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Fuel Consumption, Operational Attributes and Potential Markets for Plug-in Hybrid Technologies

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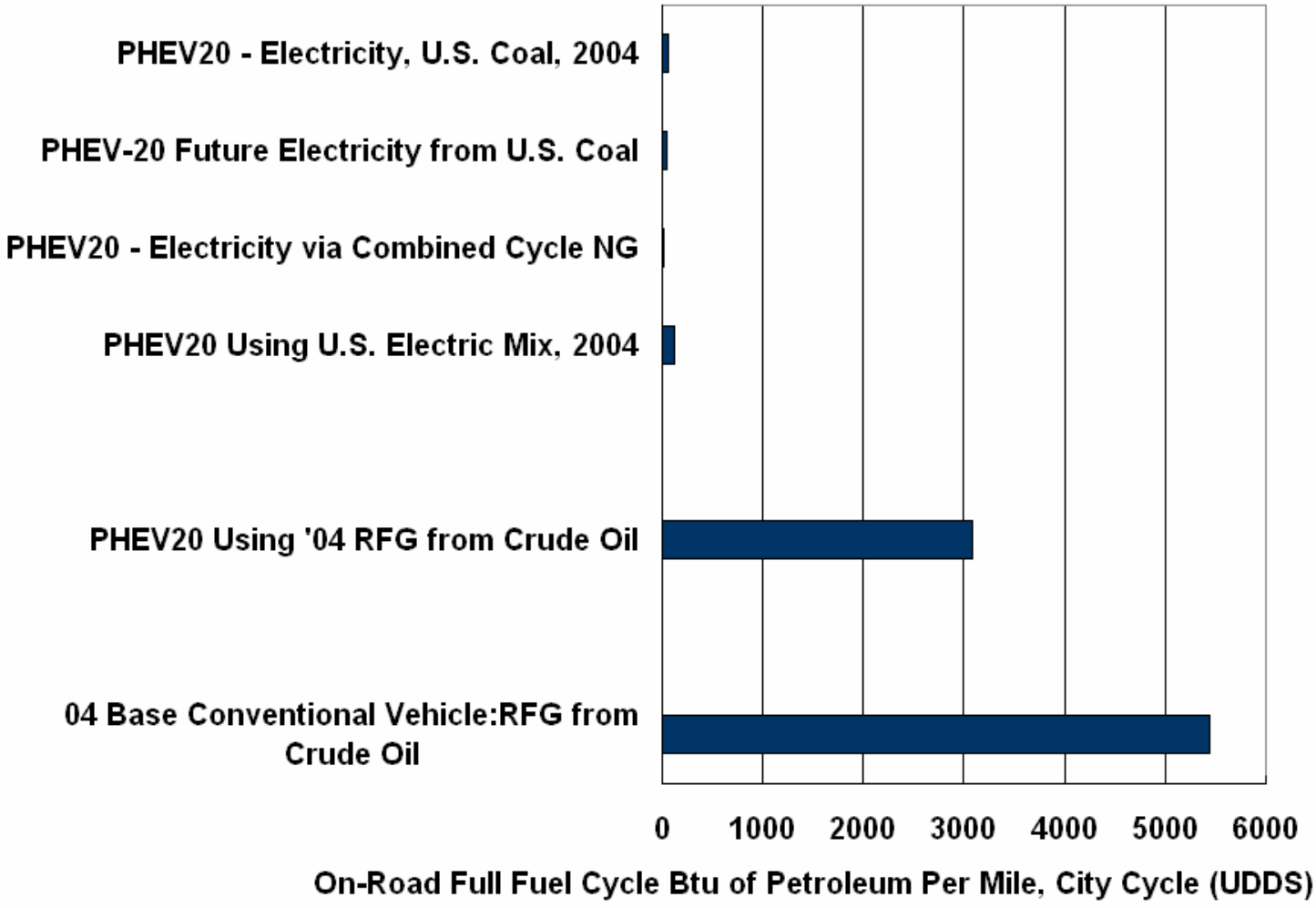
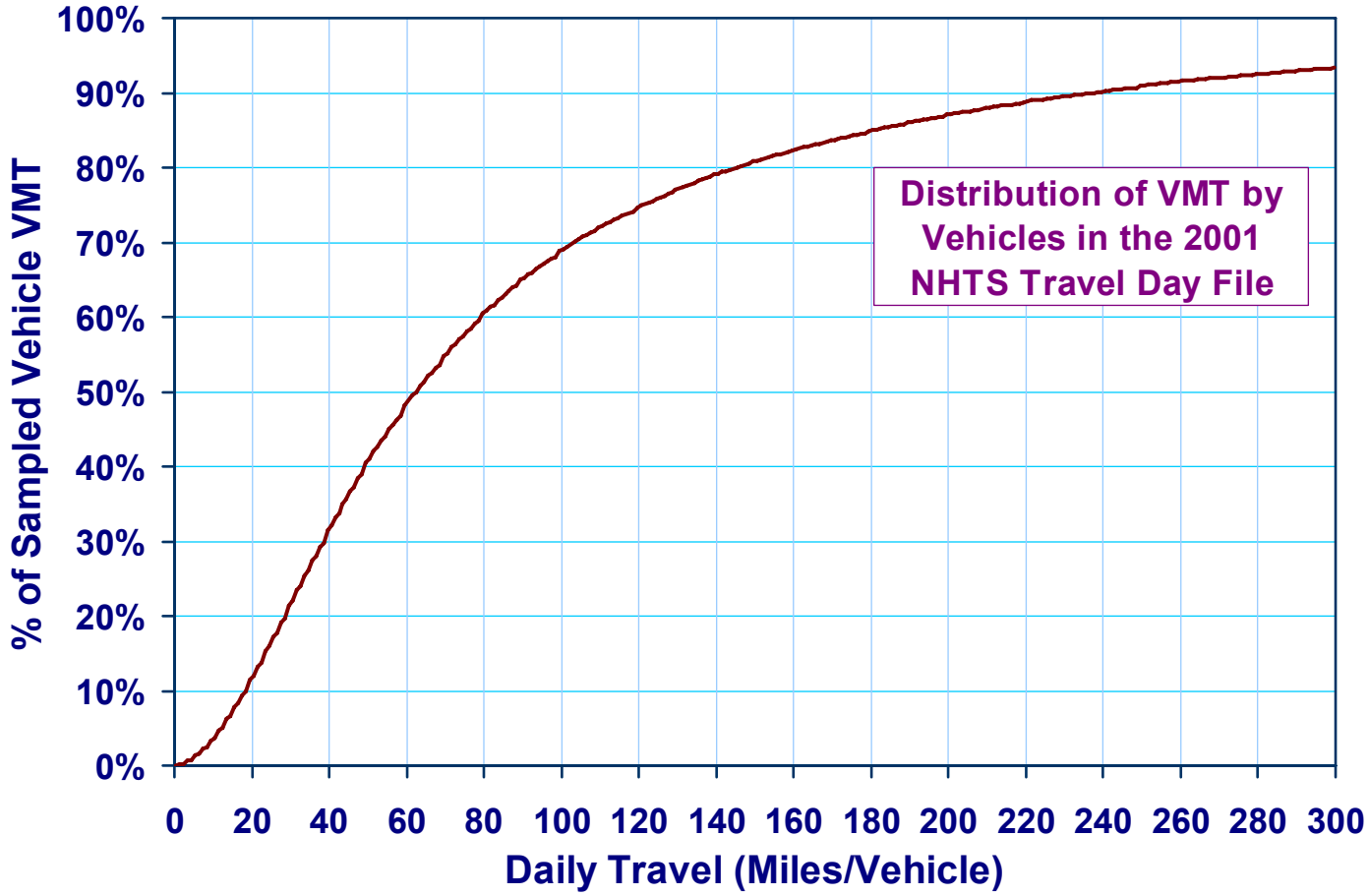
Many Questions and Technology Options Were Not Previously Examined

- **Items not addressed in 2001 studies by EPRI and Argonne**
  - **Li-ion batteries**
  - **Varying electric operations capabilities – top speed, acceleration rate**
  - **Effects of highly variable, often wide SOC swings on battery power/life**
  - **Multiple HEV powertrain configurations**
  - **In-use vs. certification cycle fuel economy**
  - **Charge depletion w/o EV only operation ("blended mode")**
  - **Incremental cost/benefit evaluations**
  - **Towing requirement effects**
  - **Isolation of HEV vs. PHEV incremental benefit/cost**
  - **Urban vs. non-urban & morning vs. other emissions**
  - **Detailed comparison of trip characteristics to potential PHEV capabilities**

Oil Savings: Each PHEV (Full HEV) Sharply Reduces Oil Use Even If No Electricity is Used, Far More if Electricity is Used



Question: Is Potential for Replacing Gasoline VMT With Electric VMT ~ 12% if a PHEV20, ~ 50% if a PHEV60?



Estimate of Daily VMT Pattern From NHTS 2001:
11.5% of National VMT by Those Traveling <=20 Miles; 48.2% for <=60 Miles

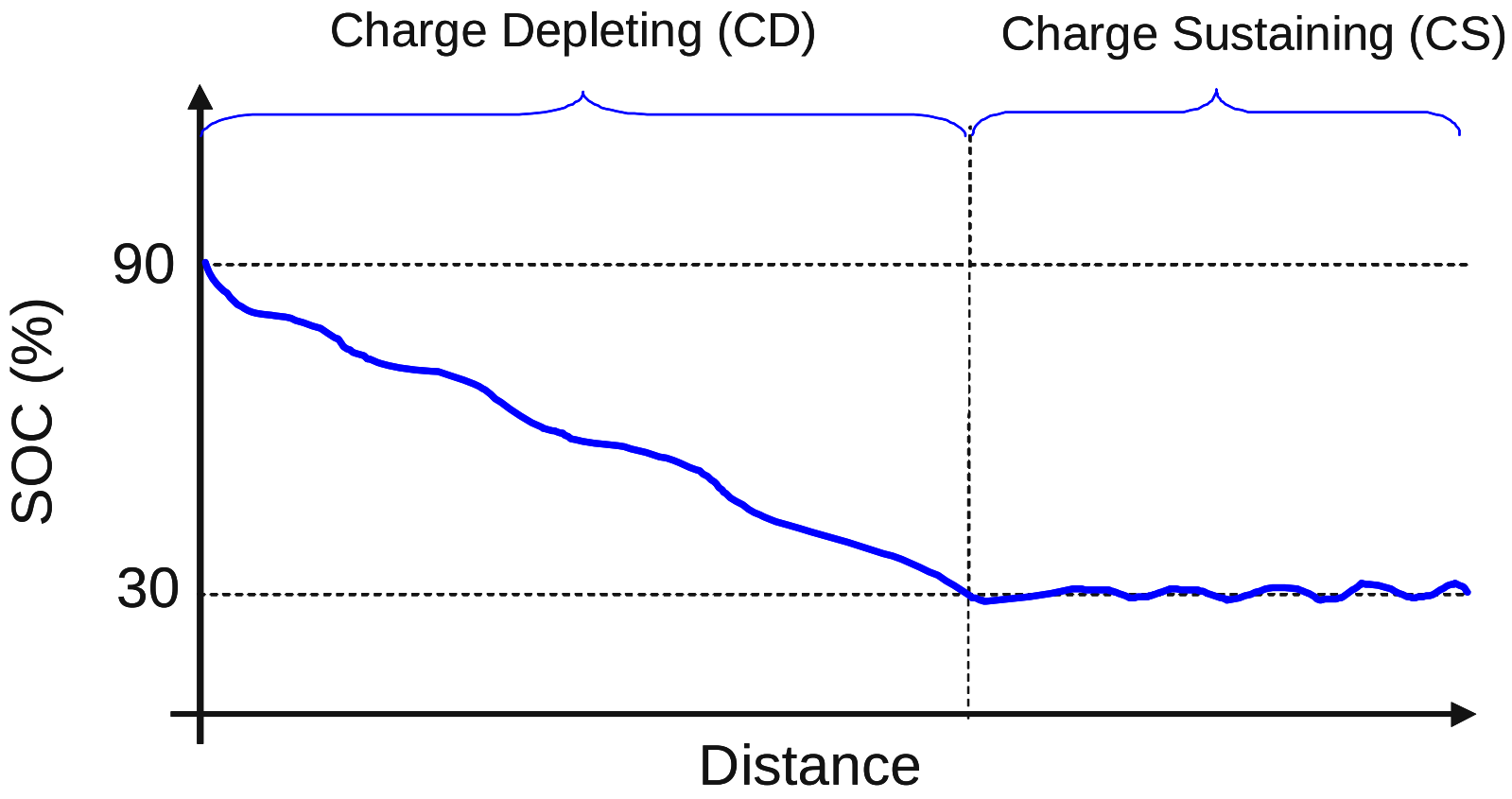
Reality: Potential is Greater. Regardless of Daily Miles, PHEVs Can Travel Initial Miles Via Grid Electricity

Daily Travel Range of Vehicle	VMT Share in NHTS 2001	PHEV TYPE		
		PHEV 10	PHEV 20	PHEV 60
		Max % VMT by Electricity	Max % VMT by Electricity	Max % VMT by Electricity
Up to 10 Miles	3.3%	3.3%	3.3%	3.3%
10.01-20 Miles	8.1%	5.3%	8.1%	8.1%
20.01-60 Miles	36.8%	10.1%	20.2%	36.8%
Over 60 Miles	51.8%	4.5%	8.9%	26.7%
Sum	100.0%	23.2%(19.9%)	40.6%(29.1%)	74.9%(26.7%)

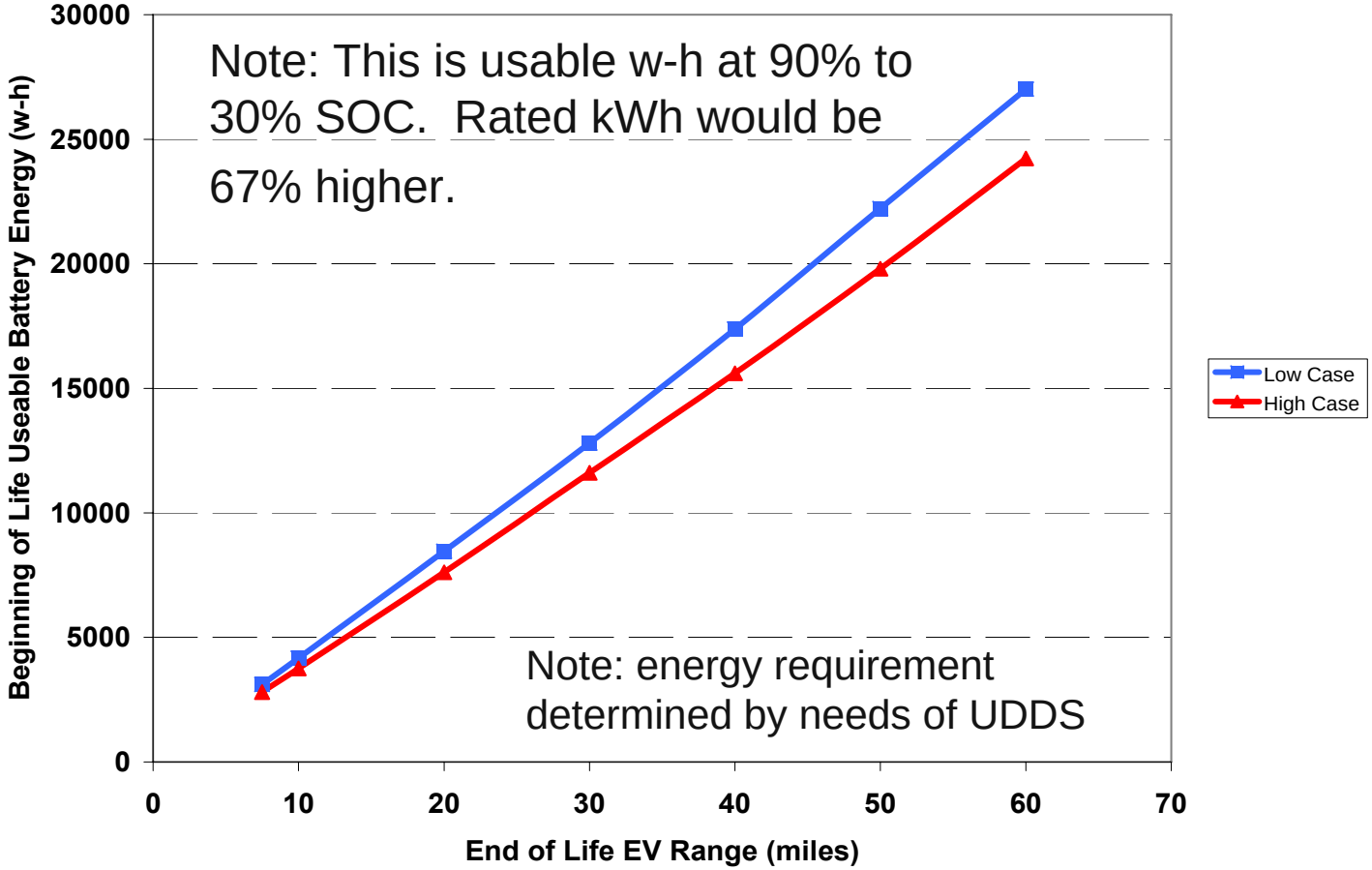
Note: the value in ( ) in the sum row is savings by those that usually exceed all electric range capability.

Key assumptions: one charge per day (night?); 100% market penetration of the specified PHEV technology; all electric drive until battery depletion (not blended charge depletion). Blended charge depletion requires more miles to use a given amount of grid kWh

Designing PHEVs for ZEV Range – EPRI 1.0 2001 and Argonne EVS-22 2006



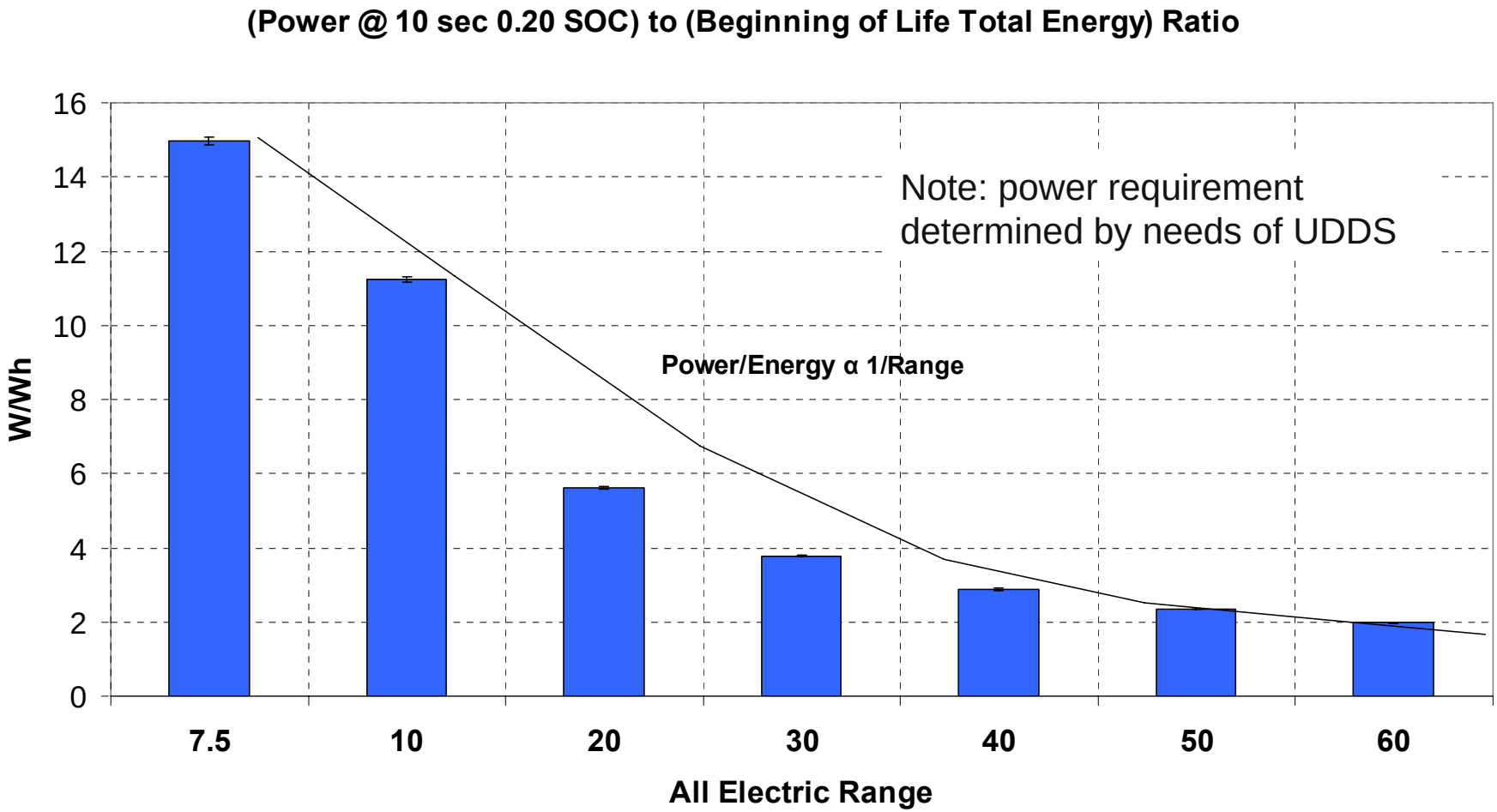
Amount of Battery Energy Needed is Estimated to Go Up Linearly With ZEV Range



Battery energy capacity requirements as a function of ZEV range

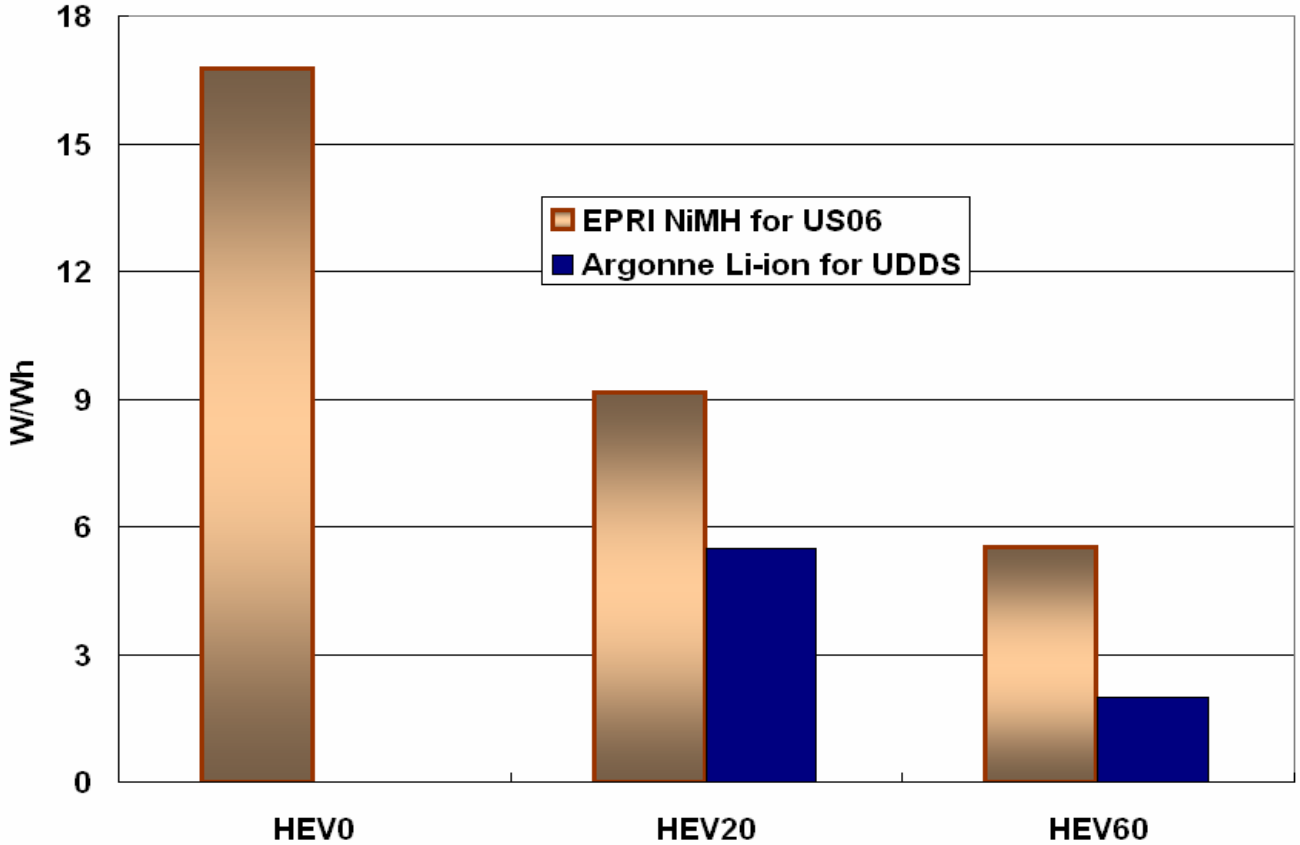
Source: Sharer et al: Vehicle Simulation Results for Plug-in HEV Battery Requirements, EVS-22, Oct. 23-28, 2006

As Range of PHEVs Rises, the Needed Battery Power to Energy Ratio Declines.
(This reduced $/kWh costs in EPRI study)



Source: Sharer et al: Vehicle Simulation Results for Plug-in HEV Battery Requirements, EVS-22, Oct. 23-28, 2006

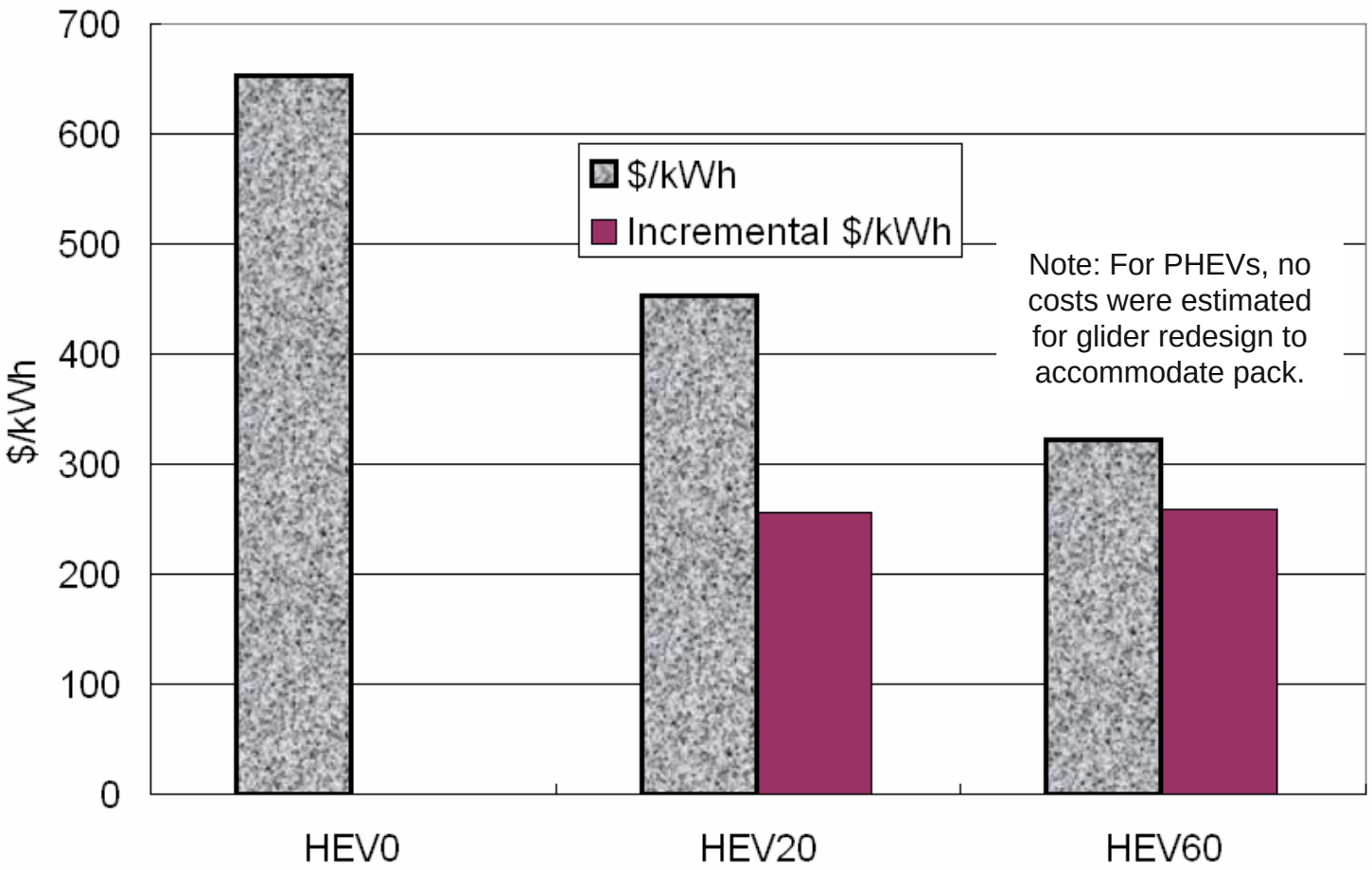
With a Less Aggressive Target All Electric Range Capability and Lighter Battery Packs, Argonne Estimates A Lower Needed Ratio of Power to Energy than did EPRI in '01



Mid-size HEV Type

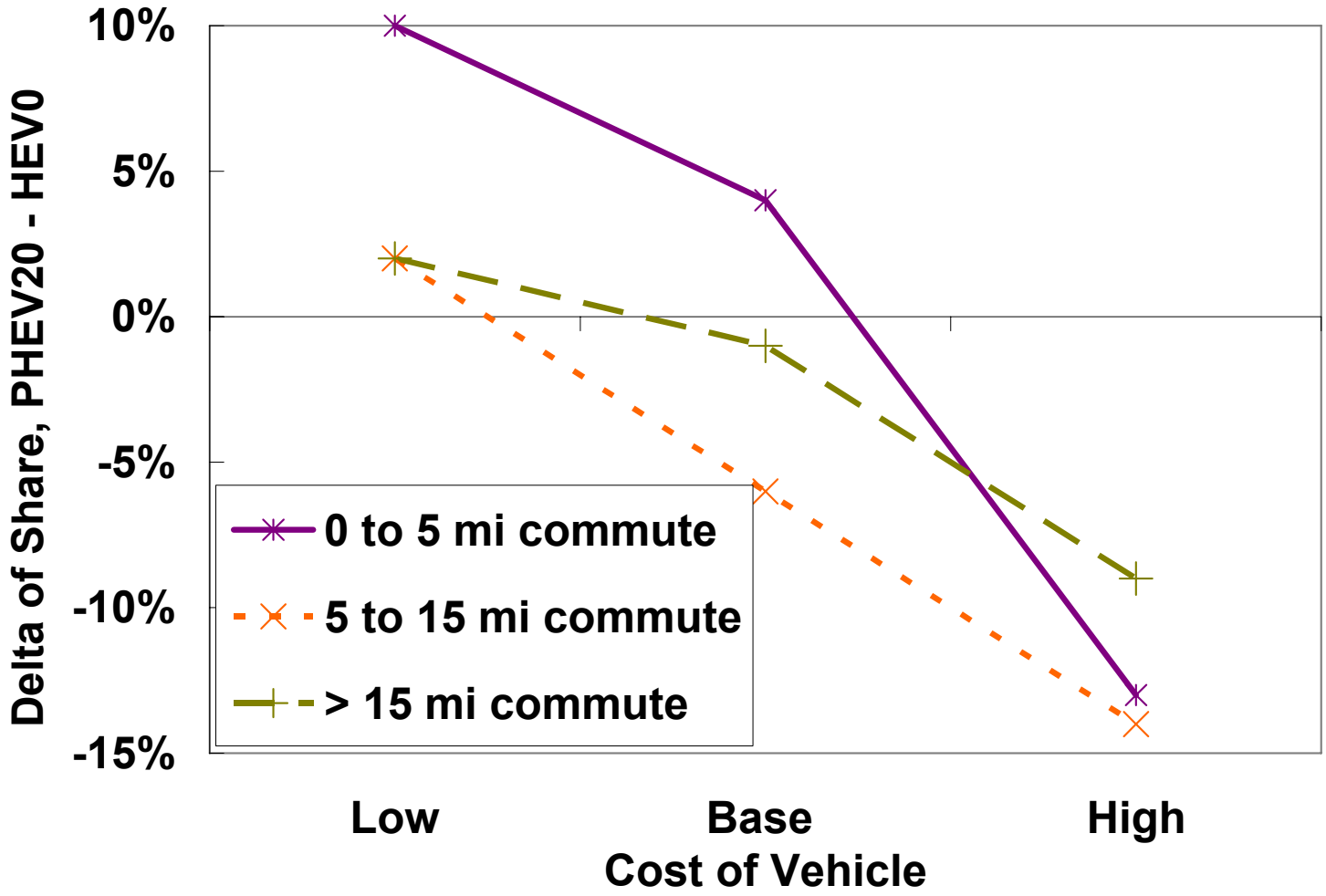
Sources: Sharer et al: Vehicle Simulation Results for Plug-in HEV Battery Requirements, EVS-22, Oct. 23-28, 2006
Graham et al; Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options, EPRI 1000349, 2001

EPRI Estimates for NiMH Batteries Have Costs/kWh Dropping for More ZEV Range; Low Incremental $/kWh Costs

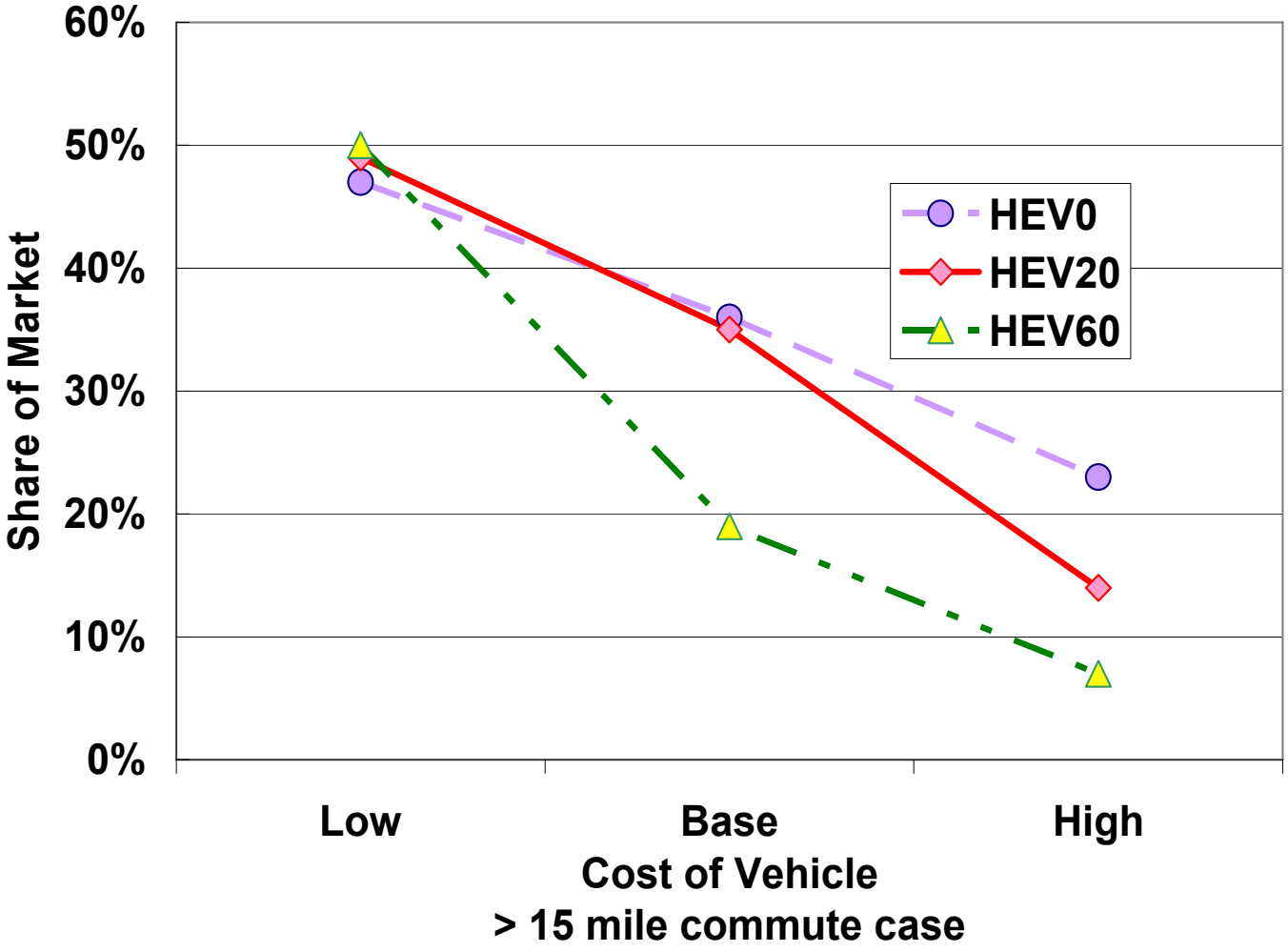


Battery Pack $ Per Rated kWh by HEV Type, EPRI 2001, Table 4-4

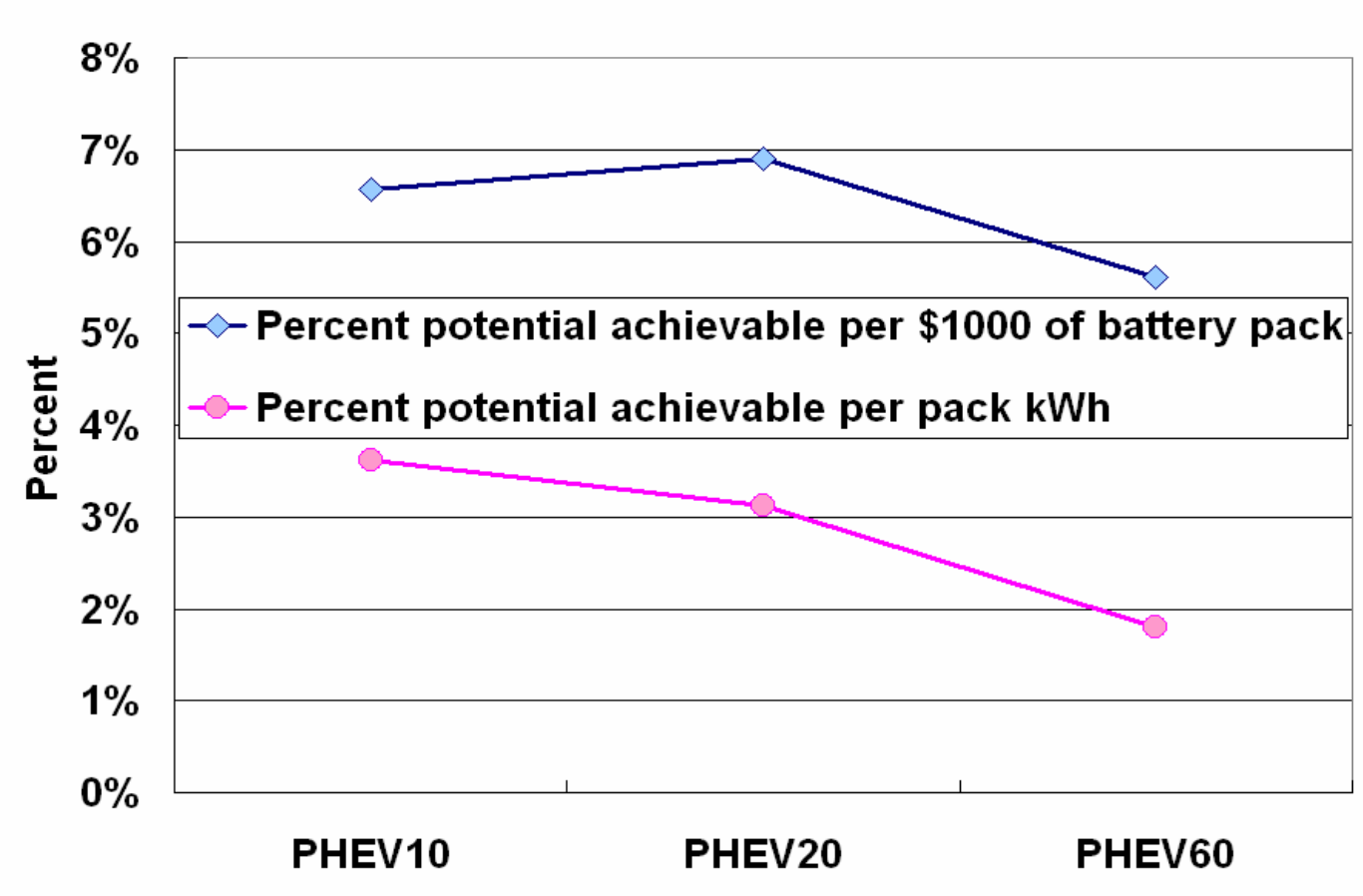
Those With Short Commutes in the EPRI 2001 Survey Had Most Interest in a PHEV20



As Powertrain (Battery!) Costs Drop, EPRI Predicted Share of All Urban HEVs Rises; For Long Commutes, Low Cost Leads to Purchase of More ZEV Range



Thinking the Problem Through; Illustration 1: Measures of Effectiveness per Unit of Battery Used

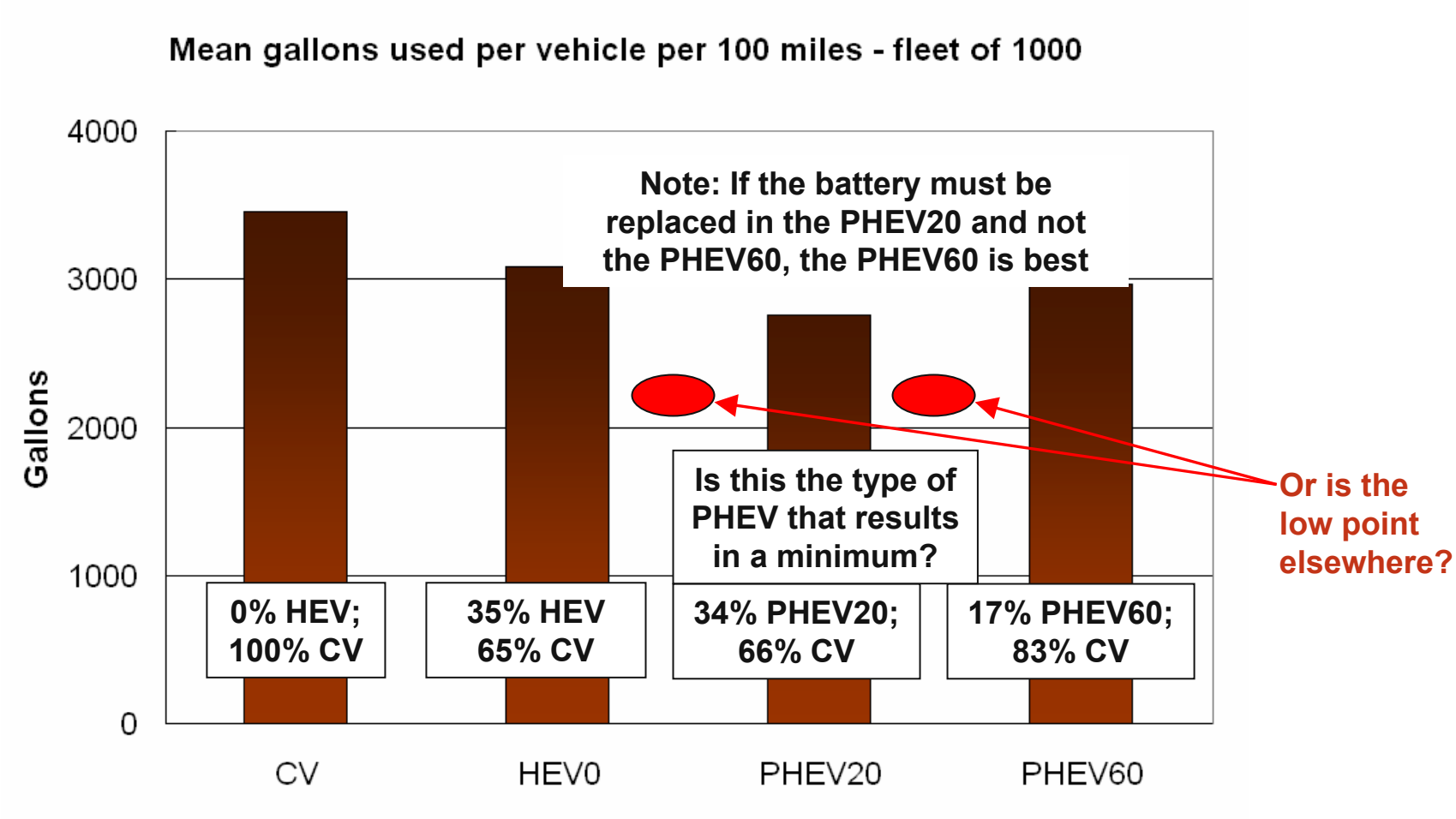


Percent of National Potential Created Per Estimated kWh of Battery Pack

Maximum National "Technical" Potential From the "Sum" Row on Slide 5.

Note: This is illustrative, not definitive. Li-ion pack costs are assumed to be same per kWh as in EPRI 1.0. kWh of packs from recent Argonne simulations. Potential shares from Table presented earlier. The primary point is diminishing marginal returns to adding battery to PHEVs, at least from 20 to 60 mi. ZEV range

Illustration 2: Considering EPRI HEV Type Market Share (not potential) Estimates, Which PHEV Will Save Most Oil?

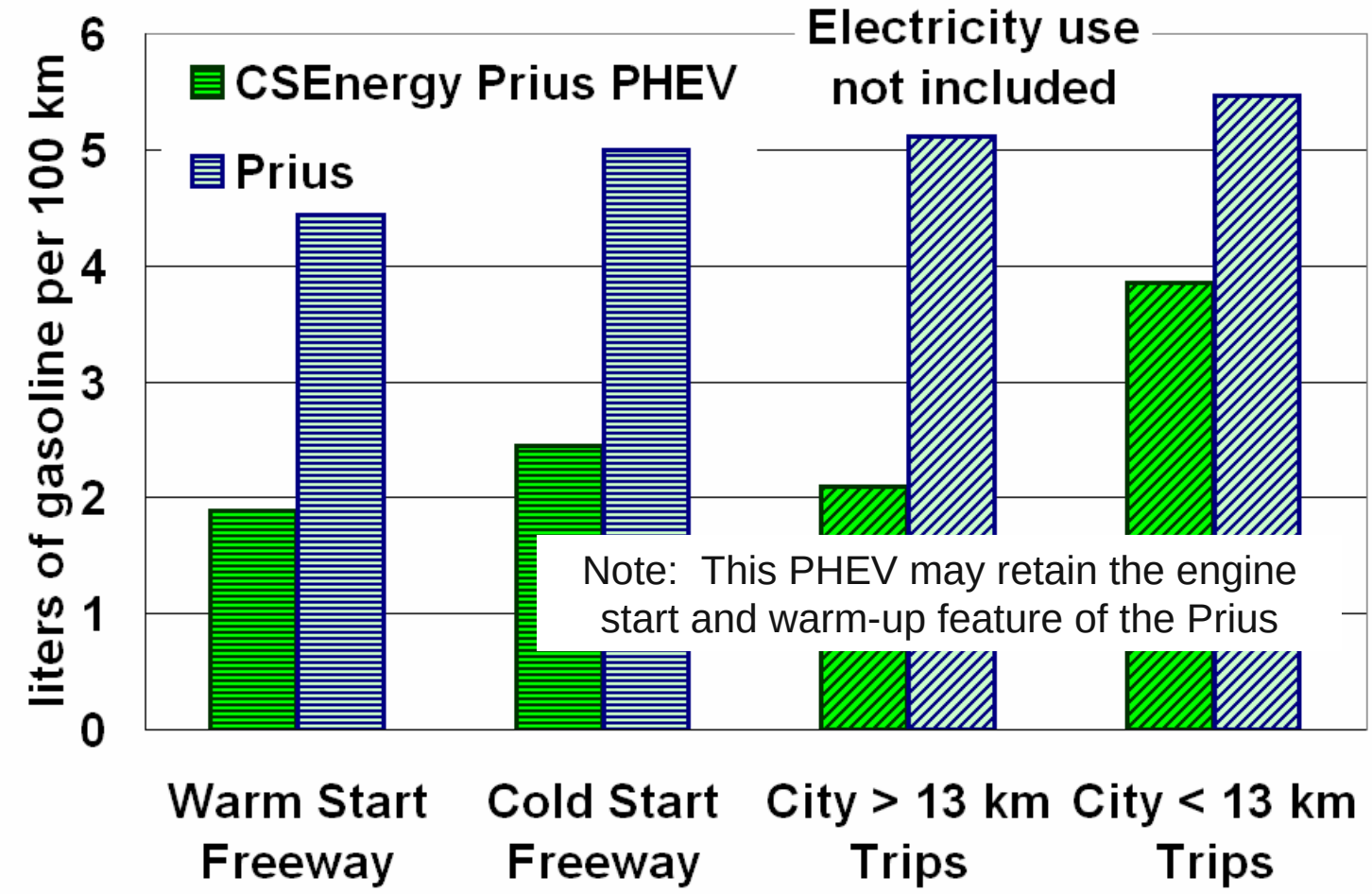


Source of market share estimates: EPRI 1000349, 2001 (base case vehicle costs)

Mid-size car – HEV powertrain paired against the conventional (no other HEV competitor)

Does not use the same market share estimates as for slide 13. Here cost of the vehicle – marketability – has an effect on percent of the market that can be served

First Field Tests of a Prius-Based PHEV on Blended Mode (ZEV Capability Limited) Imply Considerable Oil Reduction



Sacramento Municipal Utility District Summer Field Test Results (AC on): CS Energy Prius PHEV vs. Prius

Data source: D. MacCurdy; PHEV Prius Test Program by Sacramento Municipal Utility District, presentation CARB ZEV Symposium, Sept. 25-27, 2006

Initial Charging Infrastructure

- Plug-in hybrids require relatively low power charging
- Wide availability of infrastructure
  - Initial focus on private chargers
- Array of options
  - 120 VAC, 15 amp (~1.4 kW)
  - 120 VAC, 20 amp (~2.0 kW)
  - 208/240 VAC, 30 amp (~6 kW)
- 120 VAC strongly preferred due to cost, availability

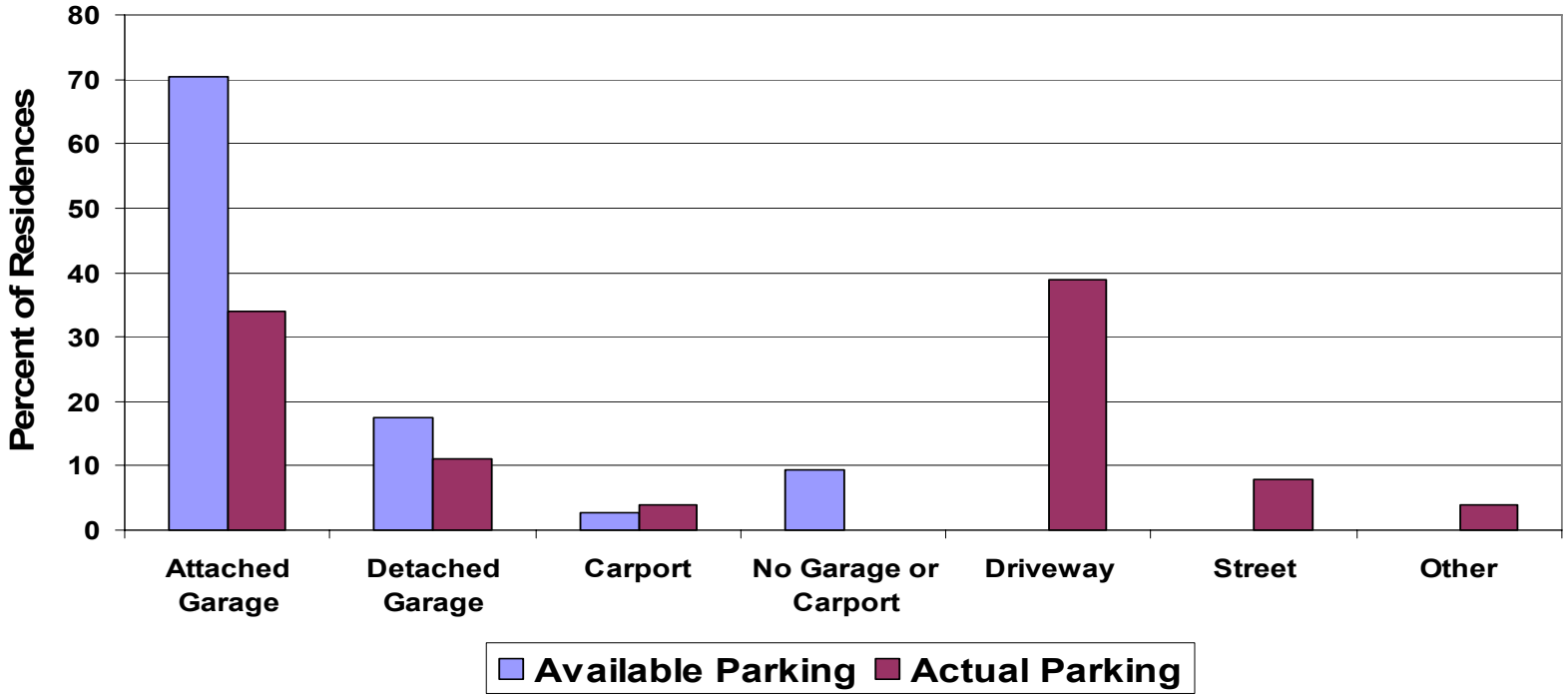
PHEV 20 Vehicle	Pack Size	Charger Circuit	Charging Time 20% SOC
Compact Sedan	5.1 kWh	120 VAC / 15 A	3.9 – 5.4 hrs
Mid-size Sedan	5.9 kWh	120 VAC / 15 A	4.4 – 5.9 hrs
Mid-size SUV	7.7 kWh	120 VAC / 15 A	5.4 – 7.1 hrs
Full-size SUV	9.3 kWh	120 VAC / 15 A	6.3 – 8.2 hrs

1.2 – 1.4 kW power, 1 or 2 hours conditioning

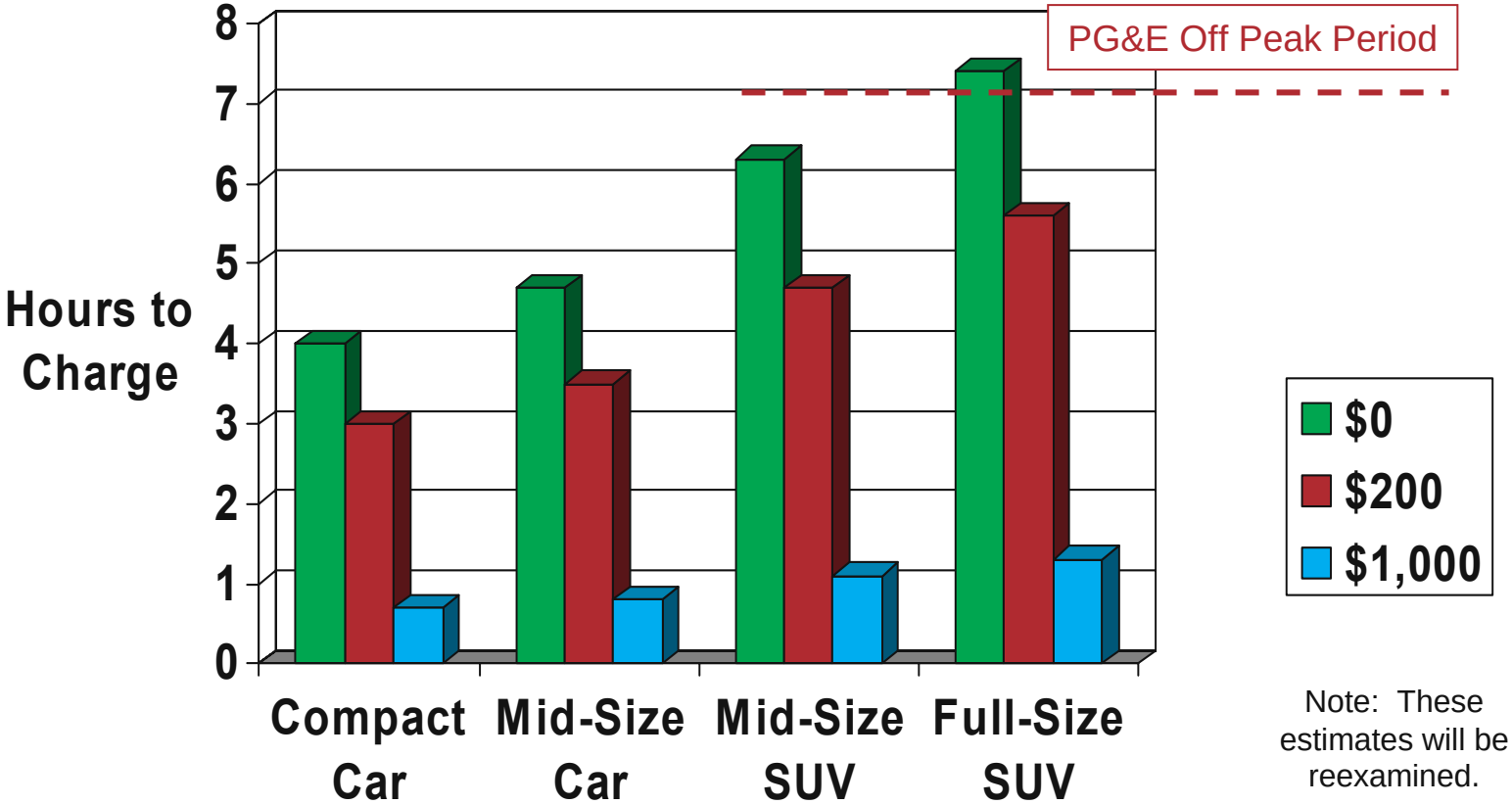
More than 30% of Present Households Park their Vehicles in a Garage or Carport

Available Parking Facilities and Actual Parking (of the most used vehicle) for People in Detached Residences

(59% of all U.S. households live in detached residences)



Even With No Infrastructure Investment (on Board Vehicle Charger), PHEV20s in Garages and Carports Charge Overnight



Note: These estimates will be reexamined.

EPRI Estimate of Infrastructure Cost vs. Hours to Charge

Example: PG&E's TOU Summer time periods

	12am		7am		2pm		9pm	12am
Monday	Off peak		Partial Peak		Peak			Partial Peak
Tuesday								
Wednesday								
Thursday								
Friday								
Saturday						Partial Peak		Off Peak
Sunday								

Pacific Gas and Electric Company®

Source: S. Thesen, Electrical Service Options for Residential Customer EV and PHEV Users, 9/26/06, CARB ZEV Symposium

A CA Utilities Survey Shows $/kWh of Off- and On-Peak Rates

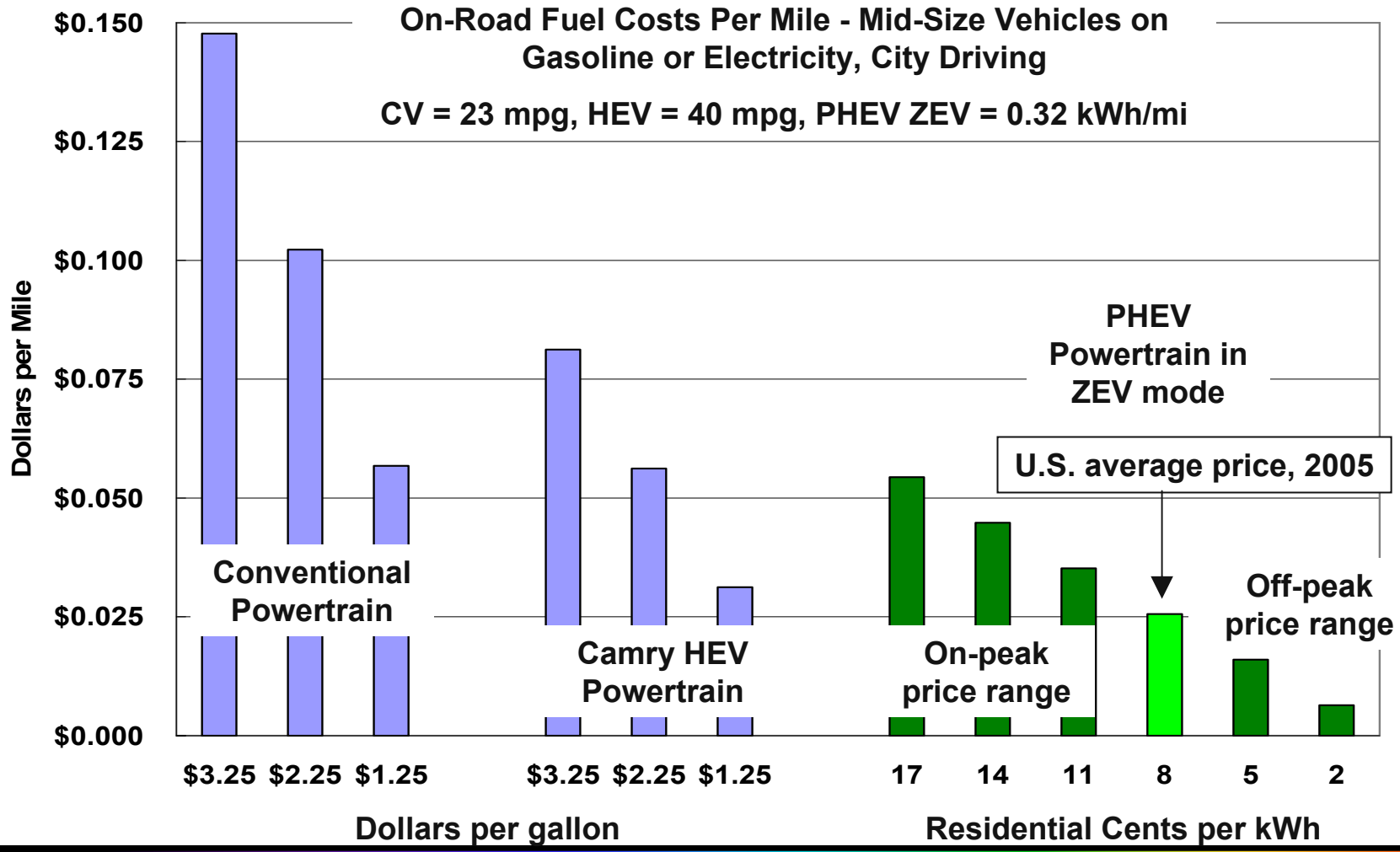
Minimum and Max Rates ($/kWh)

	Min	Max
Winter Off-peak	0.0468	0.0800
Winter On-peak	0.0664	0.1756
Summer Off-peak	0.0497	0.0800
Summer On-peak	0.0813	0.3300

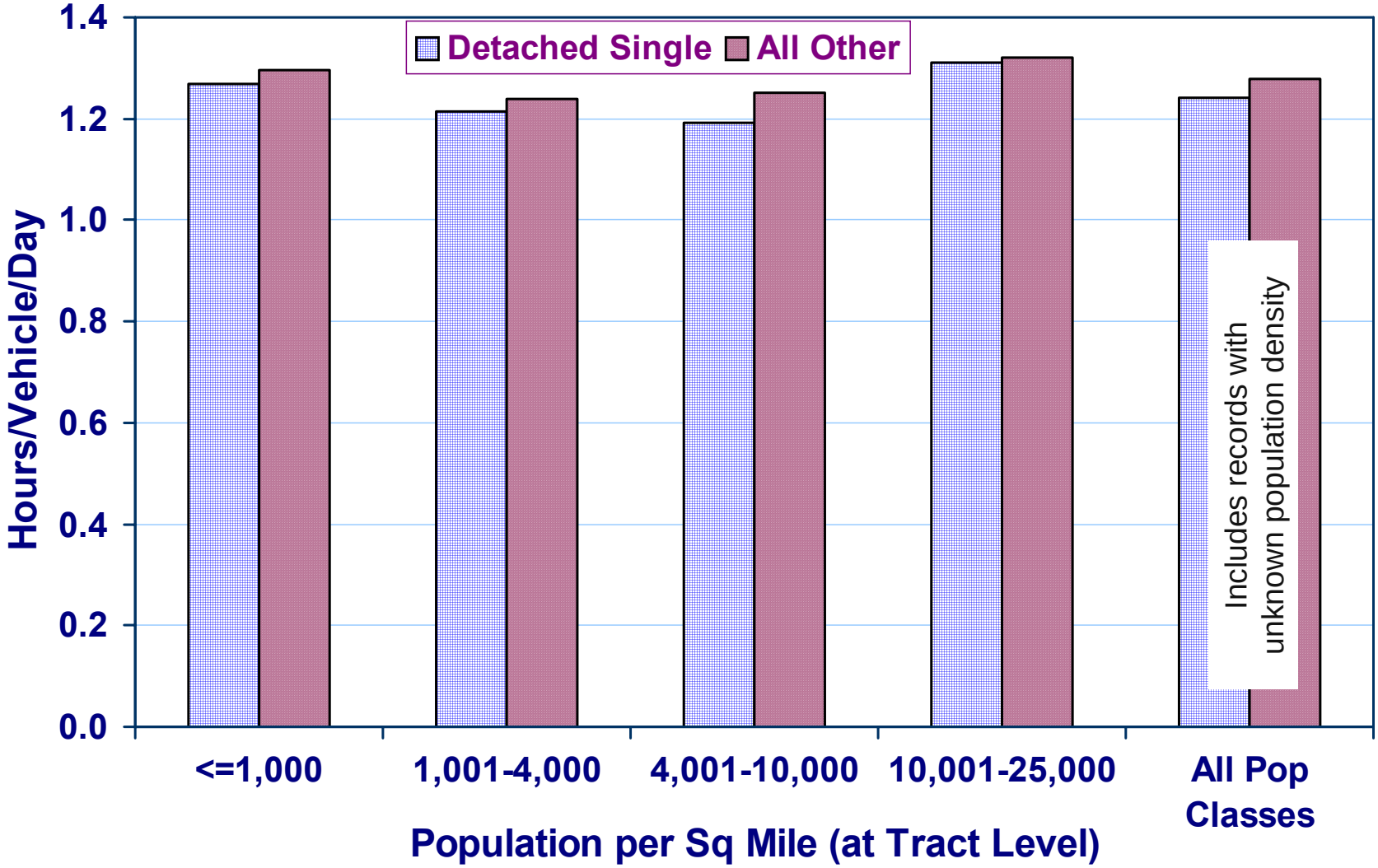
Pacific Gas and Electric Company

Source: S. Thesen, Electrical Service Options for Residential Customer EV and PHEV Users, 9/26/06, CARB ZEV Symposium
Note: A national study of rate structures is desirable. CA may be atypical.

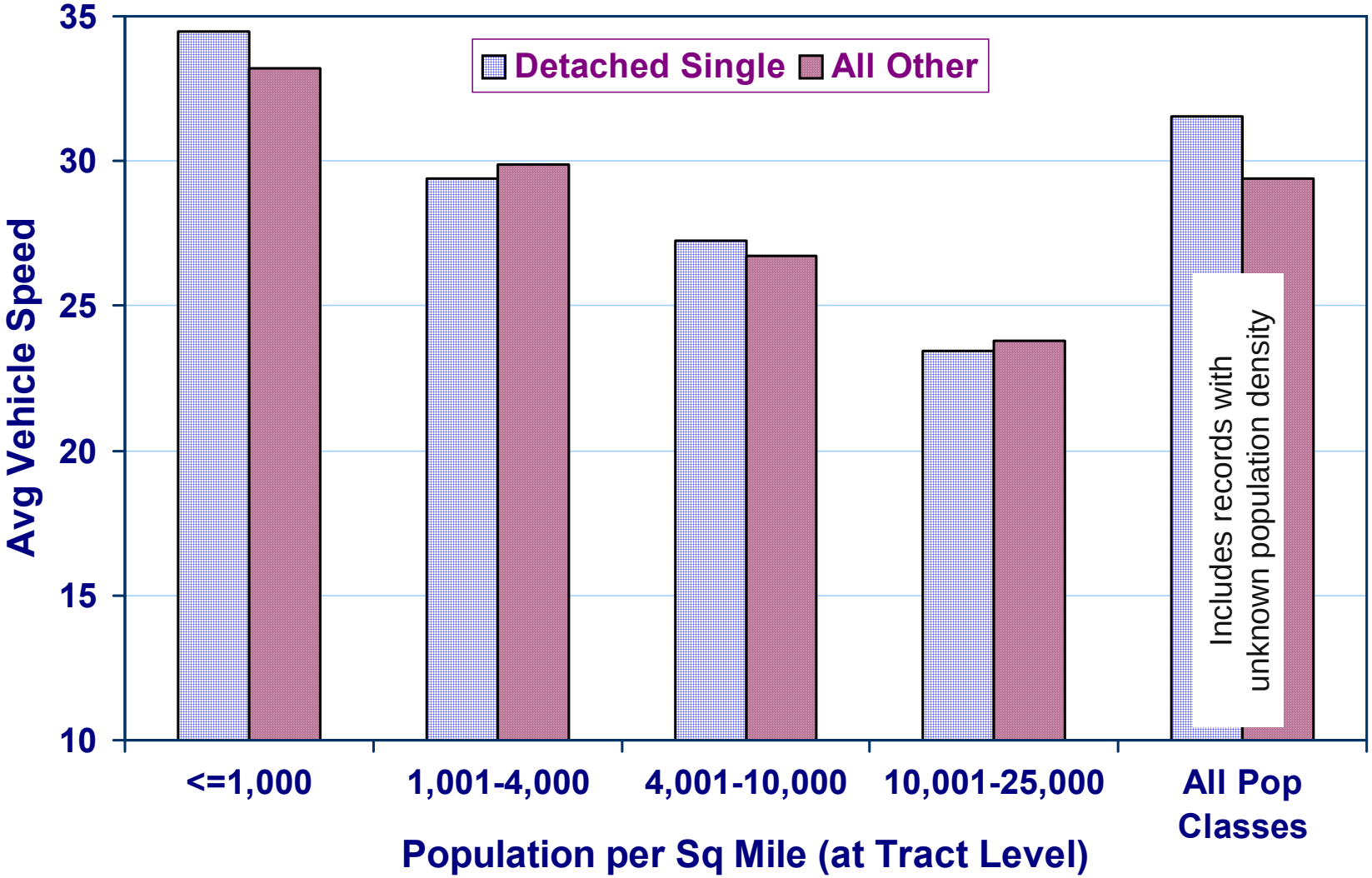
U.S. Average Electric Rates Imply Considerable Per Mile Savings for PHEV20 Electricity Use at Present Gasoline Prices



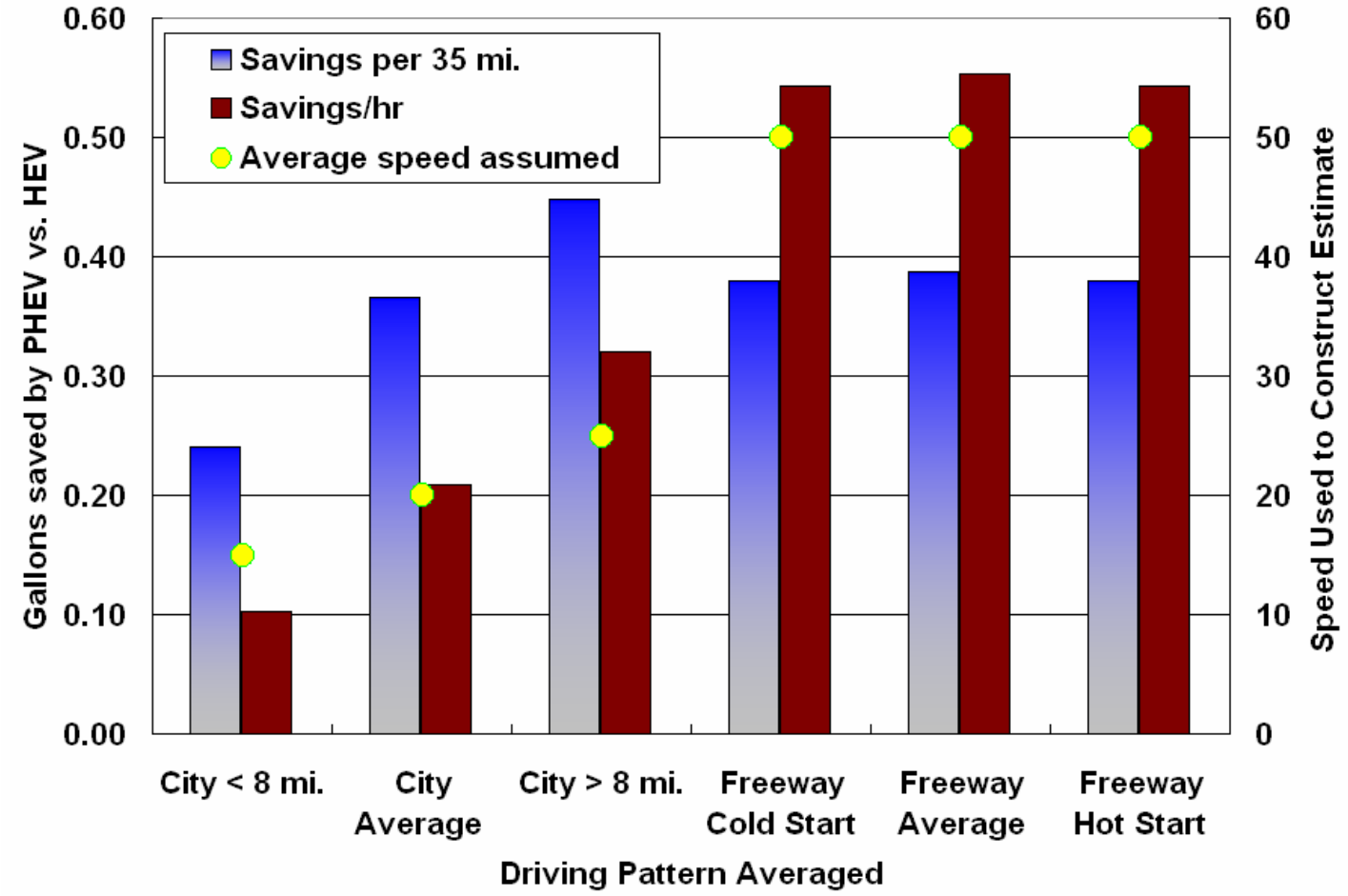
On Average, Hours per Vehicle Per Day are Relatively Constant Across Population Densities



Vehicle Speed (1) Increases As Population Density Decreases (2) Is Higher Nationally For Detached Units



For the CSEnergy Type of PHEV to Save Most Gasoline vs. a Prius, It Should be Used Where Average Driving Speeds are Higher – Suburbia, Uncongested Cities, and Rural America!



<u>Estimate</u> of fuel saved by EnergyCS Prius vs. Prius, Standardized on Miles vs. Hours of Driving, by Driving Pattern

Data source: D. MacCurdy; PHEV Prius Test Program by Sacramento Municipal Utility District, presentation CARB ZEV Symposium, Sept. 25-27, 2006

Summary

- Both charge-sustaining (current) HEVs and charge-depleting (plug-in) HEVs reduce petroleum. Plug-in HEVs could cut oil use even more than full HEVs.
- Substantial travel, in terms of miles driven, can be transferred to electricity through plug-in HEVs
- As plug-in HEV's ZEV range increases, power to energy ratio for the battery pack declines, and battery costs should not rise linearly with additional kWh. Incremental battery cost per kWh should be carefully investigated.
- Charging PHEVs initially at low voltage on available residential circuits can keep initial charger and grid modification costs low.
- Perhaps only summer peak charging of PHEVs in most U.S. utilities would increase PHEV energy cost per mile compared to HEV mode. Thus, if a fleet of PHEVs enters the market, even low gasoline prices would not make PHEV operation on gasoline cheaper than on off peak electricity. Therefore, promised GHG and oil use benefits over and above the HEV would likely be secure.
- For an initial PHEV Prius, it has been estimated that the best market for oil use reduction is suburbia, uncongested cities, and rural areas.
- The technology is very complex, as are possible combinations and permutations with the grid. Designs and results can vary with priorities.