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More Complications in Estimation of Oil Savings via Electrification of Light Duty Vehicles

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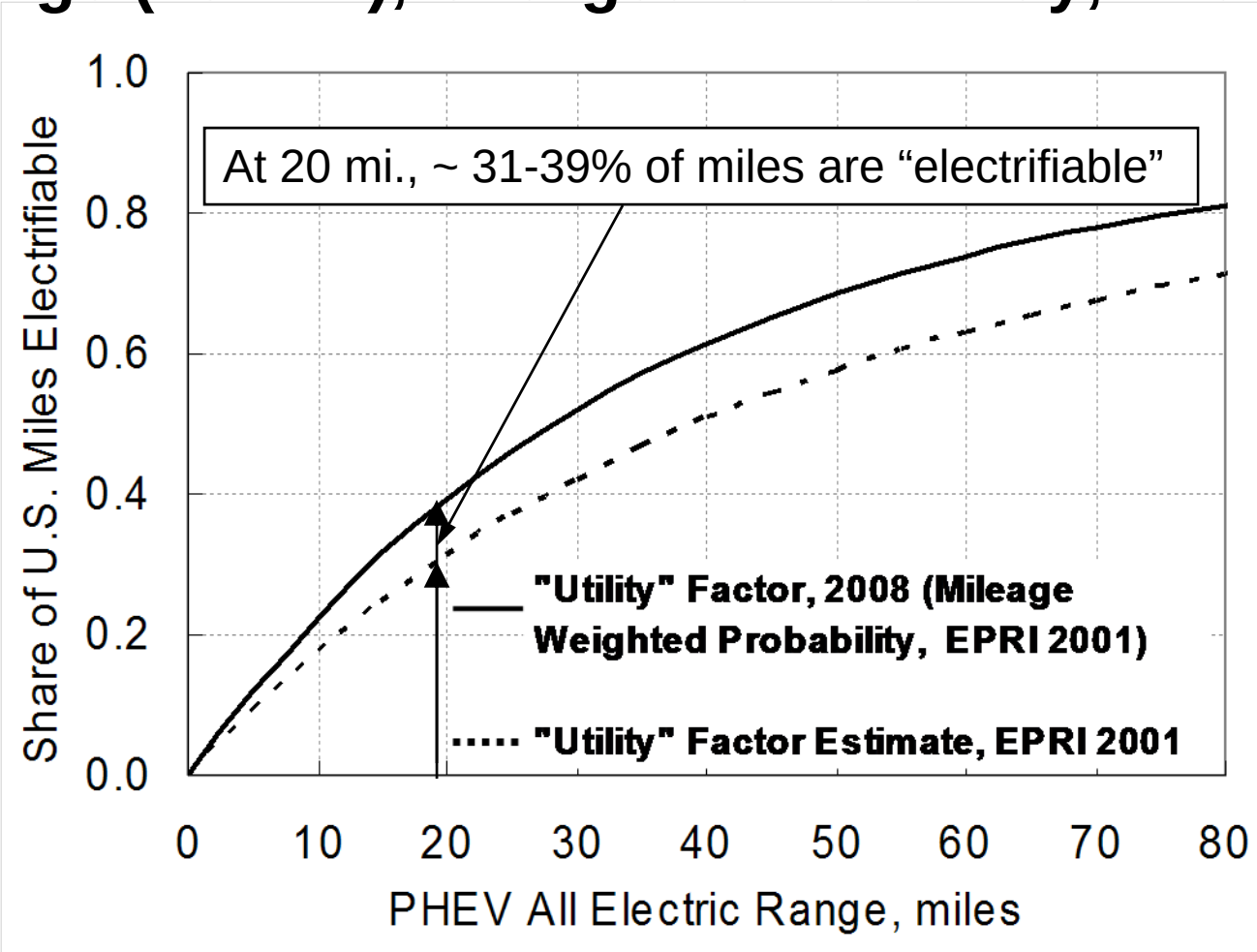
Vehicle Technologies Program

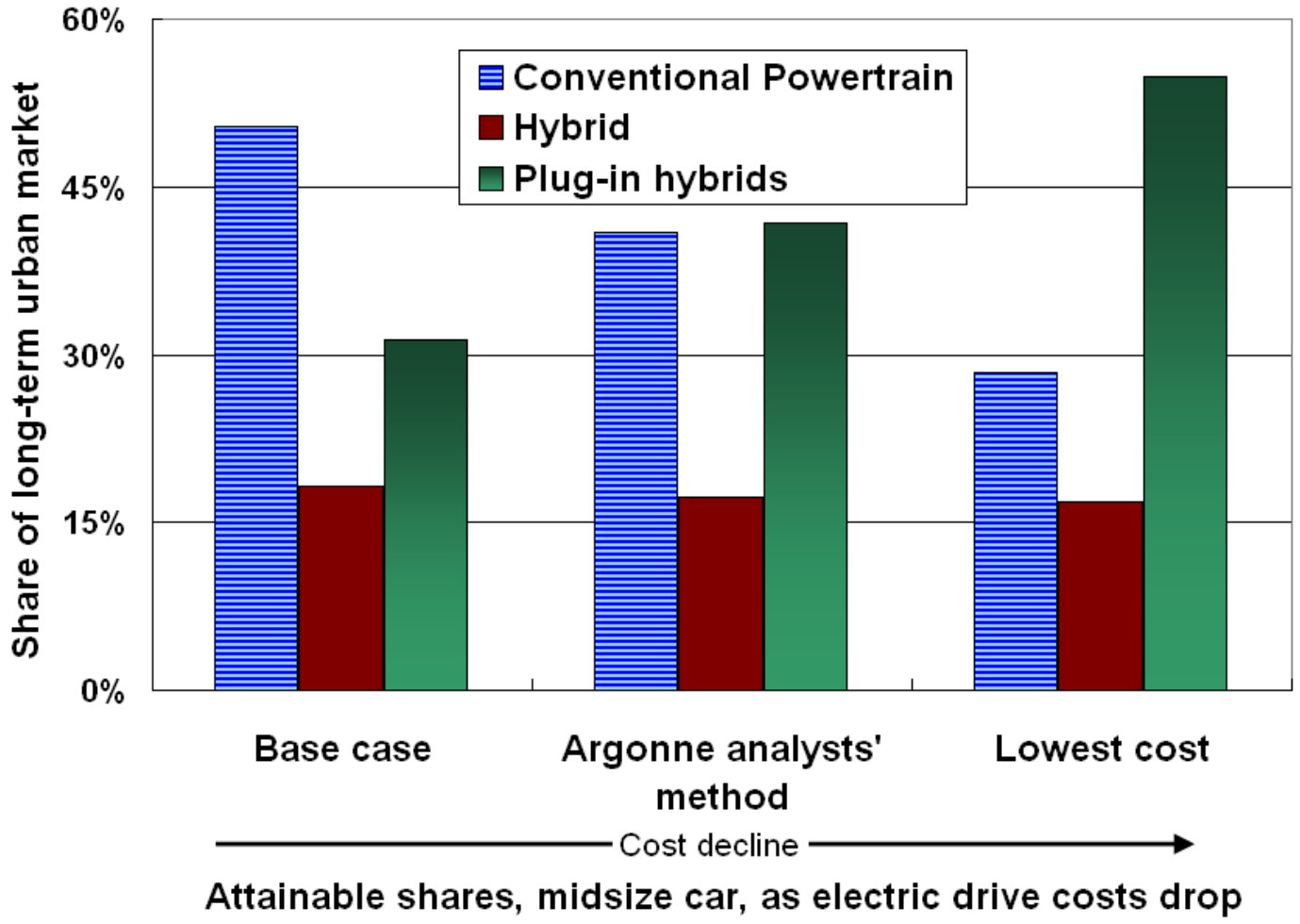
Candidate Method – If All Owned a PHEV of Specified Range (20 mi?), Charged Once a Day, Then …



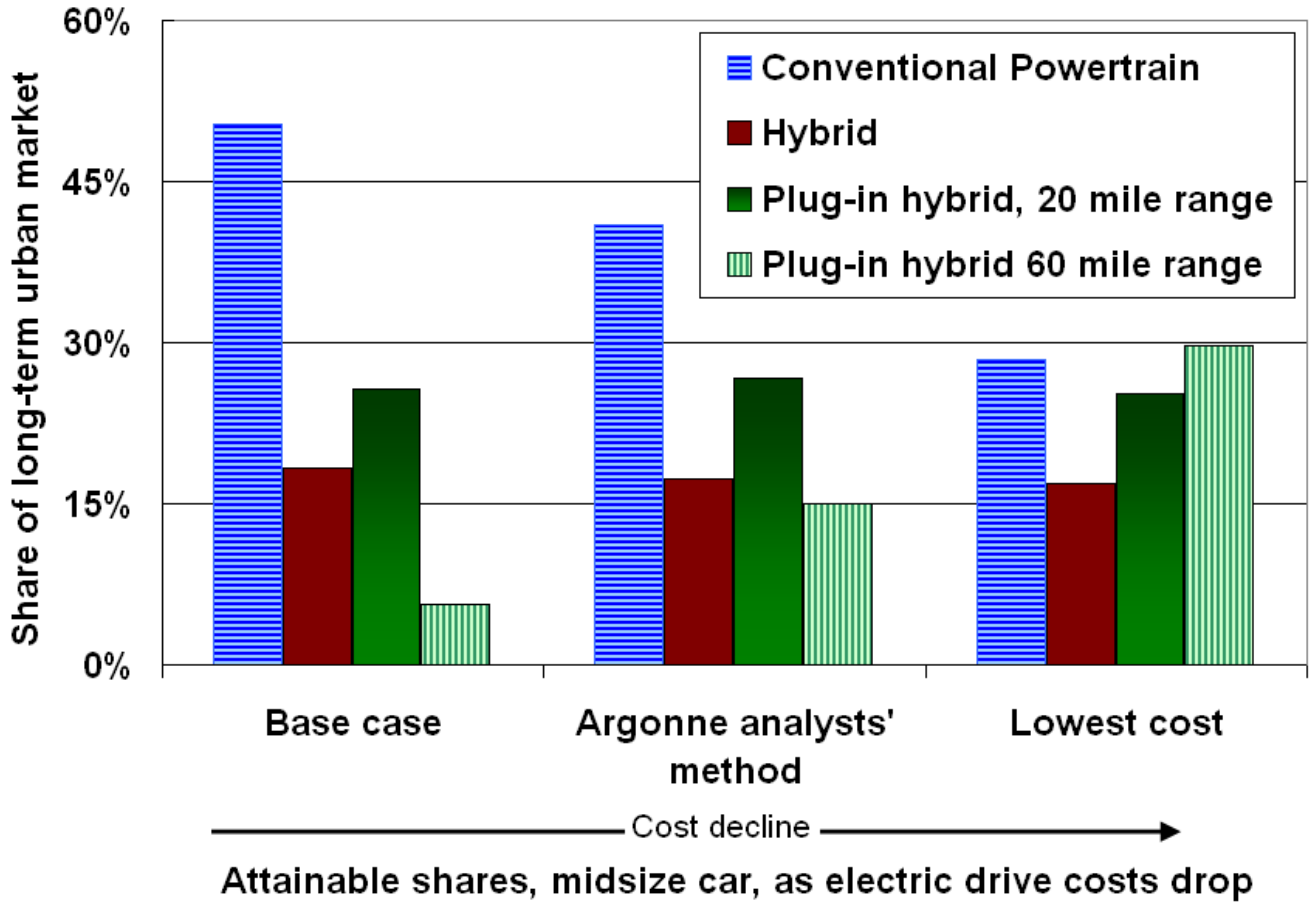
There are many details that will matter to ultimate national savings

1. Not everyone will purchase a PHEV.
2. PHEVs will complement HEVs, expand the long term hybrid drivetrain market.
3. Not everyone will purchase a PHEV with the same range capability, nor the same motor/battery vs. engine power.
4. PHEVs purchased with a nominal range capability will not realize only that single range value in practice.
5. The first “n” miles from the garage are driven more slowly than remaining miles, use less fuel per hour.
6. The PHEV may not always be charged at the house.
    - In a moderate power split PHEV, if the battery is small enough to be routinely depleted, such PHEVs may be charged > 1 time/day
    - A high power series PHEV (or E-REV), even though having long range, can deplete kWh quickly at high speeds. If so it could be charged > 1 time/day

Not everyone will purchase a PHEV. PHEVs will expand the long term hybrid drive market.



Not Everyone Will Desire PHEVs With The Same Range Capability



Very Different PHEV Concepts are Scheduled for Introduction to the Market

- "Split" Parallel HEVs such as the Prius and Ford Escape are being developed as PHEVs
  - Blended mode charge depletion will be typical
  - Charge depleting range will likely be less than 20 mi.
  - Battery and motor power < than engine
- The Chevrolet Volt "E-REV" is a Series drive PHEV
  - All electric capability in many circumstances
  - Rated electric range ~ 40 mi.
  - Battery and motor power > than engine

Hypothetical Future Split Parallel and Series PHEVs Were Modeled

- **Improved "Prius-like" glider**
- **Small mid-size car**
- **PSAT model used for simulations**

	Power split HEV	Power split PHEV10 **(short)**	Power split PHEV20 **(medium)**	Power split PHEV40* **(long)**	Series PHEV40 **(long)**
Engine kW	68	69	70	71	110
Motor kW	57	57	59	57	112
Battery peak kW @ min SOC	37	63	63	90	89

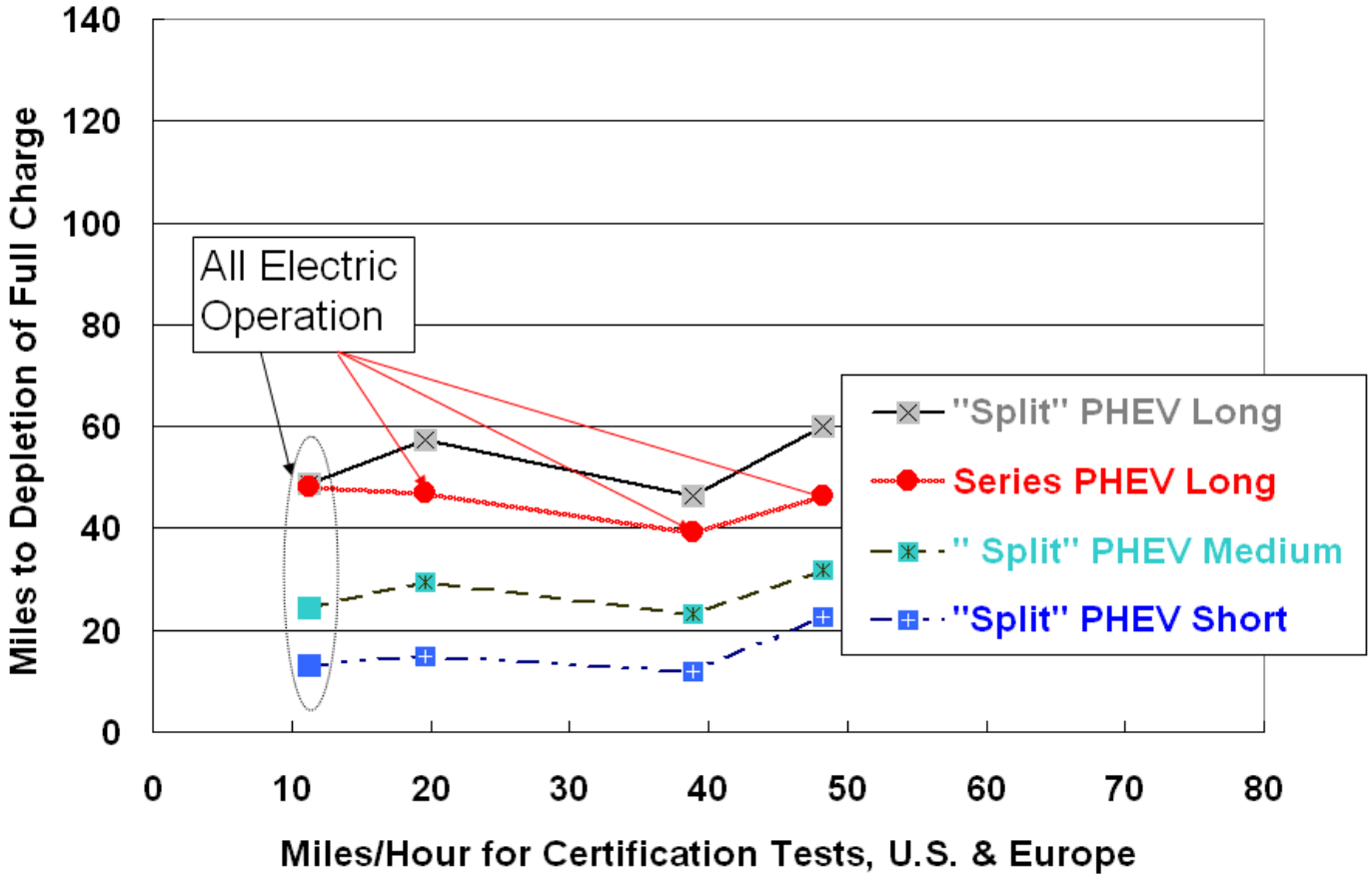
* Recognized as least likely of the simulated alternatives

Both Certification-Test and On-Road Driving Cycles Were Used in Simulations

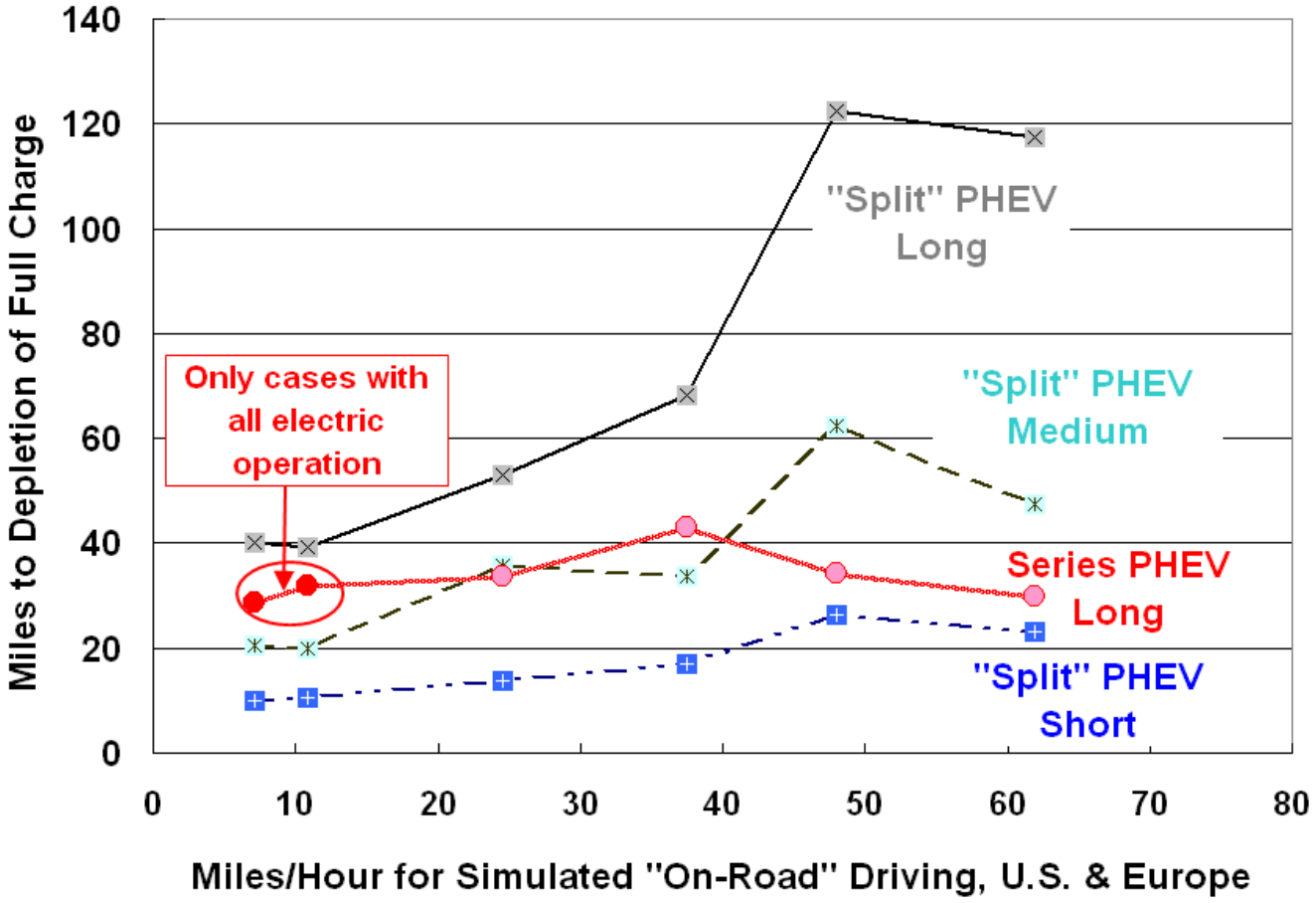
- **On-Road (ave. mph)**
  - New York City (7.1)
  - Artemis Urban (10.9)*
  - LA92 (24.5)
  - Artemis Route (37.5)*
  - US06 (48.0)
  - Artemis Motorway (61.9)*
- **Certification (ave. mph)**
  - European ECE (11.3)
  - U.S. UDDS (19.6)
  - Europe EUDC (38.9)
  - U.S. Highway (48.3)

* Developed from a European study of real world driving

Certification Drive Cycles Seem to Imply Frequent All Electric Operation and/or Reliable Depletion



"On-Road", Simulated PHEV Charge Depletion Distance Varied and Blended Mode was Typical

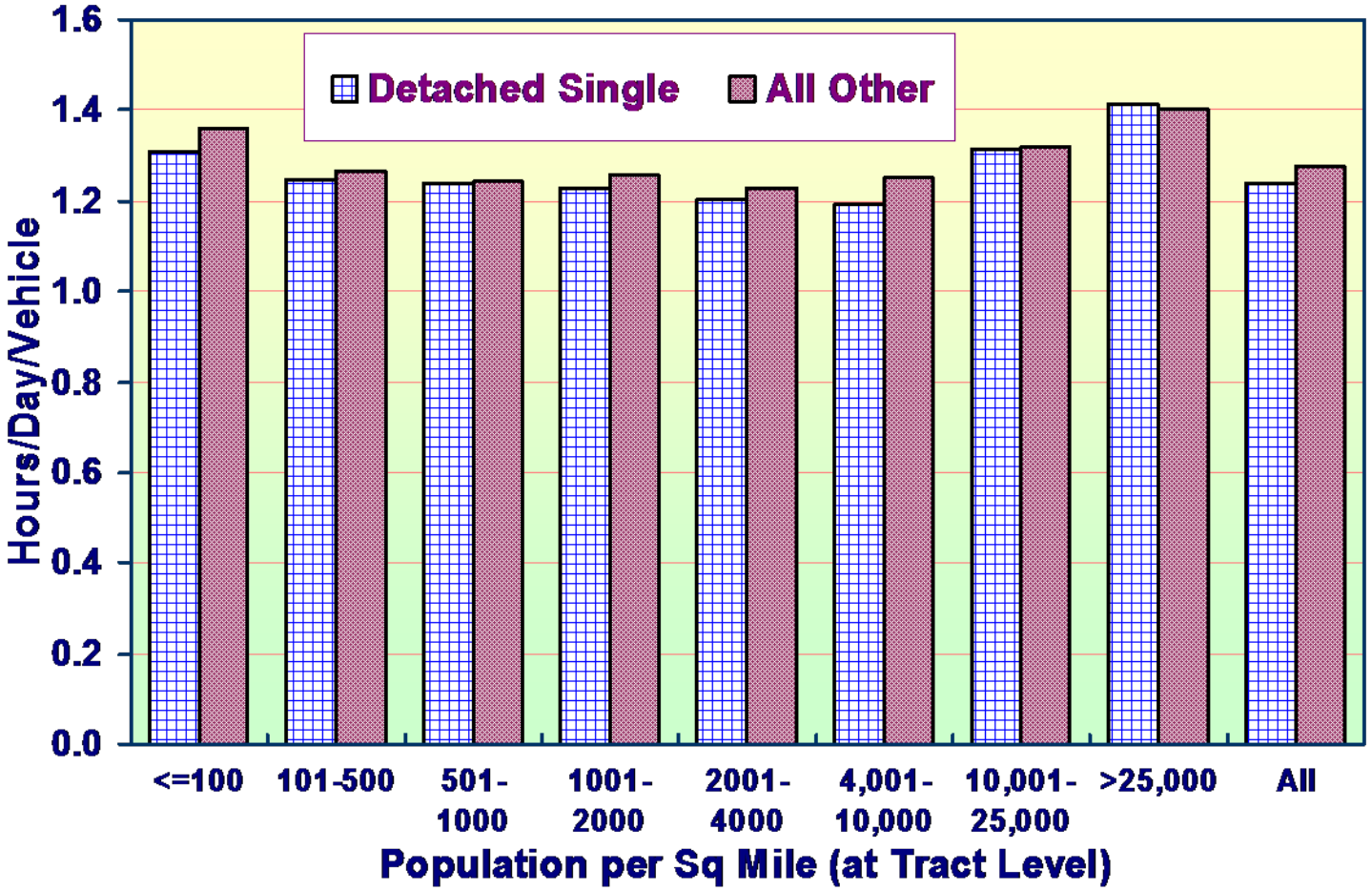


For Non-House Charging to Make Sense, Charge Must be Depleted in ~ ½ of Day's Time in Vehicle

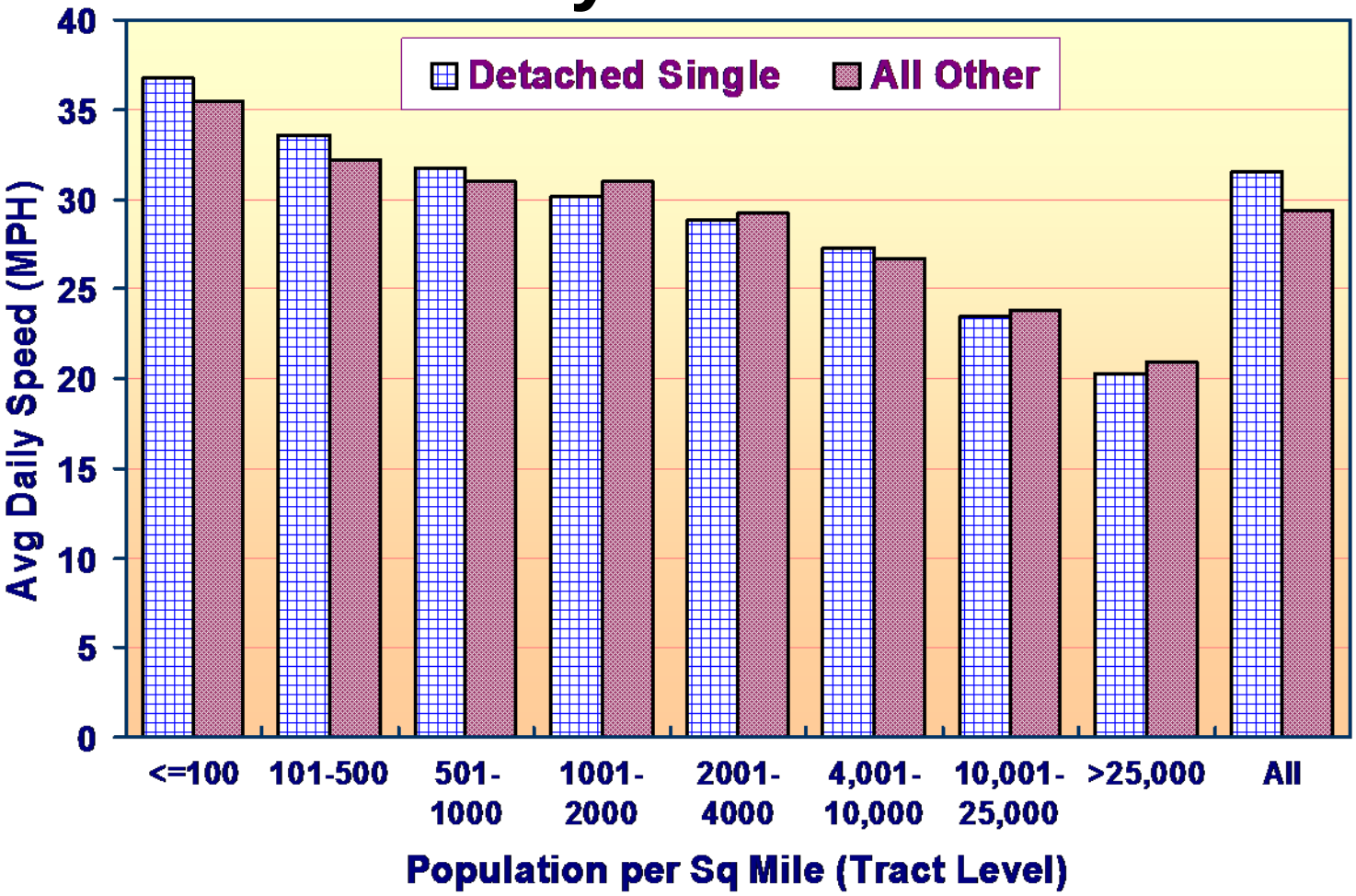
Extension of depletion time is caused by

- Low battery and/or motor power
- Considerable battery energy
- Low rate of vehicle speed
- Aggressive accelerations

Over a Large Span of Population Density, Average Hours Per Day per Vehicle are Remarkably Constant



Vehicle Speed Increases As Population Density Decreases



The First "n" Miles From the Garage are Driven More Slowly Than Later Miles

U.S. NHTS travel as a function of segments of daily distance driven

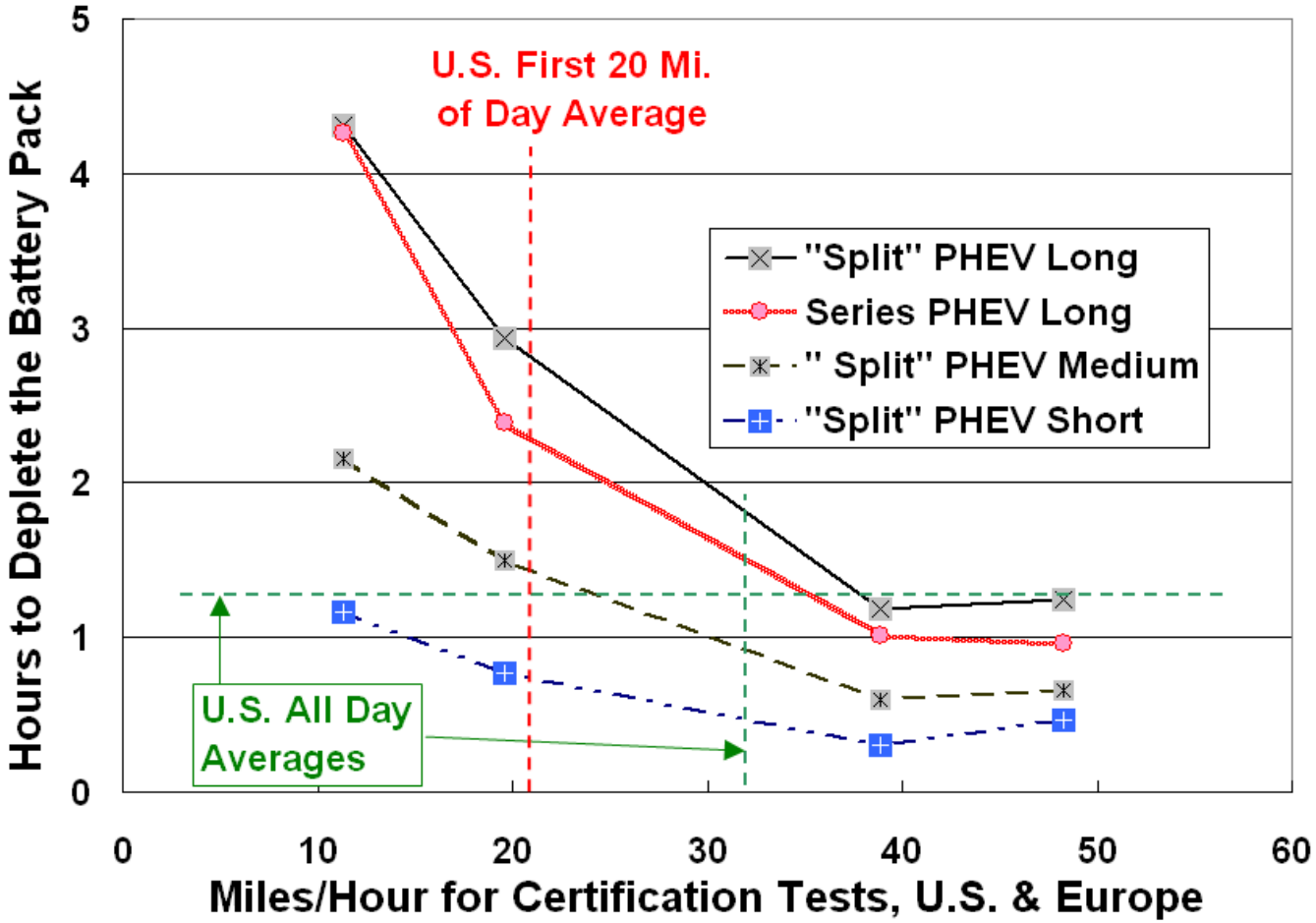
Distance from day's starting point (miles)	First 0–20*	Next 20–40#	Remainder >40	All
Trip share (%)	60	21	19	100
Share of time spent (%)	41	23	36	100
miles/hour	21	31	43	31
miles per trip	4.2	9.4	24	9.0

* Includes day's with travel up to 20 miles, and the first 20 miles of days > 20 miles

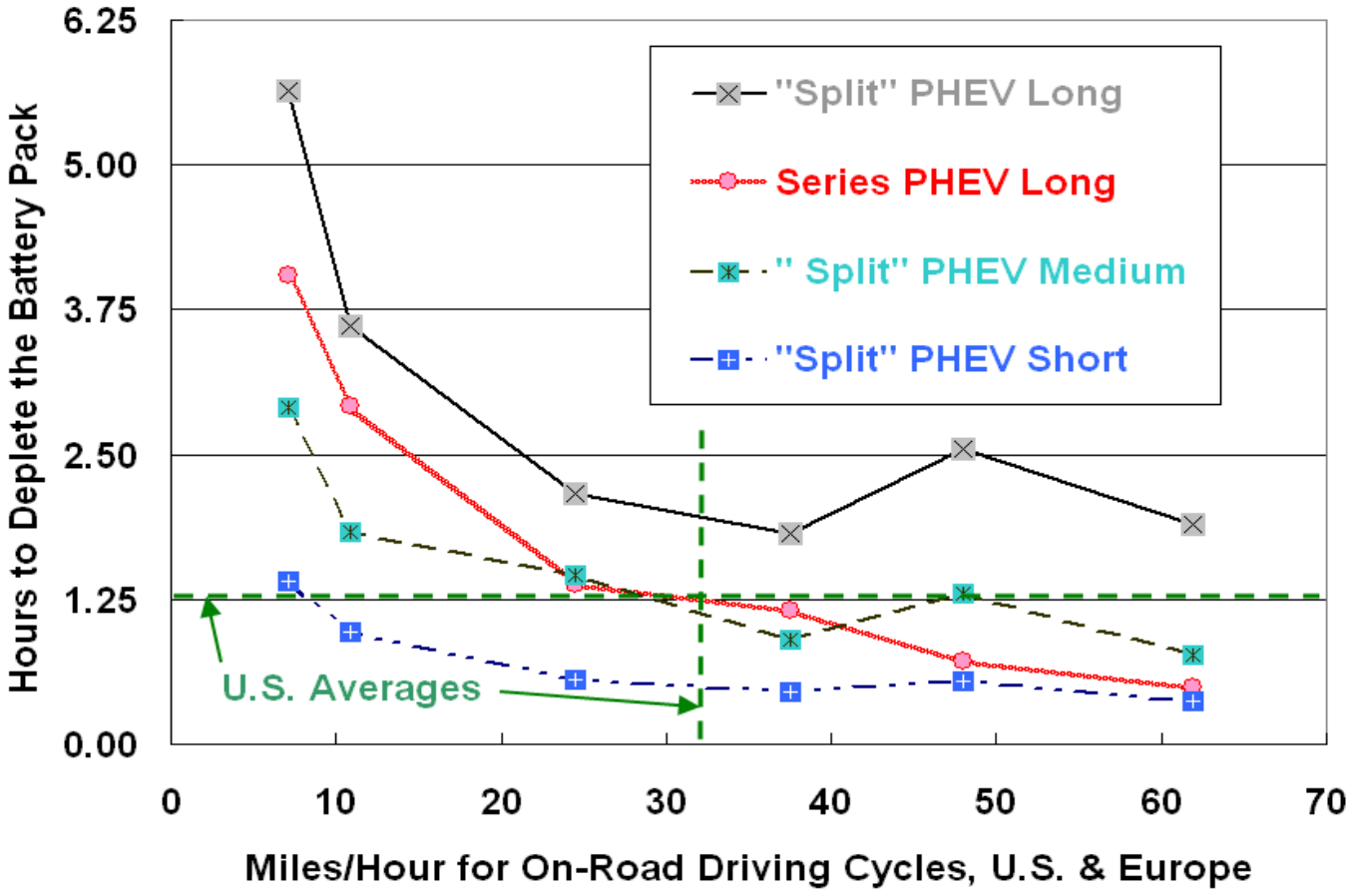
Includes 20+ mile portion of days of travel > 20 mi. but < 40, and for days of travel > 40, includes 20 - 40 mile portion

Source: Developed from U.S. Department of Transportation, 2001 National Household Travel Survey

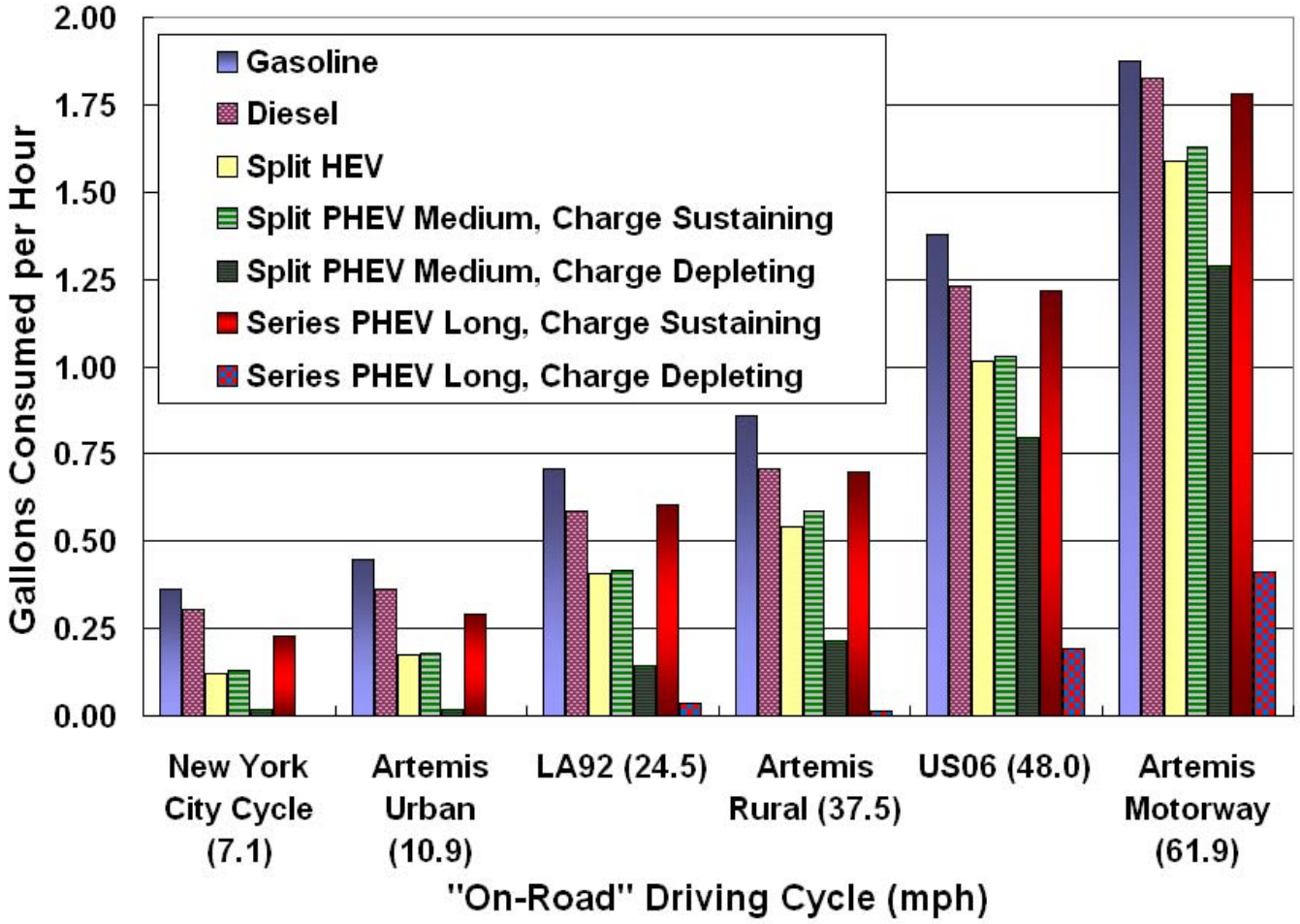
At Low Speeds, the PHEVs with Medium and Long CD Distance Would Not Need Recharging



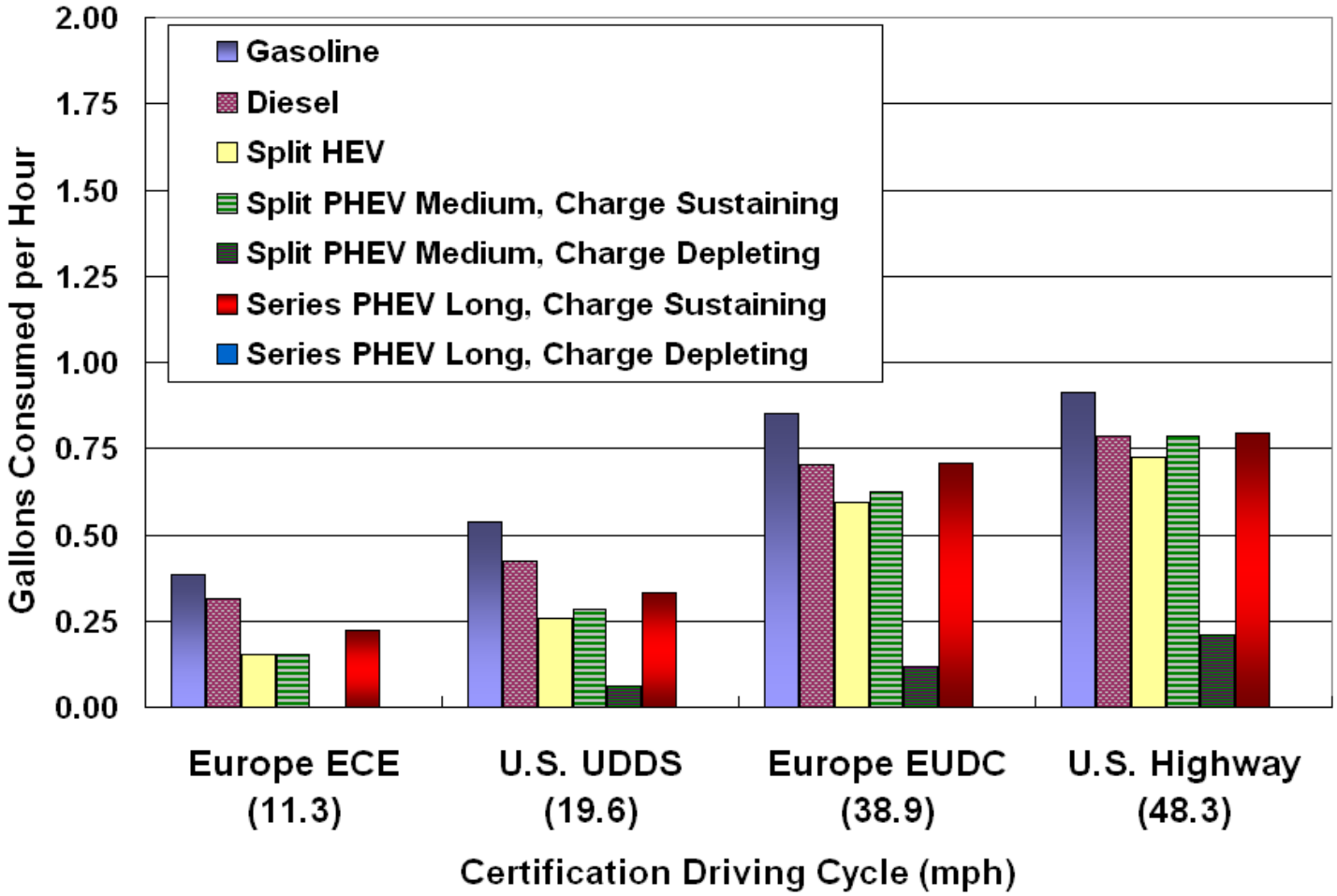
Power (Series Case) Allows kWh to be Used Rapidly at High Speed, "On-Road"



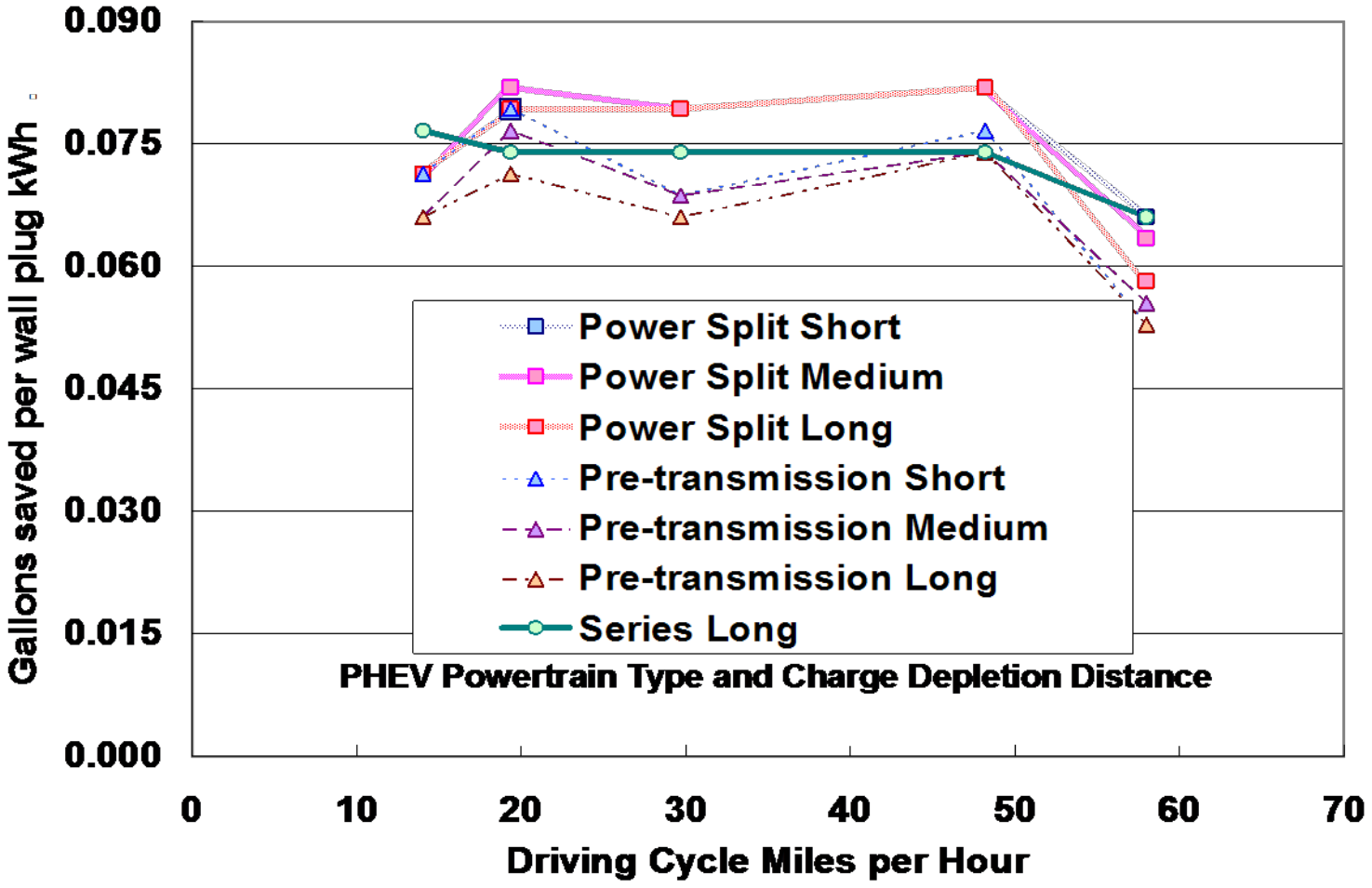
Electrifying Low Speed Miles Will Save Less Fuel Per Hour Than Would Electrifying High Speed Miles



Certification Fuel Use Also Increases With Speed, For All Powertrains (Series PHEV Depleting = 0)



At Usual U.S. Speeds, Initial Estimates Imply ~ Constant CD Fuel Saved / kWh, vs. CS



Passier, G., et al. (2007). *Status Overview of Hybrid and Electric Vehicle Technology(2007):Final Report Phase III, Annex VII, IA-HEV, IEA,* TNO Report MON-RPT-033-DTS-2007-02955, Delft, Netherlands, Dec. 6 (Table 7.2.1)

For "Electrification of Miles" to Succeed, Will Improved City EVs Help?

Battery improvements may provide better technical performance per $

- Increasing real world range
- Increasing top speed
- Improving acceleration capability
- Opening up more passenger or luggage space

Recent "City EVs" (~ 60 mph capable) Alone Could Not Save the U.S. Much Oil

*Data suggests a market share for City EVs in the range of 2 - 4 % of annual CA new vehicle, if priced $10,000 - $20,000, for examined range, seating, cargo room, and trim levels. If City EVs have two-seats and minimal cargo the share estimate is at the low end — maybe lower.**

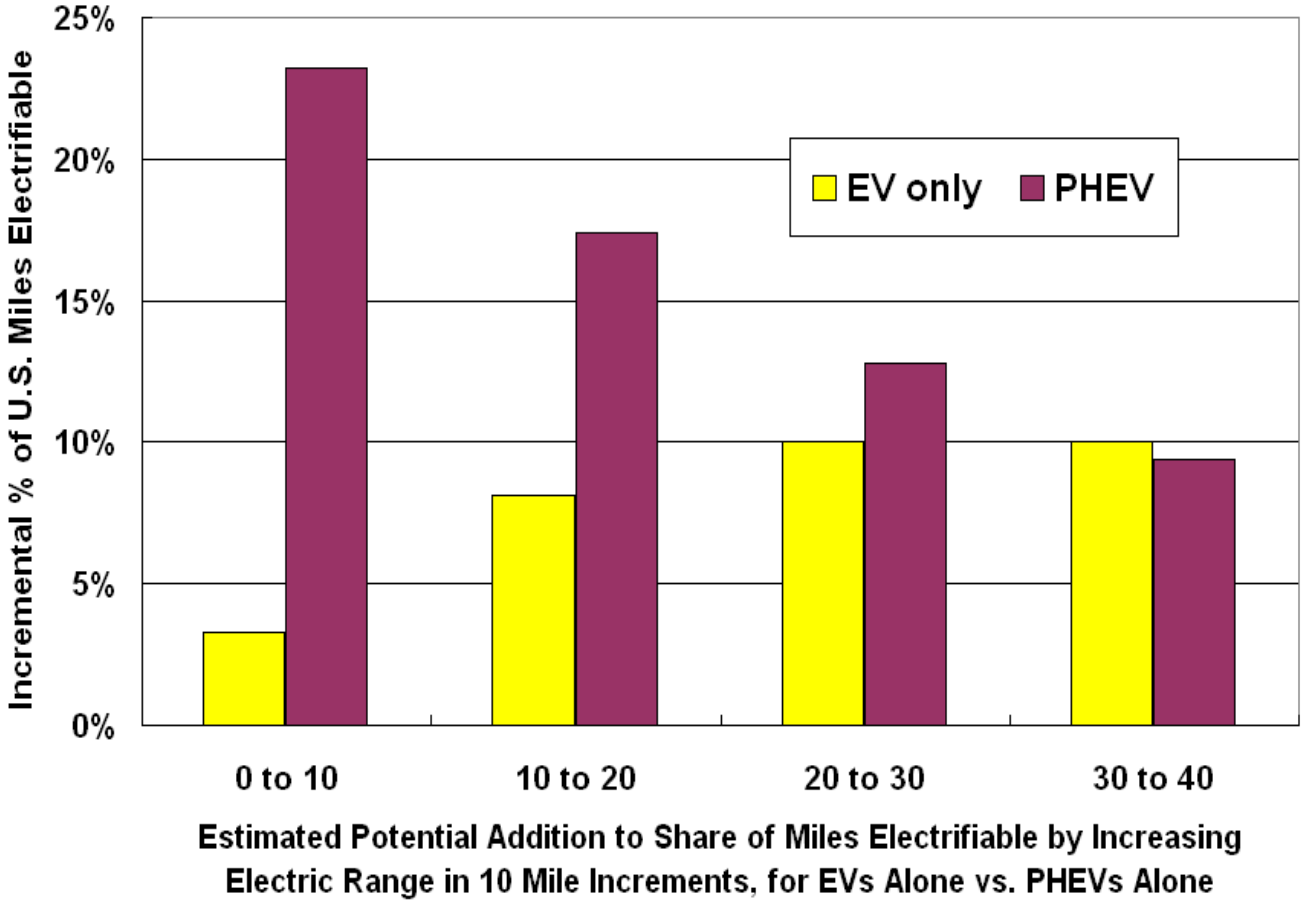
"Limits on long-distance travel included … cannot drive … to test locations … 20 miles from town."

***Paraphrased from: Final Report: City EV Demonstration and Market Research Program K.S. Kurani, C.D. Congleton, Thomas S. Turrentine. ITS, U. of CA, Davis. Sept. 2004**

EV Share is Limited by Range, PHEV Share is Not, Allowing >> Miles Electrifiable

Daily Travel Range of Vehicle	1 charge/day - % "electrifiable" VMT			
	EV10	EV20	EV30	EV40
	PHEV 10	PHEV 20	PHEV 30	PHEV 40
Up to 10 Miles	3.3%	3.3%	3.3%	3.3%
10.01-20 Miles	5.3%	8.1%	8.1%	8.1%
20.01-30 Miles	3.9%	7.9%	10.0%	10.0%
30.01-40 Miles	2.8%	5.7%	8.5%	10.0%
40.01-60 Miles	3.4%	6.7%	10.1%	13.5%
Over 60 Miles	4.5%	8.9%	13.4%	17.9%
Sum if only EVs	3.3%	11.4%	21.4%	31.4%
PHEV Boost	19.9%	29.2%	32.0%	31.4%
Sum with PHEVs	23.2%	40.6%	53.4%	62.8%
10 mi. Increments	23.2%	17.4%	12.8%	9.4%

Even With 1/charge/day, Short/Medium PHEVs are Far More Effective Than EVs in Electrifying Miles



Conclusions

- The Utility Factor is a misleading oversimplification of PHEV potential for electrifying VMT
- The PHEVXX naming convention does not properly represent PHEV CD capabilities
- Short to Medium range PHEVs are very effective in potential to electrify miles. Addition of workplace charging could enhance this effectiveness.
- Determining U.S. potential for oil savings via “electrification of miles” is far more complicated than reading the intersection of the “miles” line with the Utility Factor curve to find electrifiable share.

Vehmile < 32k km, cum mi < 32 km = 28 km/h, 11.5% of VKT
Vehmile > 32 km, cum mi < 32 km = 47 km/h, 29.1% of VKT
Vehmile > 32 km, cum mi> 32 km = 60 km, 59.4% of VKT

Vehmile < 32k km, cum mi < 32 km = 28 km/h, 11.5% of VKT
Vehmile > 32 km, cum mi < 32 km = 47 km/h, 29.1% of VKT
Vehmile < 32 km = 40 km/h, 40.6% of VKT