



Hydrogen Workshop for Fleet Operators

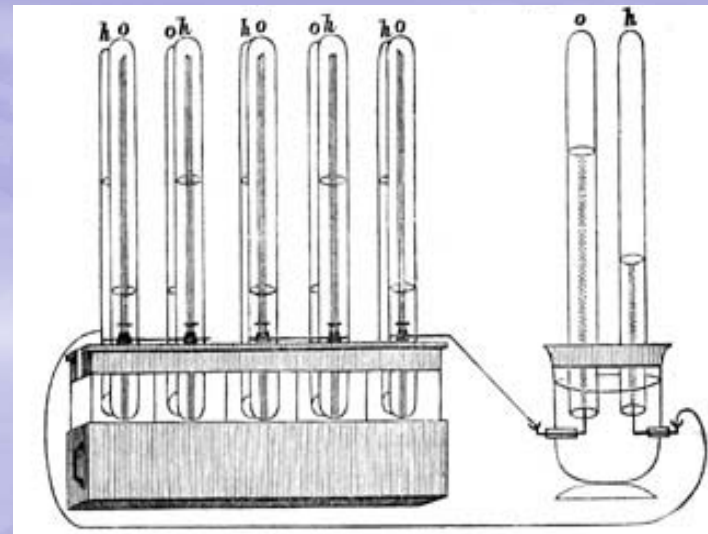


Module 4, “Hydrogen Powertrains and Vehicles”



Module 4 Outline

1. Hydrogen-Powered Vehicle Pathway
 - Conventional-fueled hybrids
 - Hydrogen-fueled hybrids
2. Hydrogen ICEs
3. Hydrogen ICE Challenges
4. How a Fuel Cell Works
5. Fuel Cell Vehicle Benefits
6. Fuel Cell Vehicle Challenges
7. Hydrogen-Powered Vehicle Safety



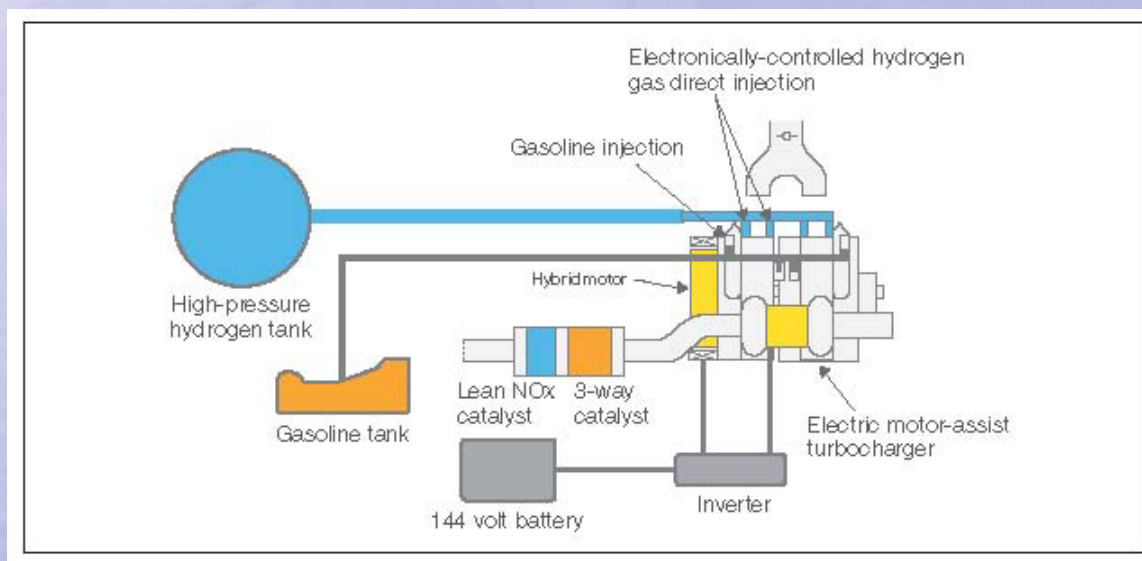
The "Grove cell" used a platinum electrode immersed in nitric acid and a zinc electrode in zinc sulfate to generate about 12 amps of current at about 1.8 volts. Grove realized that by combining several sets of these electrodes in a series circuit he might "effect the decomposition of water by means of its composition." He soon accomplished this feat with the device he named a "gas battery", the first fuel cell (1843)



Hydrogen-Powered Vehicle Pathway

- ▶ Gasoline hybrid electric powertrain
 - Increased fuel economy resulting in lower fuel consumption and lower emissions
- ▶ Hydrogen hybrid electric powertrain
 - Hydrogen eliminates CO₂ and CO emissions
 - Properly tuned or with the addition of a lean NOx trap, can achieve zero NOx emissions

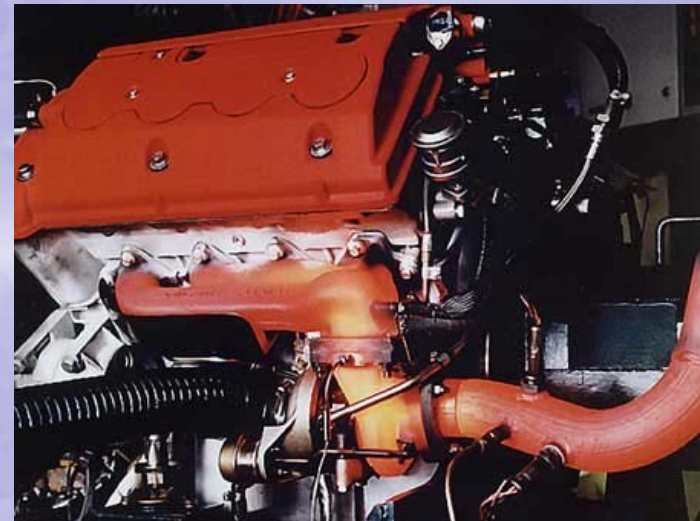
*Mazda RENESIS
Hydrogen Rotary
Engine*





Hydrogen ICEs

- ▶ Gasoline ICE Efficiency Rule of Thumb
 - 30% output power
 - 30% heat loss in exhaust
 - 30% heat loss to coolant
 - 10% heat loss to radiation
- ▶ Typical gasoline ICE engine
 - 30% output power – 120 hp
 - 30% heat loss in exhaust – 305,400 Btu/hr
 - 30% heat loss to coolant – 305,400 Btu/hr
 - 10% heat loss to radiation – 101,800 Btu/hr



Red hot exhaust manifold

Hydrogen Engine Center



Hydrogen ICEs

Efficiency vs. Compression Ratio

Comp. Ratio	Efficiency (%)	Power hp	Exhaust (%)	Coolant (%)	Radiation (%)
9:1	30	120	30	30	10
10:1	31	124	29	30	10
11:1	32	128	28	30	10
12:1	33	132	27	30	10
13:1	34	136	26	30	10
14:1	35	140	25	30	10
15:1	36	144	24	30	10

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Hydrogen ICEs

- ▶ Hydrogen ICEs burn hydrogen directly with no other fuels and produce water vapor and NO_x exhaust (no carbon to form CO or CO₂)
- ▶ Isaac de Rivas built the first hydrogen-fueled IC vehicle in 1807 (unsuccessful design)
- ▶ Energy efficiency is 20 to 25% better than that of a gasoline ICE due to leaner AFR and higher compressions ratios
- ▶ Maintenance is much the same as a gasoline ICE
- ▶ 1.5 times the cost of an installed gasoline ICE



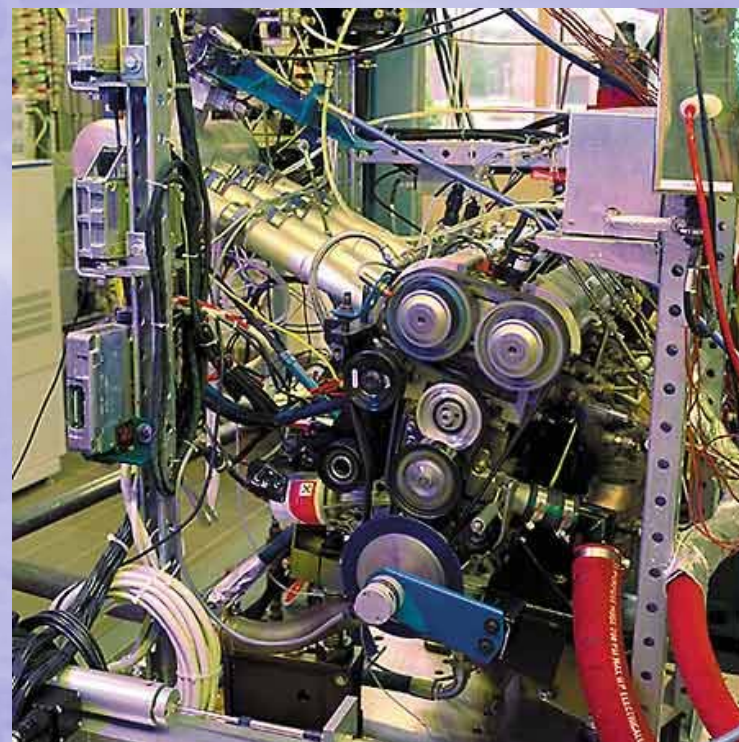
Hydrogen ICE inside a transit bus

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Hydrogen ICEs

- ▶ Slightly modified version of a traditional gasoline ICE
 - Higher compression ratio
 - Increased air intake (turbocharger)
 - Oil separator to eliminate hydrogen in the oil pan
 - More sophisticated engine controls
 - Special oil
 - Special exhaust to withstand water
 - Variable cylinders for increased efficiency



Hydrogen ICE in Ford's dynamometer lab



Hydrogen ICEs

- Port injection
 - ▶ Forms fuel-air mixture on intake stroke
 - ▶ Injection at inlet port
 - ▶ Uses mechanical cam to time injection
 - ▶ Uses common rail fuel injectors
- Direct injection
 - ▶ Forms fuel-air mixture inside combustion chamber
 - ▶ Engine cannot backfire into intake manifold
 - ▶ Higher power output than carbureted engines



Hydrogen-Powered Ford 427

College of the Desert, "Module 3: Hydrogen Use in Internal Combustion Engines", December 2001



Hydrogen ICEs

► Ignition System

- Spark plugs should have a cold rating and non-platinum tips (platinum is a catalyst causing hydrogen to oxidize with air)

► Crankcase Ventilation

- Sudden pressure rise when hydrogen is ignited in the crankcase
- Pressure relief valve must be installed on the valve cover



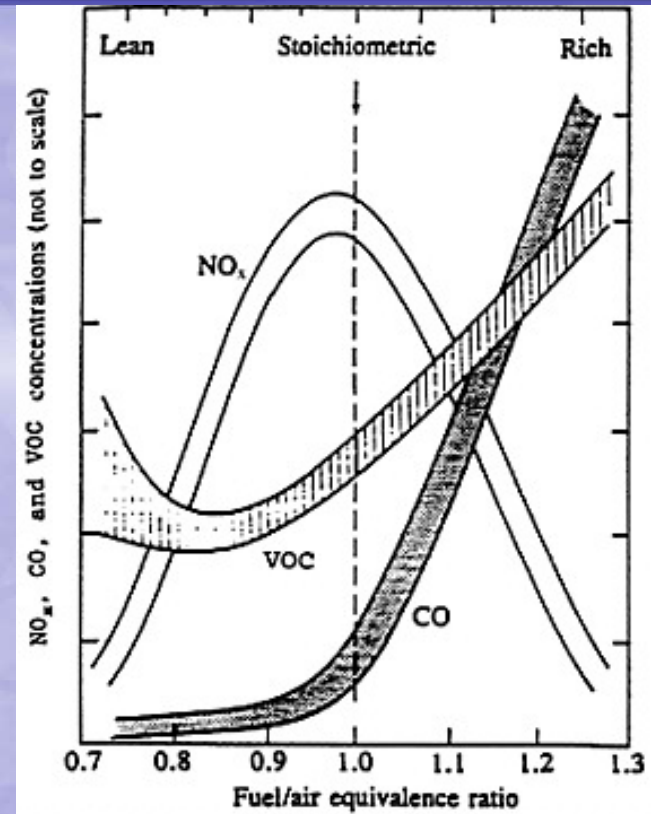
Pressure Relief Valve

College of the Desert, "Module 3: Hydrogen Use in Internal Combustion Engines", December 2001



Hydrogen ICE Challenges

- ▶ NO_x increases rapidly over 0.4 equivalence ratio
- ▶ Turbo or supercharger is required to achieve full power (requires approximately 2 times the air)
- ▶ 1 lb of hydrogen generates 9 lb of water
- ▶ Hydrogen storage
 - Typically cost more than the engine for a given vehicle
- ▶ Hydrogen is easily ignited
 - Cannot fire spark plugs on exhaust cycle

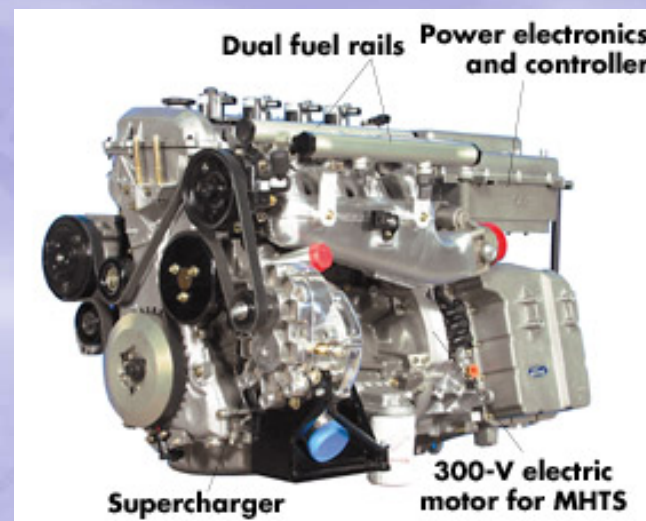


Variation of CO, VOC, and NO_x concentration in the exhaust of a conventional SI engine. Adapted from J.B. Heywood, "Internal Combustion Engine Fundamentals", 1988



Ford 2.3L

- ▶ Zero warm-up
- ▶ No cold start issues
- ▶ All weather capable
- ▶ Supercharged, intercooled
- ▶ 52% peak indicated efficiency
- ▶ SULEV emissions or better
- ▶ 99% reduction in CO2 emissions
- ▶ 25% increase in fuel economy (engine only)
- ▶ 50% increase in fuel economy (aggressive hybrid strategy)



Ford 2.3L Hydrogen-Powered ICE

Bak, Poul Erik, "H2RV-Ford Hydrogen Hybrid Research Vehicle", August 2003



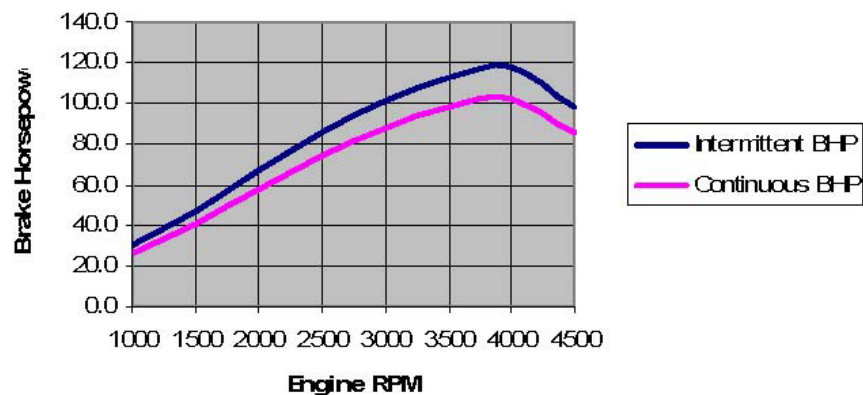
Ford 2.3L Comparison

	Hydrogen	Gasoline
Specifications		
Engine Type	2.3L, I4	2.3L, I4
Horsepower	110 hp @ 4500 rpm	151 hp @ 5750 rpm
Combined Fuel Economy	45 miles per kg	25 miles per gallon
Fuel Type	Compressed Hydrogen	Gasoline
Fuel Pressure	5,000 psi	N/A
Supercharged	Yes	No
Compression Ratio	N/A	9.7
Electric Horsepower	33 hp	N/A
Efficiency	52% Indicated	N/A
Emissions	SULEV	N/A
Platform	Ford Focus ZTW	Ford Focus ZX4



Hydrogen Engine Center HEC-F-K649

- ▶ First production hydrogen engine
- ▶ Modified Ford 4.9L, I-6
- ▶ Special “Kyoto” tuning for reduced CO₂ emissions and higher power
- ▶ Electronic fuel injected
- ▶ Stainless steel exhaust manifold
- ▶ Custom ground cam for improved low speed torque and power
- ▶ Hardened valve seats and Stellite exhaust valves for longer life on dry fuels



Hydrogen Engine Center



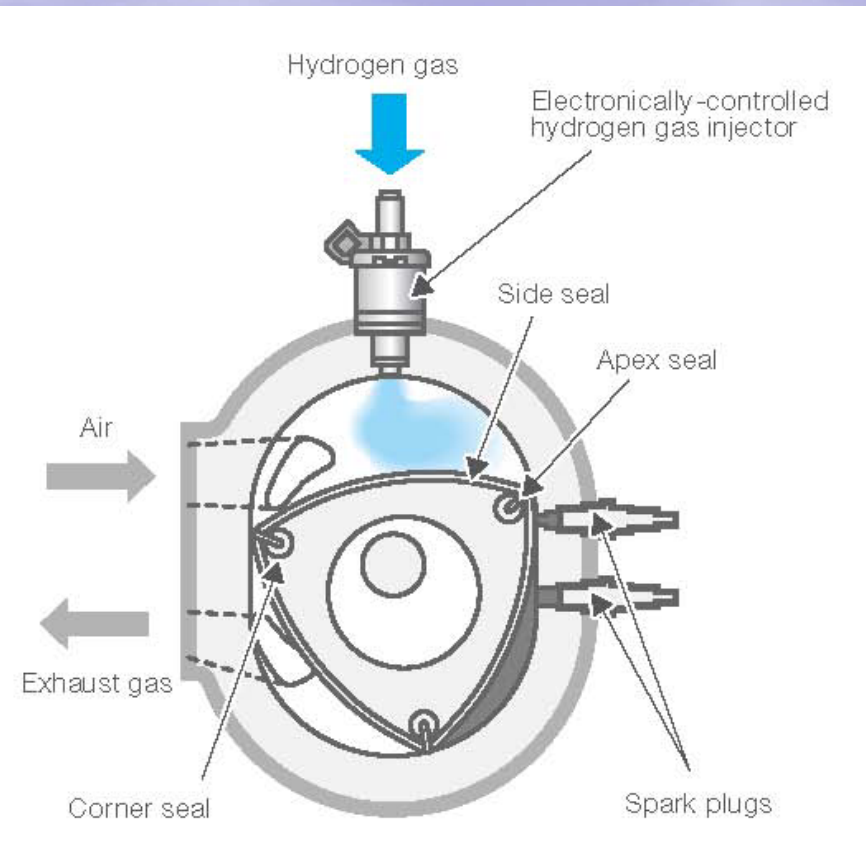
Ford 4.9L Comparison

	Hydrogen	Gasoline	LPG
Specifications			
Engine Type	4.9L, I6	4.9L, I6	4.9L, I6
Horsepower	86 hp @ 3600 rpm	107 hp	94 hp
Combined Fuel Economy	N/A	N/A	N/A
Fuel Type	Compressed Hydrogen	Gasoline	LPG
Fuel Pressure	N/A	N/A	N/A
Supercharged	No	No	No
Compression Ratio	13.5	9.0	N/A
Electric Horsepower	N/A	N/A	N/A
Efficiency	N/A	N/A	N/A
Emissions	Kyoto compliant	N/A	N/A
Platform	Various	Ford F-Series/Econoline	Industrial



Mazda RENESIS

- ▶ Electronically-controlled hydrogen injection
- ▶ Direct injection system
- ▶ Electric motor assist turbocharger at low rpm (approximately 1,000 rpm)
- ▶ At high rpm, turbocharger is driven in the conventional fashion (exhaust gas)
- ▶ Rotary engine is suited to burn hydrogen without the backfire that can occur in a piston ICE
- ▶ Twin hydrogen injectors



Mazda Motor Corporation



Mazda 1.3L Comparison

	Hydrogen	Gasoline
Specifications		
Engine Type	RENESIS 1.3L, twin rotor	1.3L, twin rotor
Horsepower	109 hp @ 7200 rpm	238 hp @ 8500 rpm
Combined Fuel Economy	N/A	20 mpg
Fuel Type	Compressed Hydrogen/Gasoline	Gasoline
Fuel Pressure	N/A	N/A
Turbocharged	Yes	No
Compression Ratio	N/A	10.0
Electric Horsepower	N/A	N/A
Efficiency	N/A	N/A
Emissions	N/A	N/A
Platform	Mazda RX-8	Mazda RX-8



How a Fuel Cell Works

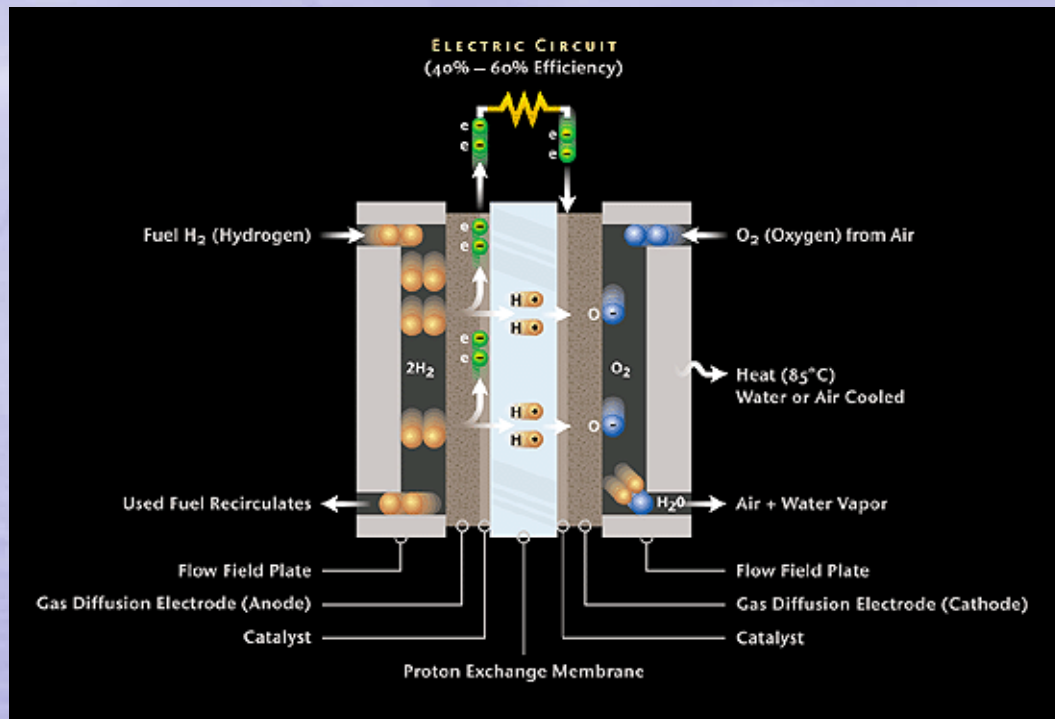




How a Fuel Cell Works

- ▶ Receives a constant supply of hydrogen and oxygen
- ▶ Reaction produces approximately 0.7 volts
- ▶ Will never run down or need to be recharged
- ▶ Operates like a battery

*Ballard PEM
fuel cell*





Hydrogen Fuel Cell Vehicle Benefits

- No greenhouse gases if powered by pure hydrogen
- Some greenhouse gases emitted if powered by reformed fossil fuels but much less than that of a conventional vehicle
- No harmful air pollutants emitted
- Strengthen national economy by reducing the dependency on foreign oil
- More energy efficient than a heat engine, converting 40-60% of the fuel's energy



Ballard Mark 902 Transportation Fuel Cell



Hydrogen Fuel Cell Vehicle Benefits

- Fuel cells can generate more than 12 volts as in a conventional vehicle leading the way for drive and steer-by-wire, eliminating the steering column
- No transmission
- Affords automobile manufactures flexibility in design vehicle interiors
- Quieter than conventional gasoline and diesel engines



*GM's HyWire
Concept Vehicle*

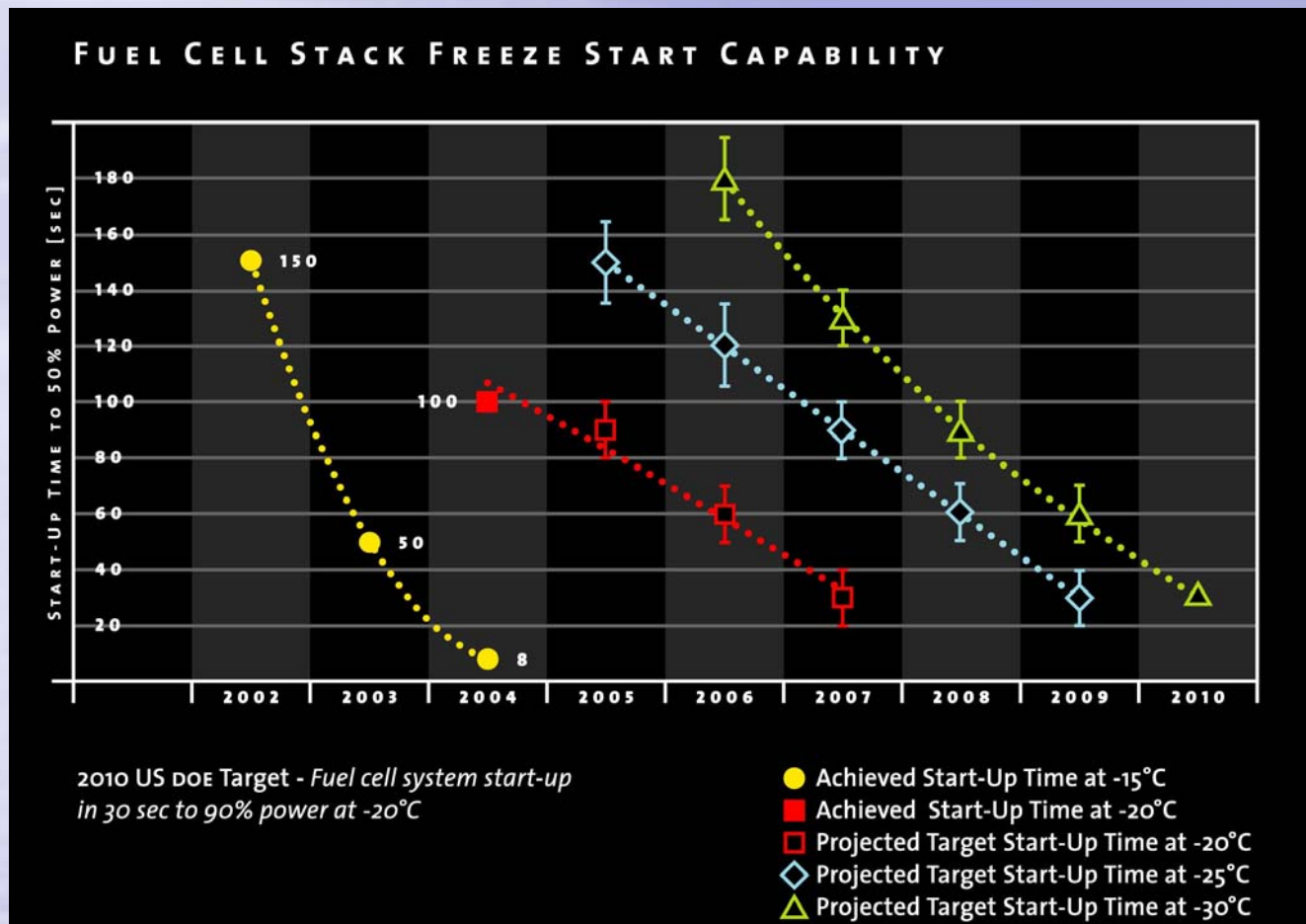


Hydrogen Vehicle Challenges

- ▶ Hydrogen storage
 - Difficult to store enough hydrogen onboard to allow it to travel as far as a conventional vehicle on a full tank of fuel (300+ mile range)
 - Overcome problem by increasing the hydrogen storage pressure or using novel storage technologies.
- ▶ Cold weather operation (fuel cell vehicles only)
 - Contains water, both as a byproduct and for humidifying the fuel cell, which can freeze at low temperatures
 - Must reach a certain temperature to attain full performance
 - ▶ Achieved start-up at -20°C (-4°F) within 100 seconds to 50% power
- ▶ Stack cost (fuel cell vehicles only)
 - Needs to be competitive with today's ICEs for technology to be adopted



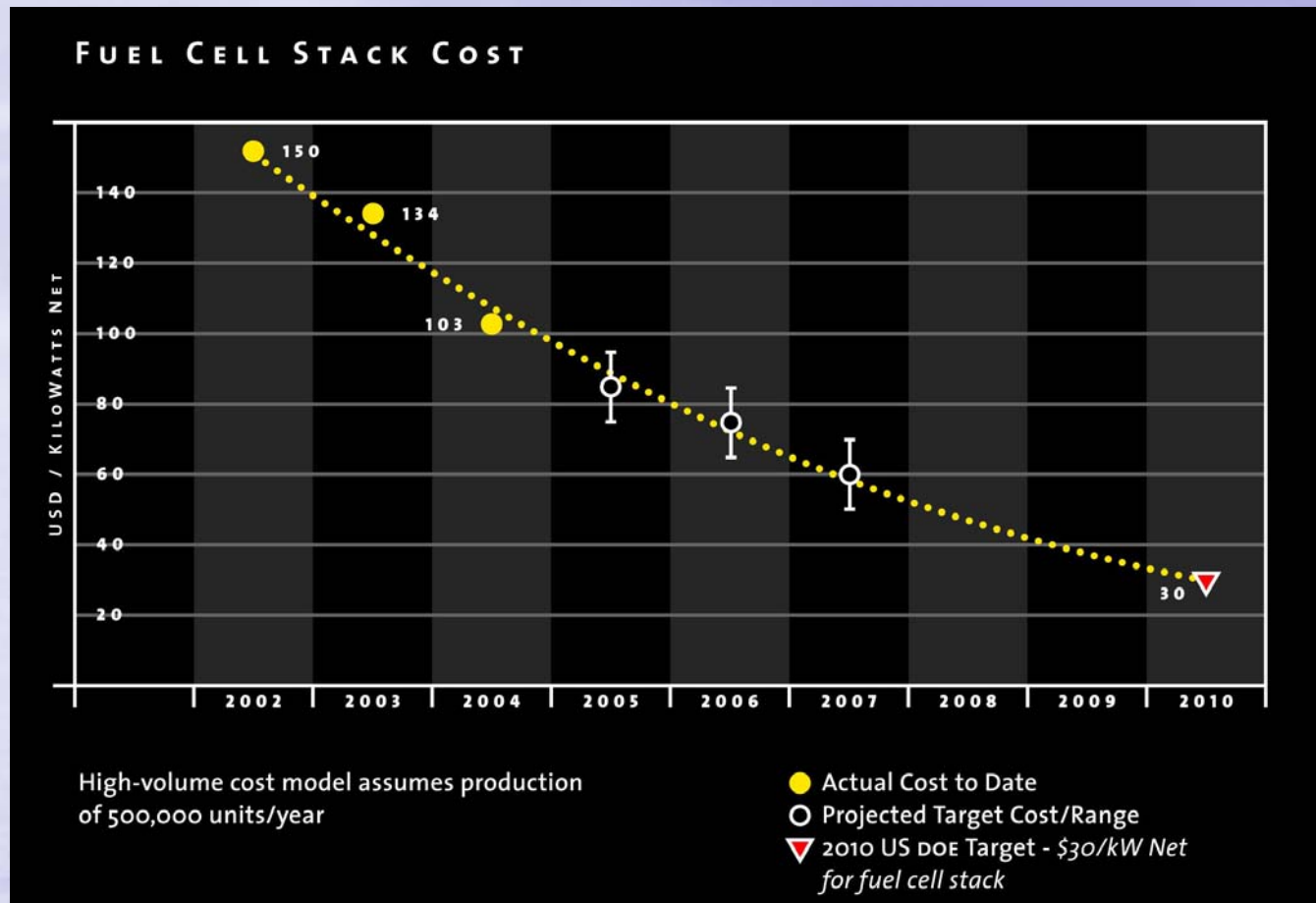
Hydrogen Vehicle Challenges



Ballard Power Systems Inc.



Hydrogen Vehicle Challenges



Ballard Power Systems Inc.



Hydrogen Vehicle Challenges

- ▶ Competition with other technologies
 - Diesel and gasoline powered vehicles
 - Hybrid electric vehicles
- ▶ Public acceptance
 - Availability of hydrogen as a fuel
 - Hydrogen is more expensive than gasoline
 - Complete overhaul of every gasoline station
 - Dependability and safety of fuel cell vehicles
 - Develop and improve public acceptance
 - ▶ California Fuel Cell Partnership Road Rally
 - ▶ NHA Annual Hydrogen Conference Ride-n-Drive





Hydrogen Vehicle Safety

**Hydrogen Fueled Vehicles Have
Multiple Safety Systems**

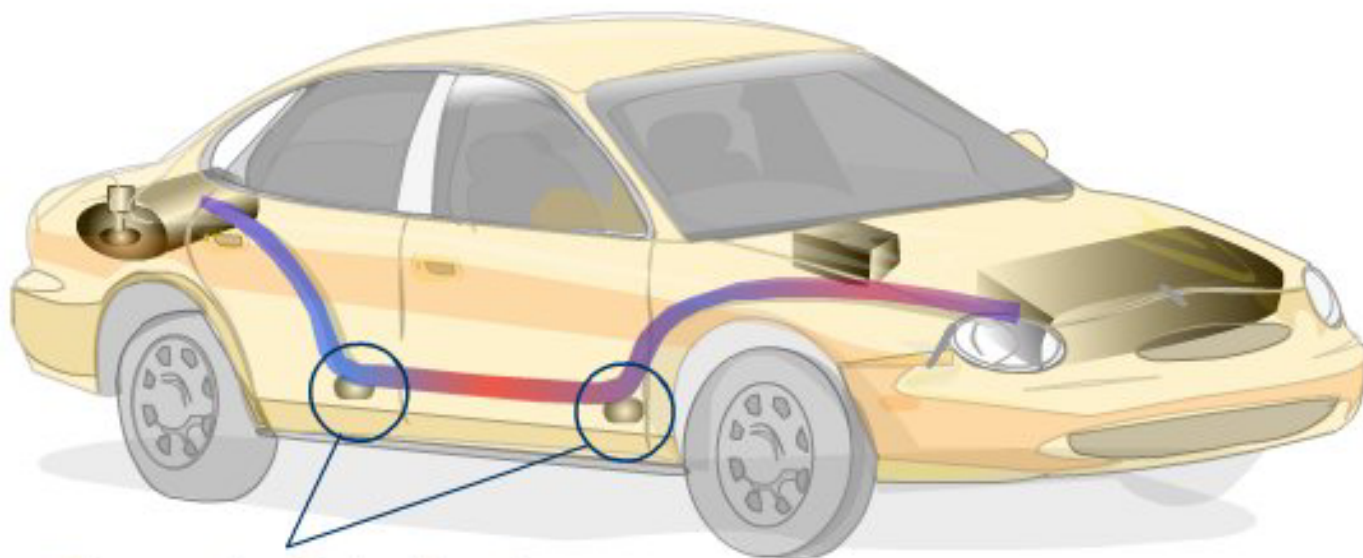


US Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program



Hydrogen Vehicle Safety

Hydrogen Fueled Vehicles Have Multiple Safety Systems



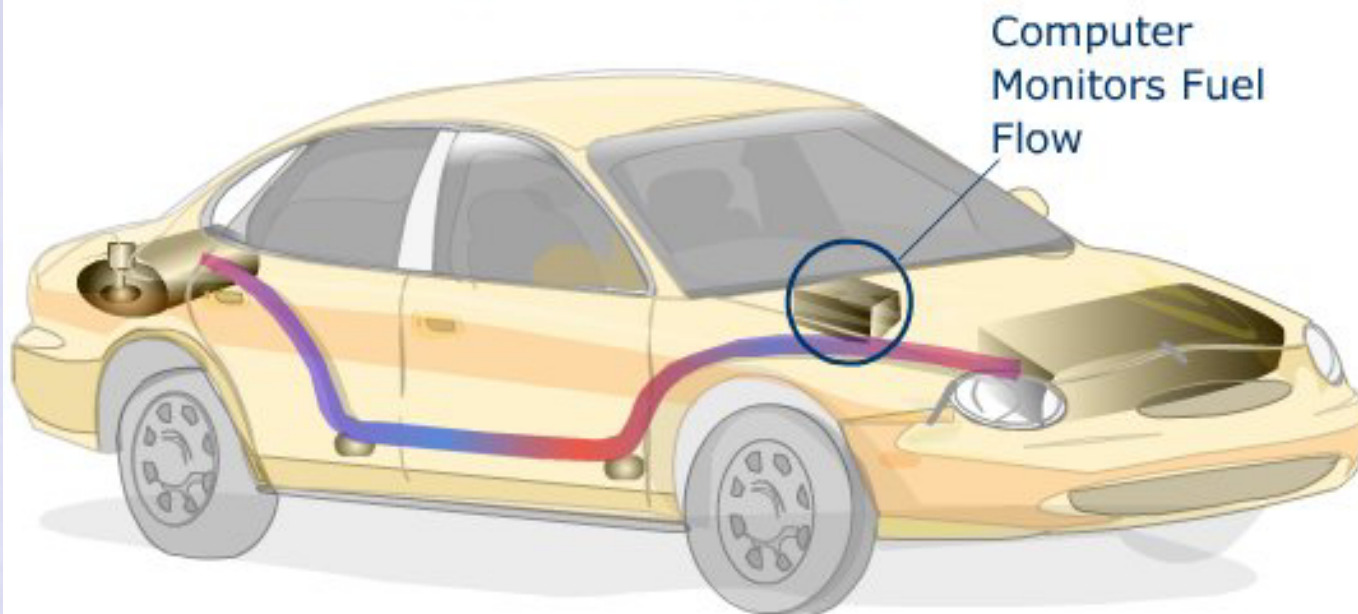
Sensors to Detect Leaks

US Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program



Hydrogen Vehicle Safety

Hydrogen Fueled Vehicles Have Multiple Safety Systems

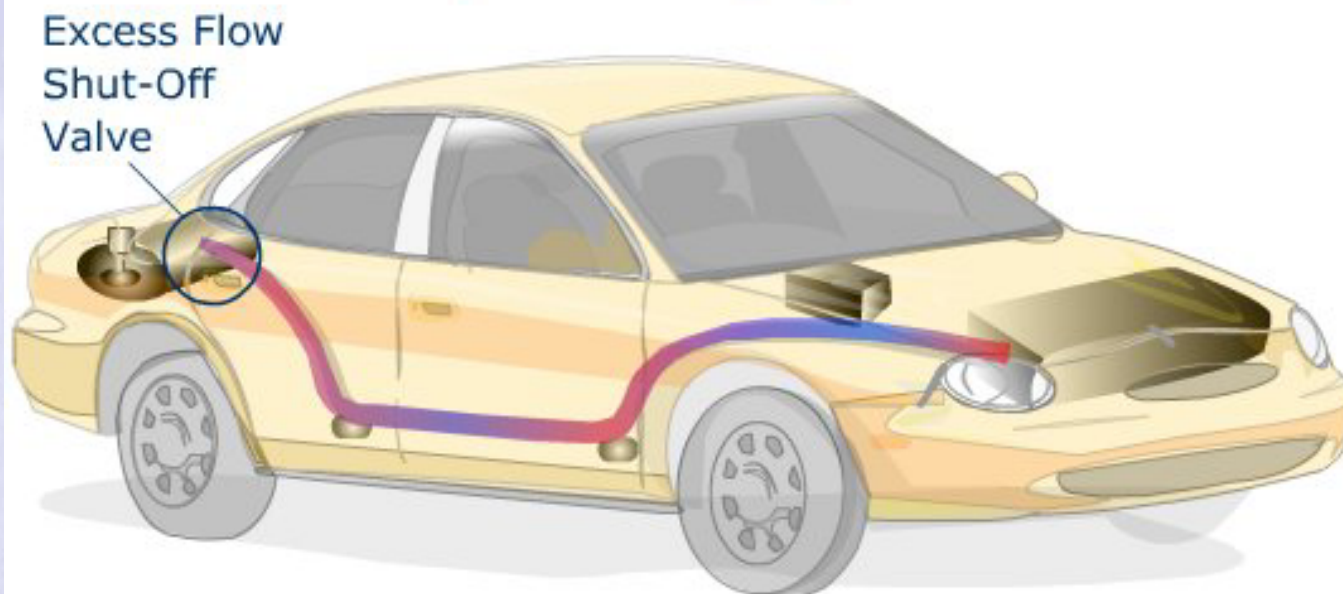


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Hydrogen Vehicle Safety

Hydrogen Fueled Vehicles Have Multiple Safety Systems

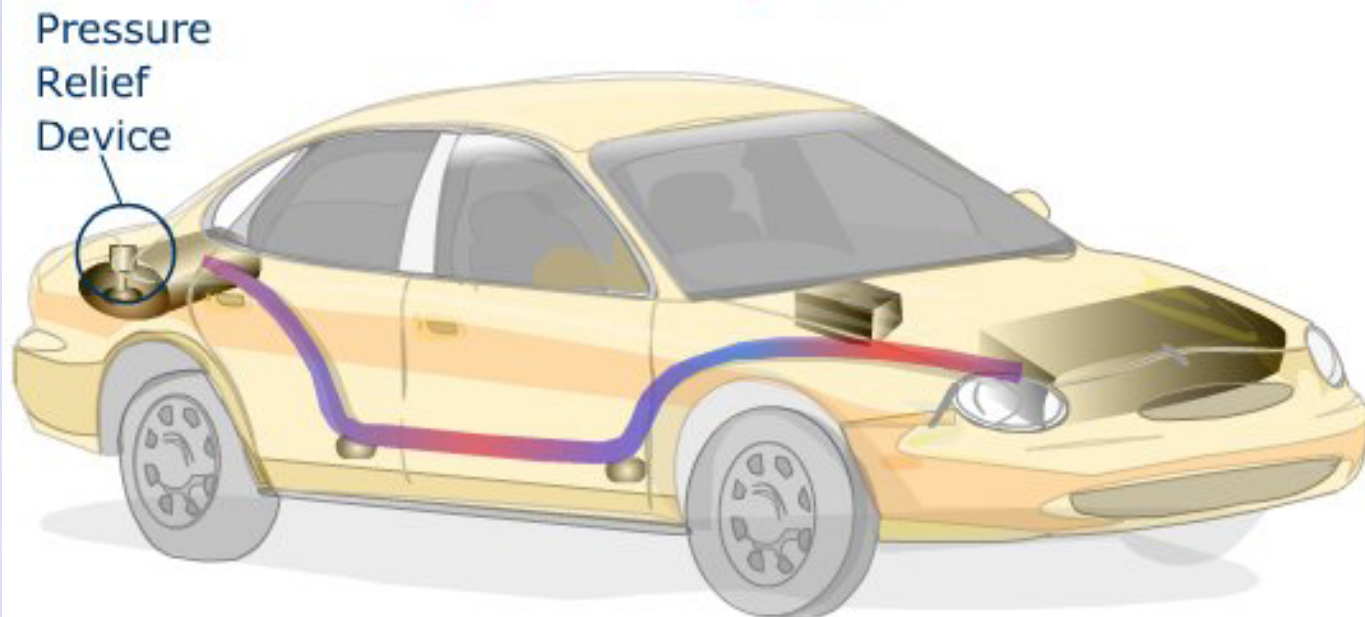


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Hydrogen Vehicle Safety

Hydrogen Fueled Vehicles Have Multiple Safety Systems

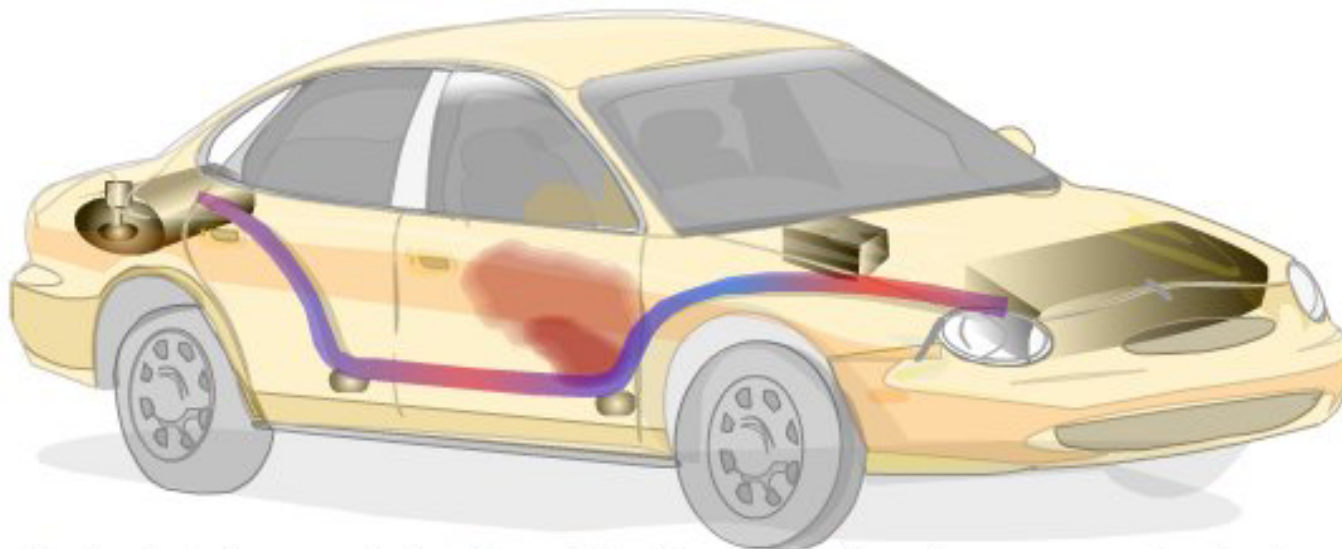


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Hydrogen Vehicle Safety

Hydrogen Fueled Vehicles Have Multiple Safety Systems



If a leak is detected, the flow of fuel is shut off so the amount that leaks would be small and most likely vent harmlessly into the air.

US Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program



Hydrogen Vehicle Safety



Photo from a video comparing an intentional hydrogen tank release and a small gasoline fuel line leak. After 60 seconds, the hydrogen flame has begun to subside, while the gasoline fire is intensifying. After 100 seconds, all of the hydrogen was gone and car's interior was undamaged (the maximum temperature inside the back window was 67°F). The gasoline car continued to burn for several minutes and was completely destroyed.

Dr. Michael Swain, University of Miami



Module 4, “Hydrogen Powertrains and Vehicles”