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Prospects on Fuel Efficiency Improvements for Hydrogen Powered Vehicles

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Chicago

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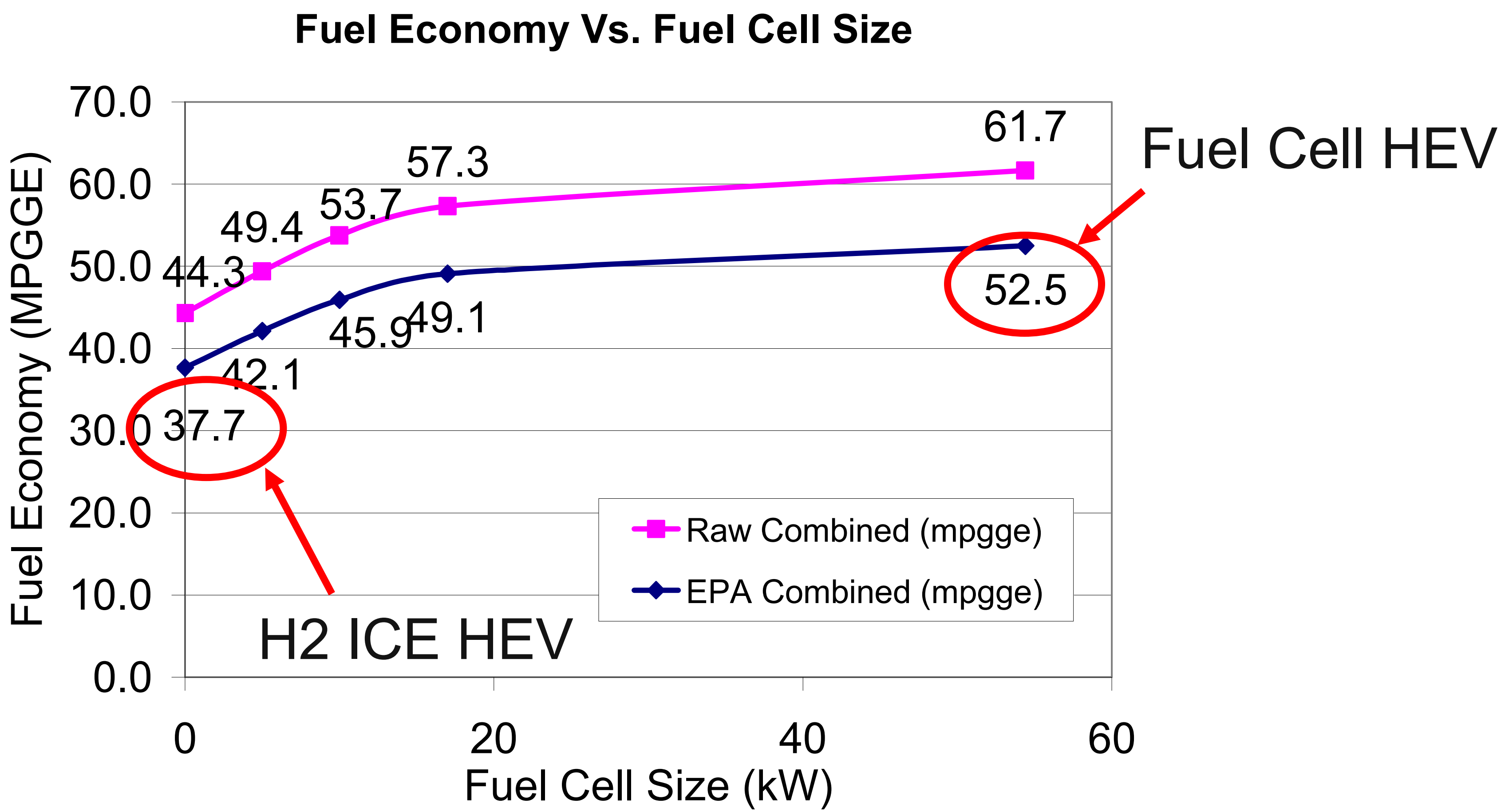
Sponsored by Lee Slezak

U.S. DOE

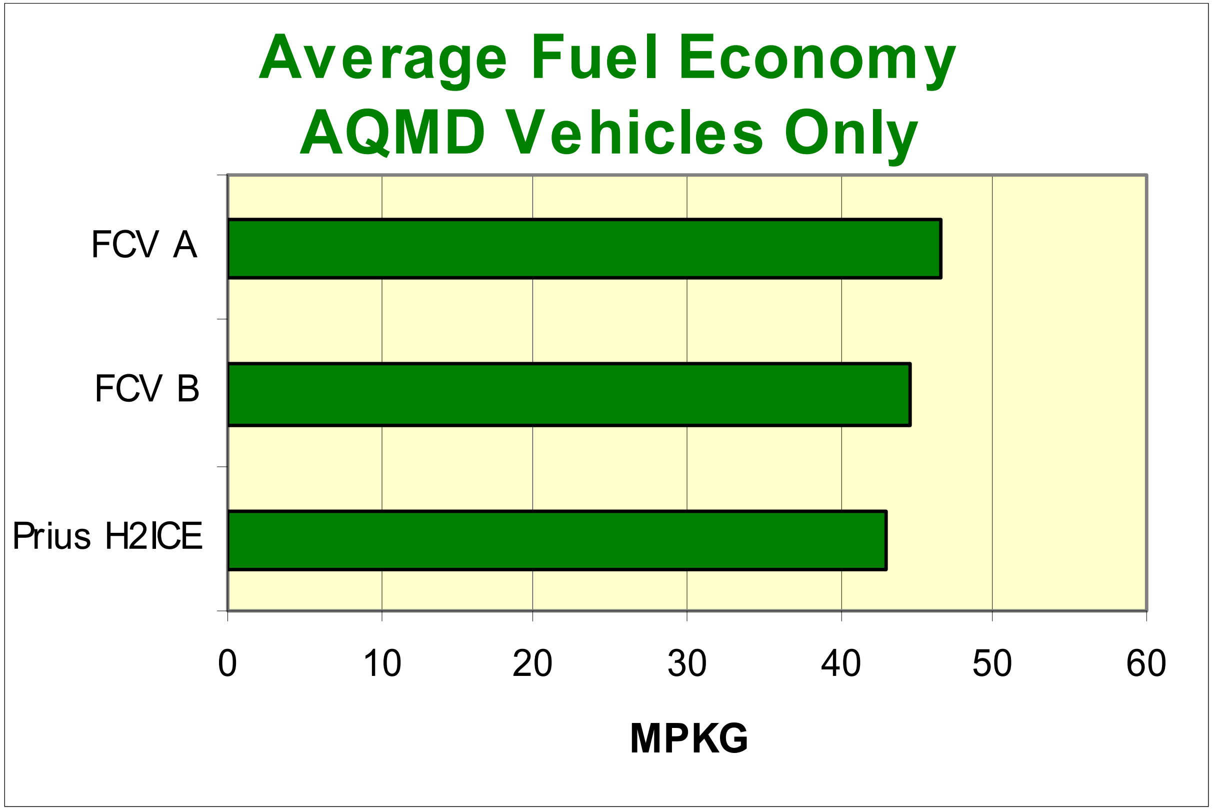
FreedomCAR & Fuel Partnership

Initial Study Performed Showed Significant Disadvantage of H2 Engine vs. Fuel Cell



Source: NREL (Vehicle Range Impacts from Adding a Fuel Cell to a Hydrogen ICE Hybrid Vehicle, 2005)

However, On-Road Testing Showed Closer Results



FCV A – 2 Vehicles

FCV B – 2 Vehicles

Prius H2ICE – 5 Vehicles

(Data - 12 Months)

Issue: Vehicles, drive cycles, test conditions different for each vehicle

Source: Berry, N. 'SCAQMD – Hydrogen ICE Projects' Weststart-Calstar Conference 'Hydrogen Internal Combustion Engines 2007 - Where do we go from here?' Los Angeles. 2007.

Outline

- PSAT Modeling Assumptions
  - Vehicle
  - Fuel Cell System
  - Hydrogen Engine
  - Other Components
- Component Sizing
- Simulation Results

Vehicle Assumptions

- Midsize car platform
- Both non-hybrid and hybrid configurations considered
- All vehicles achieve similar performances (0-60mph, grade)
- All vehicles have same amount of onboard H2 (5kg) and use the same amount of H2 from the tank
- Component uncertainties taken into account
- UDDS and HWFET drive cycles considered
- Ratios based on fuel economy gasoline equivalent using 2008 EPA corrections

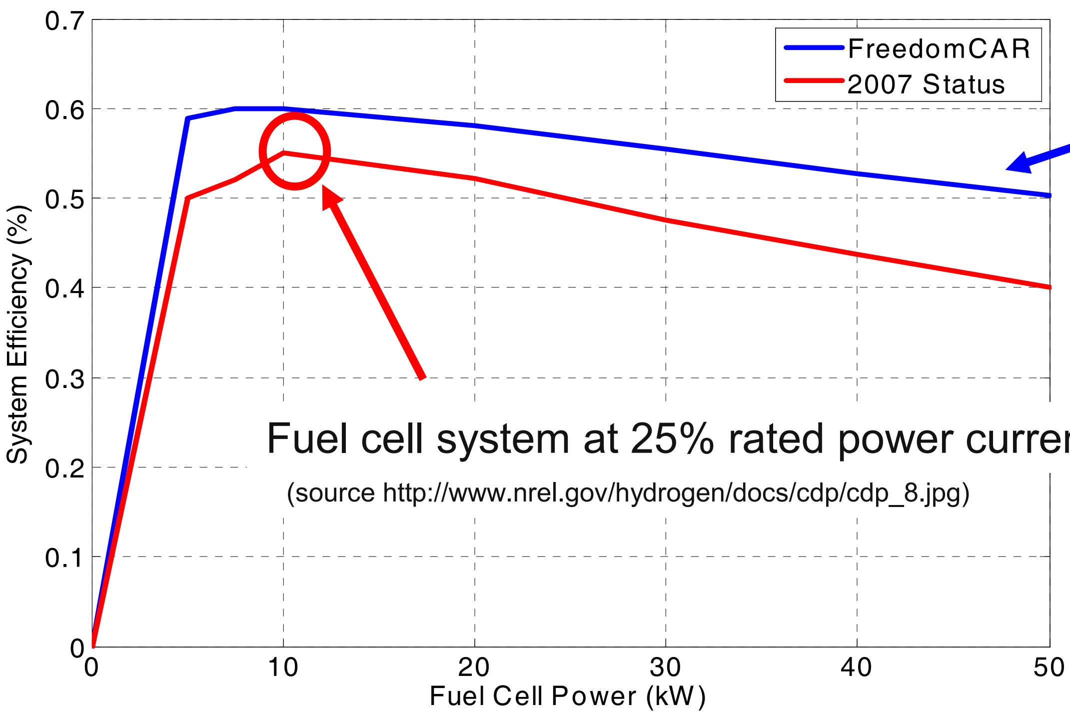
Parameter	Unit	Midsize Car
Glider Mass	kg	990
Frontal Area	m^2	2.1
Drag Coefficient		0.29
Wheel Radius	m	0.317
Rolling Resistance		0.008

Parameter	Unit	Value
0–60mph	s	9 +/- 0.1
0–30mph	s	3
Grade at 60 mph	%	6
Maximum Speed	mph	> 100 (1)

(1) Two gear transmission used for series

Fuel Cell System Assumptions

Parameter	Unit	Current Status	FreedomCAR Goal
Specific Power	W/kg	500	650
Peak Efficiency	%	55	60

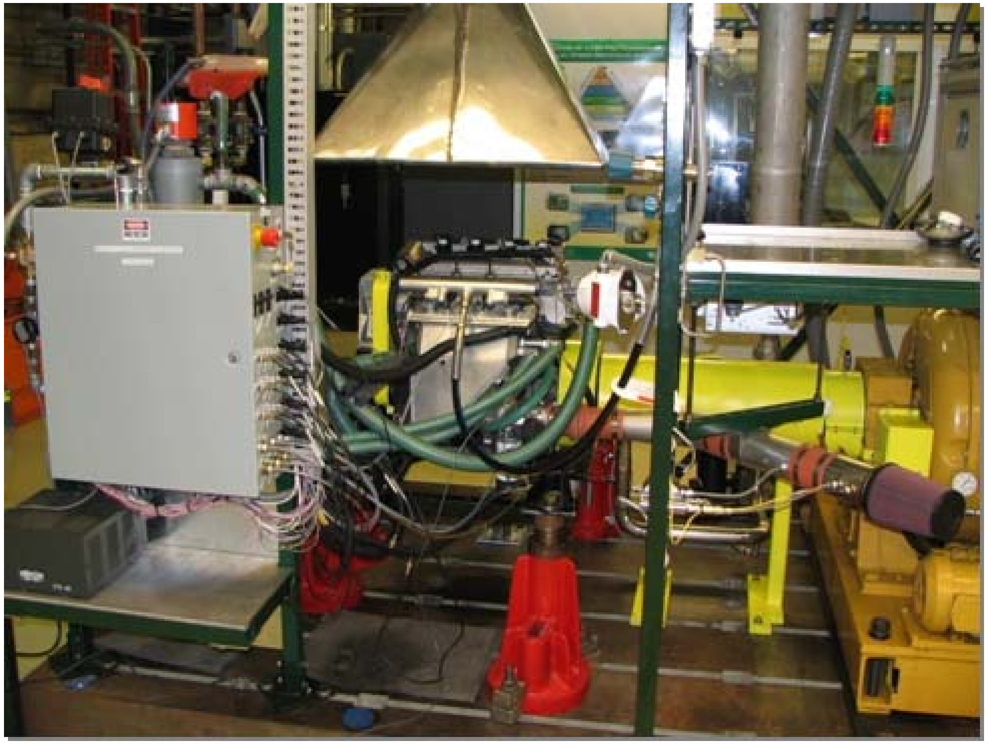


Source: Fuel Cell Tech Team

Fuel cell system at 25% rated power currently range from 52.5 to 58.1%

(source http://www.nrel.gov/hydrogen/docs/cdp/cdp_8.jpg)

Hydrogen Engine Characteristics for Current Technology Generated from Experimental Data

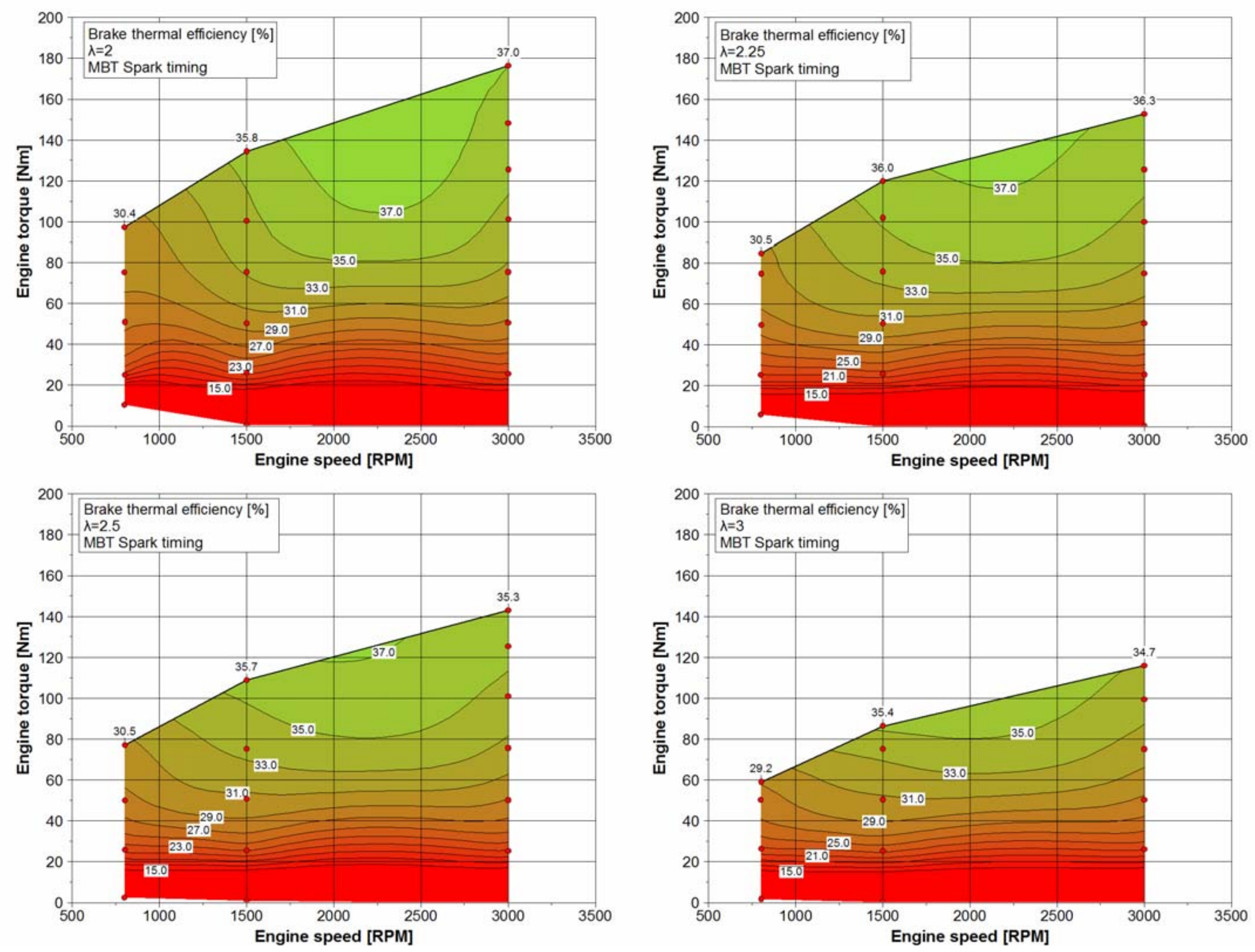


4-cylinder hydrogen engine setup

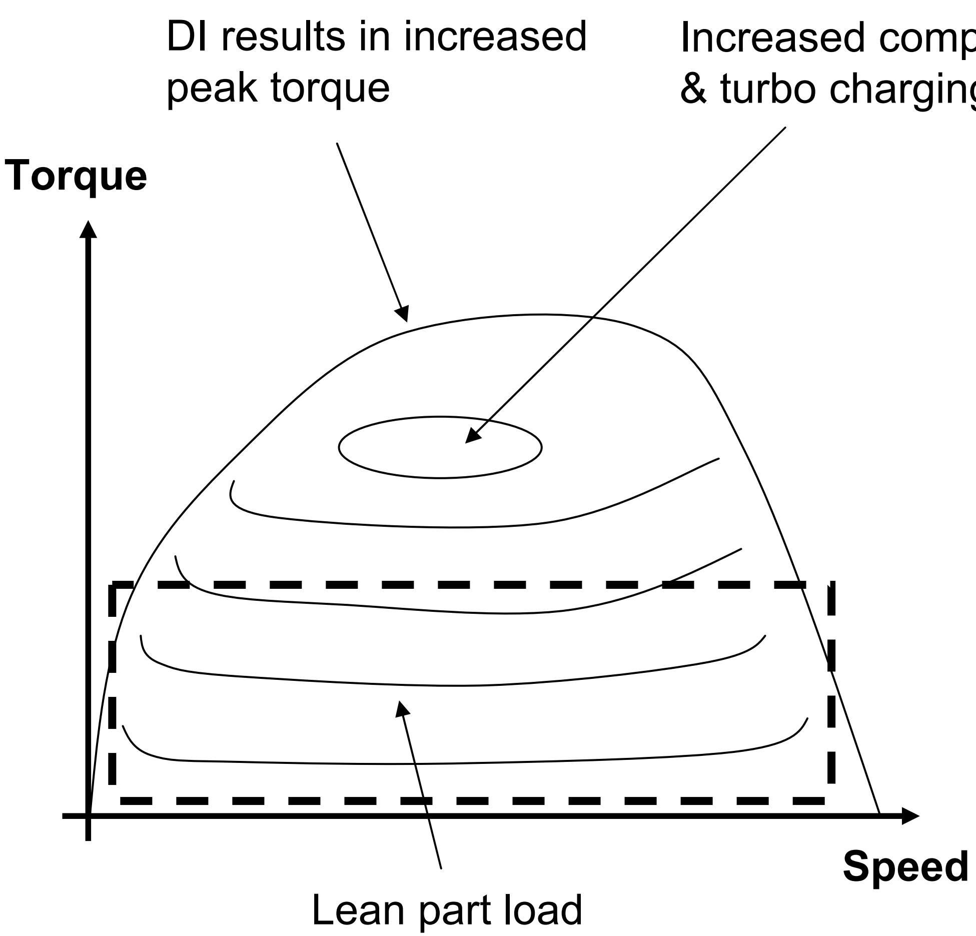
Manufacturer	Ford Motor Co.
Model	2.3L Duratec
Cylinders	4
Bore	87.5 mm
Stroke	94 mm
Compression ratio	12
Valve train	4V DOHC
Speed range	6000 RPM
Modifications	

- Supercharger and intercooler
- Hydrogen port fuel injection
- After-market ECU

Port Injected Maps Generated for Different Air/Fuel Ratios



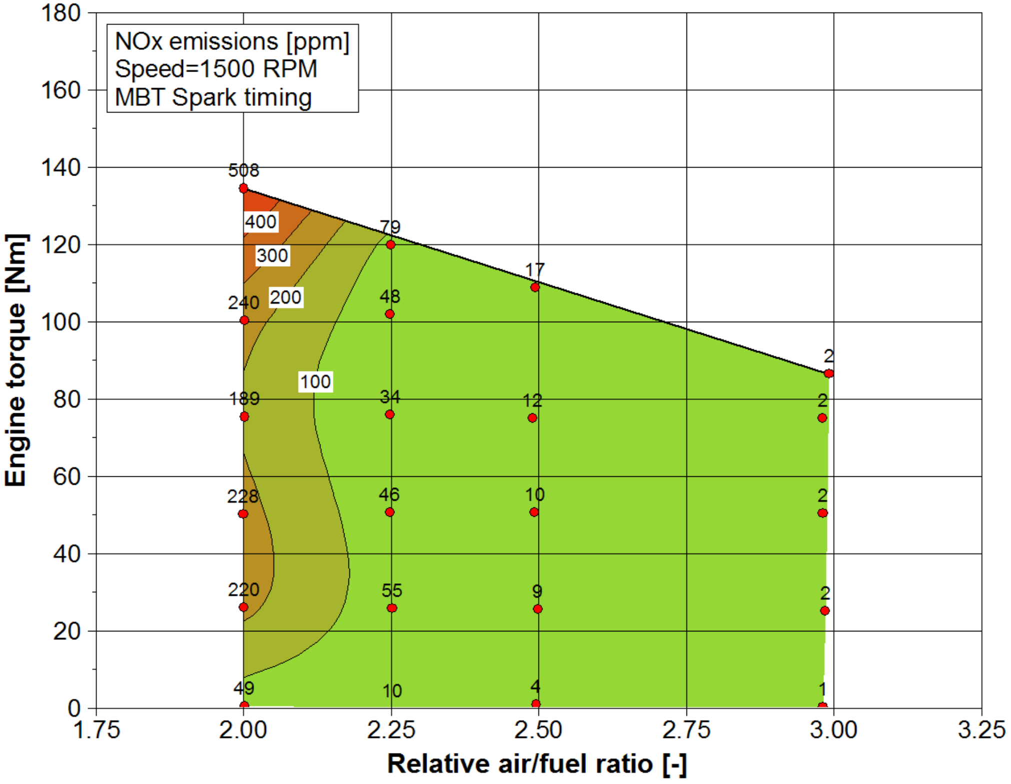
Direct Injection Hydrogen Engine Operation Estimated from Single Cylinder Test Data



- Hydrogen Direct Injection will increase the peak torque curve
- Increased compression ratio will result in an increase in engine efficiency
- Turbo-charging will increase the engine efficiency compared to supercharging
- Lean part load operation will result in a further part load efficiency increase compared to throttled operation

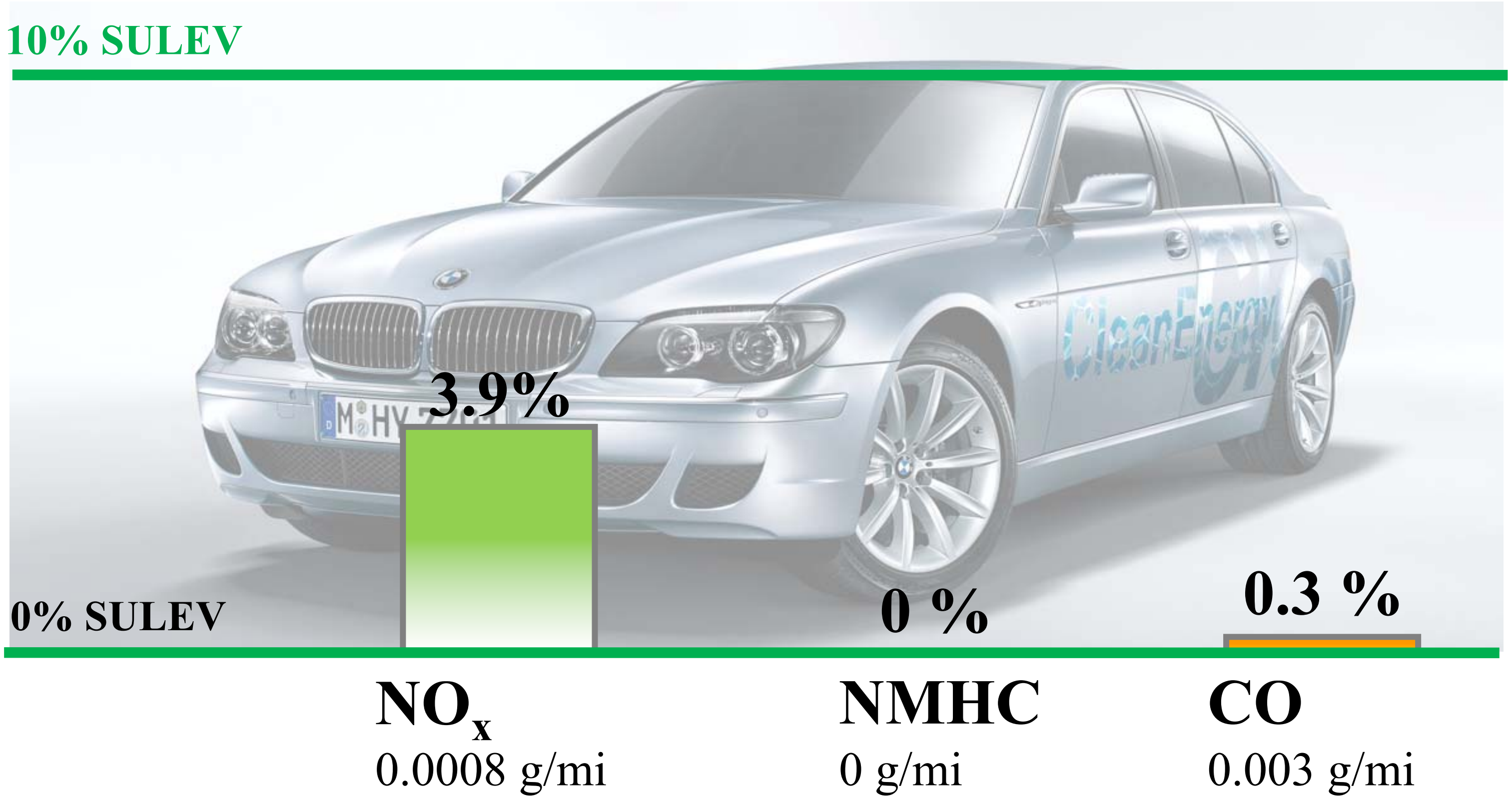
Peak efficiency of 45% assumed

NOx Emissions as a Function of Air/Fuel Ratio



- NO_x emissions decrease with increased air/fuel ratio
- At λ=2.25 NO_x emissions are below 100 ppm in the entire load range
- At λ=3 NO_x emissions approach the detectability limit of the analyzer

Drive cycle emissions results of a BMW Hydrogen 7 Mono-Fuel vehicle



* Average values for several FTP75 tests on two vehicles

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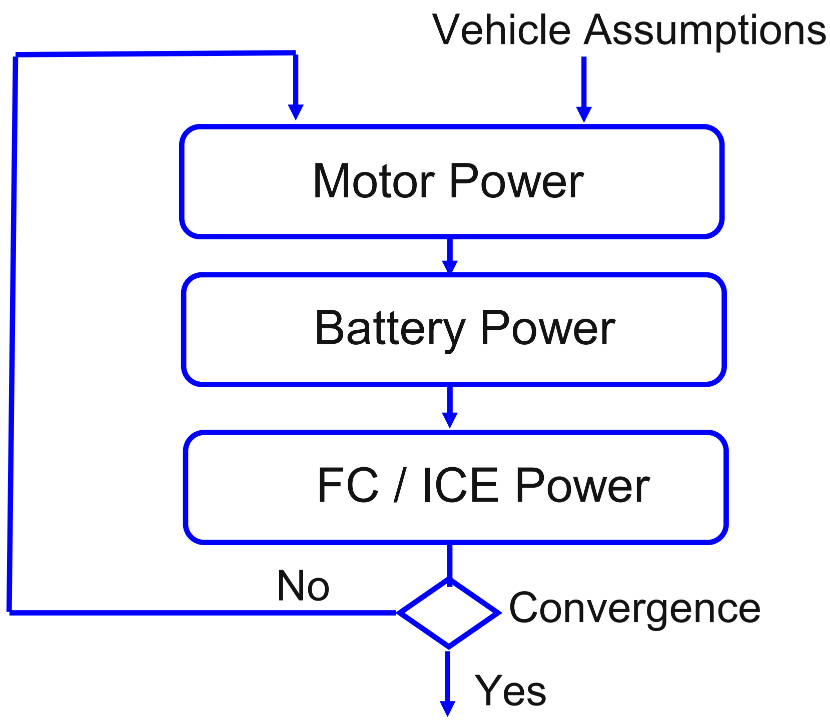
Vehicle Sizing Algorithm



<u>Associated Requirements</u>

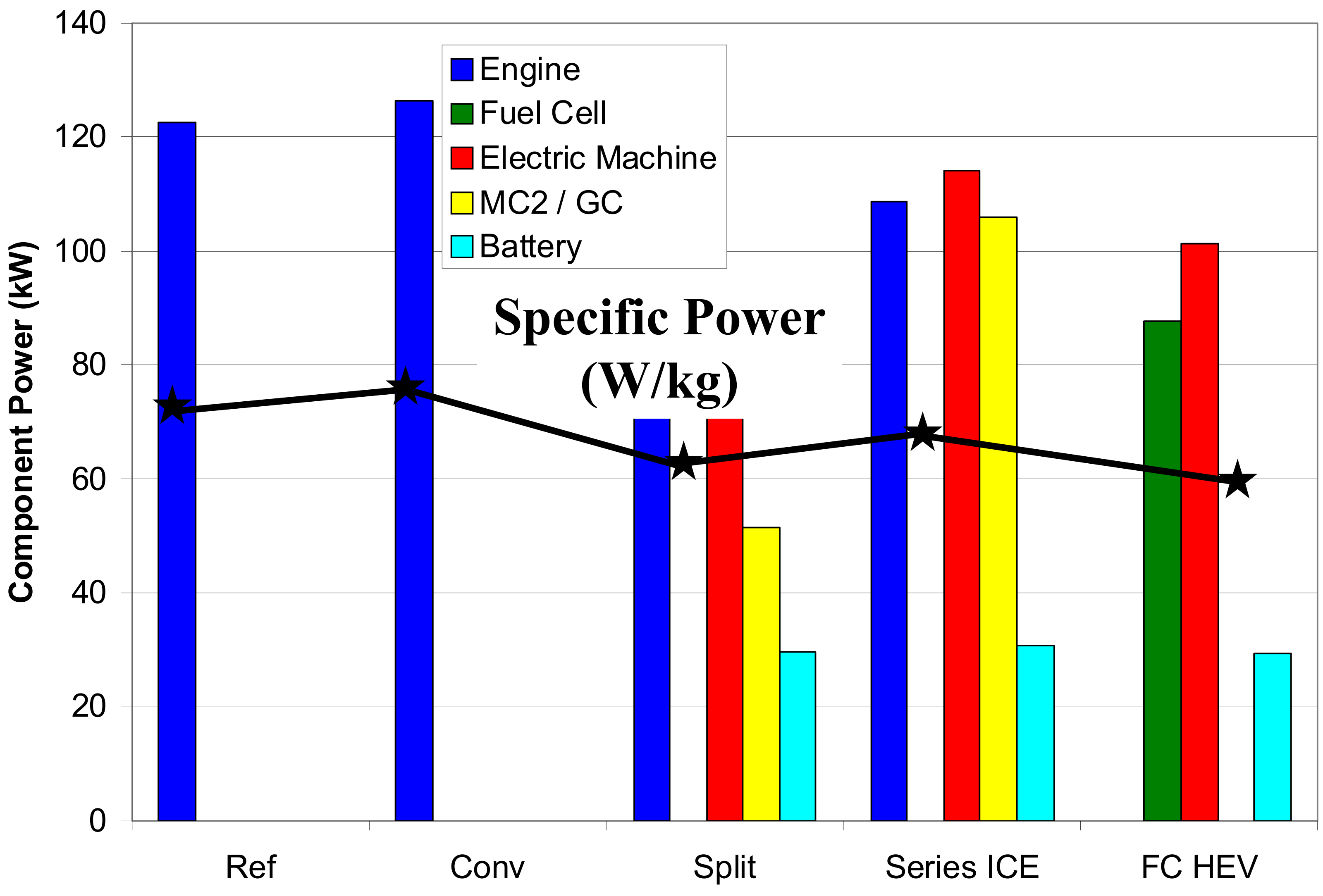
Capture all Regen on UDDS

<u>Perfo:</u>
IVM-60 mph

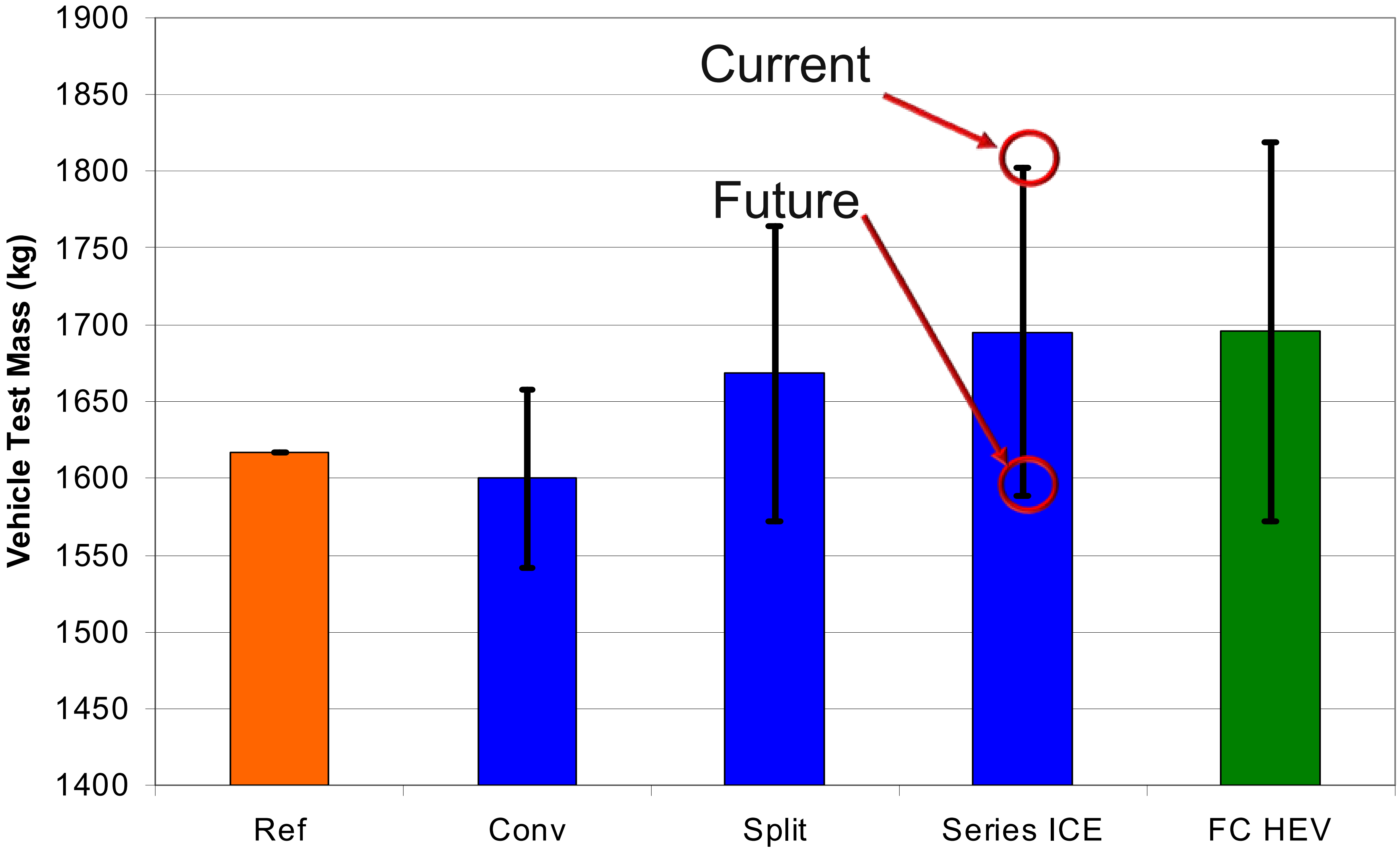
<u>Grade:</u>
60 mph 6% grade

Approach consistent with all current production HEVs based on APRF test data

Component Average Power



Vehicle Test Mass Comparison



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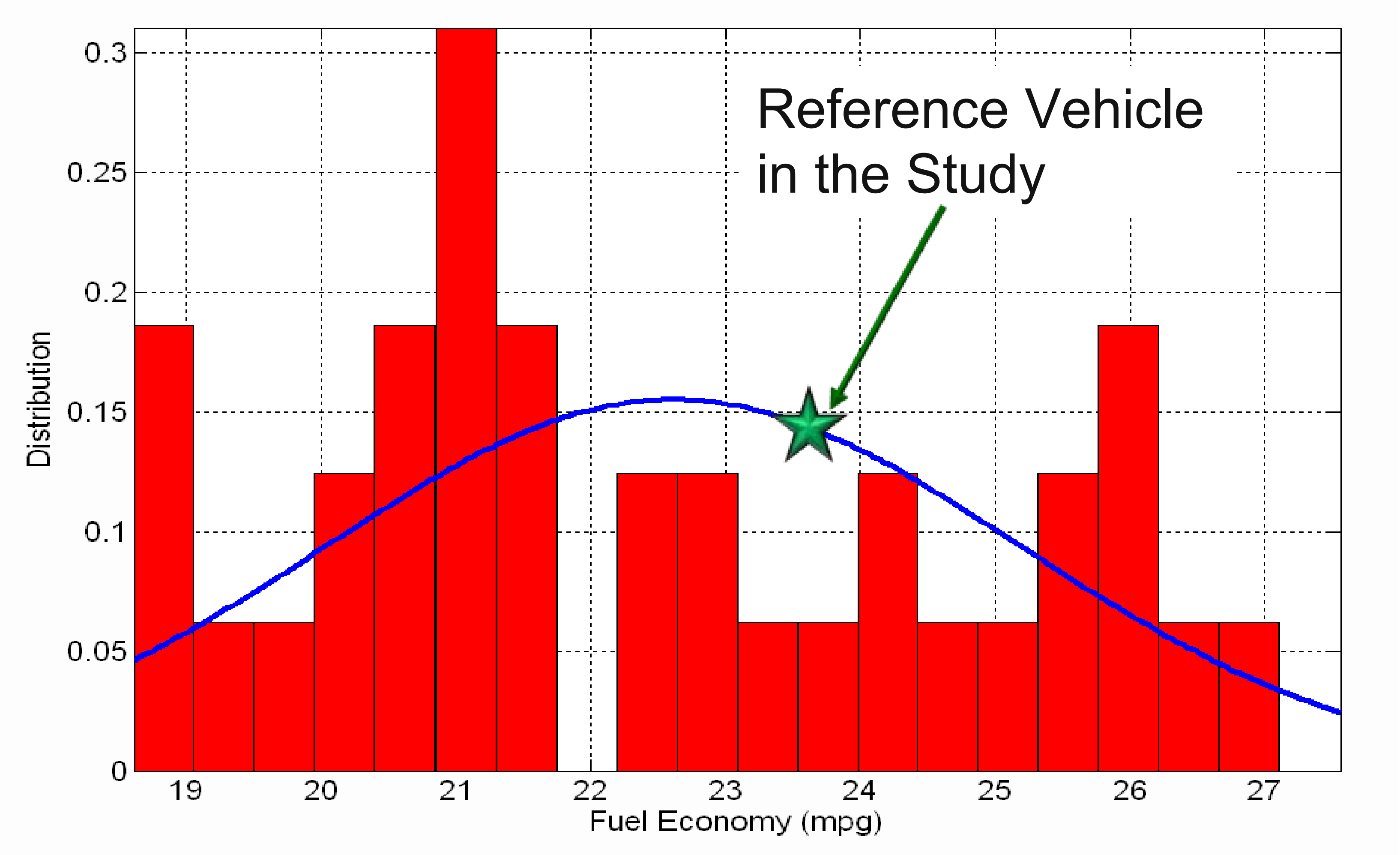
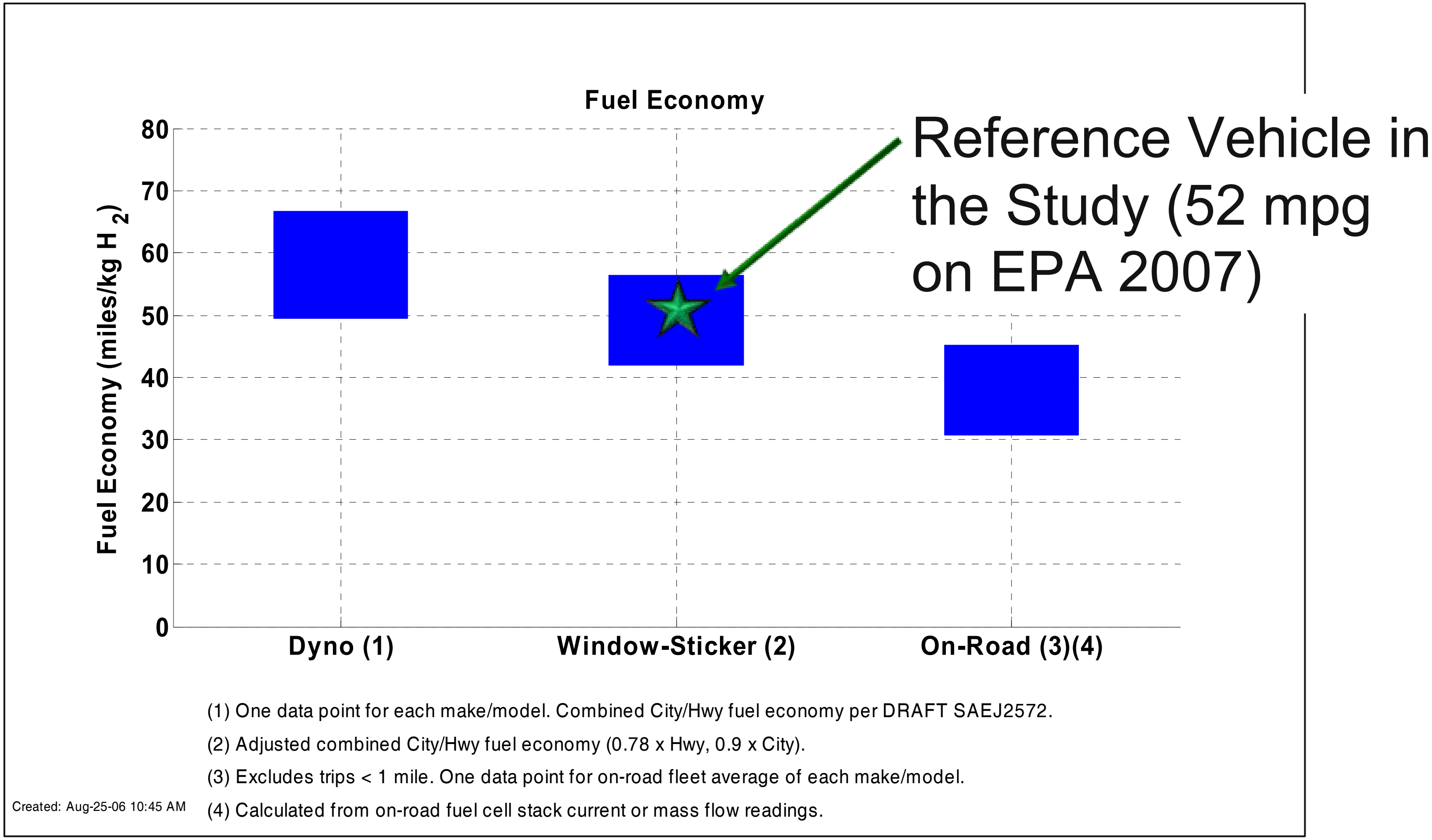
Reference Gasoline Vehicle Compared to Vehicles on the Market



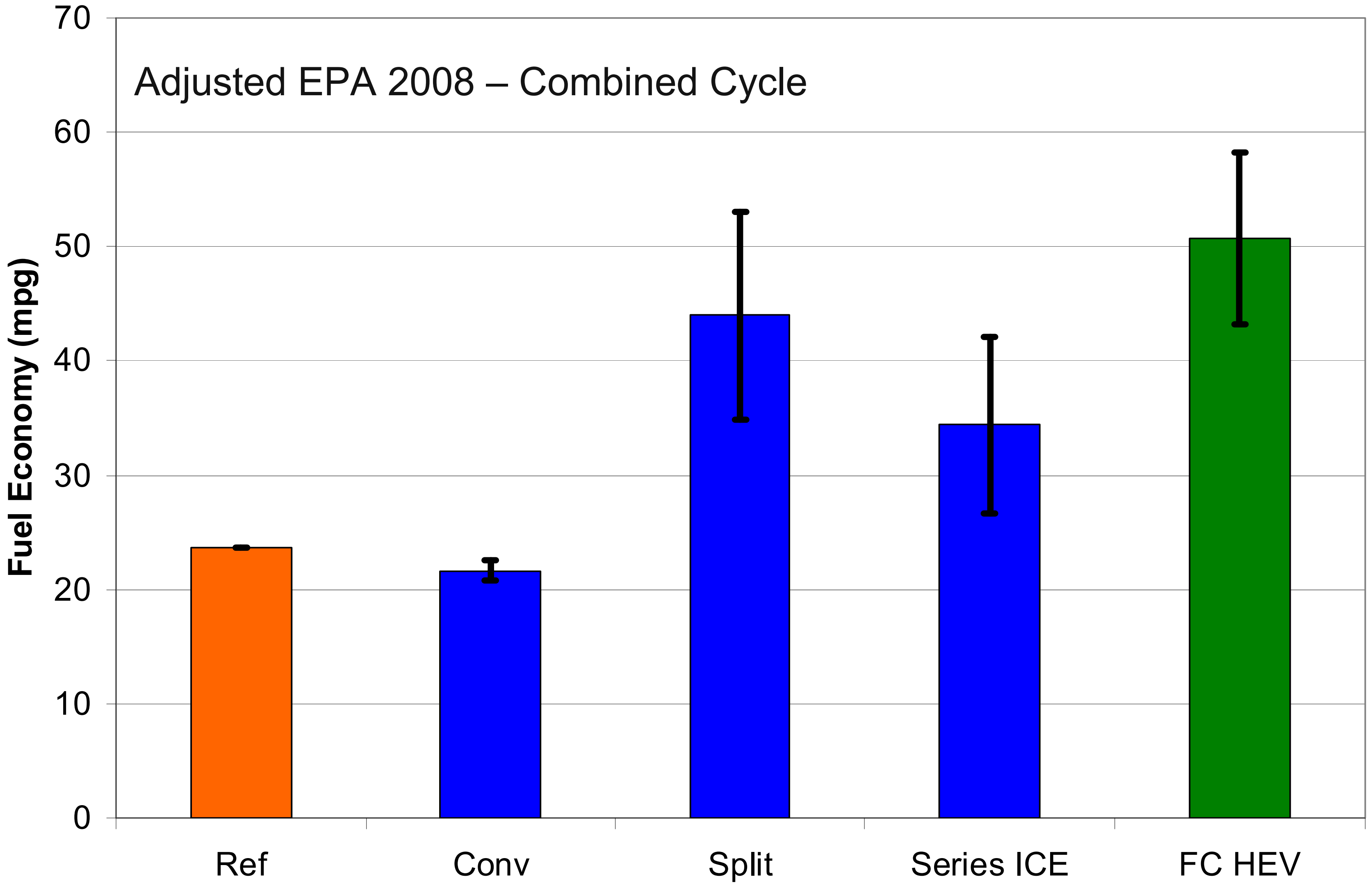
Distribution of current midsize gasoline vehicles fuel economy (2008 EPA)

Reference Fuel Cell HEV Vehicle Compared to Vehicles on the Road

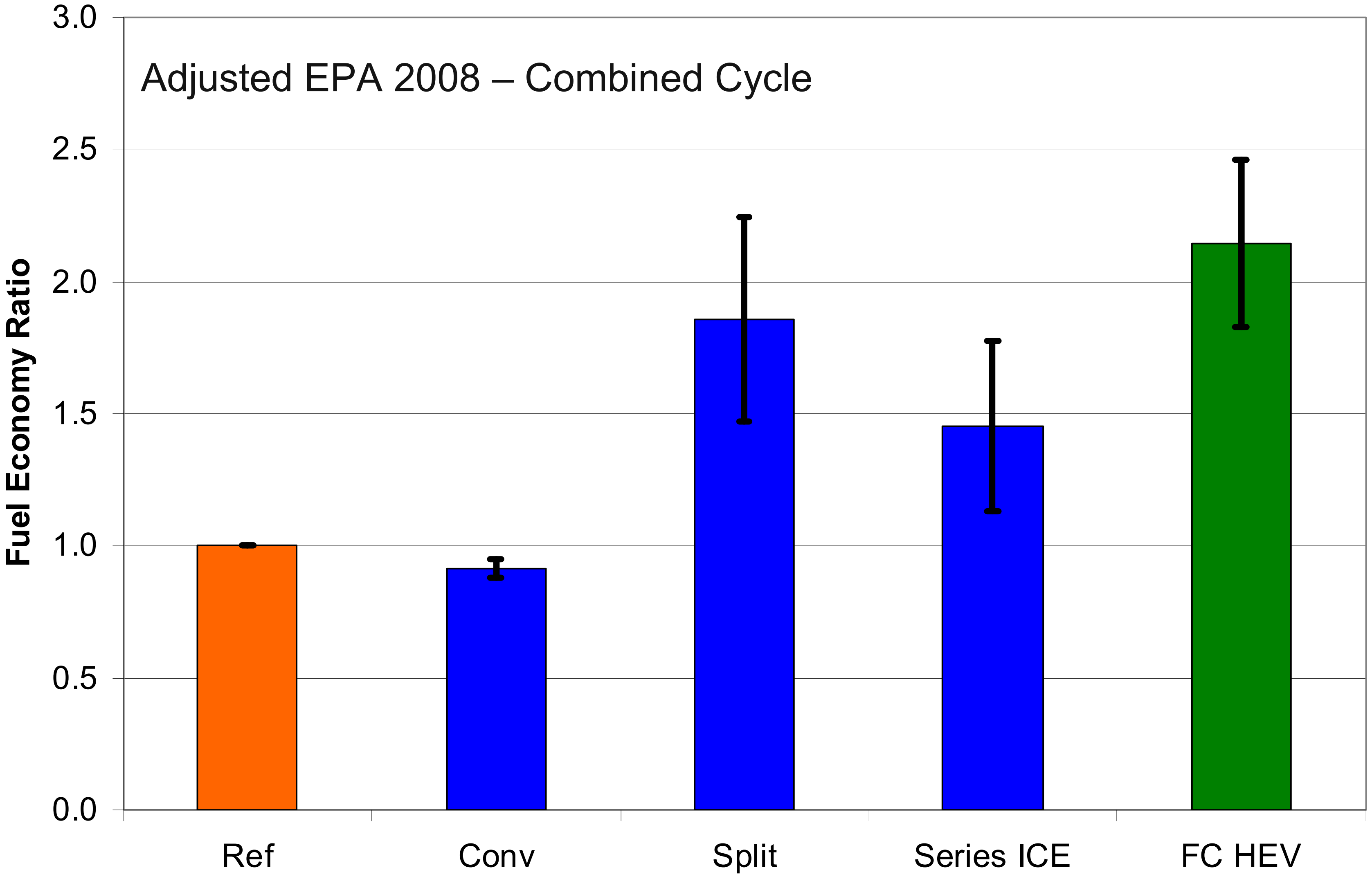


Source: NREL, Controlled Hydrogen Fleet and Infrastructure Demonstration and Validation Project, 2006

Fuel Economy Comparison



Fuel Economy Ratio



Results Summary – Combined Drive Cycles

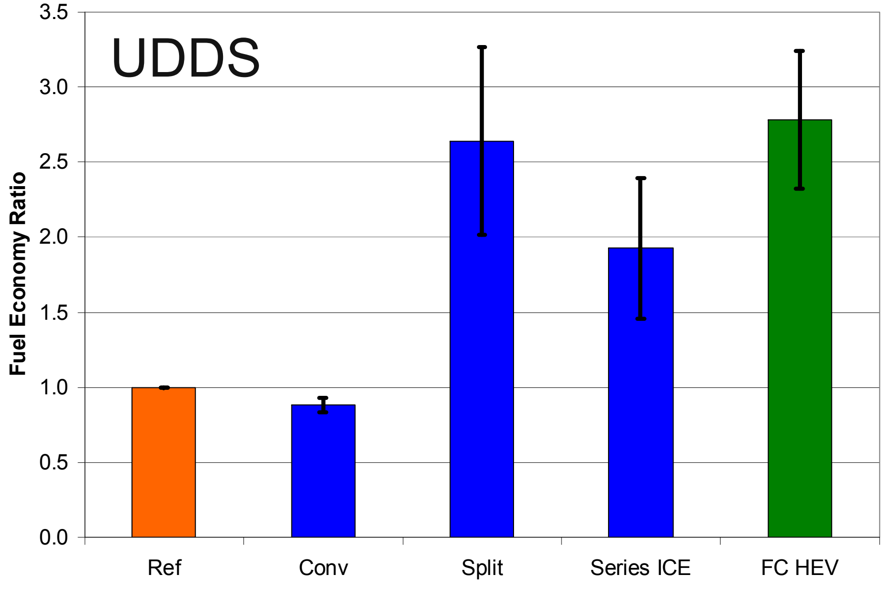
EPA 2008 Adjusted Fuel Economy (mpg)

	Ref	Conv	Split	Series ICE	FC HEV
Current	23.66	20.84	34.86	26.74	43.24
Future	23.66	22.52	53.06	42.03	58.20
Average	23.66	21.68	43.96	34.39	50.72
Error bar	0.00	0.84	9.10	7.65	7.48

EPA 2008 Adjusted Fuel Economy Ratio

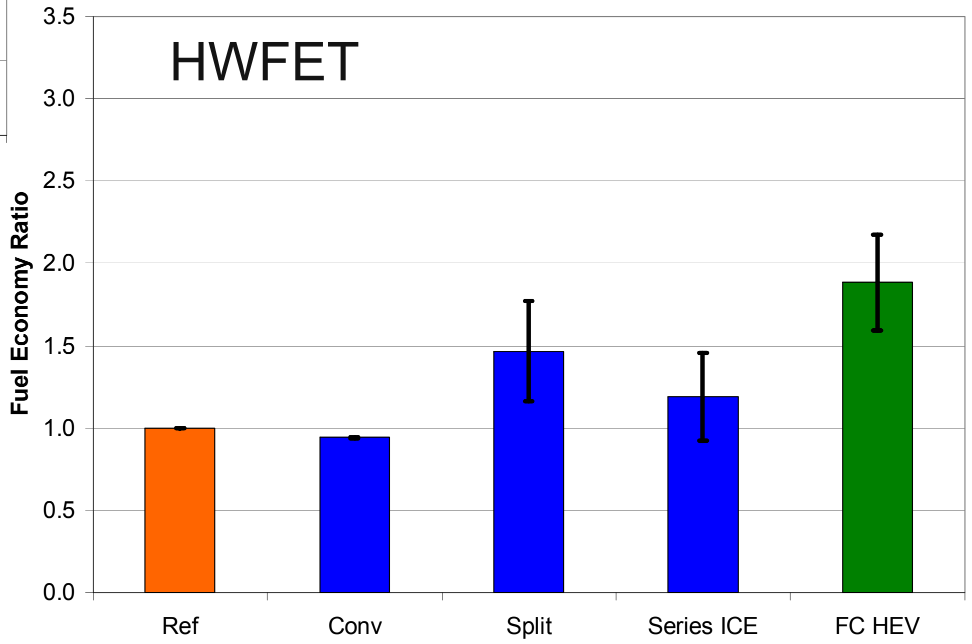
	Ref	Conv	Split	Series ICE	FC HEV
Current	1.00	0.88	1.47	1.13	1.83
Future	1.00	0.95	2.24	1.78	2.46
Average	1.00	0.92	1.86	1.45	2.14
Error bar	0.00	0.04	0.38	0.32	0.32

Impact of Drive Cycles on Fuel Economy Ratios



- UDDS shows greater gains for all systems

- H2 ICE penalized more on the HWFET than the fuel cell vehicles



* Ratios are based on unadjusted values

Fuel Economy Results Analysis

- All HEVs configuration capture similar amount of energy at the wheel during deceleration (~98% on UDDS). However, the series configurations have more losses due to lower electric machine efficiencies than the power split.
- Both HEV configurations using ICE have similar average efficiencies (~31% for port injected and ~41.5% for direct injection on UDDS).
- The fuel cell system average efficiency remains higher (~47% for current case and ~51% for future case on UDDS).
- In addition, the series configuration with H2-ICE is penalized by the driveline inefficiencies (both generator ~90% and electric machine ~81%)

Conclusion

- The DI H2-ICE has been defined based on a combination of four-cylinder and single cylinder data generated for different A/F ratios.
- H2 ICE has more potential than initially thought
- H2 ICE should be used within an HEV to be competitive with fuel cell powered vehicles
- Power split configuration offers the best fuel consumption when using H2-ICE due to added inefficiencies in the series configuration.
- The study confirms DOE position that H2 ICE is bridging technology and might help the infrastructure