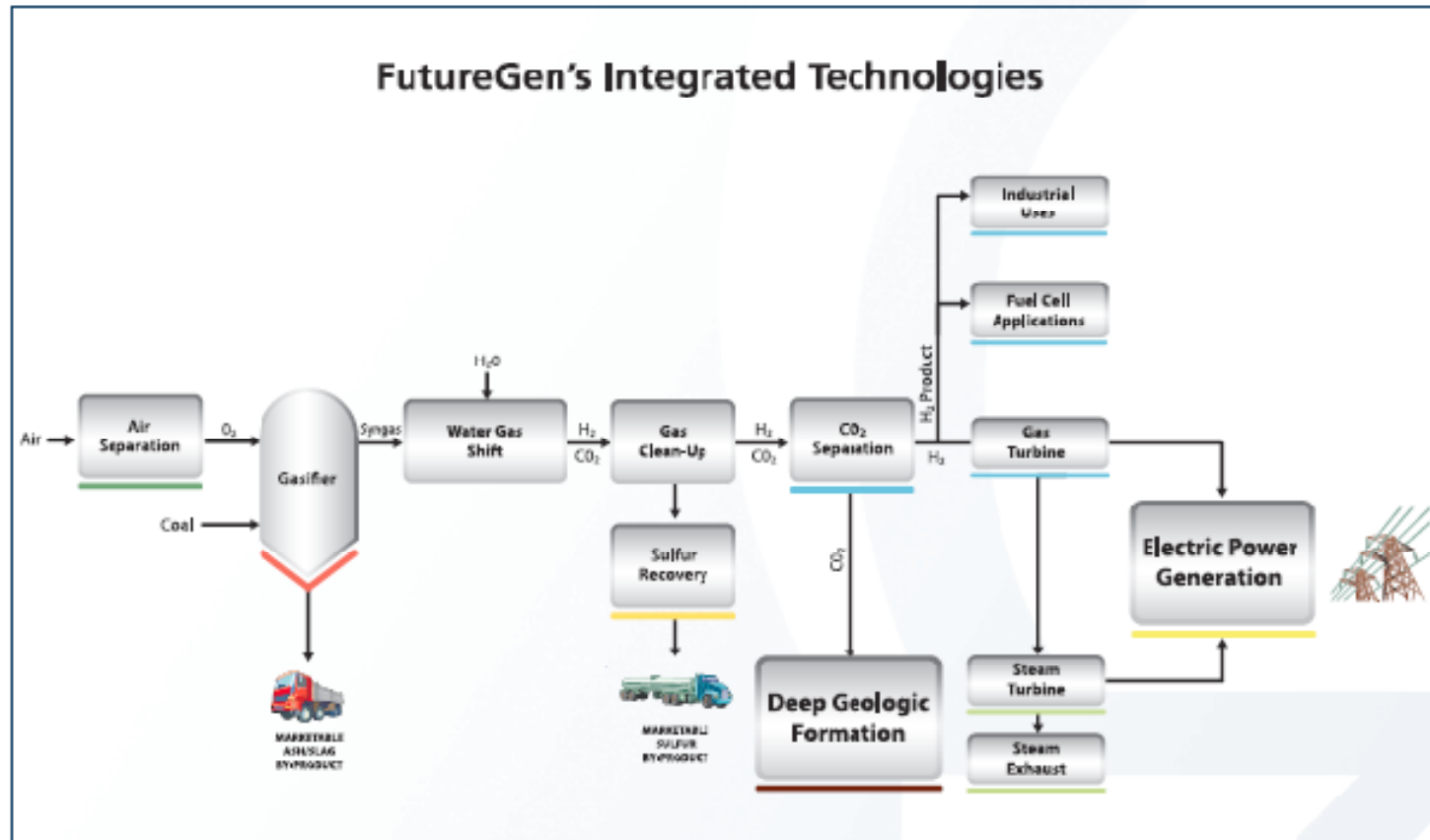


Path to CO₂-neutral Transportation



What realistic combinations of fuels and vehicle technologies can drive net CO₂ emission from light-duty transportation to zero?

Integrated Gasification Combined Cycle



Fuel Cell Vehicles





Ford Fuel Cell Technology In Iceland April, 2008

