Fuel Economy Sensitivity to Vehicle Mass for Advanced Vehicle Powertrains

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Work sponsored by
Lee Slezak,
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OFCVT/EERE/DOE

FreedomCAR & Fuel Partnership

SAE 2006 World Congress

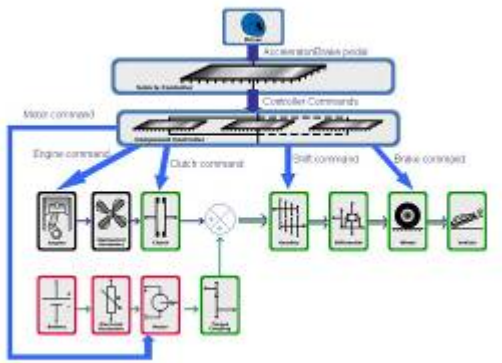
Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

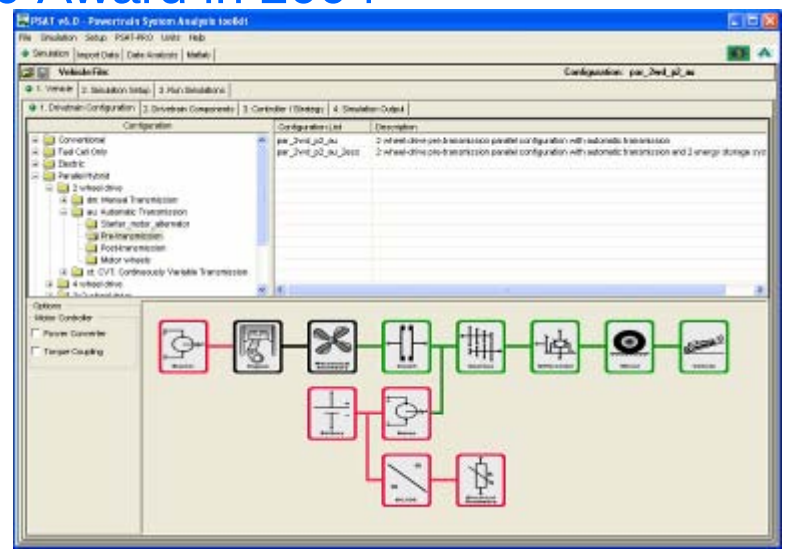
This Study Involves Knowing

- Our Sensitivity Definition: $\frac{dX}{dm}$
- Platforms: Compact, Midsize, SUV
- Drive Cycles: UDDS, HWFET
- Configuration: Conv, Parallel, Fuel Cell, Fuel Cell HEV
- Powertrain no resizing
- Powertrain with resizing
- Controller no retuning

Simulations Performed with PSAT

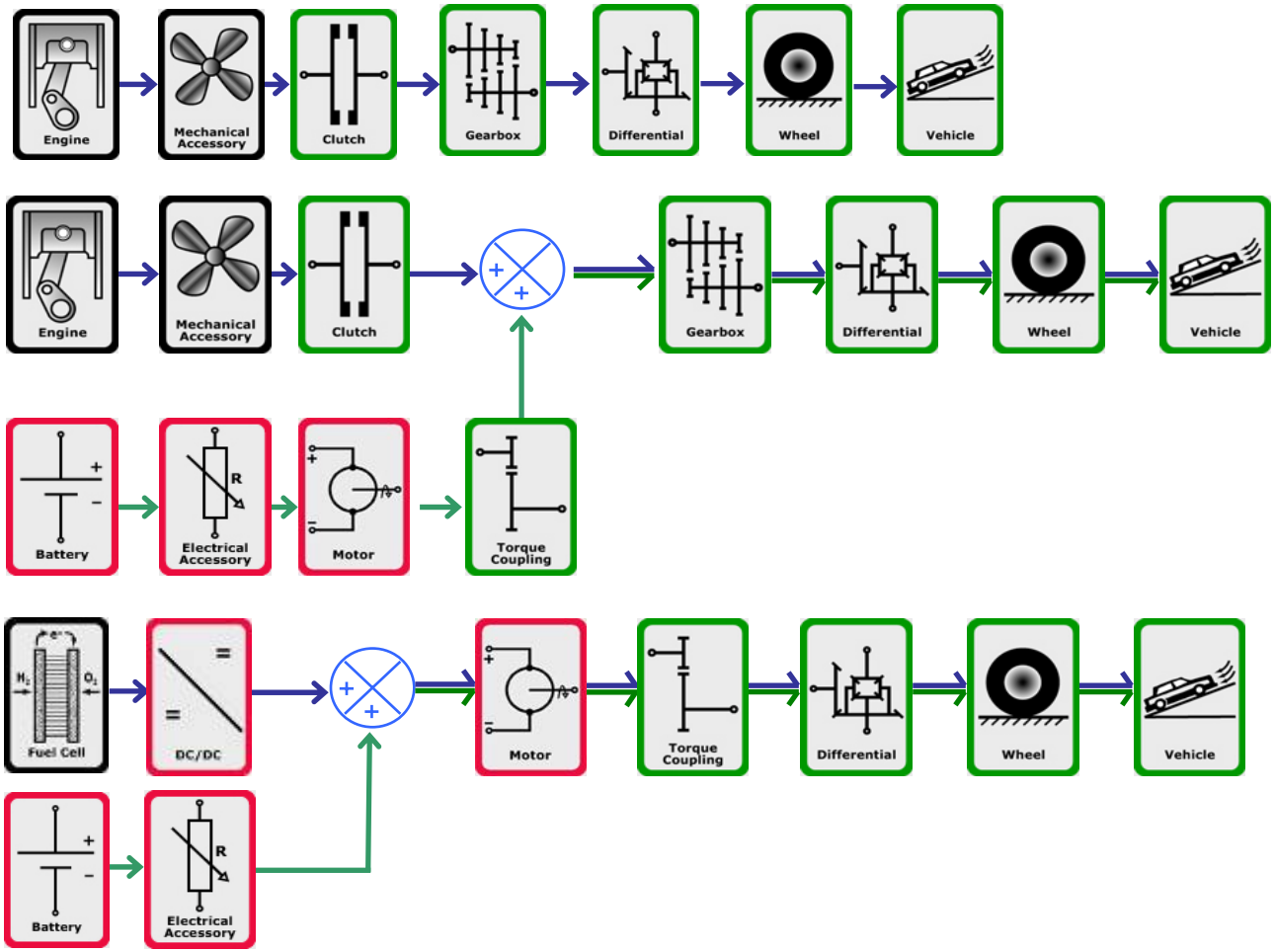
- Powertrain Systems Analysis Toolkit
- Argonne National Laboratory
- Models – Matlab & Simulink
- Graphical User Interface – C# .Net Framework
- Software Architecture – Ideal for Vehicle Level Controller Design
- Primary Vehicle Model - FreedomCAR & 21st Century Truck Partnership
- Research & Development Magazine 100 Award in 2004





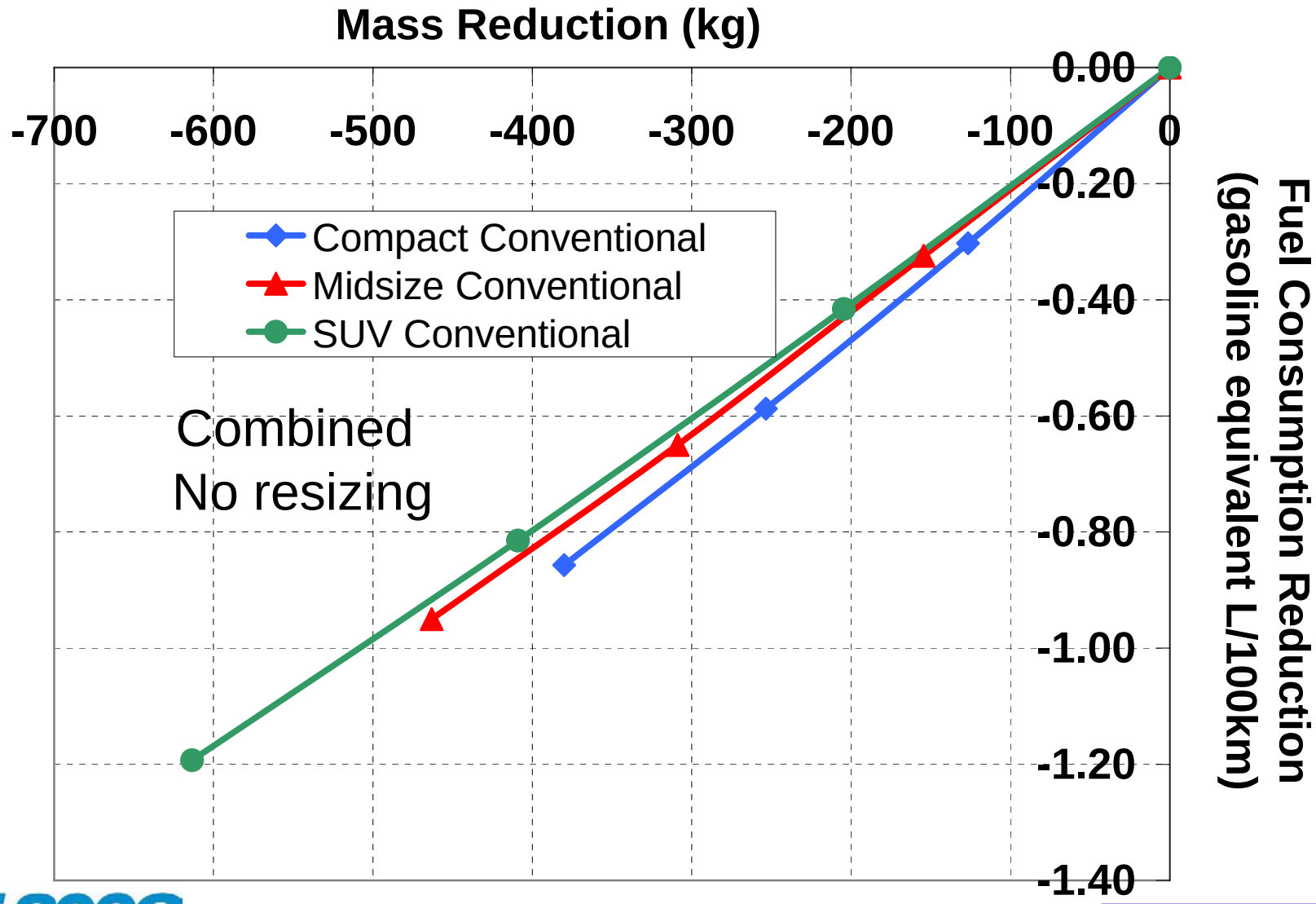
FreedomCAR Goals

Representatives of Today and Tomorrow

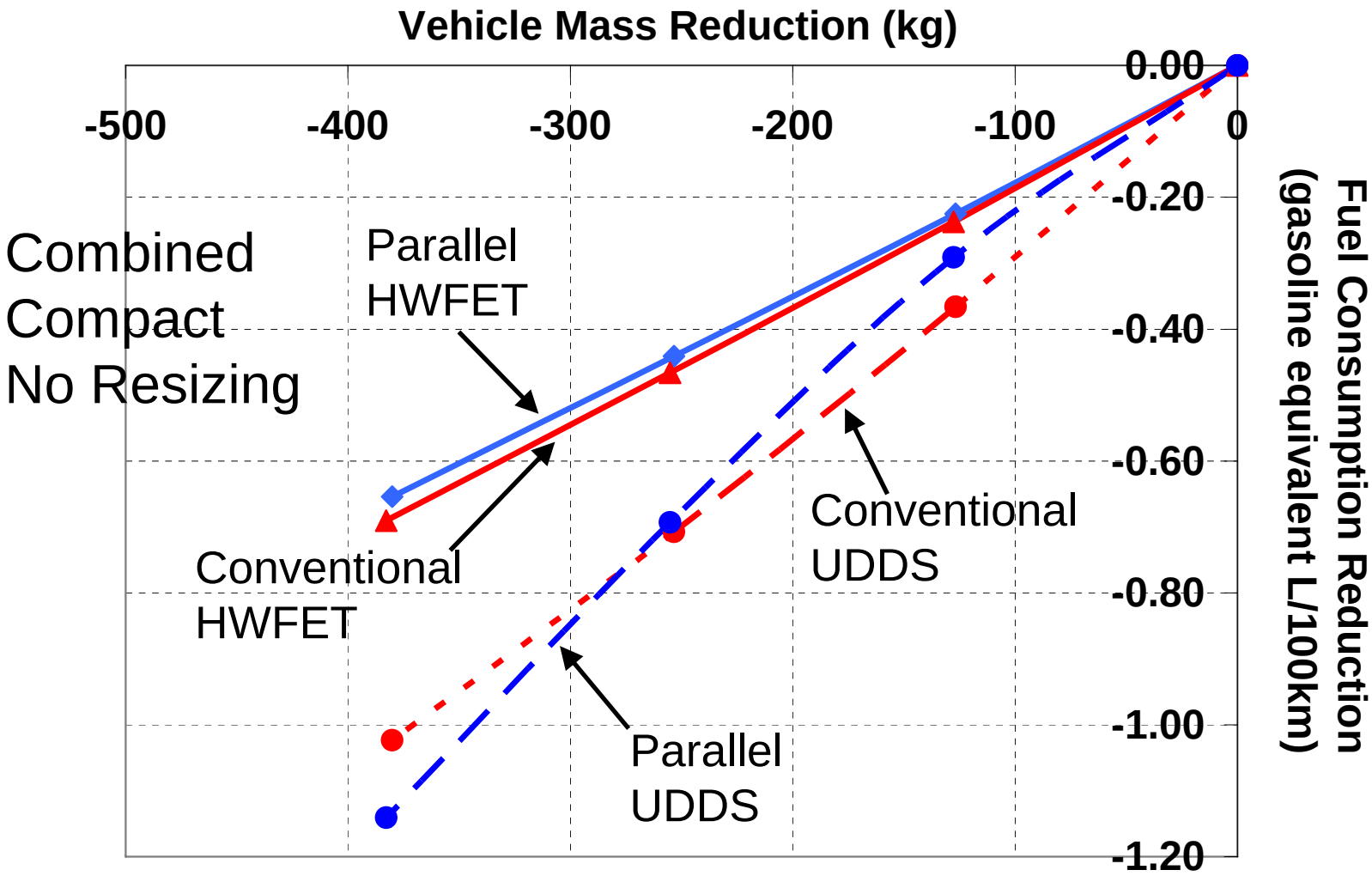


1) Conventional
2) Full Parallel
3) Fuel Cell Hybrid
4) Fuel Cell Only

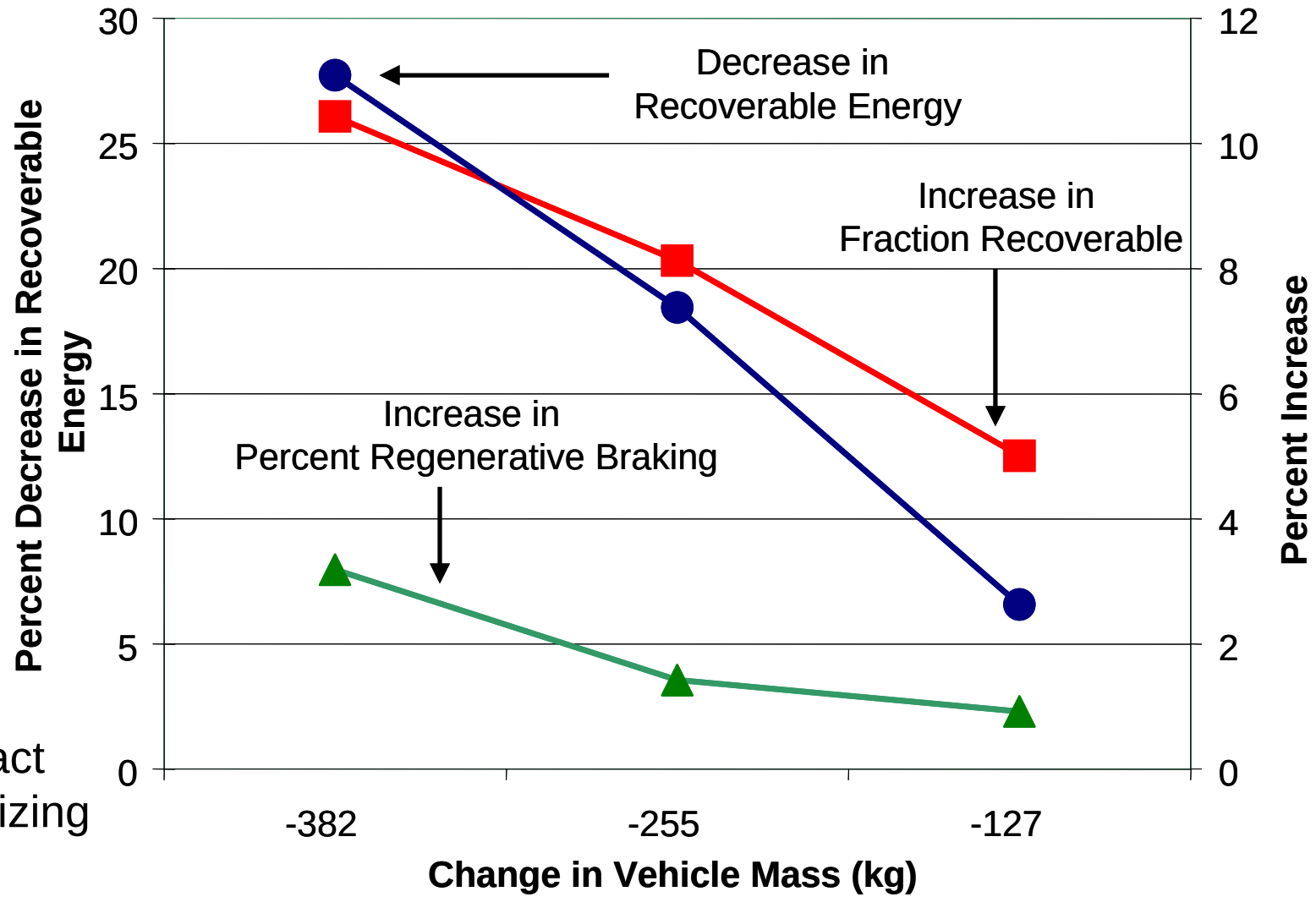
Vehicle Platform – Minimal Effect



Sensitivity UDDS > Sensitivity HWFET



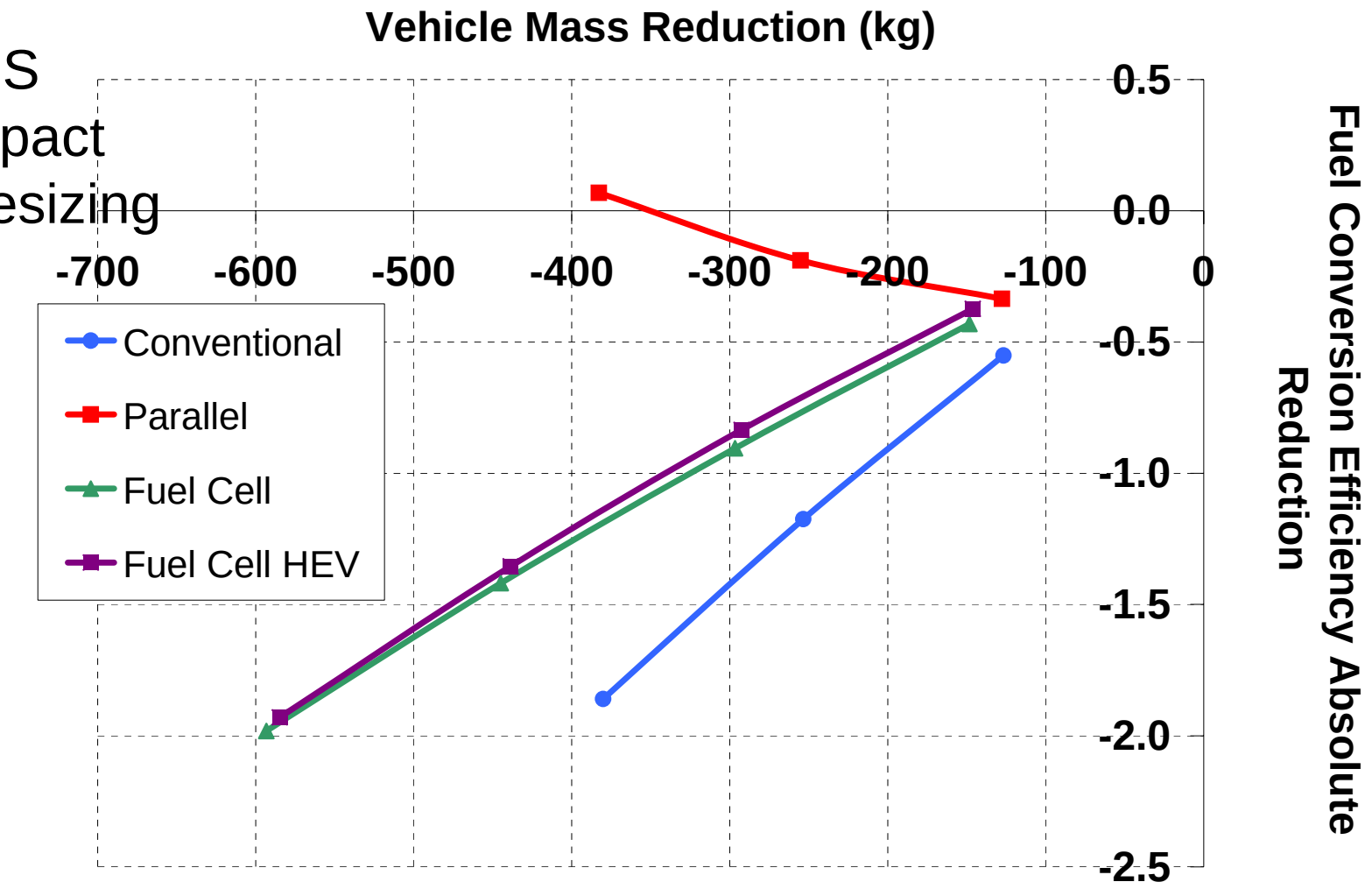
Vehicle Mass Decrease Significantly Affects Regenerative Braking Energy



UDDS
Compact
No resizing

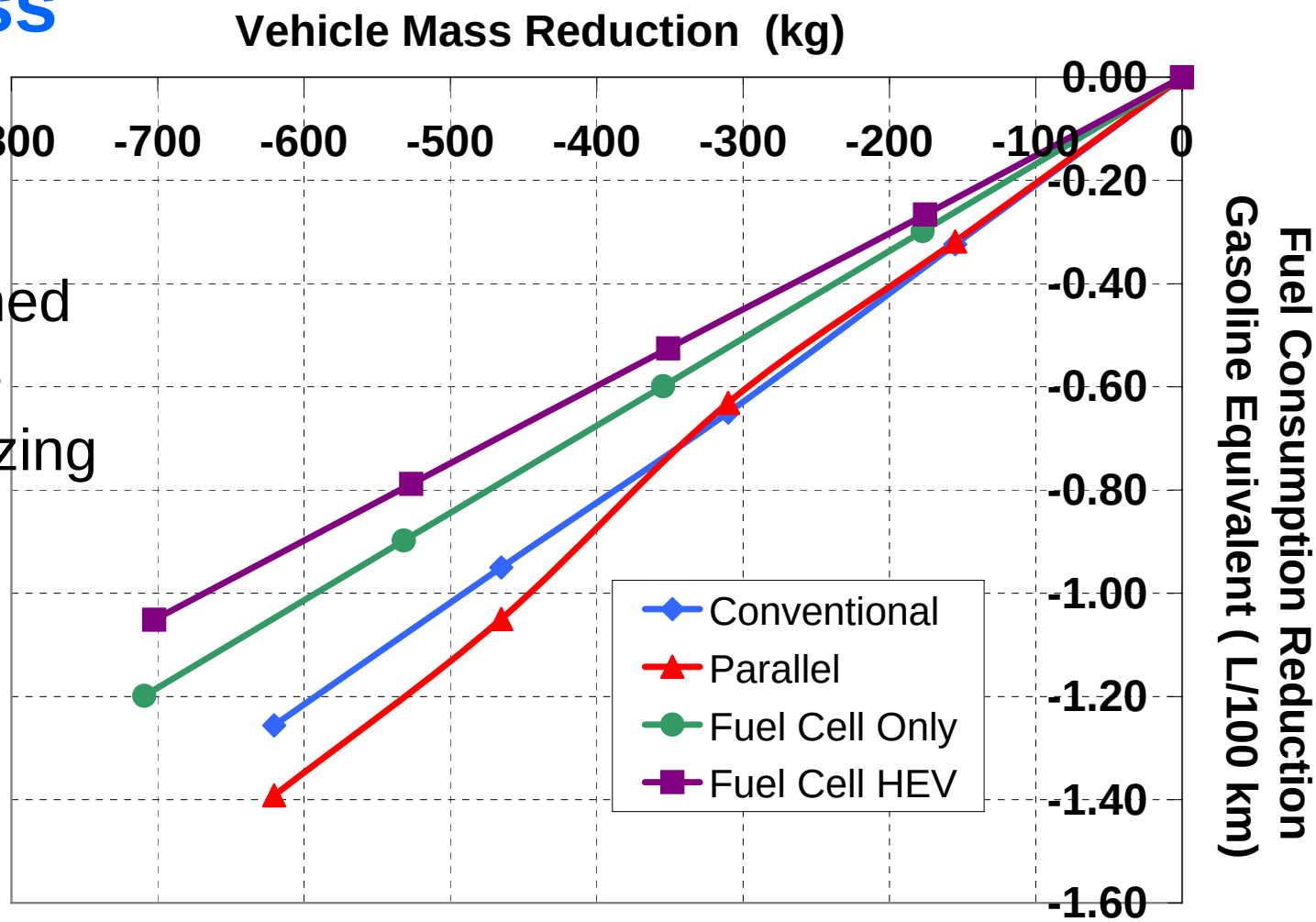
Parallel: Regen Insensitivity Partially Canceled by Engine Insensitivity

UDDS
Compact
No resizing

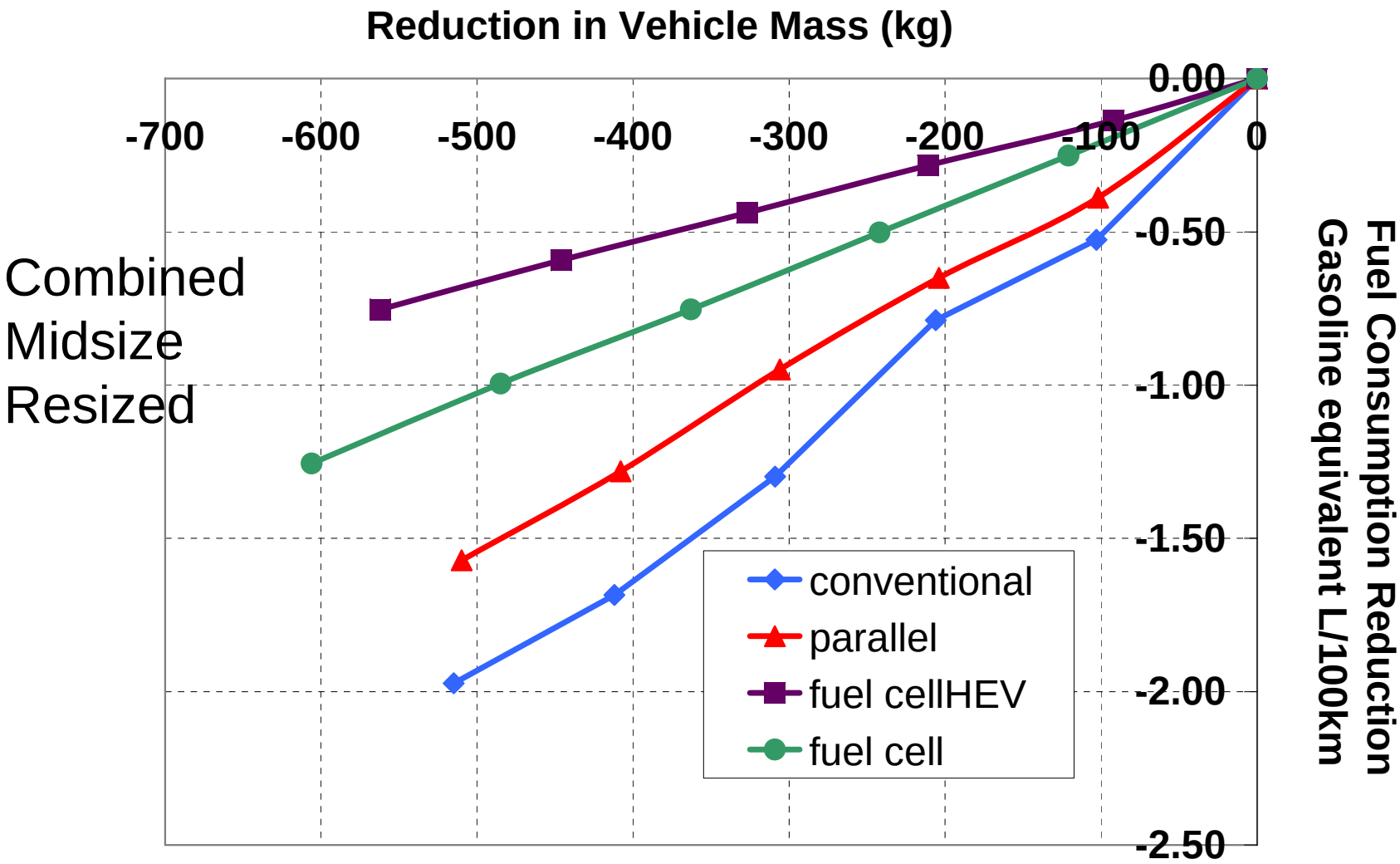


Configurations with Higher FCV Efficiency are Less Sensitive to Change in Vehicle Mass

Combined
Midsize
No resizing



Resizing Reveals Repercussions of Regen



Combined
Midsize
Resized

Scratching the Surface

$$\eta_{driveline}\eta_{fcv}P_{fuel} + \eta_{driveline}P_{ess} = P_{veh}$$

$$\frac{d}{dm}\left(\eta_{driveline}\eta_{fcv}P_{fuel} + \eta_{driveline}P_{ess}\right) = \frac{d}{dm}\left(P_{veh}\right)$$

$$\int_{a>0} \frac{d}{dm}\left(\eta_{driveline}\eta_{fcv}P_{fuel} + \eta_{driveline}P_{ess}\right)dt = \int_{a>0} \frac{d}{dm}\left(P_{veh}\right)dt$$

Aggressive cycles will lead to higher sensitivity

$$\frac{dE_{fuel}}{dm_{vehicle}} = \int_{a\geq 0} \frac{P'_{veh}}{\eta_{driveline}\eta_{fcv}} dt - \int_{a\geq 0} \frac{\eta'_{driveline} P_{fuel}}{\eta_{driveline}} dt - \int_{a\geq 0} \frac{\eta'_{fcv}\ P_{fuel}}{\eta_{fcv}} dt$$

$$- \int_{a\geq 0} \frac{\eta'_{driveline} P_{ess}}{\eta_{driveline}\eta_{fcv}} dt \quad - \int_{a\geq 0} \frac{P'_{ess}}{\eta_{fcv}} dt$$

The greater the fuel converter and driveline efficiencies, the lower the sensitivity

$$\frac{dE_{fuel}}{dm_{vehicle}} = \int_{a\geq 0} \frac{P'_{veh}}{\eta_{driveline}\eta_{fcv}} dt - \int_{a\geq 0} \frac{\eta'_{driveline} P_{fuel}}{\eta_{driveline}} dt - \int_{a\geq 0} \frac{\eta'_{fcv}\ P_{fuel}}{\eta_{fcv}} dt$$

$$- \int_{a\geq 0} \frac{\eta'_{driveline} P_{ess}}{\eta_{driveline}\eta_{fcv}} dt \ - \int_{a\geq 0} \frac{P'_{ess}}{\eta_{fcv}} dt$$

The greater the variation of fuel converter and driveline efficiencies, the lower the sensitivity

$$\frac{dE_{fuel}}{dm_{vehicle}} = \int_{a\geq 0} \frac{P'_{veh}}{\eta_{driveline}\eta_{fcv}} dt - \int_{a\geq 0} \frac{\eta'_{driveline} P_{fuel}}{\eta_{driveline}} dt - \int_{a\geq 0} \frac{\eta'_{fcv} P_{fuel}}{\eta_{fcv}} dt$$

$$- \int_{a\geq 0} \frac{\eta'_{driveline} P_{ess}}{\eta_{driveline}\eta_{fcv}} dt - \int_{a\geq 0} \frac{P'_{ess}}{\eta_{fcv}} dt$$

Battery Partially Eclipses a Mass Increase

$$\frac{dE_{fuel}}{dm_{vehicle}} = \int_{a\geq 0} \frac{P'_{veh}}{\eta_{driveline}\eta_{fcv}}dt - \int_{a\geq 0} \frac{\eta'_{driveline}P_{fuel}}{\eta_{driveline}}dt - \int_{a\geq 0} \frac{\eta'_{fcv}\ P_{fuel}}{\eta_{fcv}}dt$$

$$- \int_{a\geq 0} \frac{\eta'_{driveline}P_{ess}}{\eta_{driveline}\eta_{fcv}}dt \ - \int_{a\geq 0} \frac{P'_{ess}}{\eta_{fcv}}dt$$

Sensitivity for NO Resizing

Configuration	10% Vehicle Mass Reduction		20% Vehicle Mass Reduction		30% Vehicle Mass Reduction	
	% based on mpgge	% based l/100km	% based on mpgge	% based l/100km	% based on mpgge	% based l/100km
Conventional	4.2	4.1	8.9	8.2	13.5	11.9
Parallel	5.1	4.8	10.6	9.6	19	16
Fuel Cell	6.2	5.8	13.2	11.6	21.1	17.4
Fuel Cell HEV	6.1	5.7	12.7	11.3	20.3	16.9

Sensitivity for Resizing

Configuration	10% Glider Mass Reduction			20% Glider Mass Reduction			30% Glider Mass Reduction		
	% vehicle mass	% based on mpgge	% based l/100km	% vehicle mass	% based on mpgge	% based l/100km	% vehicle mass	% based on mpgge	% based l/100km
Conventional	6.6	6.6	7	13.3	10	11	19.9	16.4	19.6
Parallel	6.5	6	6.3	13	10	11	19.6	14.5	17
Fuel Cell	5.2	4.7	5	12	9.5	10.4	18.6	14.2	16.5
Fuel Cell HEV	6.7	3.2	3.3	13.3	6.6	7	20	10.2	11.4

From these simulations

- Platform – Minimal Effect
- Drive cycle – Aggressive Cycles
- No Resizing

1) Conventional: No Regen, ICE Drops

1) Parallel: Regen, ICE Constant

2) Fuel Cell: No Regen, FCV Higher

2) Fuel Cell HEV: Regen, FCV Higher

From these simulations

- With Resizing
  1. Conventional: No Regen, ICE Constant
  2. Parallel: Regen, ICE Constant
  3. Fuel Cell: No Regen, FCV Higher
  4. Fuel Cell HEV: Regen, FCV Higher
- FreedomCAR goals => lower mass sensitivity
  - ICE η ↑, FCV η ↑

Contact Info

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