Market Implications of Synergism Between Low Drag Area and Electric Drive Fuel Savings

by

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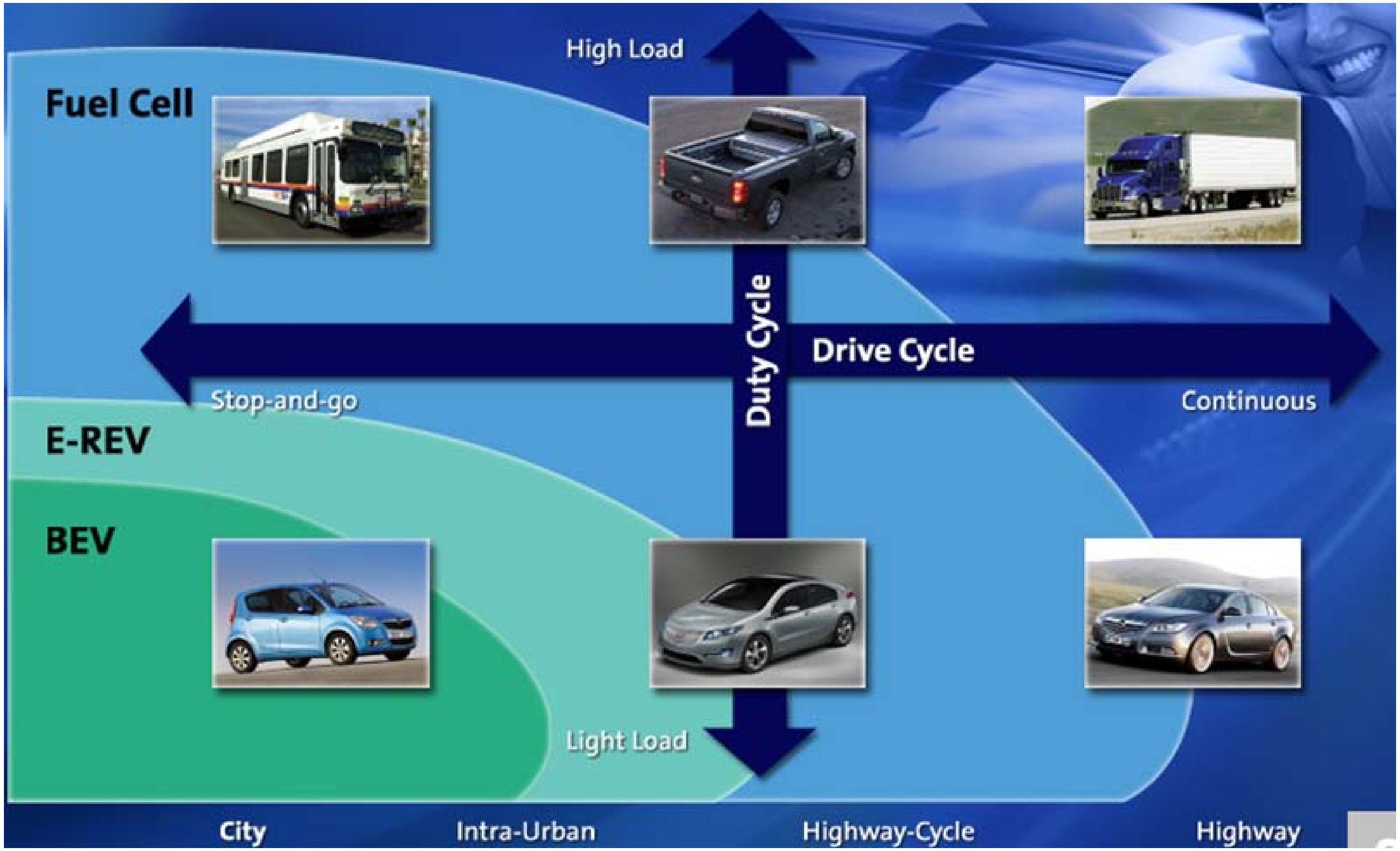
Our Evaluation is Within the "Space" Occupied by This Placement of the BEV and E-REV. Questions:

(1) Will the Conventional ICE hold the lower left & all blue in 2020?
(2) Will Split HEVs and PHEVs move into and hold the E-REV Space?
(3) Might the EV Compete in the same space as the E-REV, not the City?

Drag area (frontal area x drag coefficient)

Long duration power close to peak power



(1) City **(2) Urban** (3) Mixed **(4) Extra-Urban or Rural** (5) Highway (6) Intercity Interstate ?

Intra-Urban

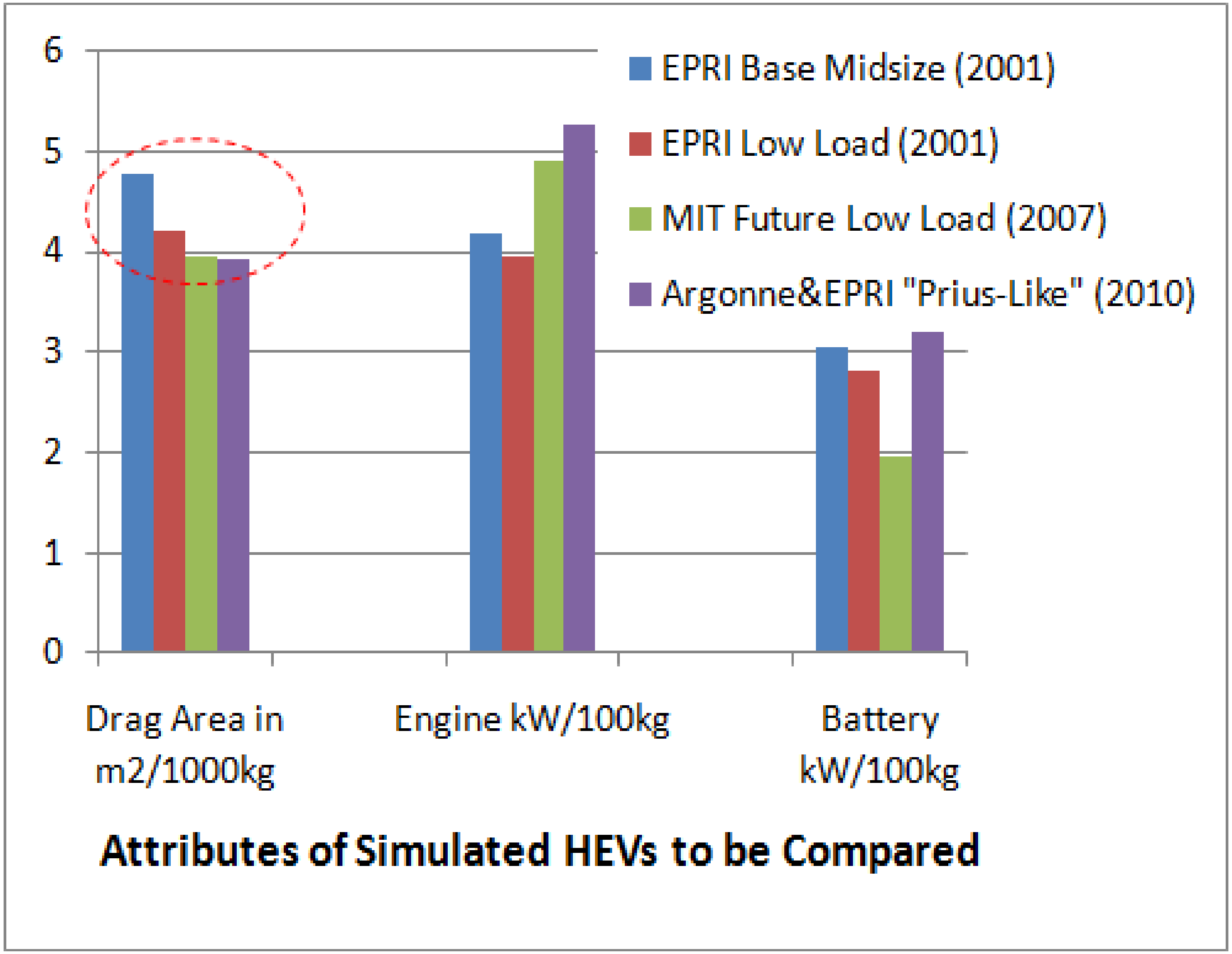
Needs of Electric Drive Have Pushed Manufacturers to Reduce Car Drag Area

These choices imply intentions to reduce vehicle tractive load when driving at suburban and Intercity Interstate highway speeds, to expand marketability of electric drive powertrains.

New suburbs are where new garages and modern residential electric infrastructure are found. NHTS results also show more miles and hours per day at higher speed; thus faster return on investment.

Valuable Synergism Between Reduced Drag Area and More HEV Fuel Savings in Intra/Extra-Urban Driving Is Implied by Cross-Study Comparisons

Across HEVs compared, Drag Area per unit vehicle mass dropped consistently from the EPRI 2001 base case vs. 3 HEVs of the future. Less air drag means brakes must exert more braking force. So … regen captures more energy.



A Relatively Few Vehicles, Driven Many Miles/Day, Equal the Miles of Many Driven a Few Miles/Day. We Evaluate These Two Markets Separately.

Charging infrastructure costs promote a one charger option for vehicles returning home and not used for work.
The vast majority of vehicles travel < 50 miles/day but …
the majority of miles is by vehicles traveling > 50 miles/day.

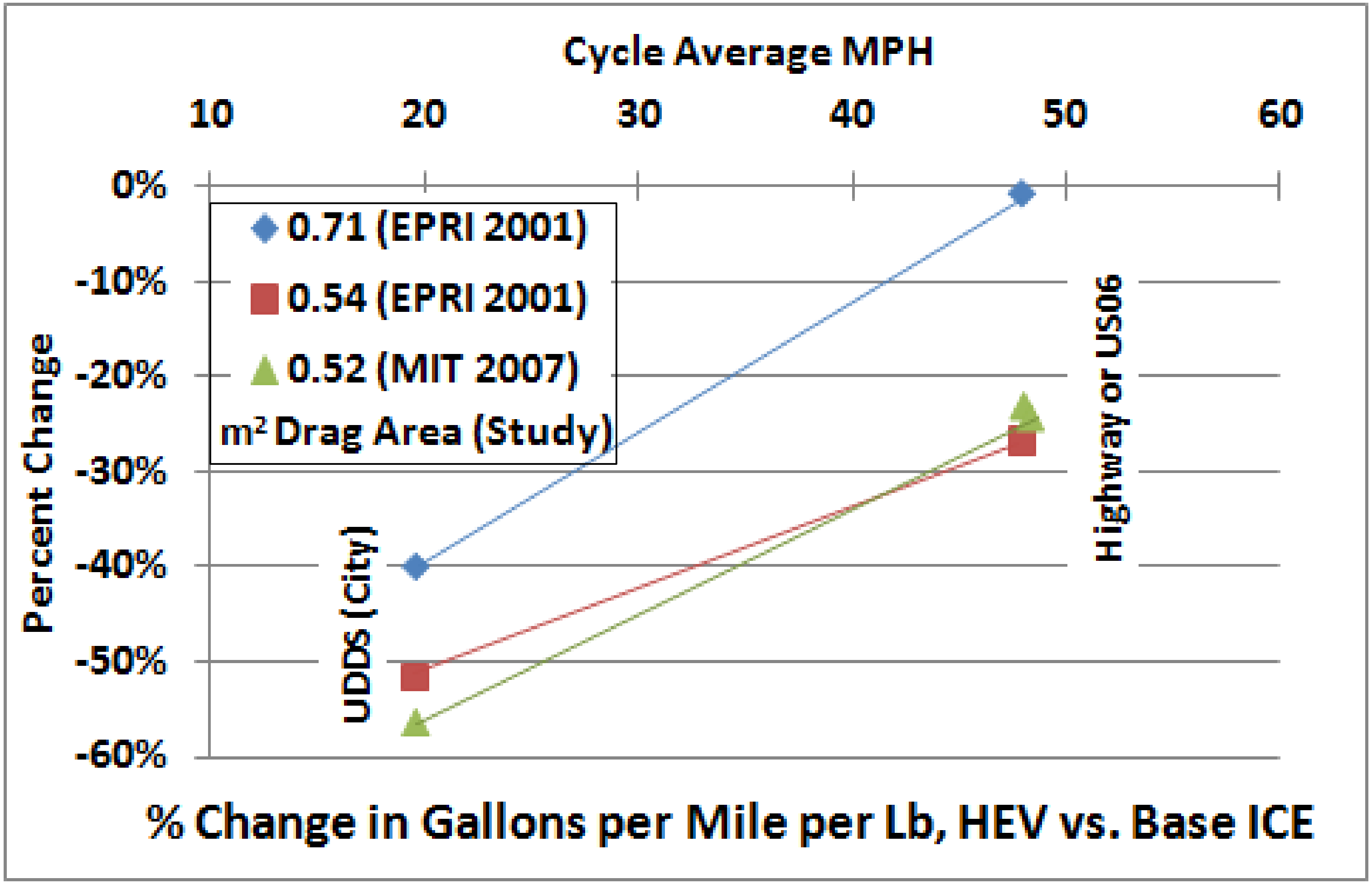
	Sample Counts, Thousands				Per Vehicle Averages		
Vehicle Age Group, Day's Travel Pattern	Vehicles	Trips	Miles	Hours	Hr/day	MPH	Mi/day
All ages, all sample vehicles	32.0	142.1	1,286.5	41.4	1.29	31.0	40.2
All ages, not Home-to-Home	4.5	17.3	226.2	6.3	1.41	35.8	50.5
All ages, Home to Home (H-to-H)	27.5	125.1	1,060.3	35.1	1.28	30.2	38.5
< 10 years old H-to-H	20.7	96.4	842.9	27.3	1.32	30.8	40.8
< 10 yrs, < 50 mi./day, work only H-to-H	2.8	7.0	59.8	2.2	0.78	27.8	21.6
< 10 yrs, < 50 mi./day, work & non-work H-to-H	4.3	22.7	112.9	4.8	1.12	23.6	26.3
< 10 yrs, < 50 mi./day, non-work only H-to-H	8.4	36.7	**164.0**	7.4	0.88	**22.1**	**19.4**
< 10 yrs, > 50 mi./day, work only H-to-H	0.7	2.3	66.2	1.6	2.17	42.3	91.9
< 10 yrs, > 50 mi./day, work & non-work H-to-H	2.1	13.4	189.8	5.1	2.44	37.4	91.3
< 10 yrs, > 50 mi./day, non-work only H-to-H	2.4	14.3	**250.1**	6.3	2.66	**39.5**	**105.1**
Car, < 10 yrs, > 50 mi./day, non-work only H-to-H	1.3	7.5	131.5	3.3	2.63	39.3	103.5
Same as above, weekend	0.5	2.9	53.4	1.3	2.53	40.8	103.2
Same as above, weekday	0.8	4.6	78.1	2.0	2.70	38.3	103.6

"Real World" "On-Road" "Intra-Urban" Driving Cycles With MPH Close to Those for Evaluated Groups are Used

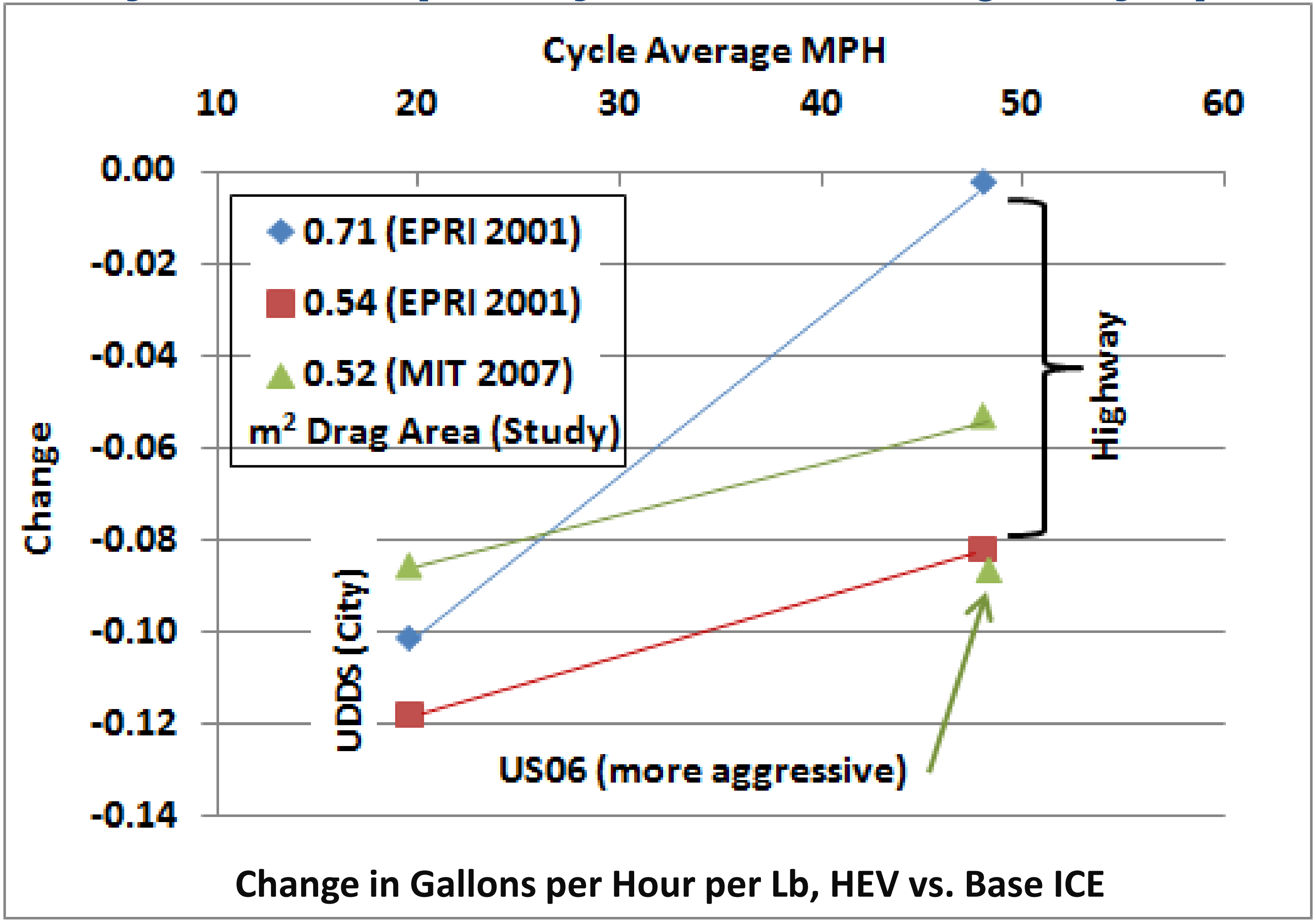
Schedule Name	Average Speed [mph]	Cycle Distance [miles]	Average Acceleration [meters/sec^2]	Average Deceleration [meters/sec^2]
UDDS (City cycle)	19.6	7.45	0.505	-0.578
LA92 (Urban, with Interstate)	**24.6**	**9.82**	**0.673**	**-0.754**
Artemis Extra Urban (Europe)	**37.5**	**10.2**	**0.482**	**-0.498**
US06 (High speed Interstate)	48.0	7.51	0.670	-0.728
Highway (no Interstate)	48.3	10.3	0.194	-0.222

GM's urban driving investigation showed UDDS, Highway, and US06 to be atypical.
UDDS – 97% of urban drivers would have a higher tractive load
Highway – 79% of urban drivers would have a higher tractive load
US06 – 97% of urban drivers would have a lower tractive load
Source: A. Weverstad. Fuel Displacement and CO2 Benefits of Vehicle Electrification (GM)

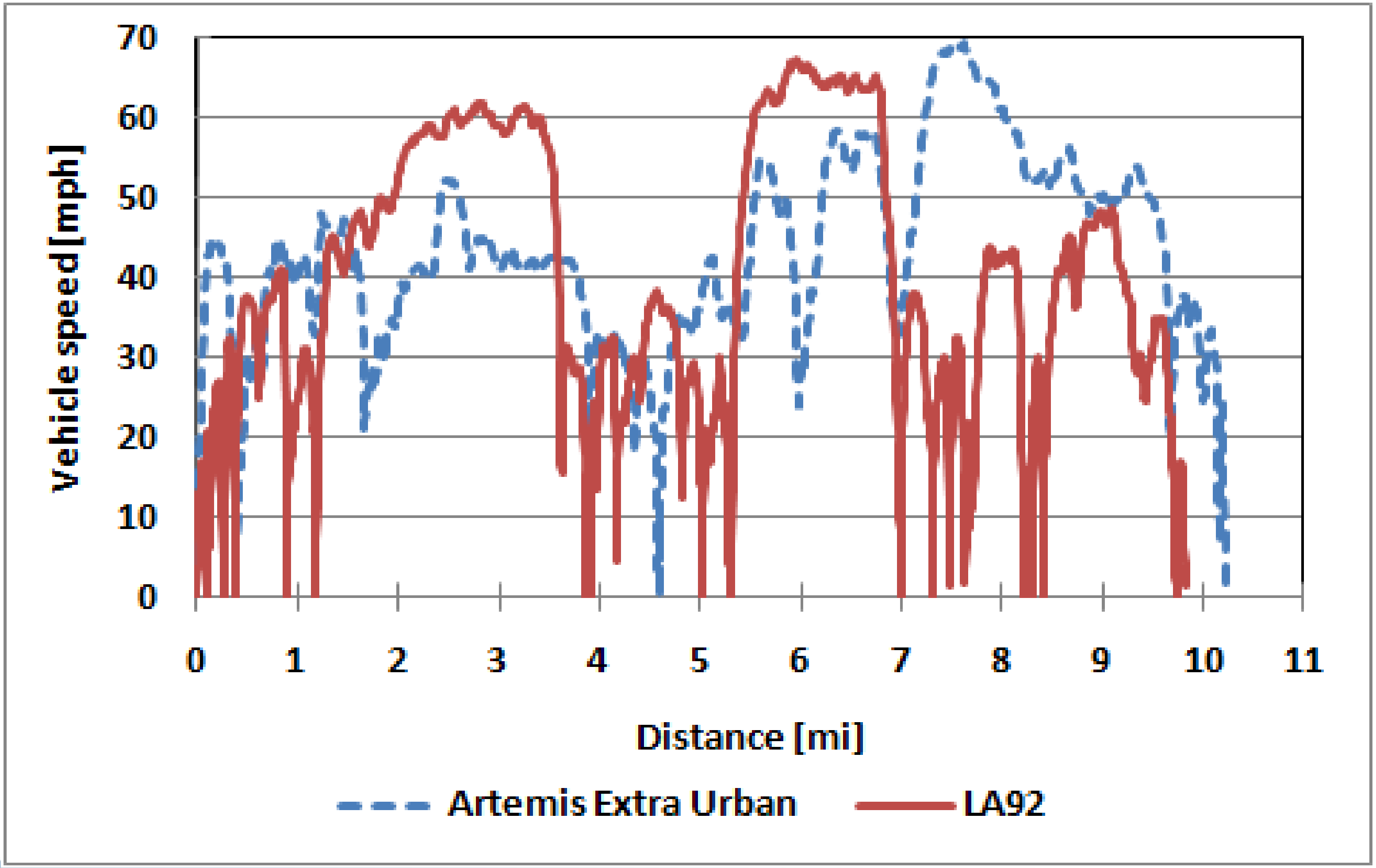
Prior Studies Have Examined the UDDS, Highway, and US06 Cycles. The 2001 EPRI Base Case Had a High Drag Area. Prius/Volt-like Drag Areas (EPRI Low Load & MIT) Improved 48 MPH "per Mile" Results Significantly



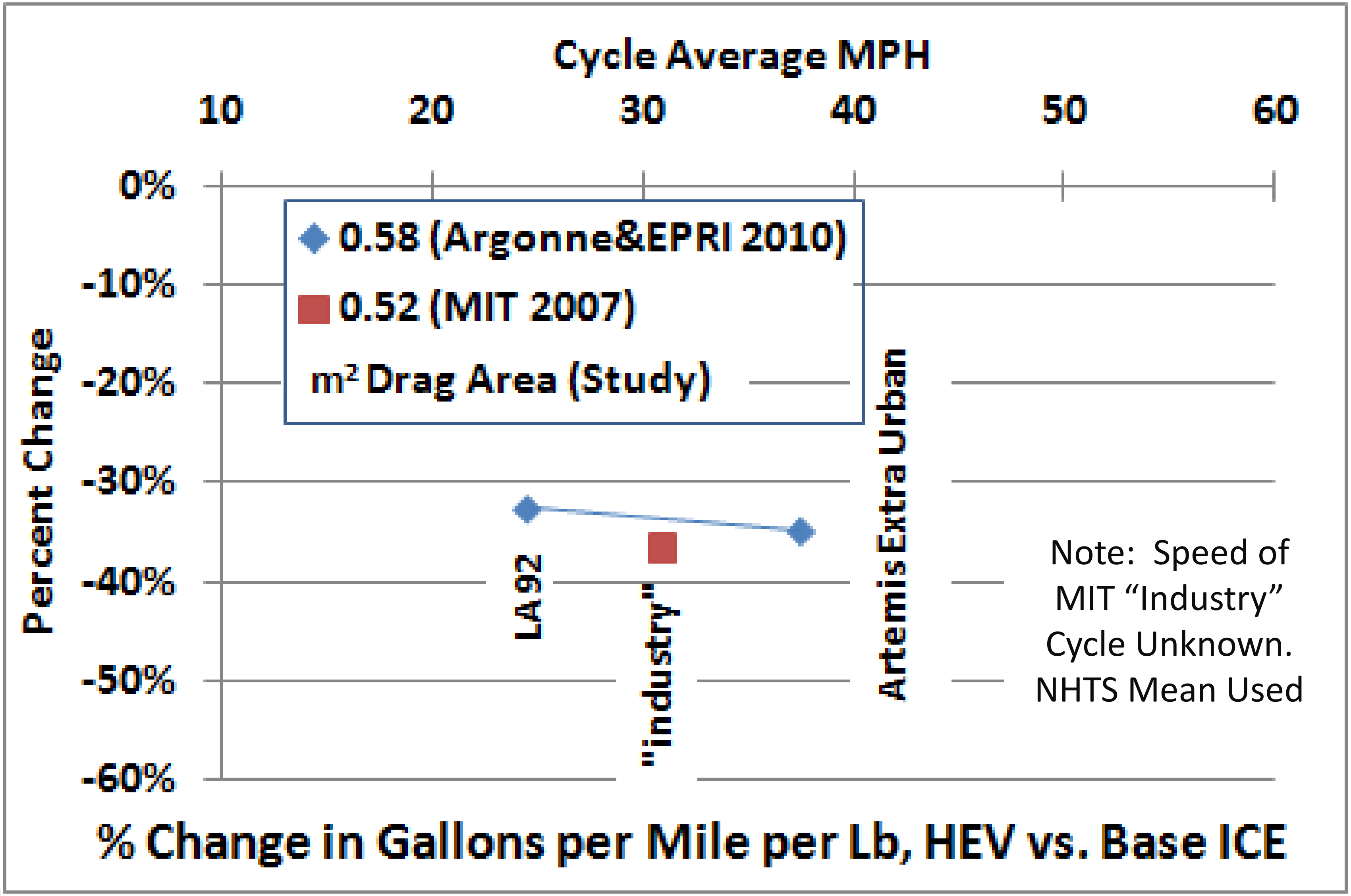
Absolute Savings per Hour With Low Drag Area Bring Highway HEV Benefits Nearer the City Cycle. More Hrs/Day Pushes up Daily Benefit at Highway Speeds



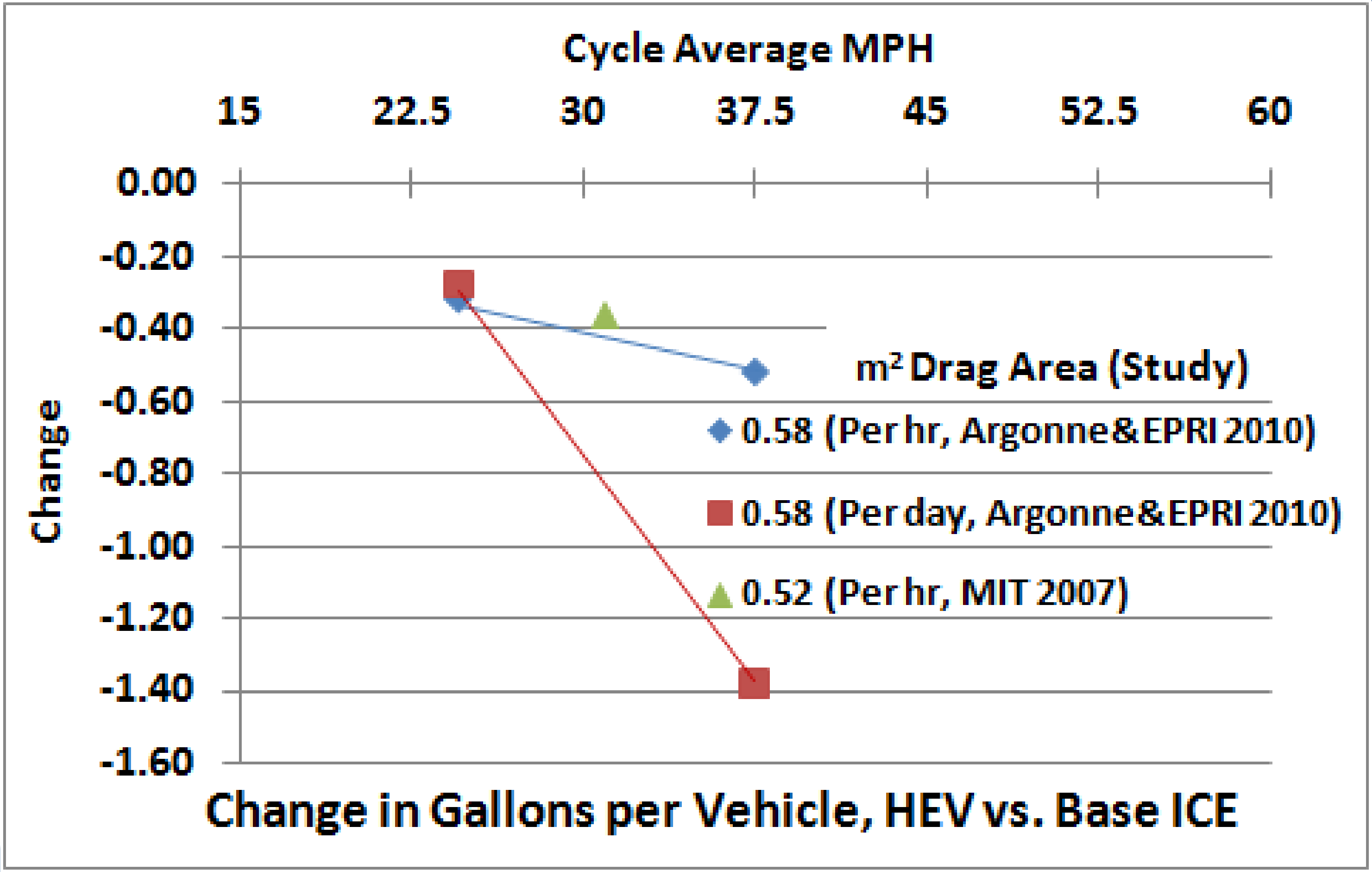
2010 Argonne/EPRI Cycles are "Real World." Top Speeds are Similar, Stops & Low Speeds Differ. Drag Area is Important on Artemis Extra Urban. Like US06, Artemis Extra Urban > Deceleration Rates than Highway



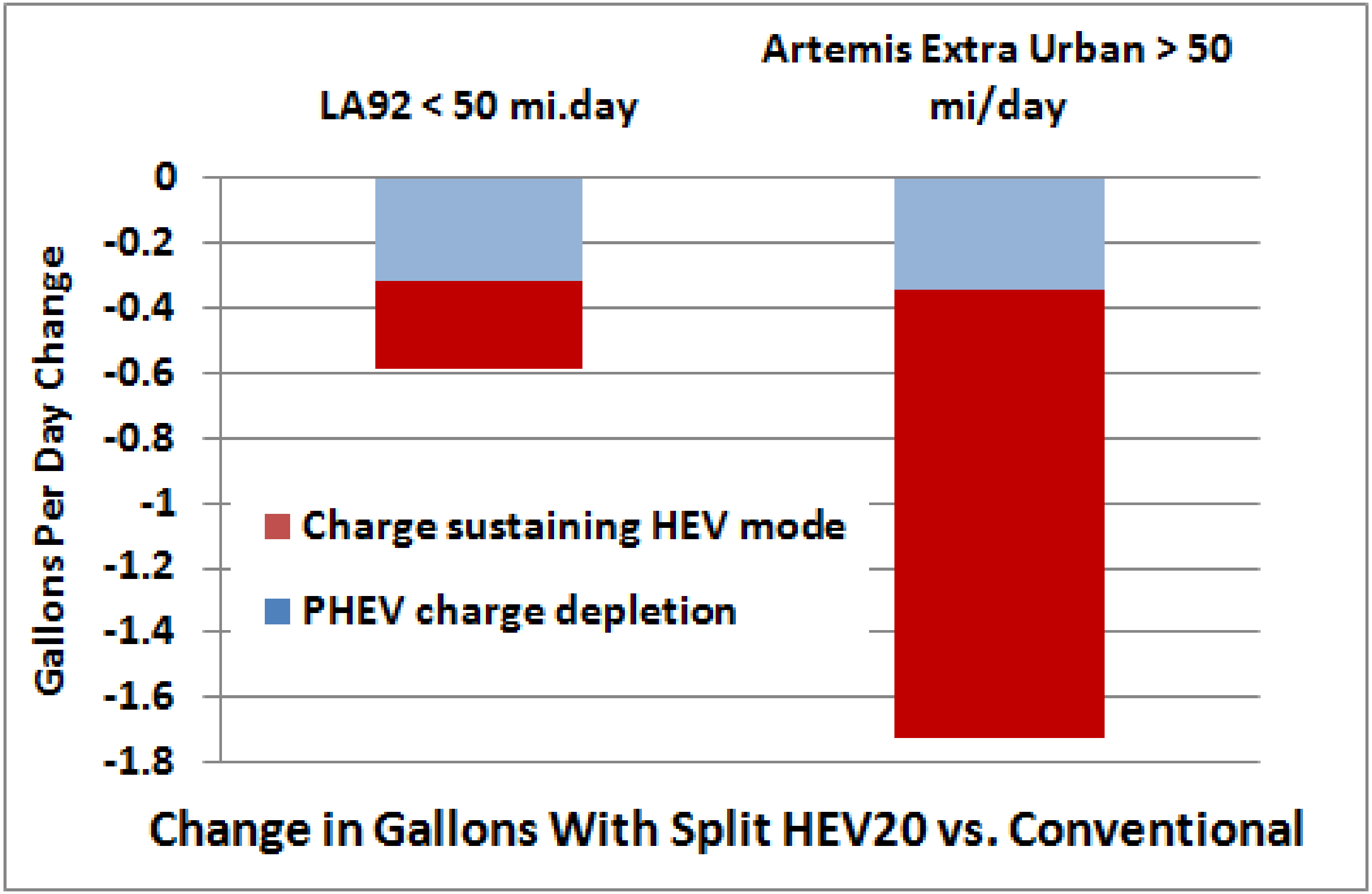
Argonne/EPRI 2010 On-Road Results Predict ~ Uniform Percent Cuts vs. MPH for HEVs (and PHEVs in CS Mode)



Argonne/EPRI 2010 Results Predict Increasing Absolute Cuts vs. MPH for HEVs (and PHEVs in CS Mode). High Hrs. of "Extra Urban" Use Push Daily Fuel Cuts Way Up



A Key Estimate is Significant "Extra Urban" Value of Charge Sustaining HEV Operation. After One Charge/Day, More Charge Sustaining Use Will Pay Off



Costs of Upgrading Charging Circuits Can be Significant. Trenching Costs Push up Public Infrastructure Costs.

Our assumptions –

Level 1 – plugs are within 25 feet, no circuit upgrade cost PHEV10, PHEV20, E-REV20, E-REV30, E-REV40 in LA92. Cord cost $200

Level 2 – Circuit boards in garage, no trenching of new cable. EVs must have level 2 due to need for at least some public charging and to charge quickly during the day when daily use exceeds range (Artemis Urban). E-REV40 upgrade, 2 charges/day evaluated. 0.25 public charge points per EV for Artemis Urban case; 0.05 for LA92 (rare need, range more than adequate). Level 2 house upgrade $1300, public charge point $1800. Less than 0.02 fast charge points per EV, at $34,000 per charge point. Cord cost $350.

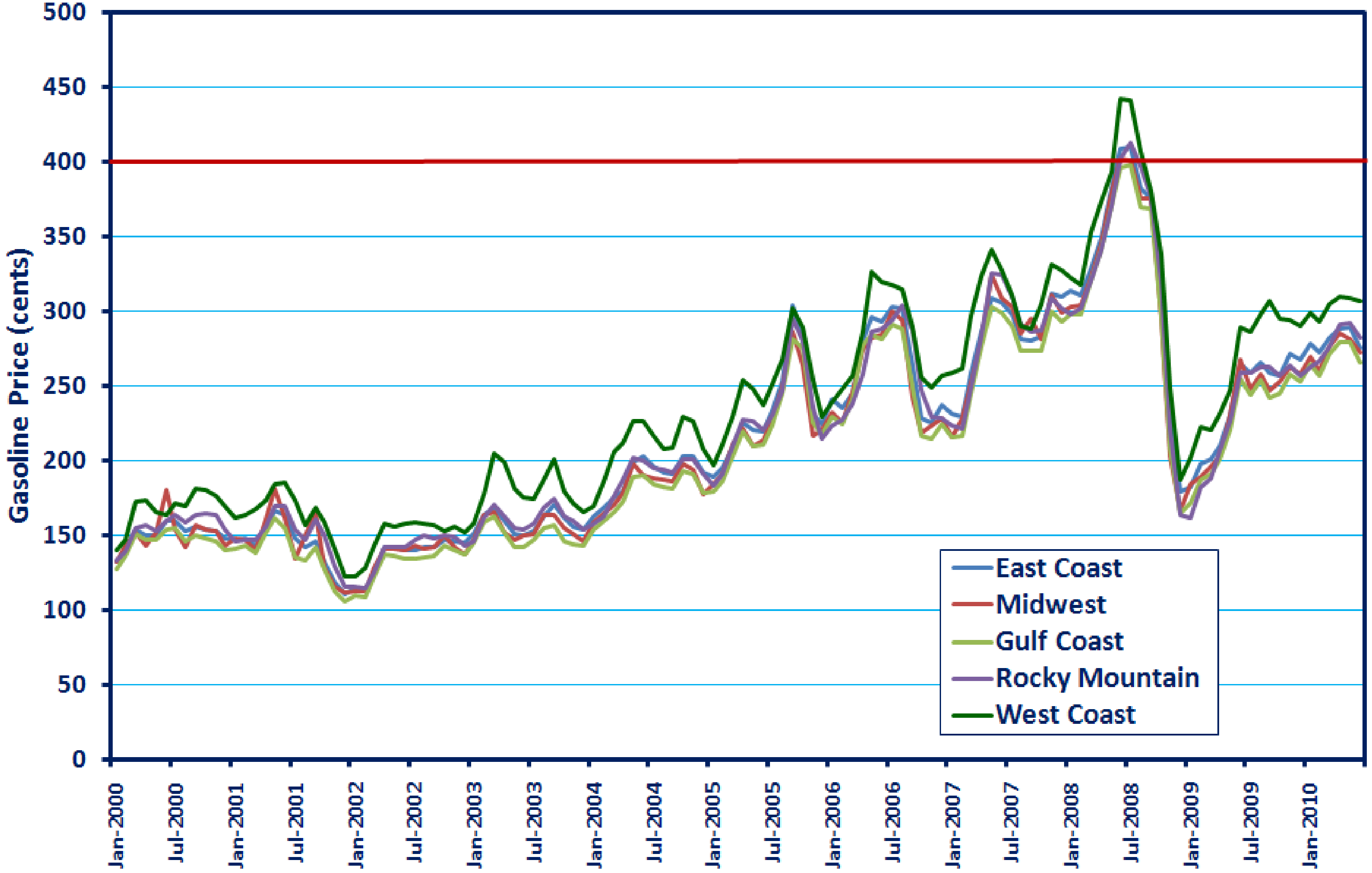
Caveat: 2 charges/day likely requires battery replacement; not evaluated.

At 105 Miles/Day, All 'Extra Urban" PHEVs & E-REVs Charged Once/Day, Drive Far More Miles in CS than CD Mode. EVs Must Have a Second Partial Charge

		Cost of Energy on Daily Average Miles Basis (329 days/Year Use)											
		<50 Miles, Home-to-Home, Non-work Daily Energy Use Over 19.4 Miles (LA92 Cycle)						>50 Miles, Home-to-Home, Non-work Daily Energy Use Over 105.1 Miles (Artemis Extra Urban Cycle)					
Vehicle Type	RPE	Galn	Est AER Miles	Wall Plug kWh	Fuel Cost ($4/g)	Electricity Cost ($0.1/kWh)	Total Energy Cost	Gallon	Est AER Miles	Wall Plug kWh	Fuel Cost ($4/g)	Electricity Cost ($0.1/kWh)	Total Energy Cost
Conventional	$19,665	0.825			$3.30		$3.30	3.501			$14.00		$14.00
Split CS HEV	$24,230	0.575			$2.30		$2.30	2.366			$9.47		$9.47
Split PHEV10	$26,065	0.374	8.9	2.7	$1.50	$0.27	$1.76	2.191	9.4	2.7	$8.77	$0.27	$9.03
Split PHEV20	$27,810	0.207	12.7	5.3	$0.83	$0.53	$1.36	2.017	16.2	5.3	$8.07	$0.53	$8.60
EREV 20	$30,280	0.217	12.1	4.9	$0.87	$0.49	$1.36	2.162	15.0	4.9	$8.65	$0.49	$9.13
EREV 30	$31,685	0.036	18.3	7.4	$0.14	$0.74	$0.89	2.030	23.2	7.4	$8.12	$0.74	$8.86
EREV 40	$33,130	0.000	24.8	7.8	$0.00	$0.78	$0.78	1.415	31.0	15.0	$5.66	$1.50	$7.16
EV 100	$35,755		64.1	6.5		$0.65	$0.65		76.2	29.7		$2.97	$2.97

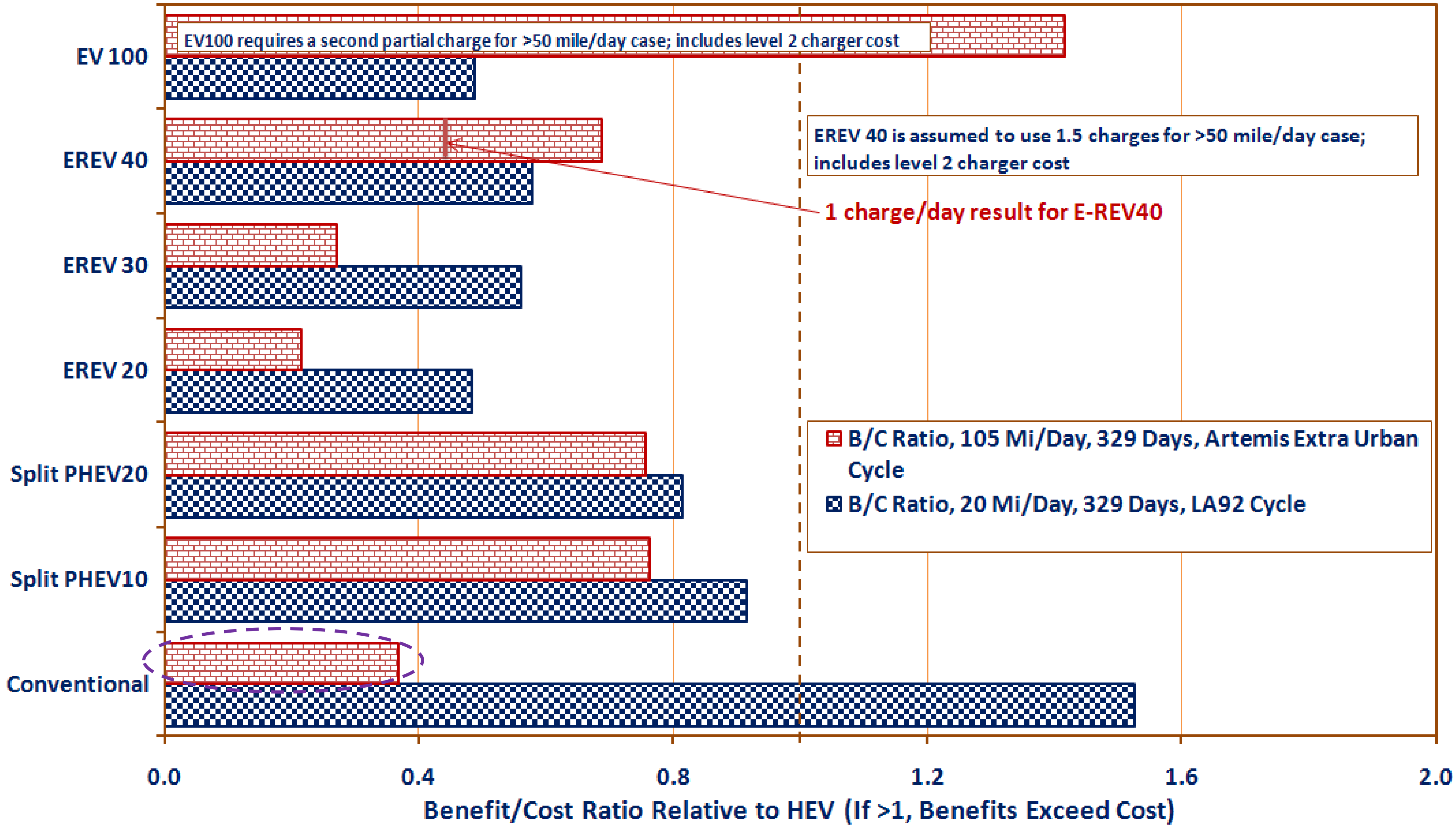
Notes: Rated "All electric" operation charge depleting distance is based on the UDDS driving cycle.
Electric drive components for the split HEVs are sized to allow all electric operation on the UDDS for the design distance.
E-REV and EV motor and battery pack power enable all electric operation on these cycles. The split HEV10 and 20 deplete blended.
On the driving cycles simulated, which are more aggressive, charge depletion distance is less.
The EV initial costs include costs of upgrading to level 2 charging to allow 2 charges per day. All others use level 1 charging, 1 charge/day
Net present value of savings is discounted at 5%/yr, assuming a ten year life.

The Focus of Our Analysis is Intermediate Term. We Use $4/gal and $5/gal Cases for 2020 Evaluation in This Presentation.

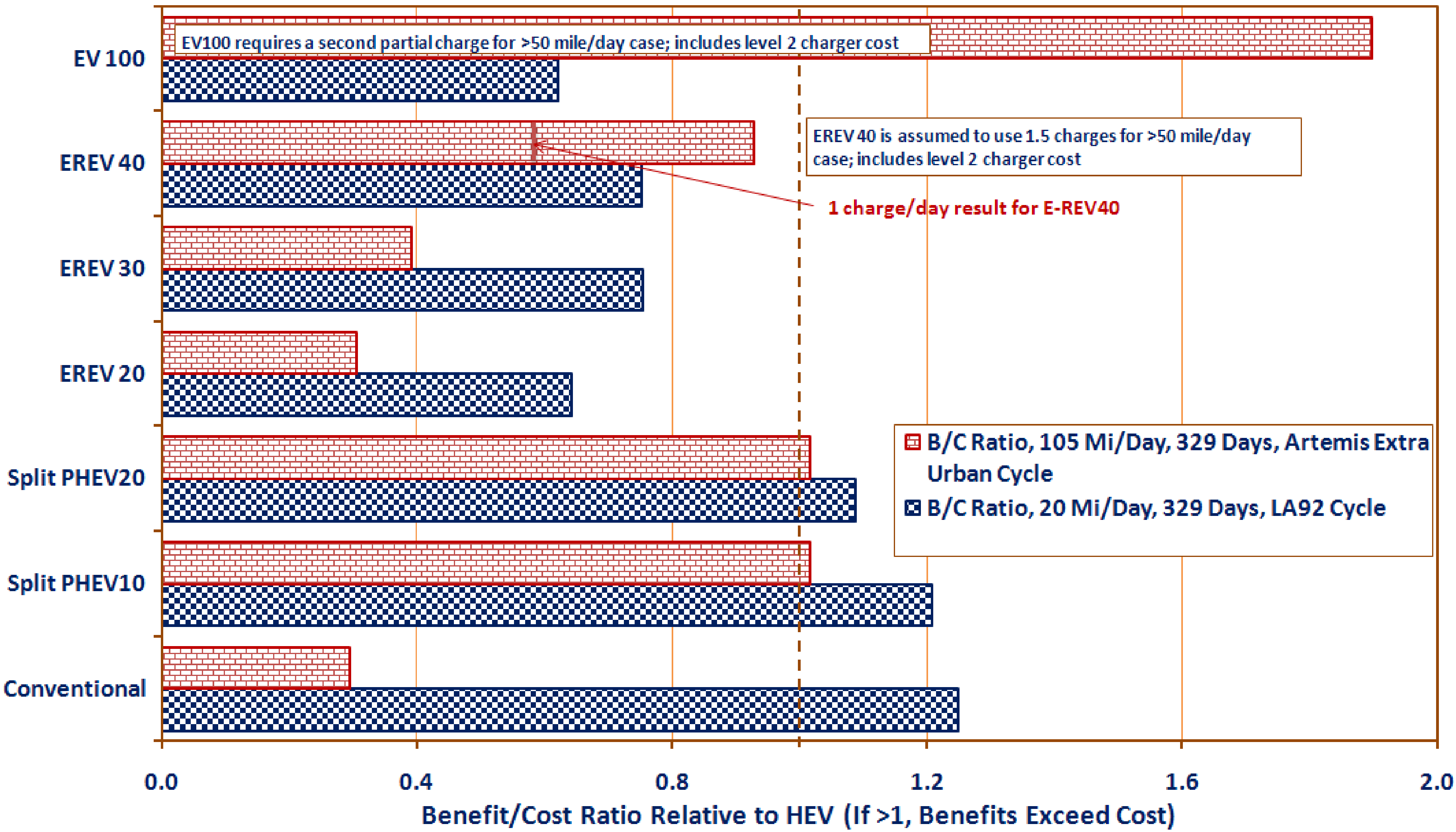


Source: U.S. EIA Retail Gasoline and Diesel Prices. http://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_m.htm

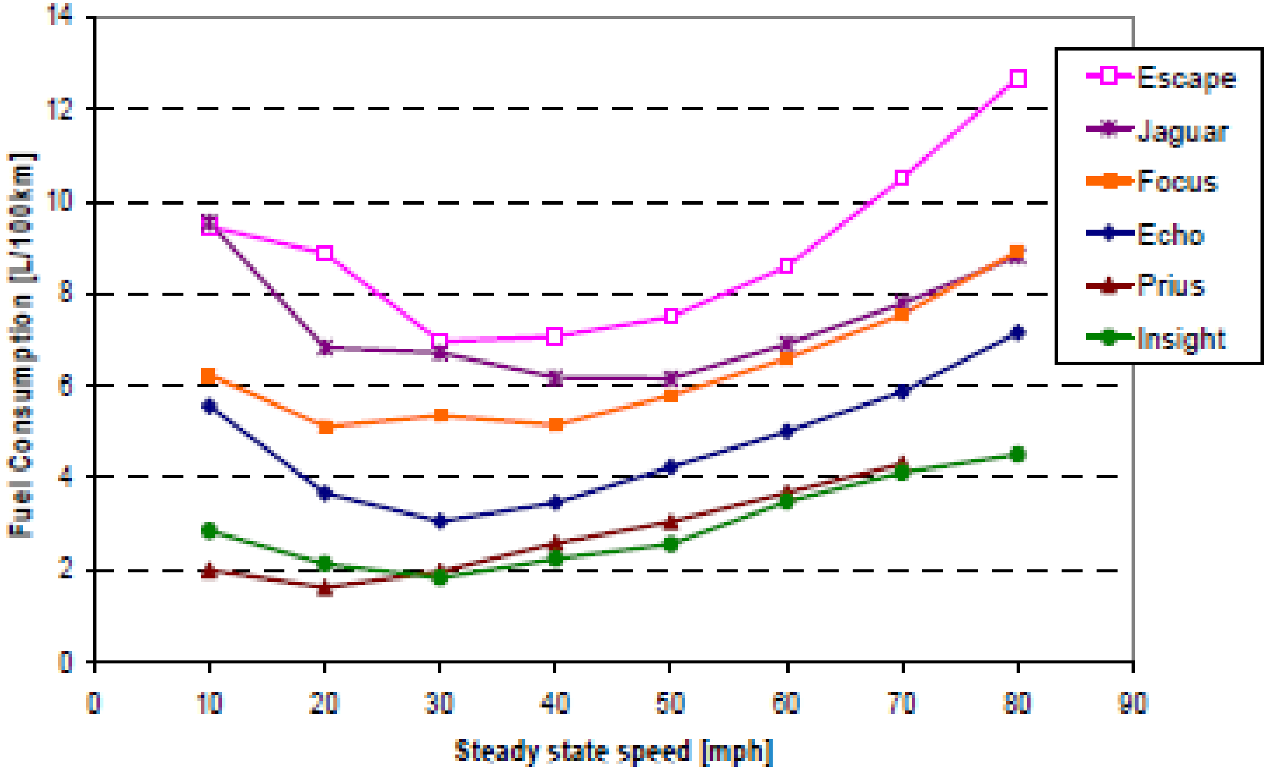
At $4/gal, for "Extra Urban" Non-Work Users, Split HEV, Split PHEV10, Split PHEV20, E-REV40, and EV all Have Higher 10 year B/C Ratios than a Conventional ICE



At $5/Gal, Split PHEV10 and Split PHEV20 Have Better 10 Year B/C Ratios Than HEV



In Addition to the Counted "Intra Urban" Driving Benefits, Low Drag Area Cars will Provide Inter-City Interstate Highway Fuel Consumption Reductions.



At High Interstate Speeds, Measured Fuel Use Advantage of Aerodynamic Car HEVs Increased

Source: Duoba et al, EVS21 - Investigating Vehicle Fuel Economy Robustness of Conventional and Hybrid Electric Vehicles

Observations:

- The conventional vehicle for the > 50 mile/day group is less desirable than coming major OEM plug-in electric cars.
- The EV is not competitive in real world urban driving (LA92). With 2 charges/day the EV may compete with one charge/day E-REVs and Split PHEVs in the high daily miles group (if the battery lasts).
- If all are charged once per day, the Split HEVs-based PHEVs consistently had superior B/C ratios vs. the E-REVs and EV
- Until batteries can demonstrate cycle life far in excess of 4000 cycles, level 2 charge circuit upgrades to allow daytime charging of E-REVs and PHEVs will probably not be cost effective.

Research Needs

- Understanding driving behavior in today's U.S. suburbs – can it be confirmed that suburbanites should generically expect considerably better payback from electric drive than city drivers?
- Understanding driving behavior on inter-city Interstate Highways
- Understanding whether vehicles driven > 50 miles per day are consistently driven a high number of miles/day, or only occasionally (variability of daily driving).
- Impacts of daytime charging of EVs and possibly E-REVs on electric utilities and cost effectiveness of electric drive
  - Infrastructure upgrade costs
  - GHG impacts
- Impacts of high rate charging (level 2) on transformer life in absence of smart control.