Impacts of Combining Hydrogen ICE with Fuel Cell System Using PSAT

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Study Goal

- Use both Hydrogen ICE and fuel cell system for propulsion to evaluate
  - Fuel economy
  - Range
  - Cost
- Perform a sensitivity analysis to assess the impact of
  - Hybridization degree
  - Battery size

Modeling Assumptions

- Simulations based on compact platform (Ford Focus)
- Vehicle performance was kept constant
  - 0-60mph ~10s
  - 6.5% grade at 55 mph
- Pre-transmission parallel HEVs
- UDDS driving cycles
- Fuel Cell System always ON (idling)
- 4kg H2 stored
- Component technologies considered:
  - Proprietary Ford H2 ICE engine (2.3L)
  - Pressurized direct hydrogen fuel cell system
  - Saft HP6 Li-ion battery

Only Hydrogen is used in this study (e.g., Conventional Reference ICE uses H2)

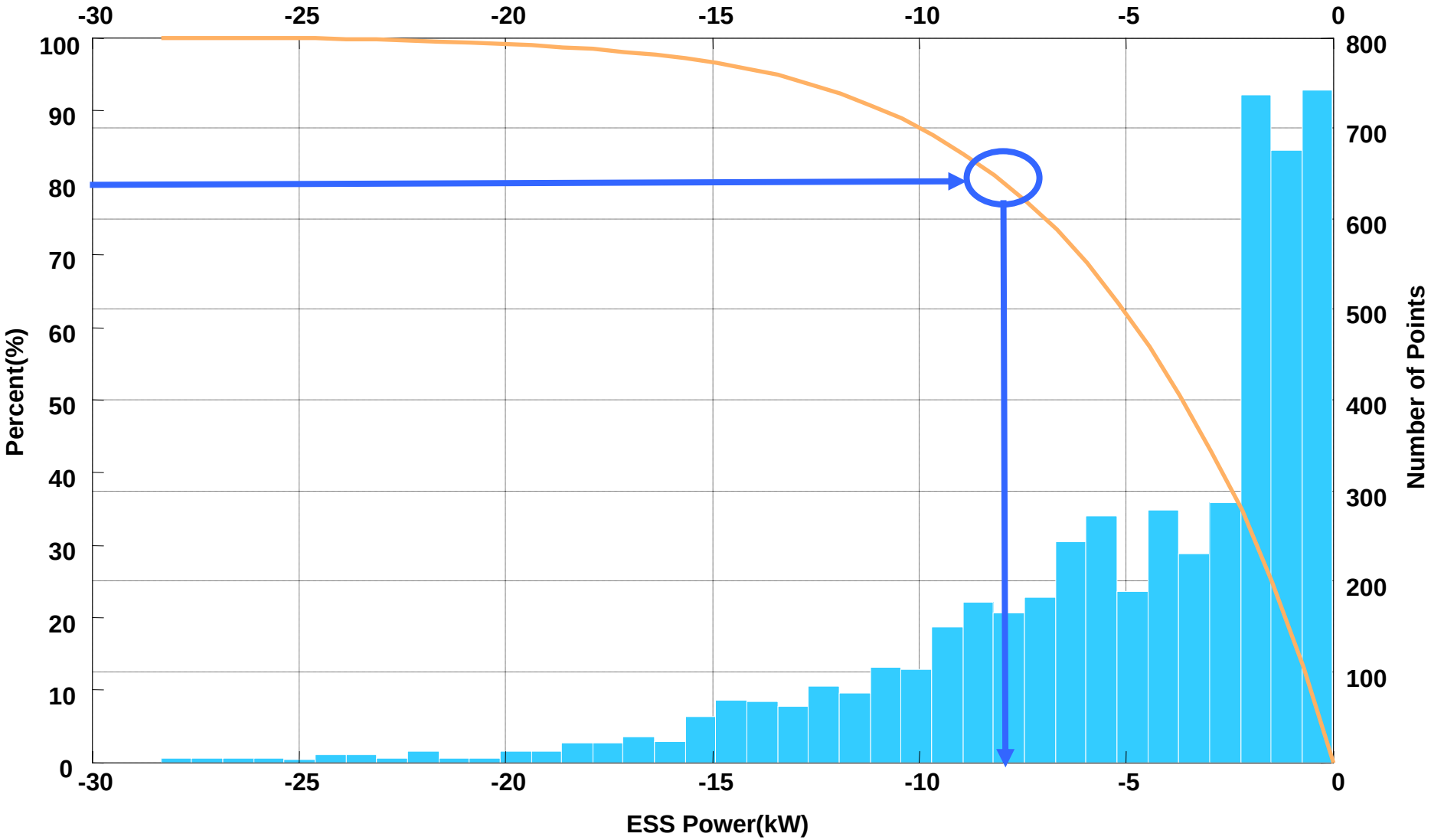
Component Main Assumptions

H2 ICE*	W/kg	Proprietary
	$/kW	35
Fuel Cell*	W/kg	650
	$/kW	45
H2 Storage	kgH2/kg	0.06
Motor	W/kg	5000
Motor Controller	W/kg	1000
Motor + Controller	$/kW	12
Battery	$/kW	30

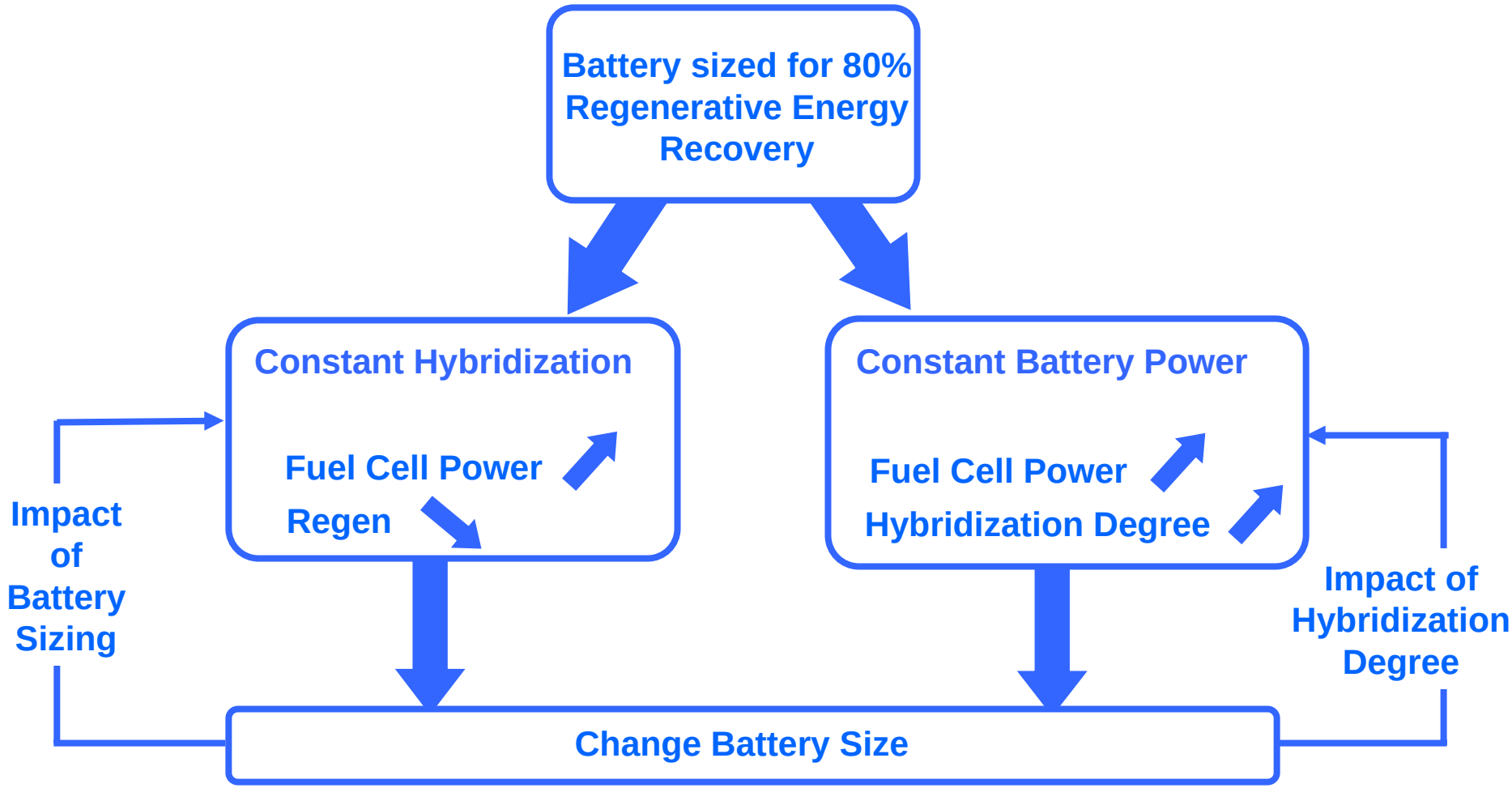
* Includes cost of storage

Most assumptions based on FreedomCAR 2010 goals

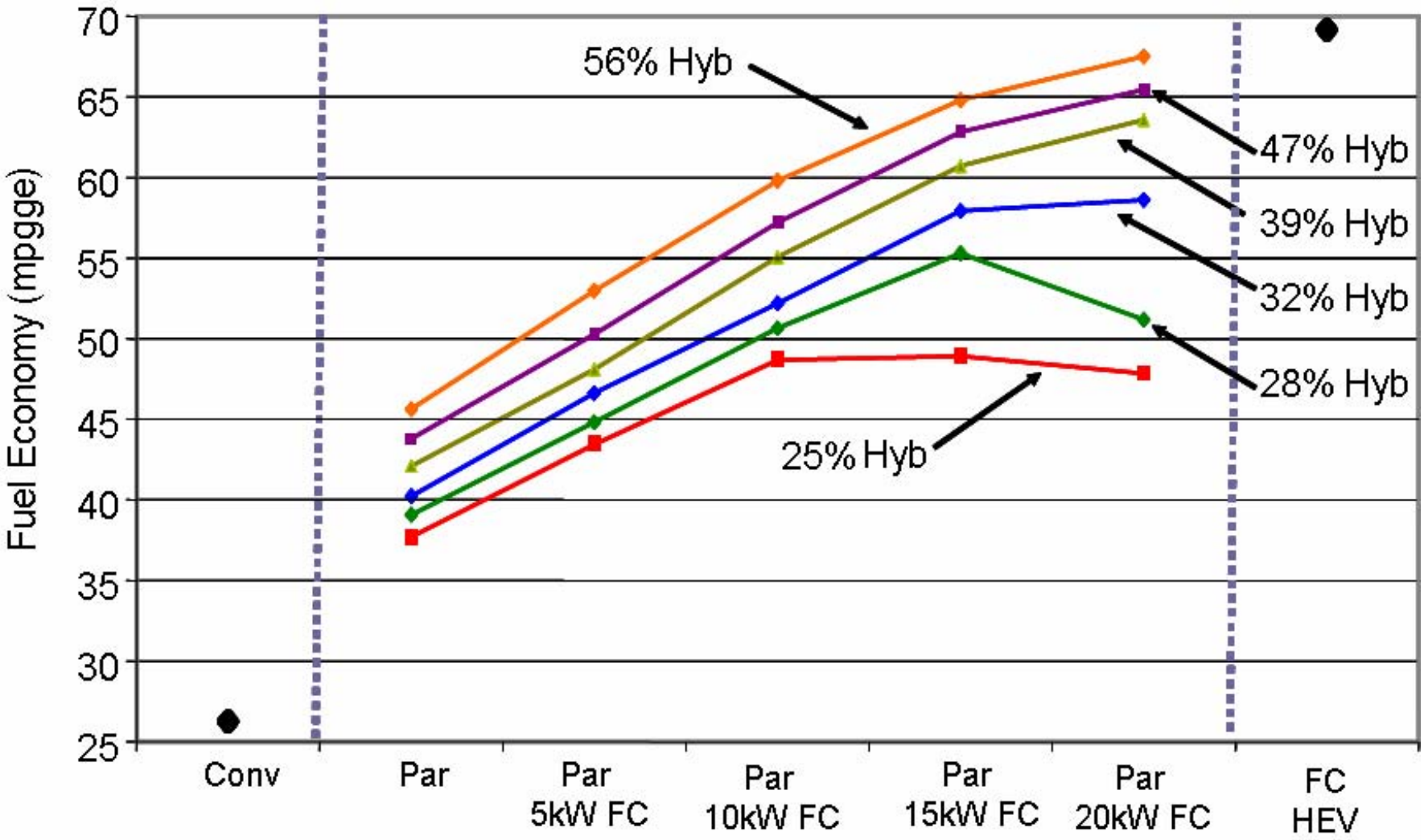
Battery Sized for Specific Regenerative Braking Percentage



Methodology Focused on Encompassing the Largest Number of Cases

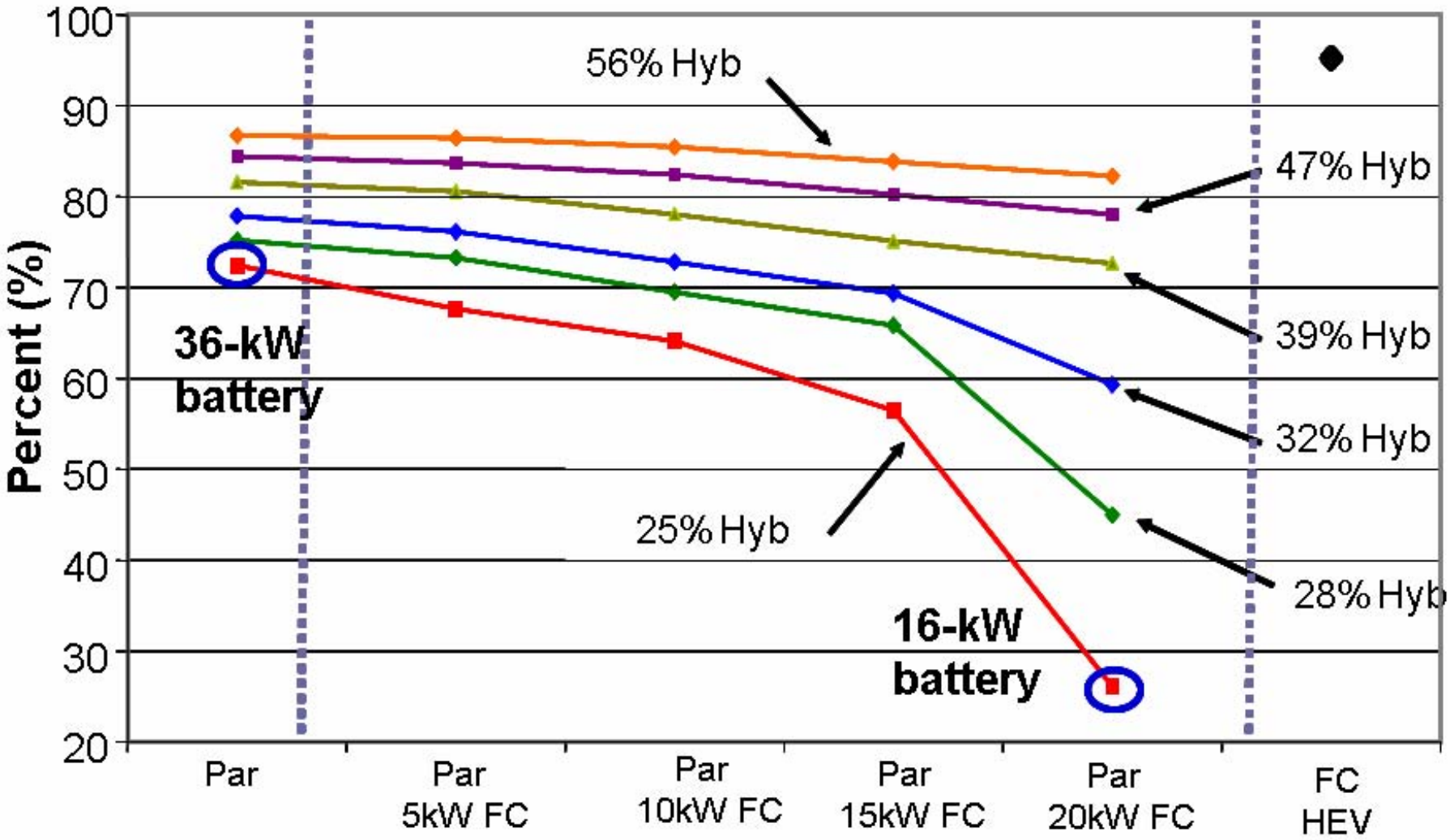


Fuel Economy Increases with Fuel Cell Peak Power



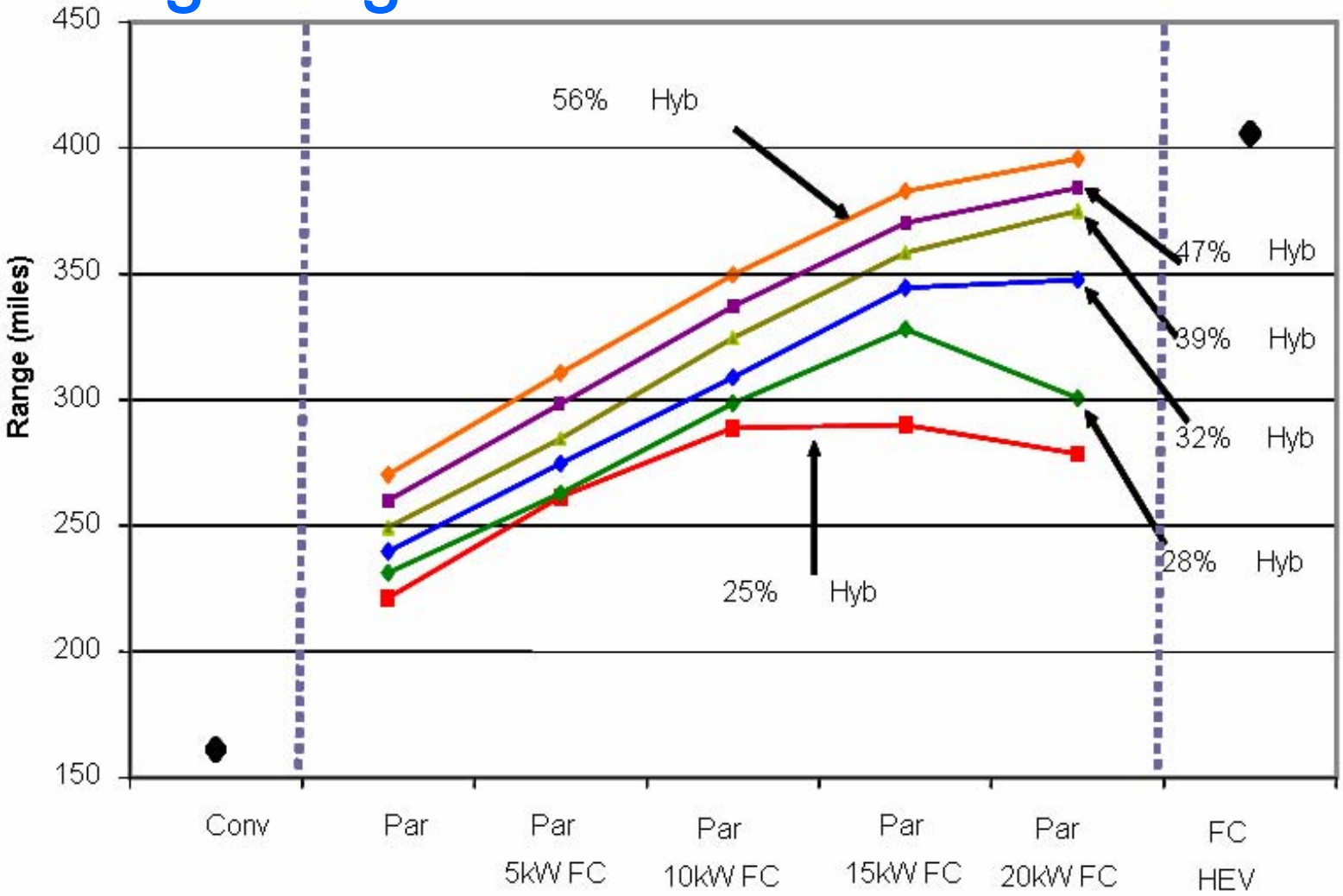
Constant Hybridization

Percent Recovered Regenerative Energy Decreases Abruptly at Low Battery Power



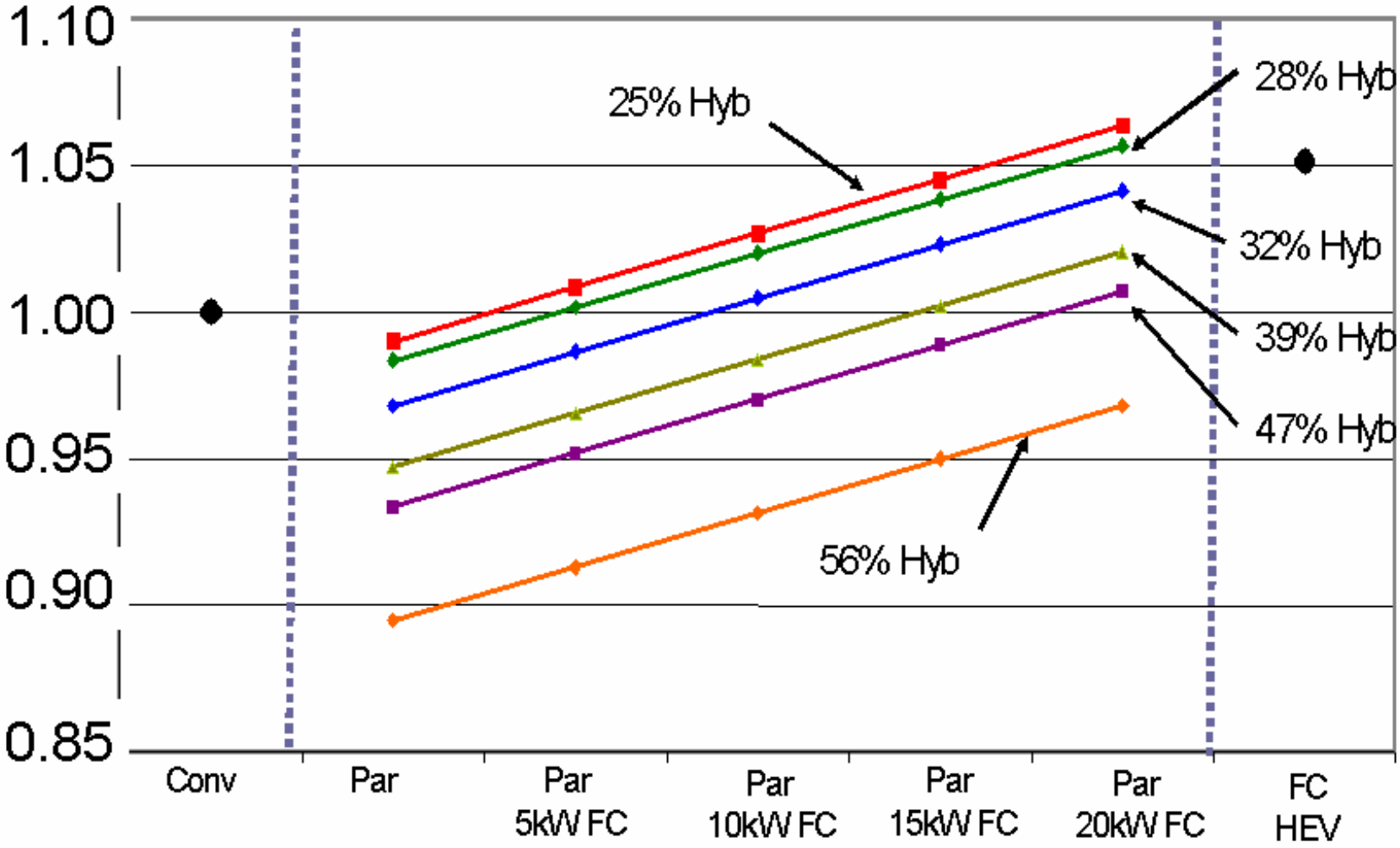
Constant Hybridization

Increase in Fuel Economy Leads to Greater Driving Range



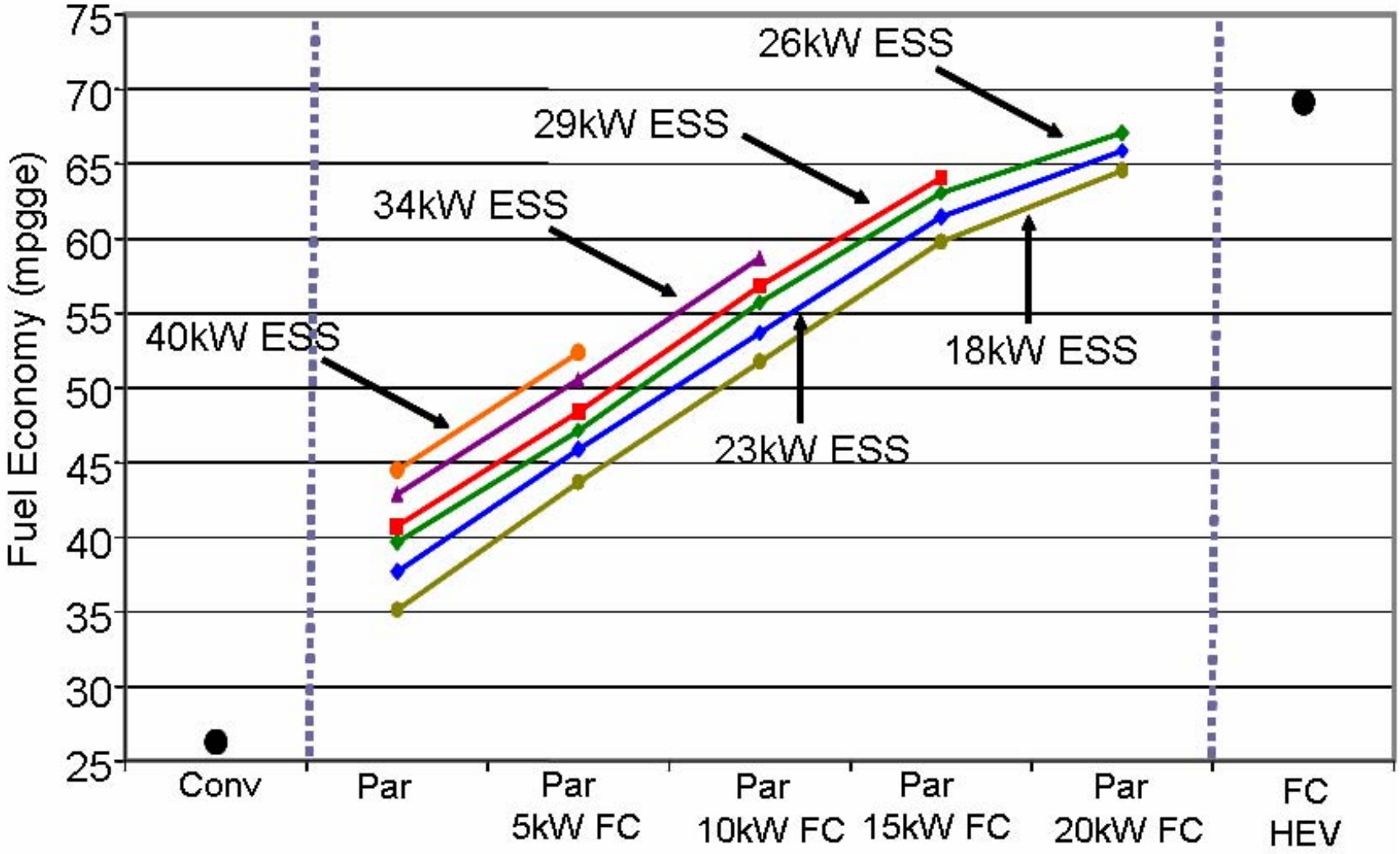
Constant Hybridization

High Degree of Hybridization Leads to Cost Reduction when Using FreedomCAR Goals



Constant Hybridization

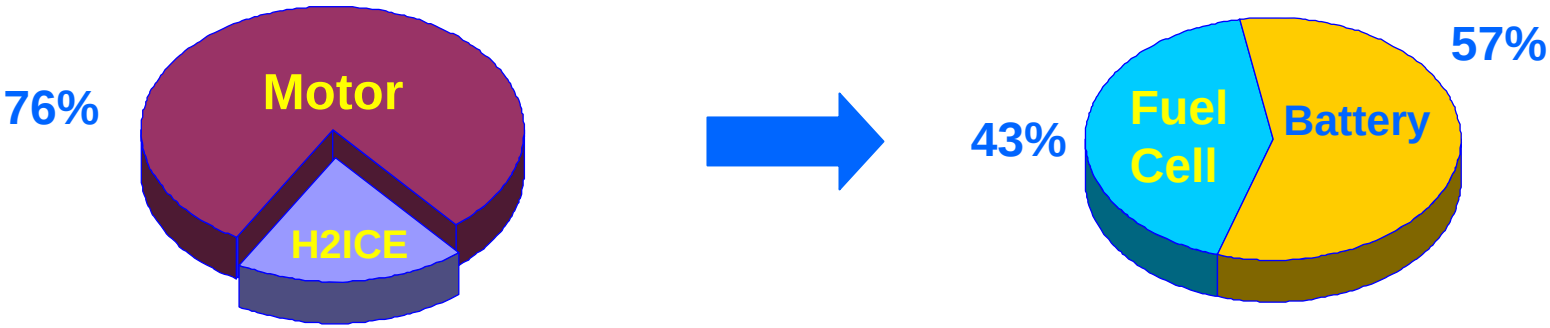
Fuel Economy Trends Are Similar when Maintaining the Battery Power Constant



Constant Battery

Increased Fuel Cell Power Leads to a Decrease in H2-ICE and Battery Usage

29-kW Battery – 5-kW Fuel Cell



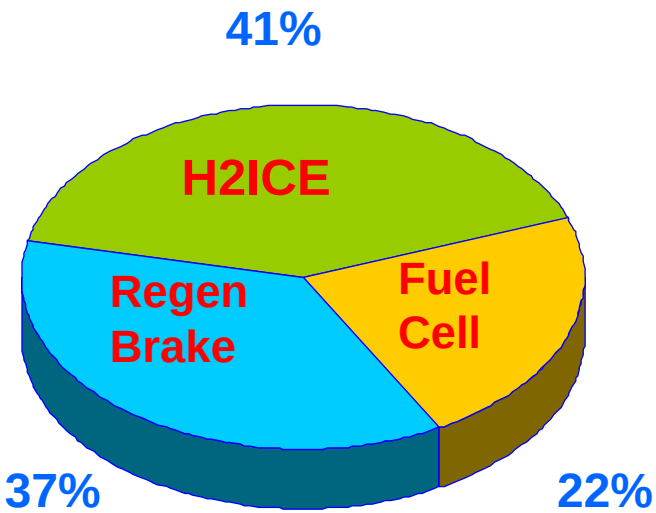
29-kW Battery – 20-kW Fuel Cell

Energy Distribution during Battery Discharging

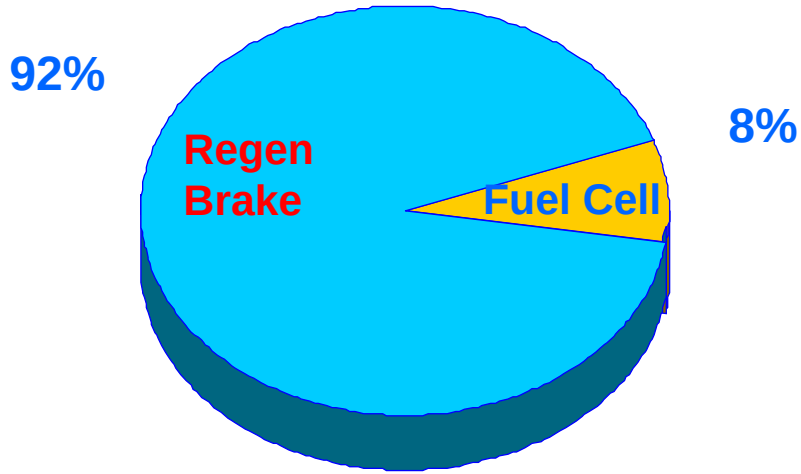
Constant Battery

With increased fuel cell power, H2-ICE is not used to recharge the battery

29-kW Battery – 5-kW Fuel Cell



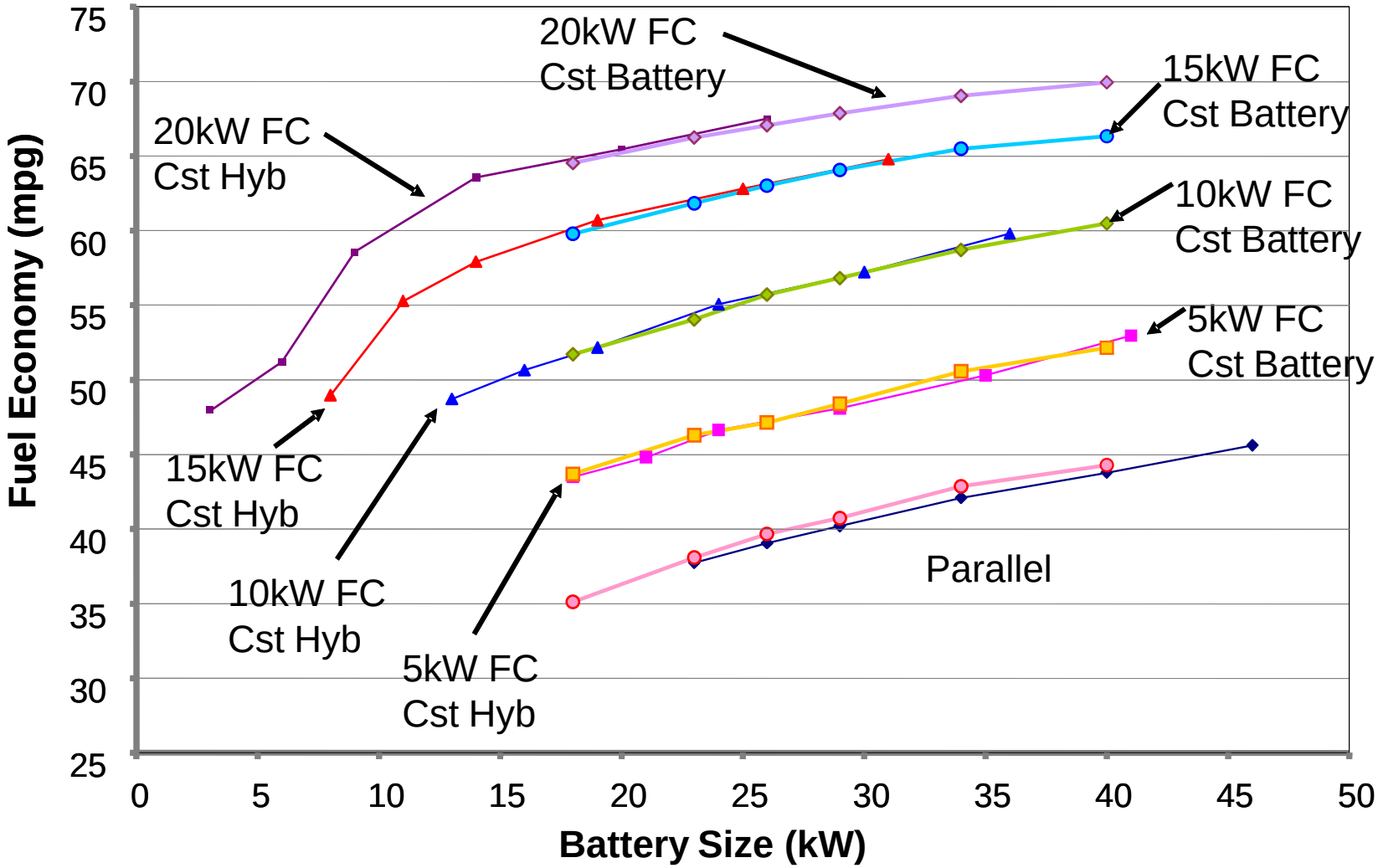
29-kW Battery – 20-kW Fuel Cell



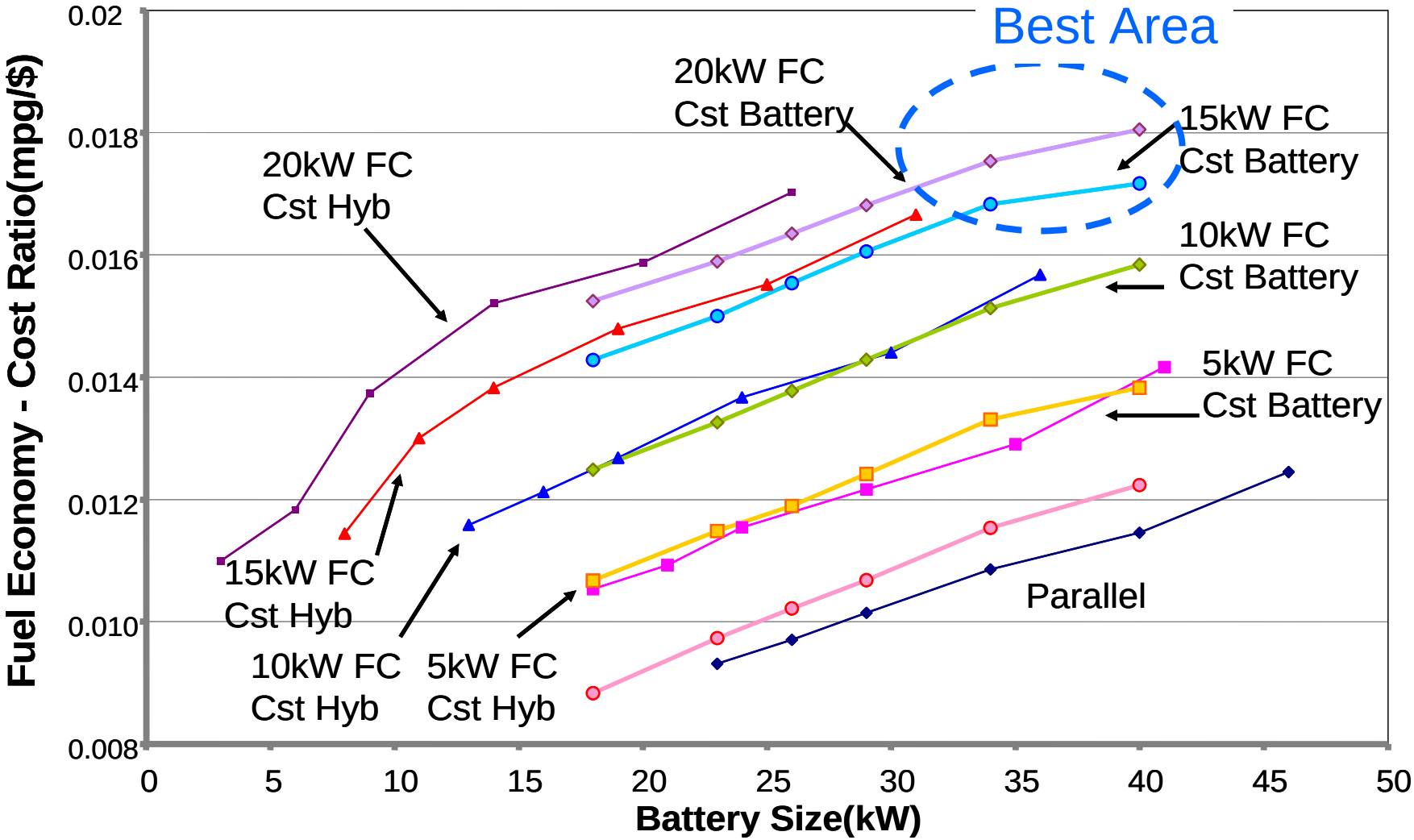
Energy Distribution during Battery Charging

Constant Battery

Comparative Fuel Economy Impact of Constant Hybridization vs. Battery Power



Large Batteries with 15- to 20-kW Fuel Cell Offer a Viable Compromise



Using Fuel Cell for Propulsion in a H2-ICE HEV can be Beneficial

- Addition of low power fuel cell allows both fuel economy and range increases.
- Adding a 10kW fuel cell system increases the range by more than 20% and 30% for a 20kW fuel cell.
- Similar fuel economy can be achieved with 20 kW FC combined with H2-ICE than Fuel Cell HEV.
- The fuel economy is more sensitive to the fuel cell power than the battery power.
- Maintaining constant battery size prevents the drop off in fuel economy that occurs due to reduced regenerative braking.
- Based on FreedomCAR goals, H2 ICE will be more cost effective when used in a hybrid vehicle vs. conventional.