ARGONNE NATIONAL LABORATORY

TRANSPORTATION TECHNOLOGY R&D CENTER

Comparing Apples to Apples: Well-to-Wheel Analysis of Current ICE and Fuel Cell Vehicle Technologies

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Scope of the Well-to-Wheel Analysis

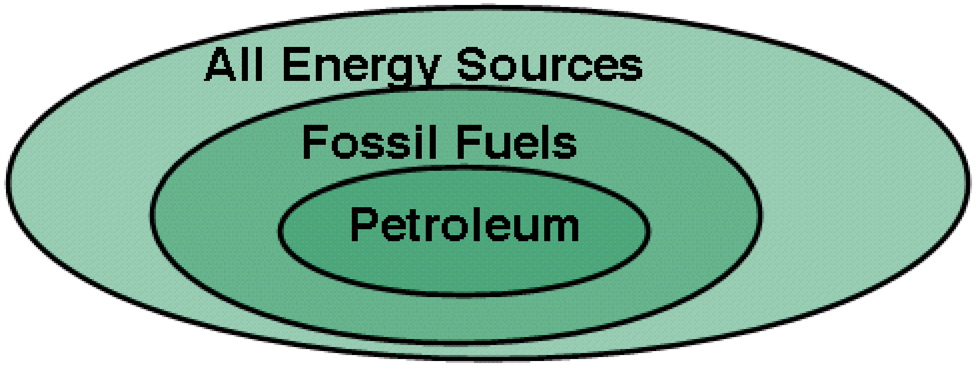
- 3 Comparison Metrics Simulated using GREET, PSAT and GCTOOL
  - Fuel Economy (SOC corrected MPGGE)
  - Well to Wheel Efficiency
  - Well to Wheel Green House Gas Emissions
- 11 Vehicle Configurations
  - Based on SUV (Explorer) Platform
  - Conventional, Parallel Hybrid (Grid Independent), Fuel Cell, Fuel Cell Hybrid (Grid Independent)
- 4 Fuel Converter Technologies
  - Gasoline, Diesel, H2 Engine, H2 Fuel Cell
- 5 Drive Cycles
  - City, Highway,Combined,US06,Japan 10-15, NEDC

Ensuring a Fair Comparison

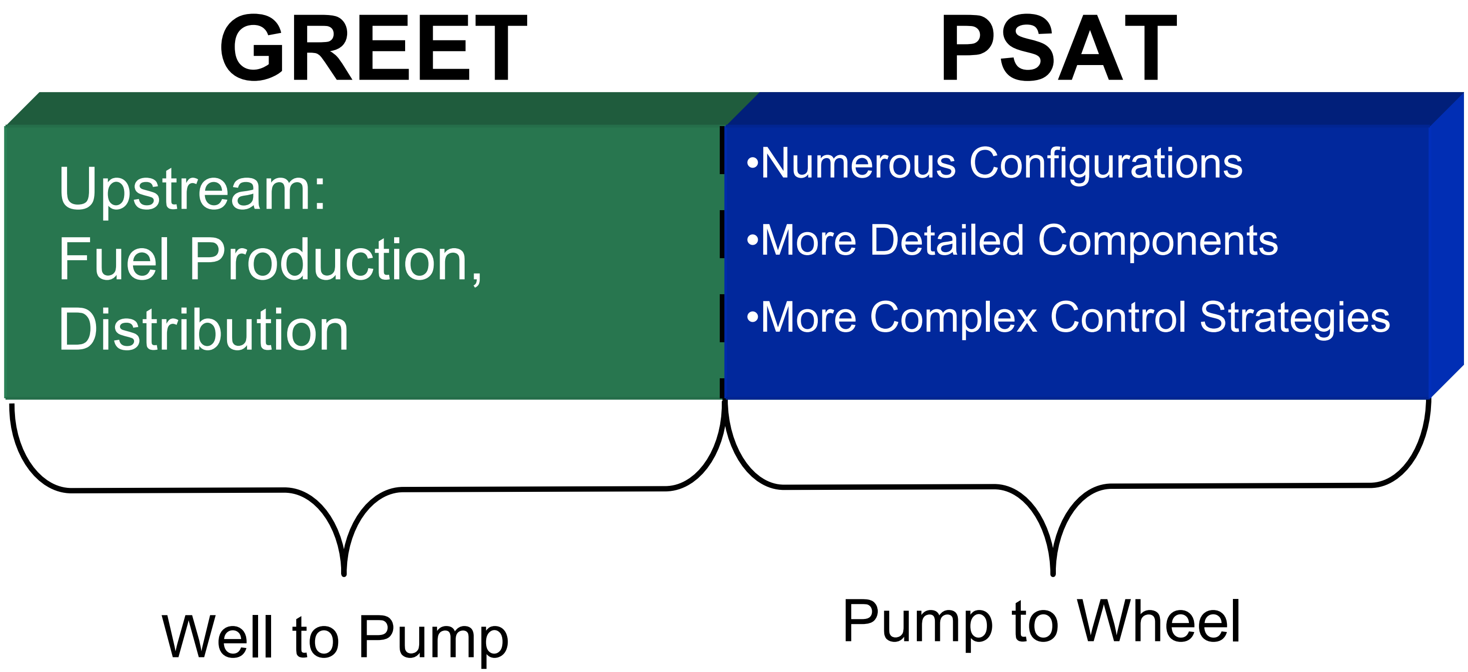
- Several key parameters are held constant:
  - Time period for technology comparison (2003)
  - Vehicle platform (glider)
  - Vehicle performance
    - 0-60mph
    - maximum speed >100mph
- Inclusion of vehicle assumptions in published paper
- Hydrogen produced from natural gas station
- Well to Pump Included all Green House Gas Emissions
- Pump to Wheel simulation only predicted CO2
- Cold start and cost estimates not included

GREET: Industry Standard Tool

- **G**reenhouse gases, **R**egulated **E**missions and **E**nergy use in **T**ransportation
- Complete cycle analysis
- Greenhouse gases
  - CO_2, CH_4 and N_2O
  - VOC, CO and NOx as optional GHGs
- Criteria pollutants
  - VOC, CO, NOx, PM10 and SOx
- Separates energy use into



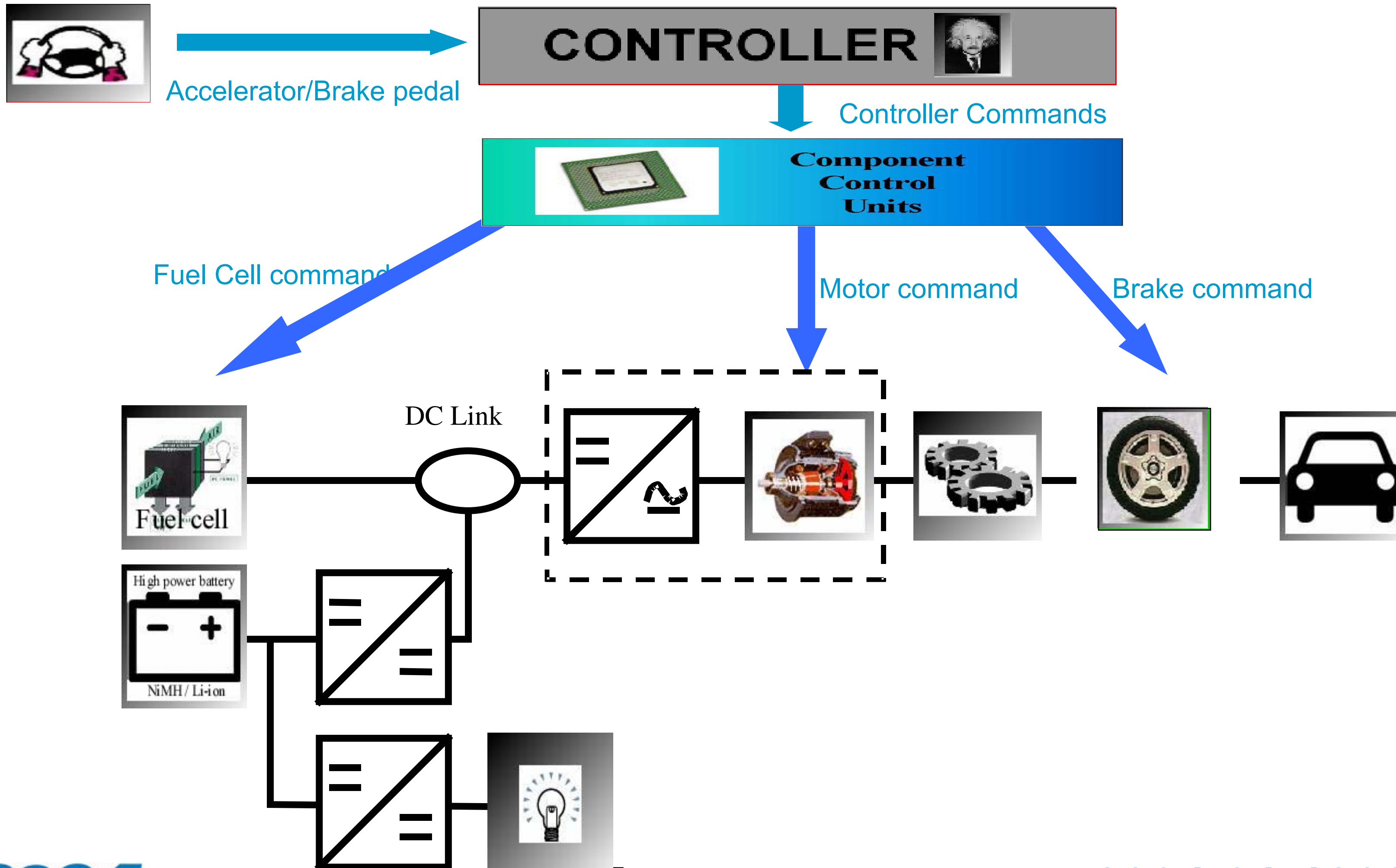
Simulating with Argonne Tools



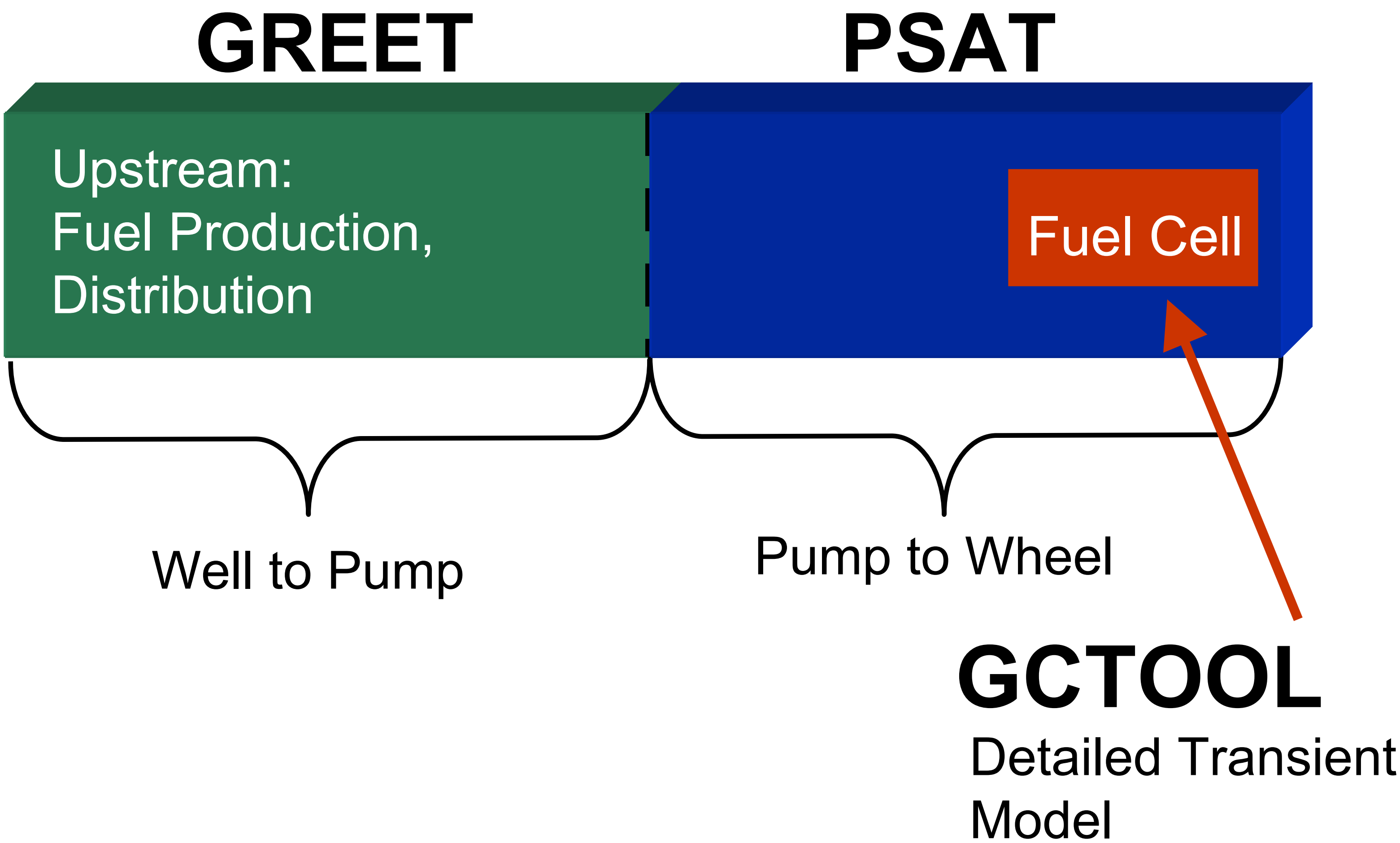
PSAT Used For Transient Vehicle System Modeling and Control

- **P**owertrain **S**ystems **A**nalysis **T**oolkit
- MATLAB / SIMULINK
- Forward-looking approach
- Needed for detailed analysis where
  - Transient component model behavior is important
  - Detailed vehicle control necessary
  - Torque blending affects component sizing
- Supports direct application of control strategy to micro-controller for hardware-in-the-loop and/or rapid control prototyping (HIL/RCP)

PSAT is a Detailed Vehicle Systems Model



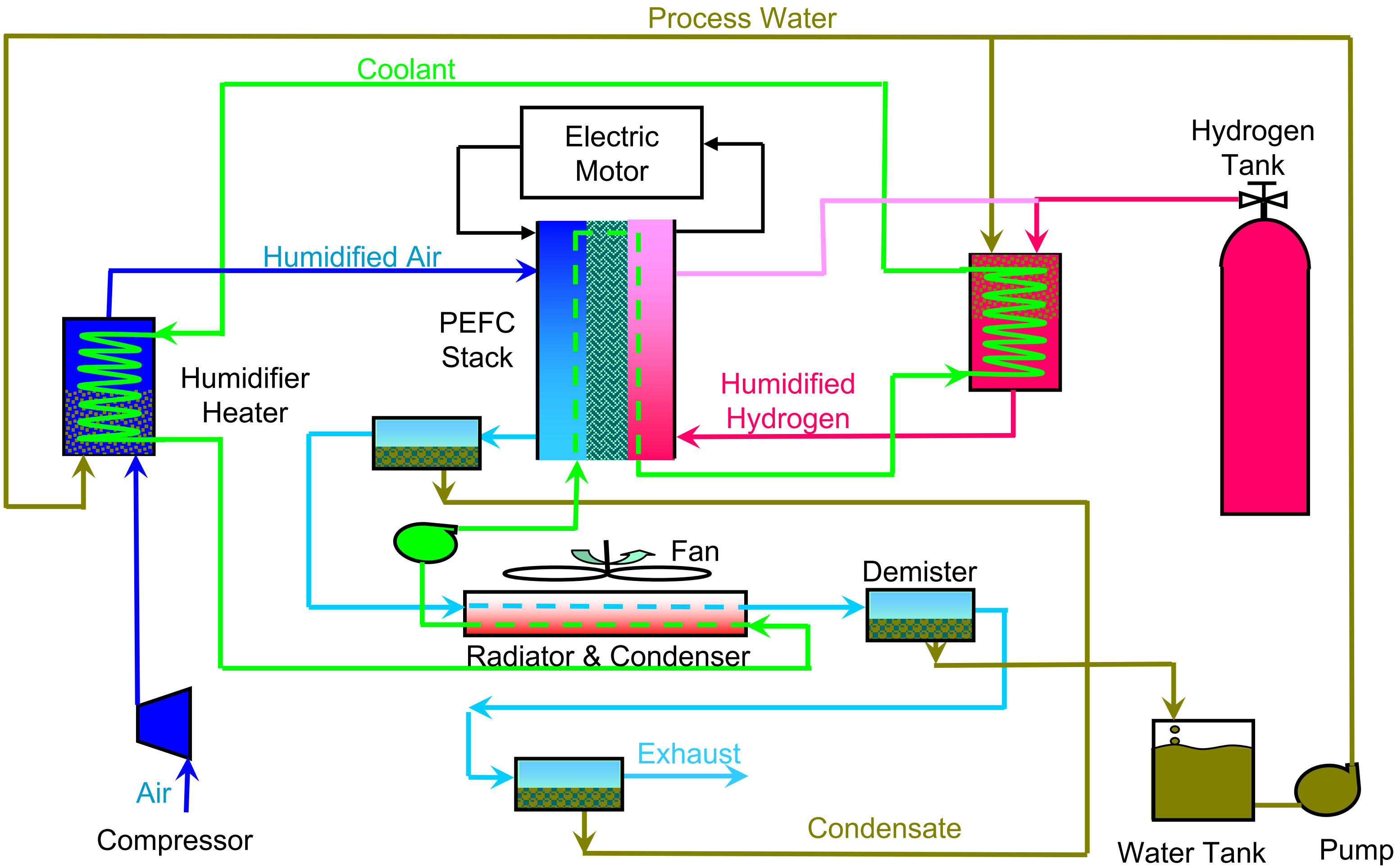
Simulating with Argonne Tools



GCtool-Eng Used for Transient Fuel Cell System Modeling

- **G**eneral **C**omputational **Tool**kit
- GCtool simulates various systems and fuels
  - Fuel Cells: **Proton Exchange Membrane**, Solid Oxide, Phosphoric Acid, Molten Carbonate
  - Fuels: **Hydrogen**, Methane, Methanol, Octane, Diesel and Gasoline
- GCtool-Eng appropriate level of detail for vehicle analysis over driving cycles
  - Engineering model solves conservation equations for energy, mass, species and momentum
  - Models are transient, can be multi-nodal and may directly interact with other components

Design-Specific FC System Modeling Required to Assess Component Impact



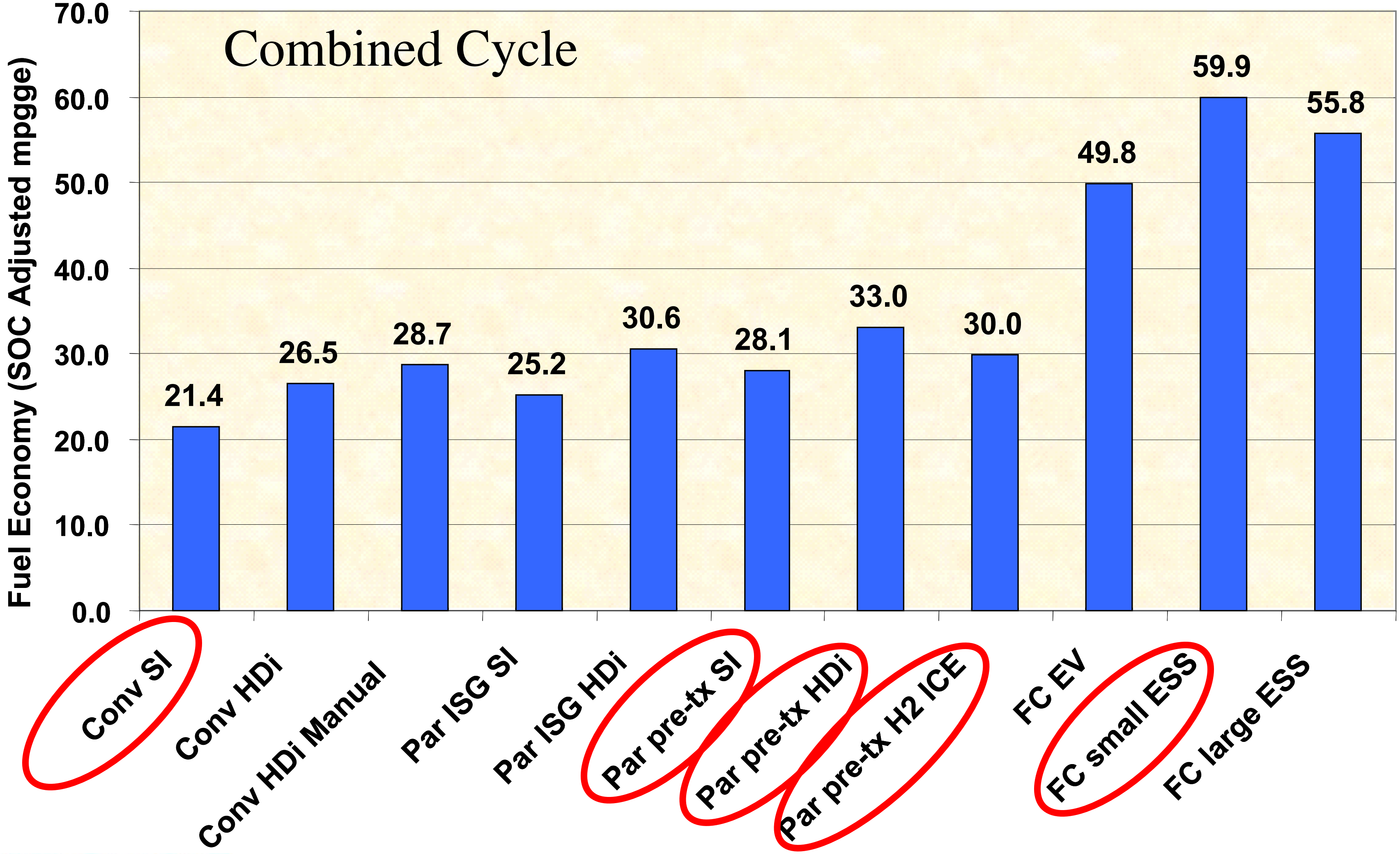
PSAT Reference Vehicle Has Been Validated

	Units	EPA Test	PSAT
Vehicle Assumptions			
Vehicle Test Mass	kg	2104	
Glider Mass	kg	1290	
Engine		4L, V6, SOHC, 210hp	
Frontal Area	m^2	2.46	
Drag Coefficient		0.41	
Rolling Resistance		0.0084	
Wheel Radius	m	0.368	
Model Validation			
Acceleration (0-60mph)	sec	10.2	10.2
Unadjusted Combined Fuel Economy	mpg	20	21

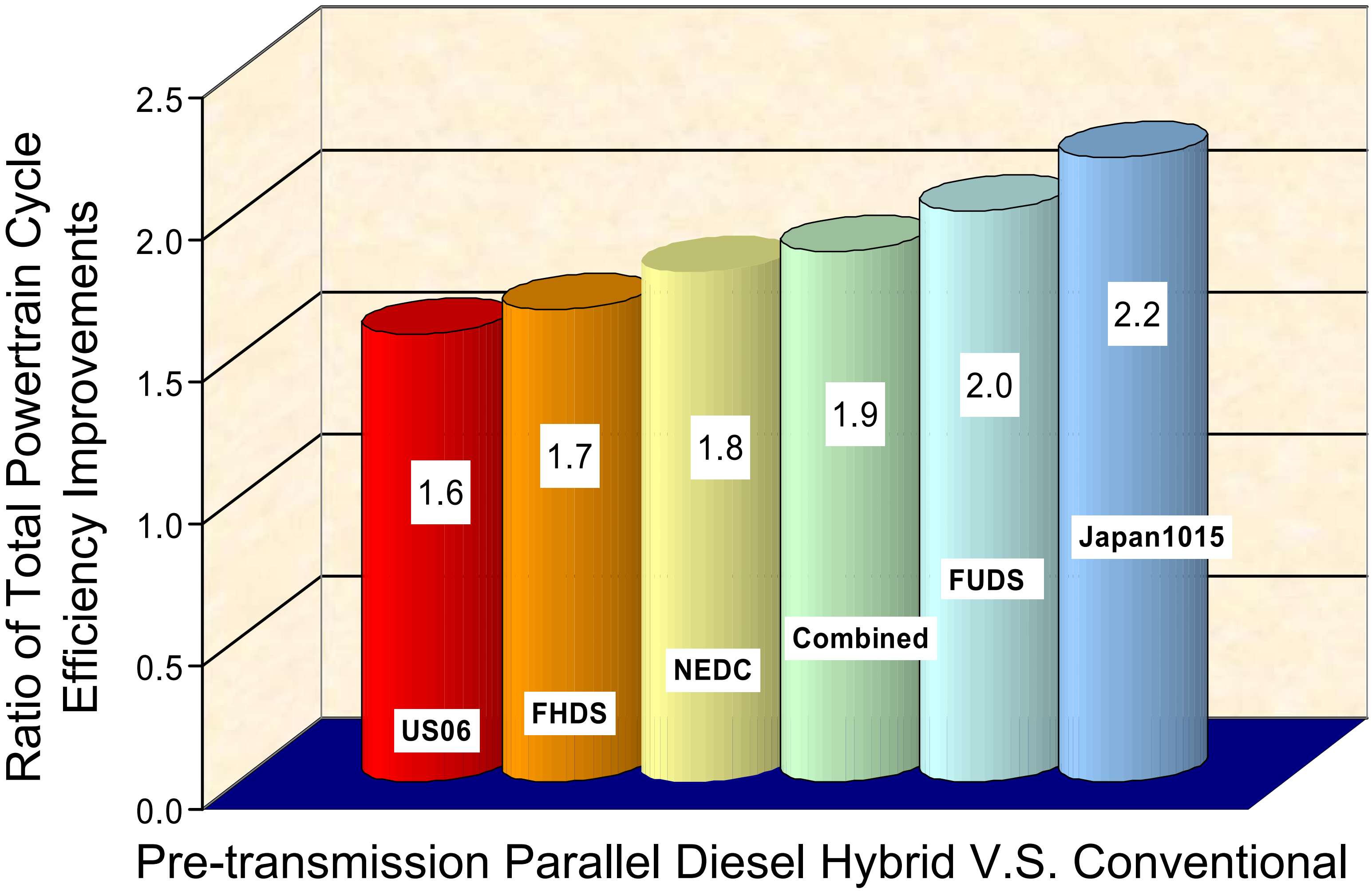
Vehicles Description

Drivetrain Label	Fuel Converter	Percent Hybrid	Location of Motor	Transmission
Conv SI	Gasoline			Automatic
Conv HDI	Diesel			Automatic
Conv HDI Manual	Diesel			Manual (Auto. Shift)
Par ISG SI	Gasoline	14%	Pre-clutch	Manual (Auto. Shift)
Par ISG HDI	Diesel	12%	Pre-clutch	Manual (Auto. Shift)
Par pre-tx SI	Gasoline	38%	Pre-transmission	Manual (Auto. Shift)
Par pre-tx HDI	Diesel	44%	Pre-transmission	Manual (Auto. Shift)
Par pre-tx H2 ICE	H2 Engine	43%	Pre-transmission	Manual (Auto. Shift)
FC EV	H2 Fuel Cell			Single Reduction
FC Small ESS	H2 Fuel Cell	26%		Single Reduction
FC Big ESS	H2 Fuel Cell	50%		Single Reduction

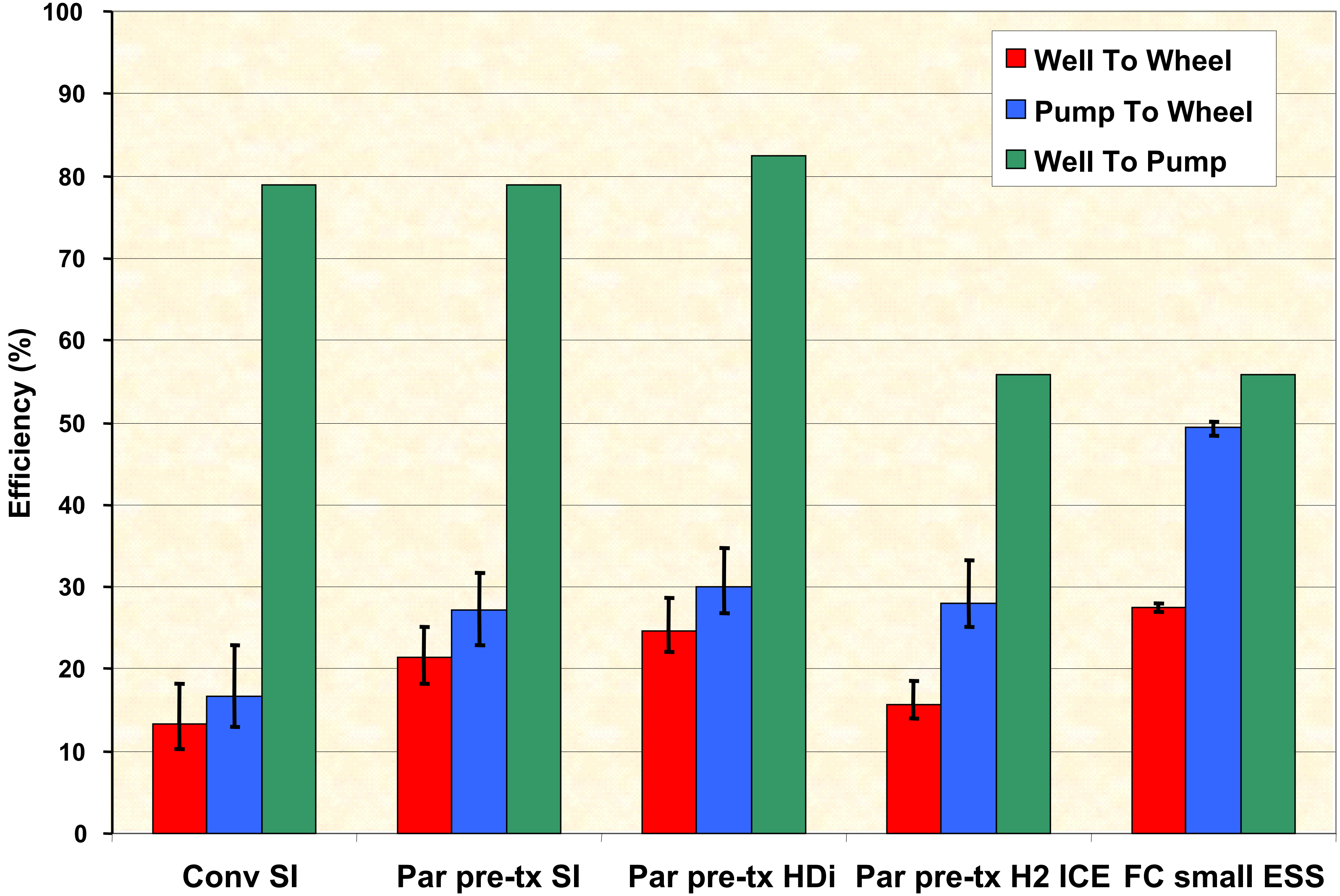
Fuel Cell Vehicles Achieve the Highest Fuel Economy Gasoline Equivalent



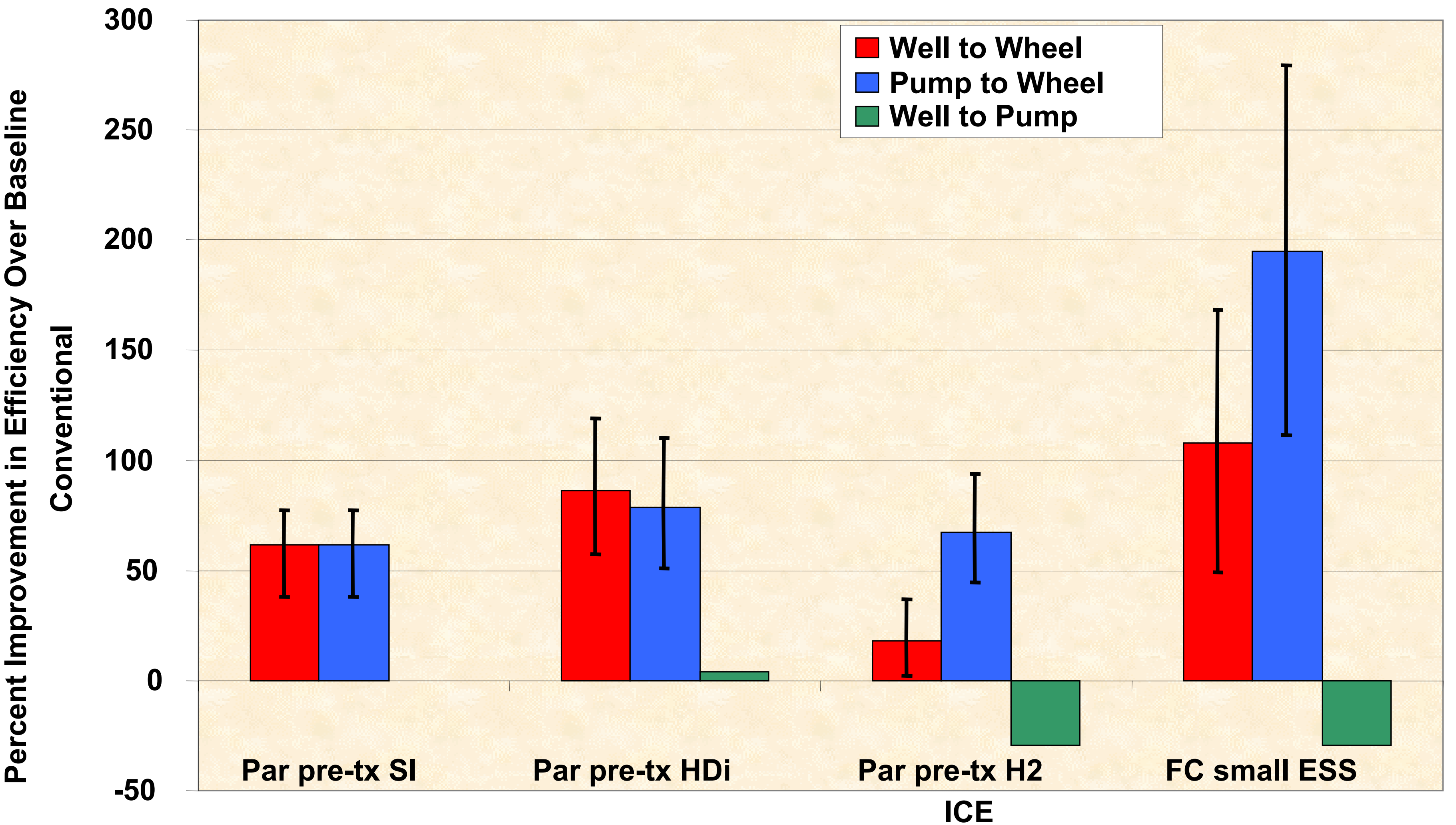
Powertrain Efficiency Gain is a Function of Drive Cycle Speed and Acceleration



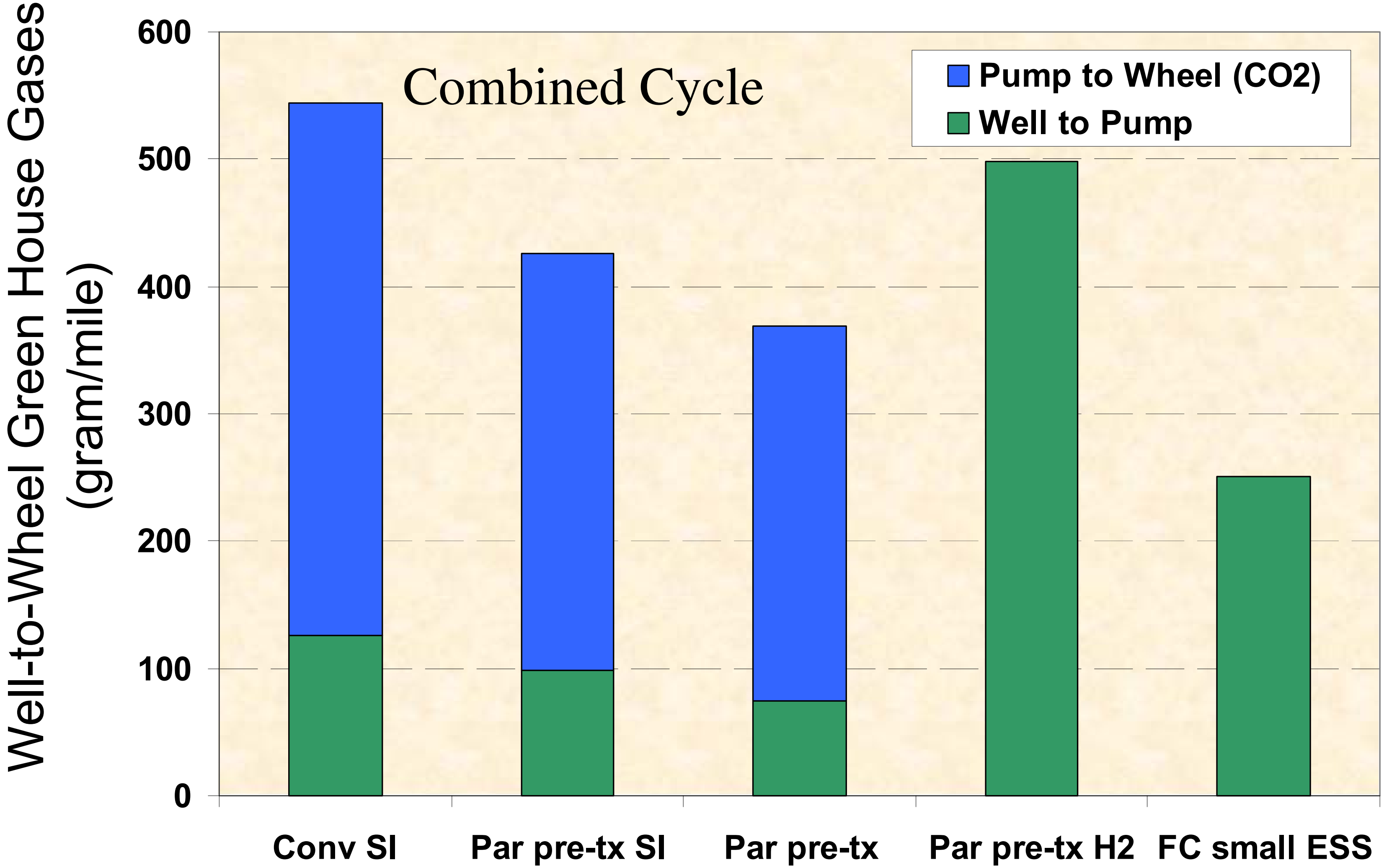
Diesel Hybrids Compete with Fuel Cell on a Well-to-Wheel Basis



Using the Conventional as a Reference Shows Large Variability for the FC



Fuel Cells Offer Significant GHG Emission Reduction



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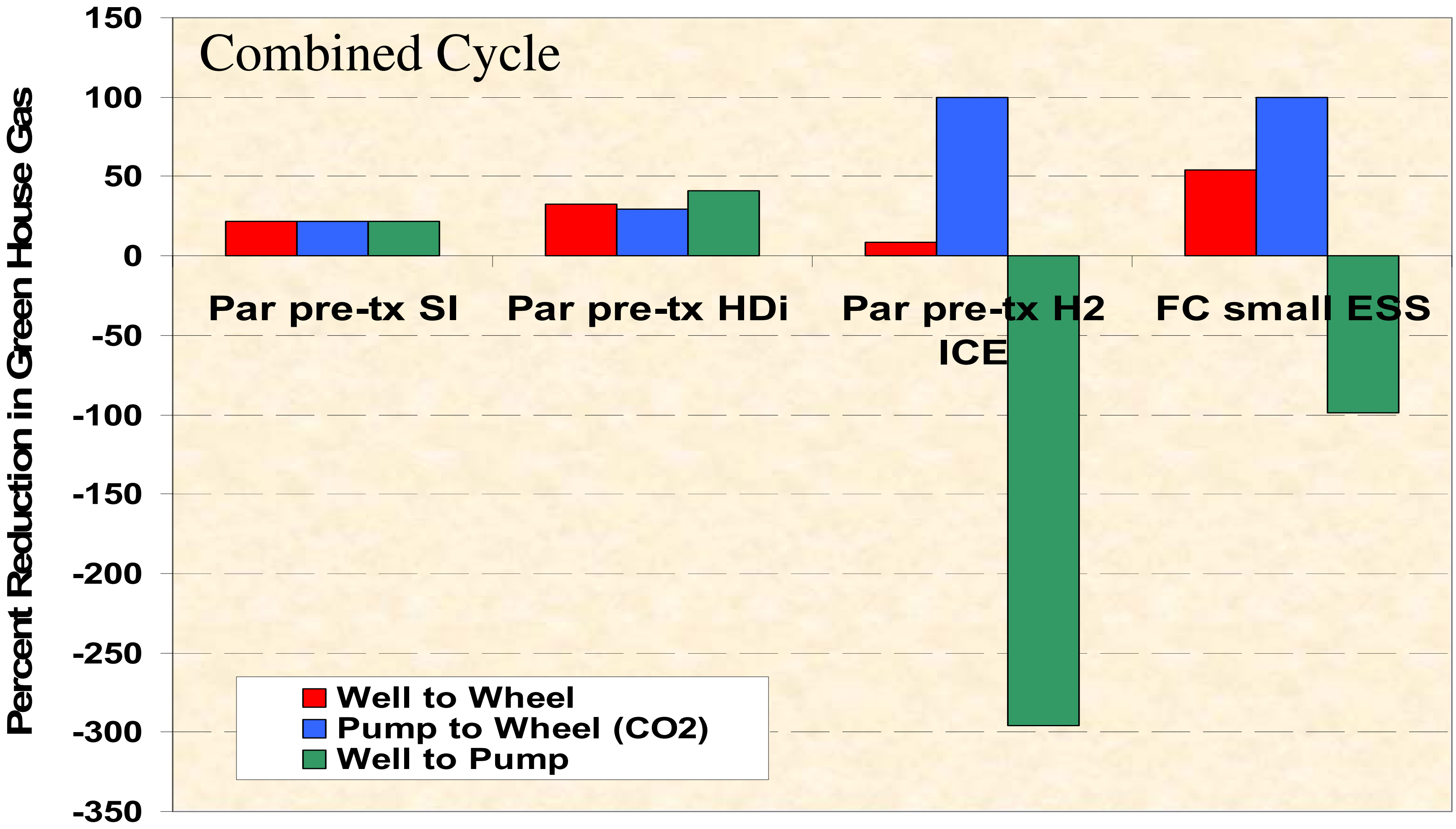
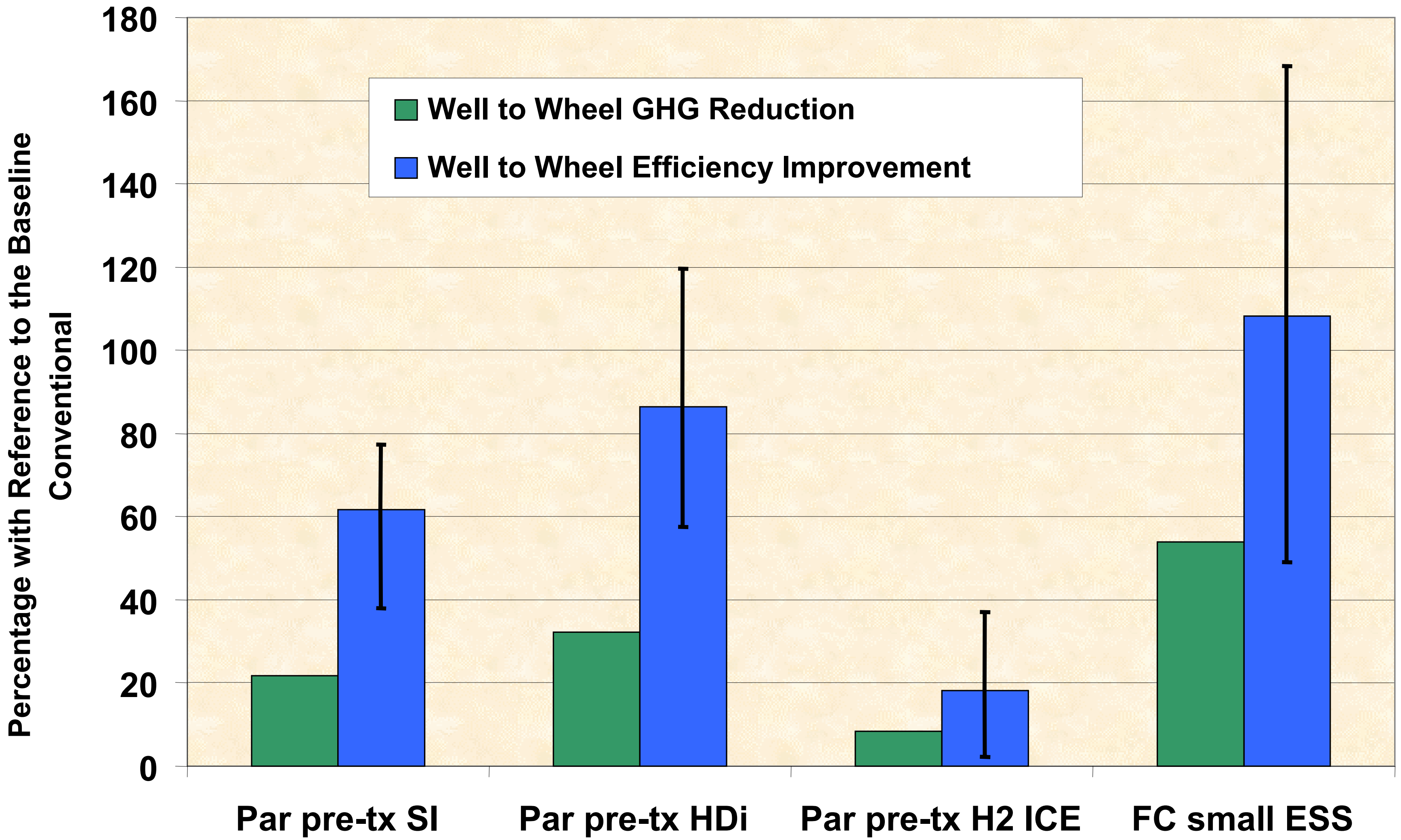


Overall, Fuel Cells Offer Great Potential



Based on this Studies Technology Assumptions

- **Long Term:** Fuel cell hybrids offer significant benefits on a well to wheel basis assuming hydrogen production from natural gas
  - Efficiency improvements
  - Green House Gas emission reduction
- **Near Term:** Hydrogen engine hybrids can pave the way to a hydrogen economy
  - Engine technology is more mature
- **Short Term:** Diesel engine and hybrid technology available today can offer dramatic benefits over conventional vehicles

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GREET	http://greet.anl.gov
Transportation website	www.transportation.anl.gov
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