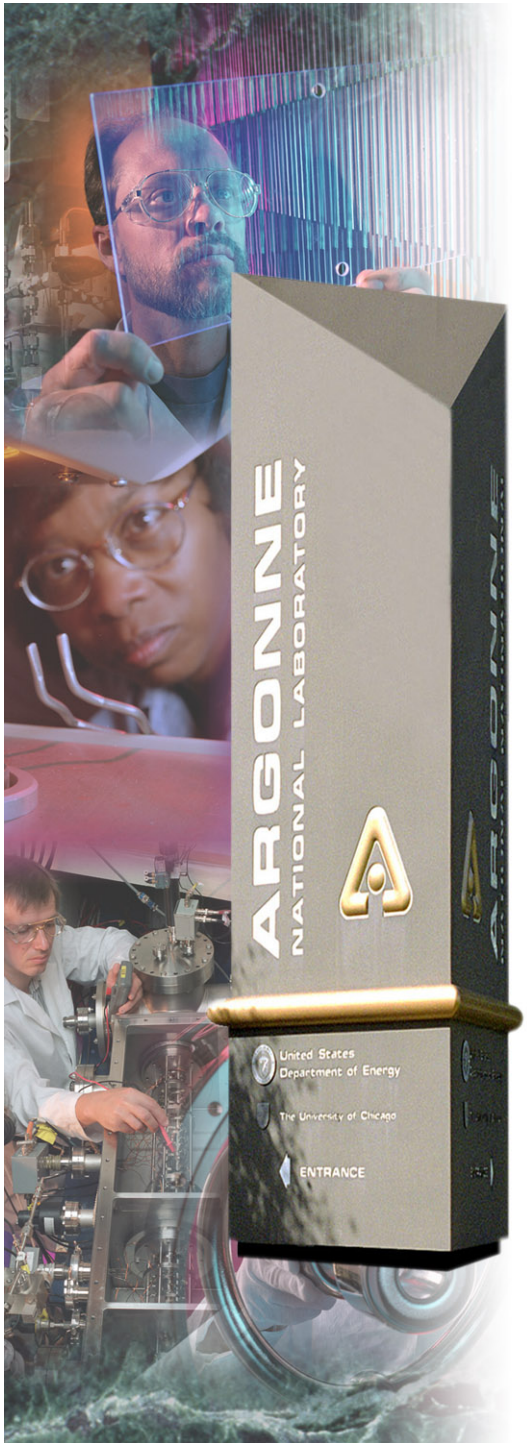


CENTER FOR TRANSPORTATION RESEARCH

Considering Plug-in Hybrids to Allow Electric Generation Infrastructure to Augment International Petroleum Reserves

By Danilo J. Santini

Plug-in Hybrid Workshop

April 3, 2005, Monaco

At EVS-21

21st Worldwide Battery, Hybrid and Fuel Cell Electric Vehicle Symposium and Exposition

April 2-6, Monaco

Argonne National Laboratory

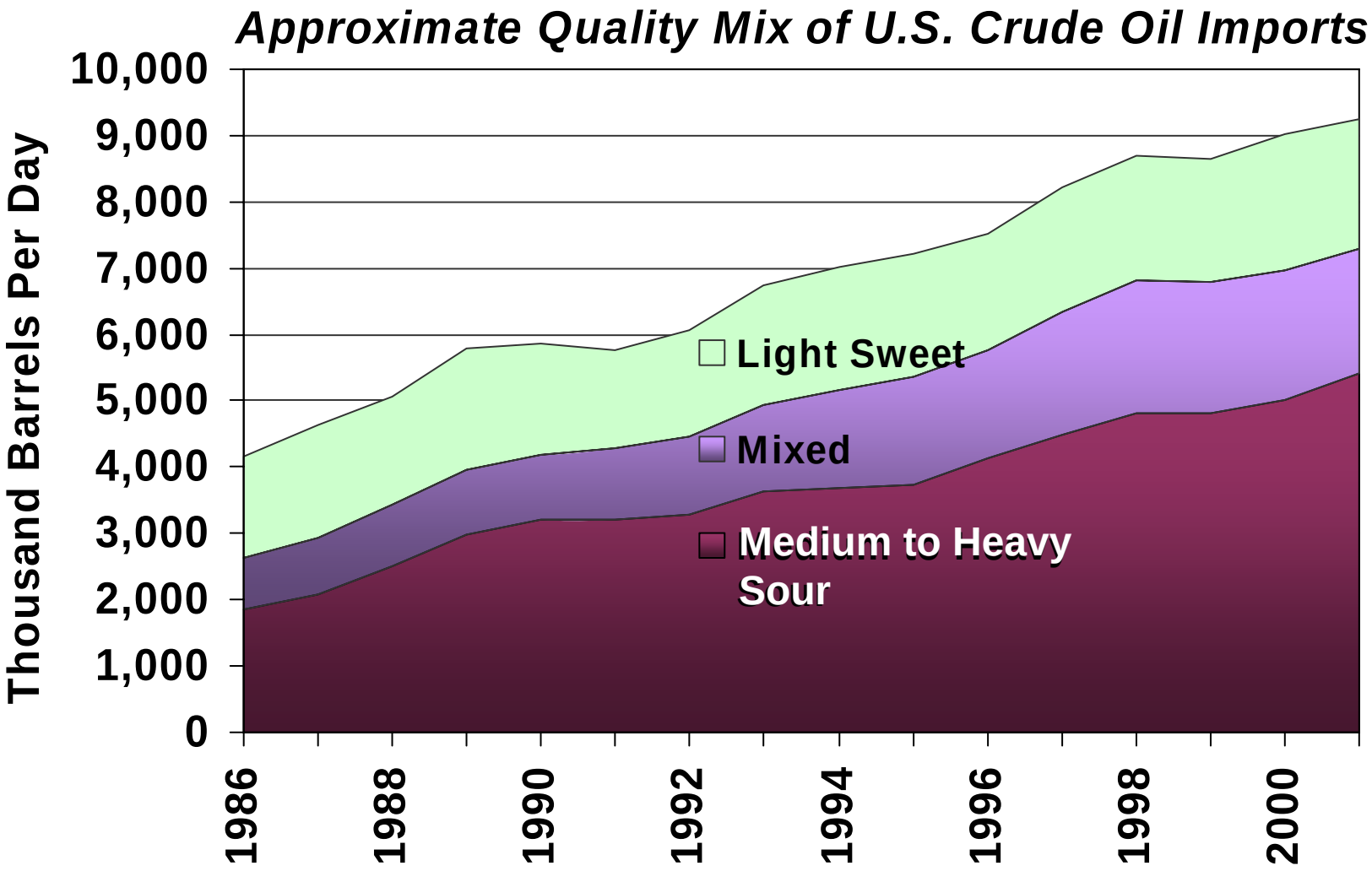
Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

The Plug-In Hybrid is a Neglected Option in the U.S. and Elsewhere, but is Under Consideration

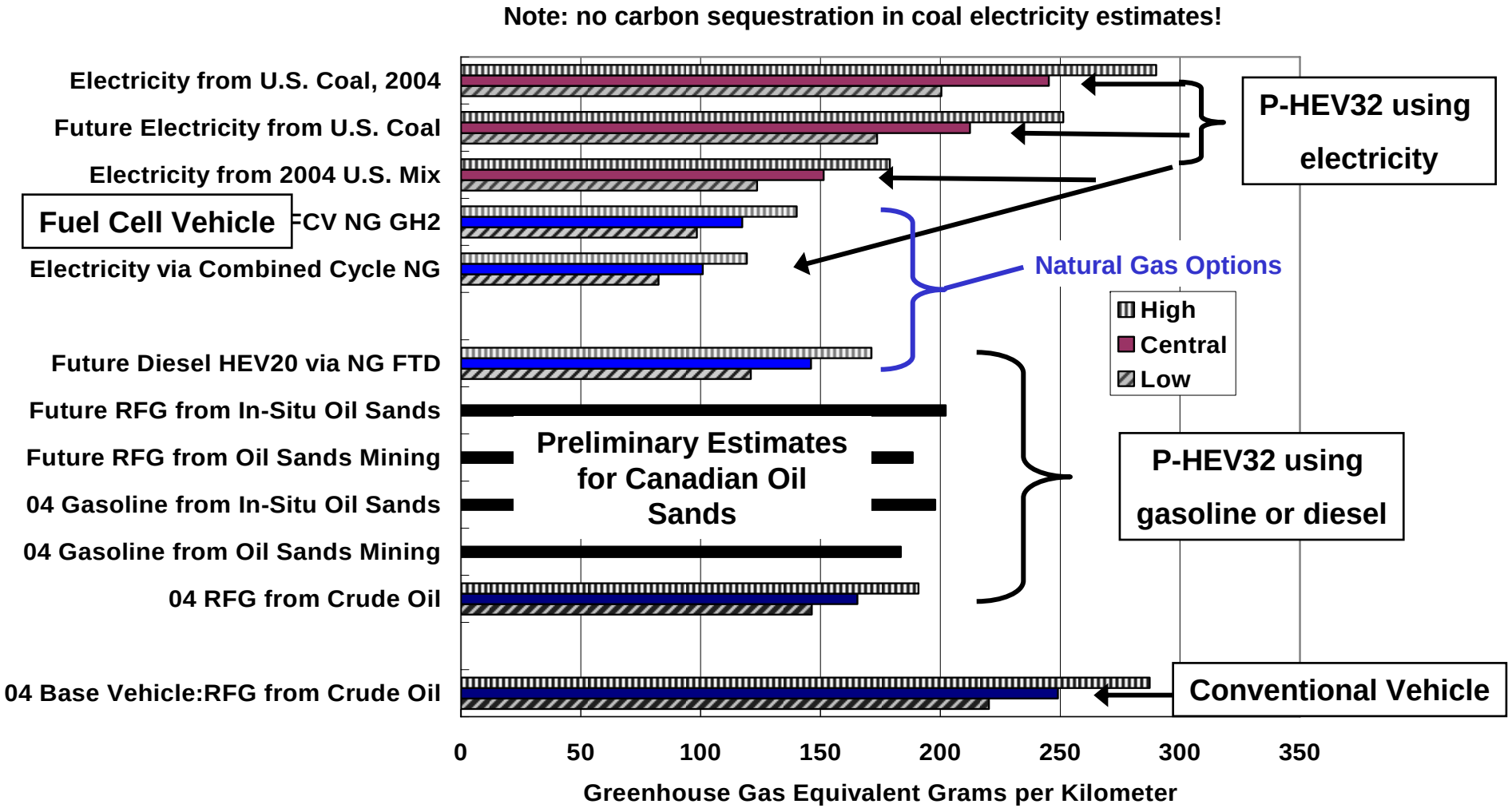
- **<u>2001.</u> CAFE credits available for HEV with 12 km EV range (no longer). In an Advanced Vehicle Technology study with ANL & 3 Oil Majors, GM simulates ICE HEVs with 12 km EV range**
- **California Air Resources Board (CARB) Zero Emissions Vehicle (ZEV) regulations allowed some ZEV credit for a plug-in HEV with 32 to 96 km of all-electric range (now give credit for 16 km)**
- **Both the U.S. Department of Energy (via Argonne National Laboratory [ANL]) and the Electric Power Research Institute [EPRI] completed studies of plug-in HEVs with 32 km of EV range. EPRI also examined hybrids with 96 km of EV range.**
- **<u>2004 +.</u> EPRI and DaimlerChrysler's commercial vehicle unit begin work on prototypes of medium duty delivery trucks with plug-in capability and ~ 32 km of all-electric range**
- **The European and Japanese Toyota Prius can operate all-electrically for about 1 km in some circumstances. Europe is interested in EV mode operation in city centers.**
- **<u>2005.</u> Badin et al of INRETS of France at EVS-21 suggest P-HEV w 20 km EV capability**

The Quality of Crude Oil is Declining, Requiring More Energy to Process

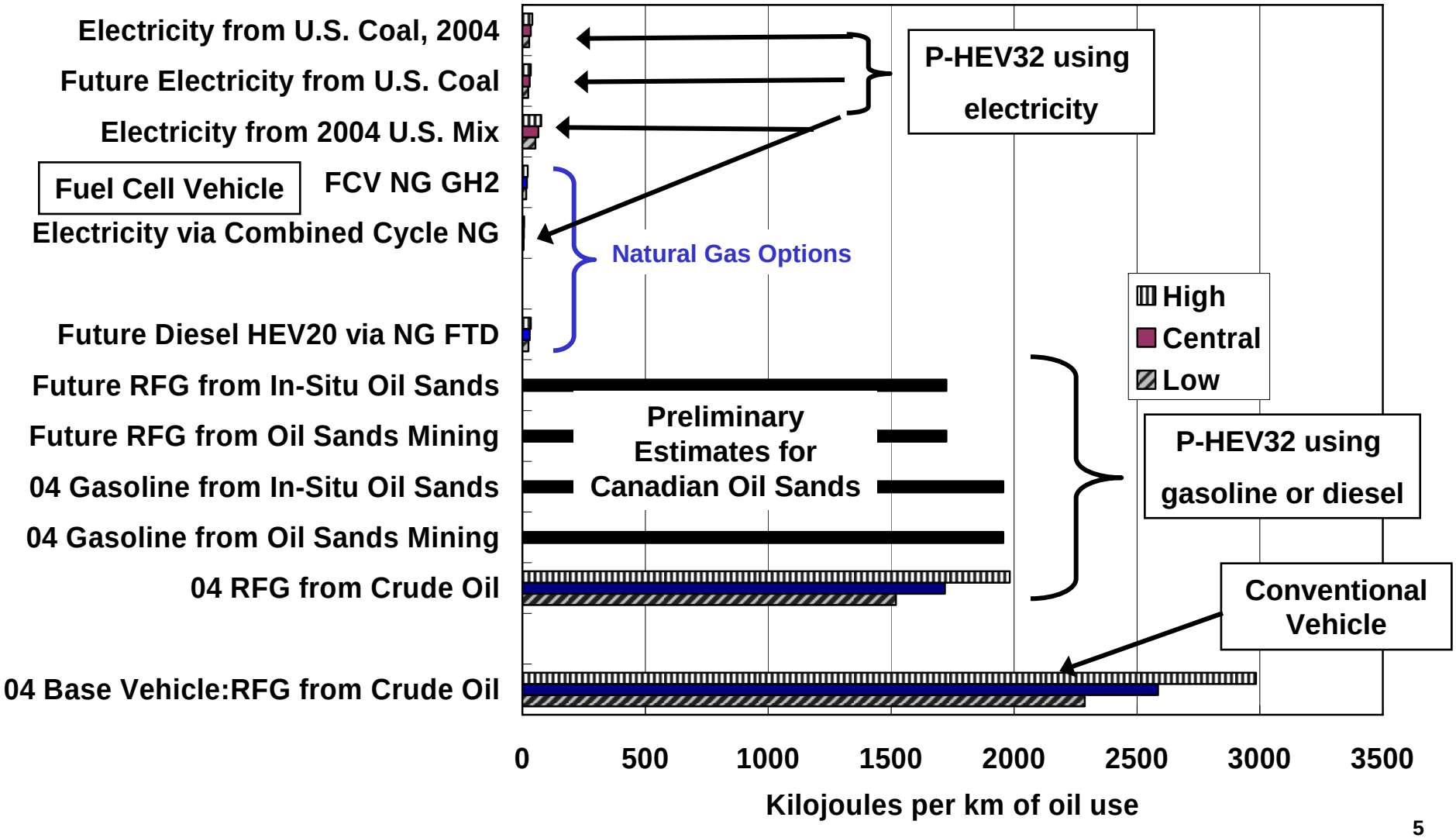


Source: EIA

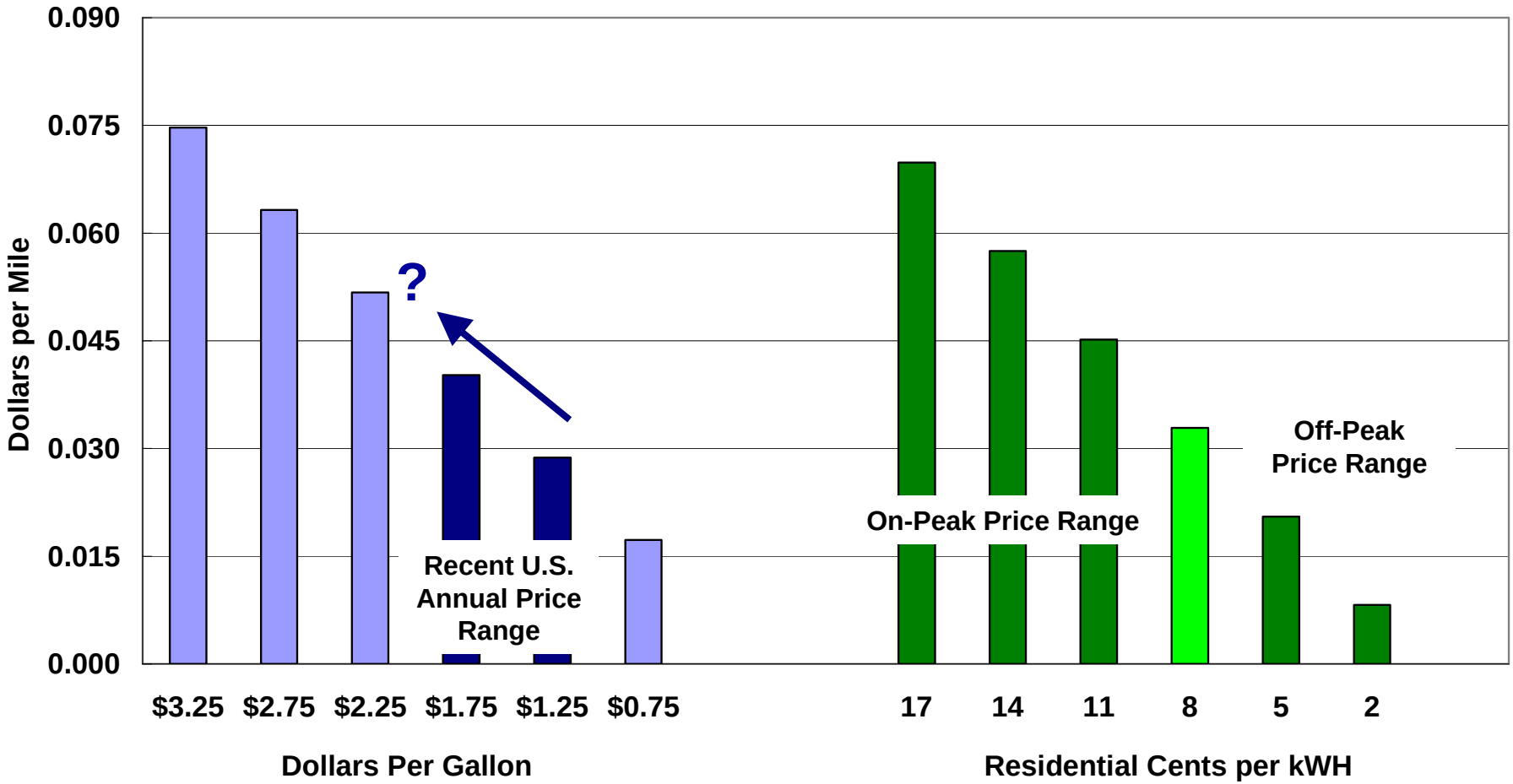
GHGs for P-HEV32s Could Consistently be Less than If No HEVs Were Promoted, Even With Coal



P-HEV32s Reduce Oil Use Considerably Even If No Electricity is Used, Far More When Electricity is Used



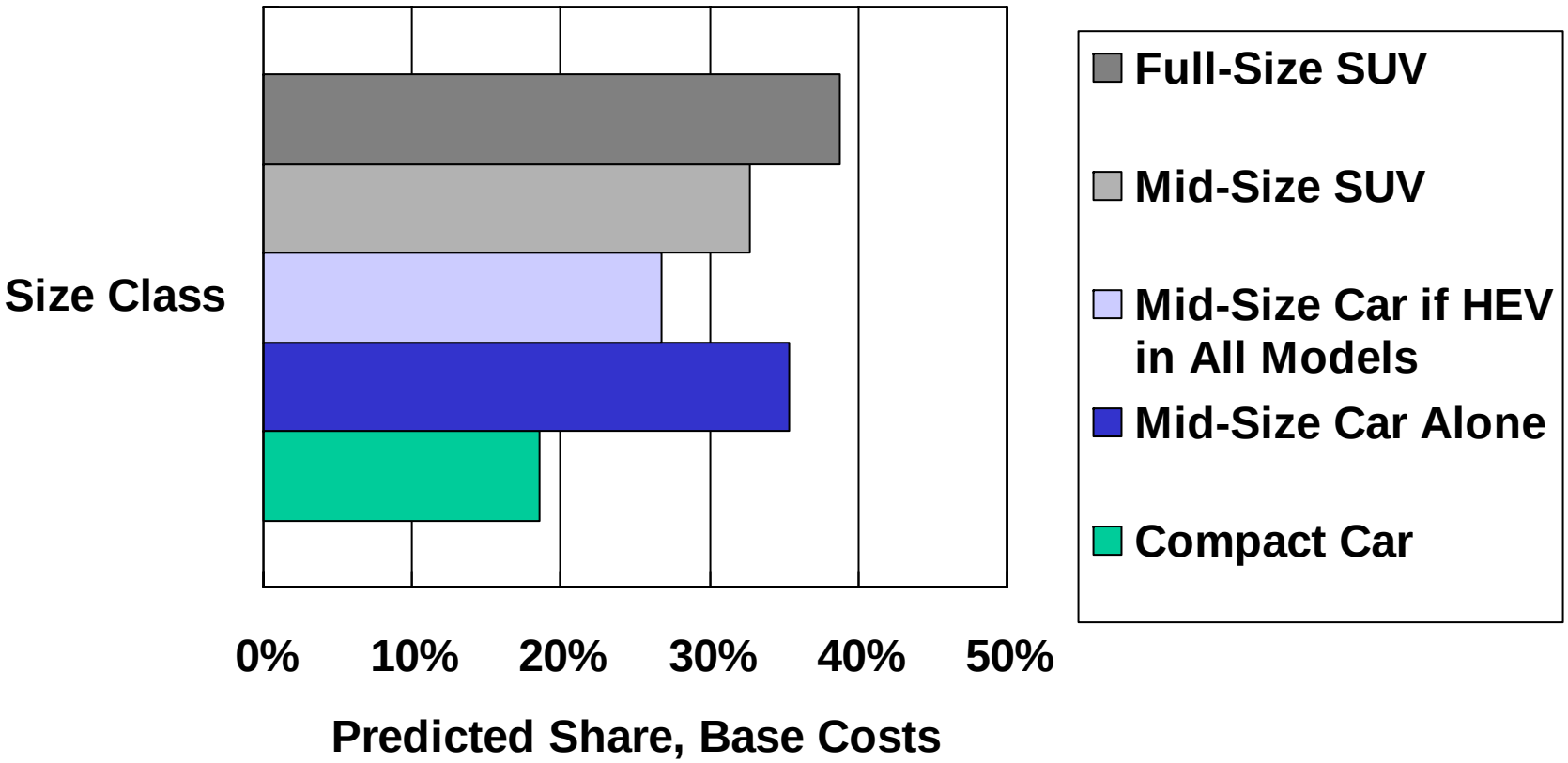
U.S. Electric Rates Imply Off-Peak (Excess Capacity) is Cost Effective if a P-HEV is Owned



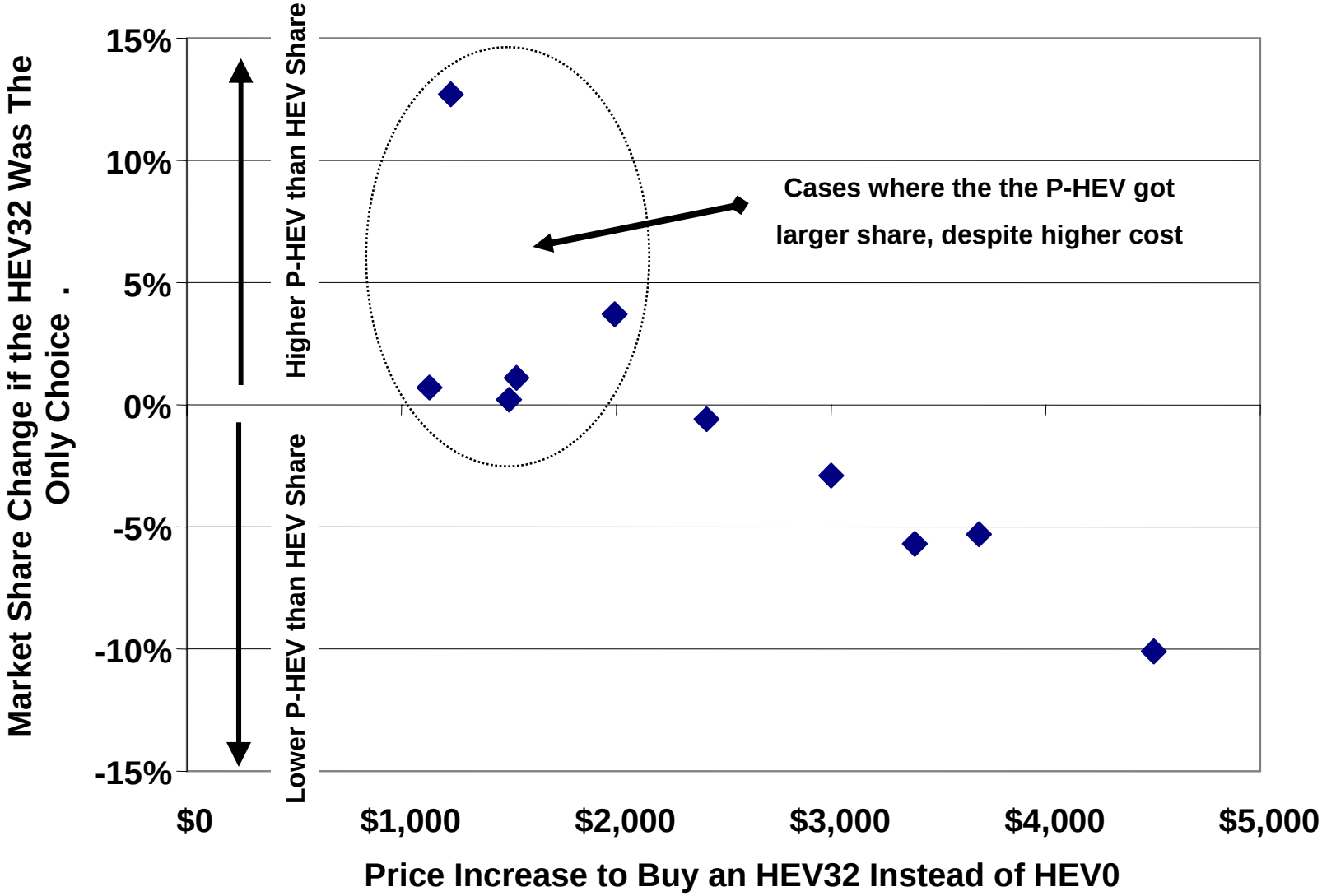
Estimated Fuel Costs Per Mile of Operation of the EPRI Mid-Size HEV20 on Gasoline or Electricity

(HEV20 is a plug-in hybrid with 20 miles [32km] of AE range)

EPRI's Market Study Implied That HEVs (not P-HEVs) Can Capture Well Over 1/6 of the Market



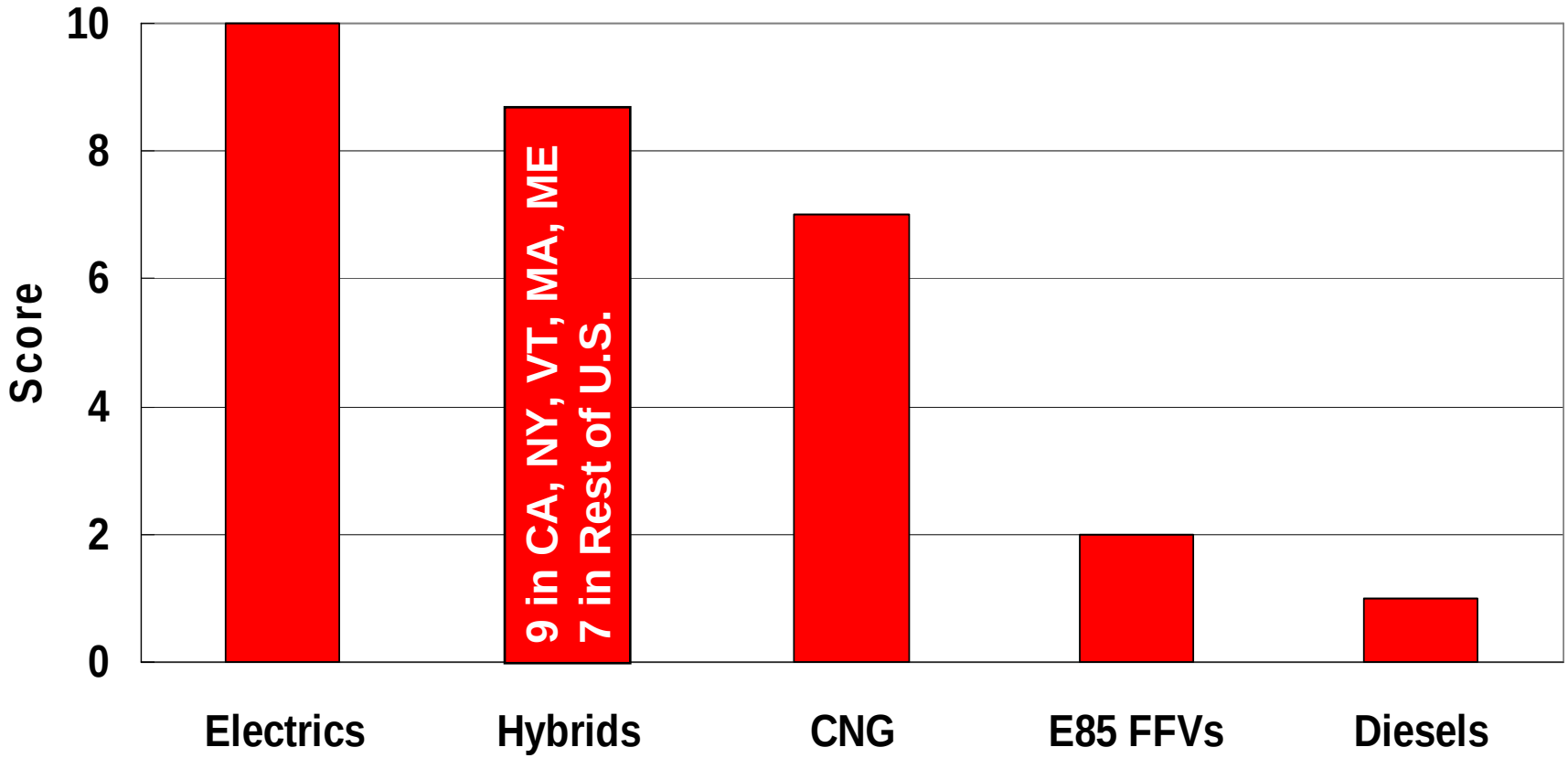
EPRI R&D Estimated Consumers Will as Readily Buy P-HEV32s as HEVs, up to $2000 More Cost!



Does a Goal of All-Electric Operation Work Against P-HEV Success?

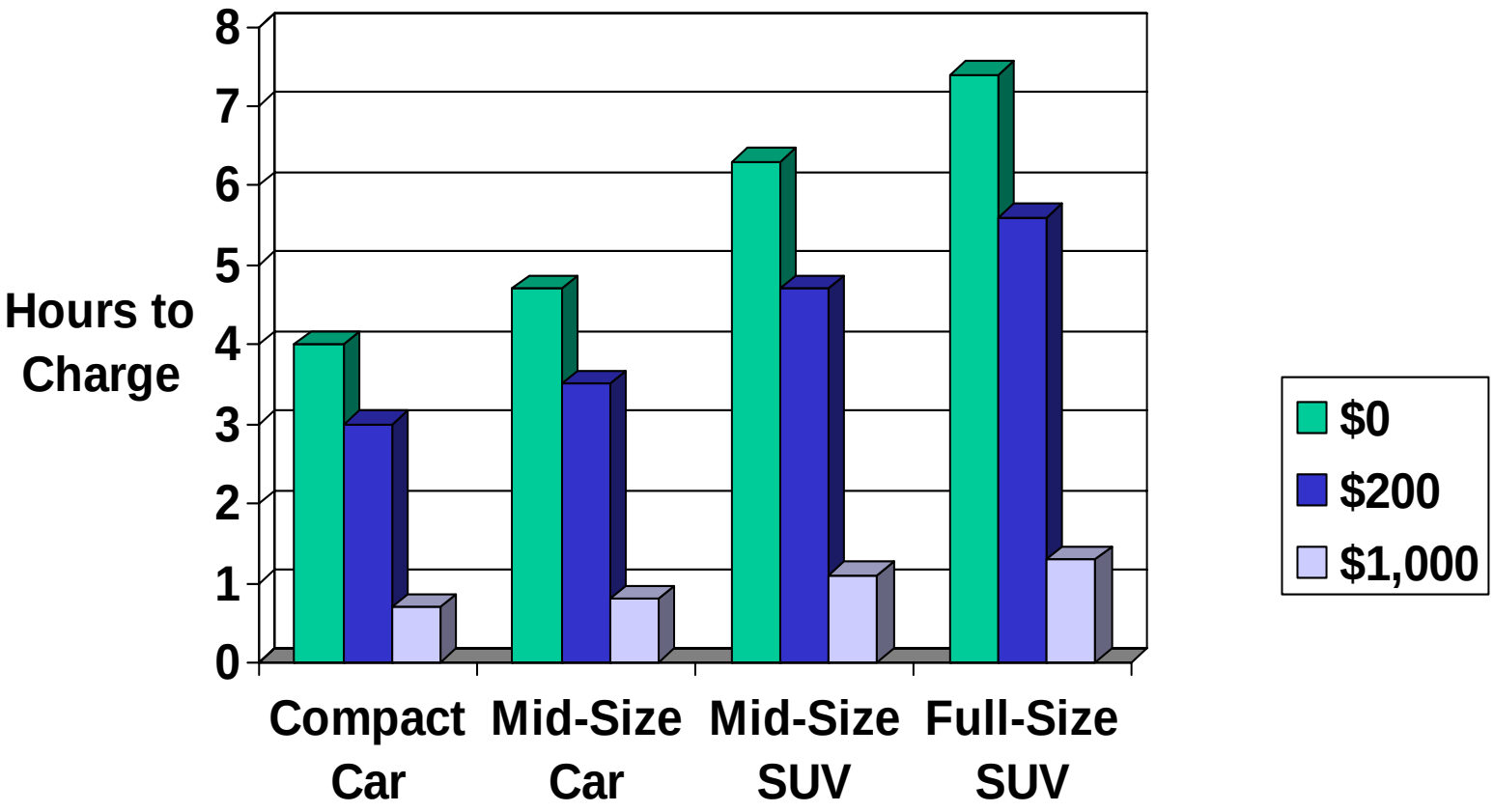
- **CARB (California) wants 16 km+ all-electric range capability.**
- **P-HEVs could "charge deplete", never running multiple miles all electrically.**
- **Charge depleting hybrids might be less expensive, more marketable, and through higher sales actually achieve higher international use of electricity and reduction of petroleum use – as well as creating an effective "petroleum reserve".**
- **These points are hypothetical. The trade-offs have not yet been fully examined (Badin et al do discuss at EVS-21).**

Even Without AE Operation, Present HEVs in U.S. are Very Clean, Cleanest in CALEV States



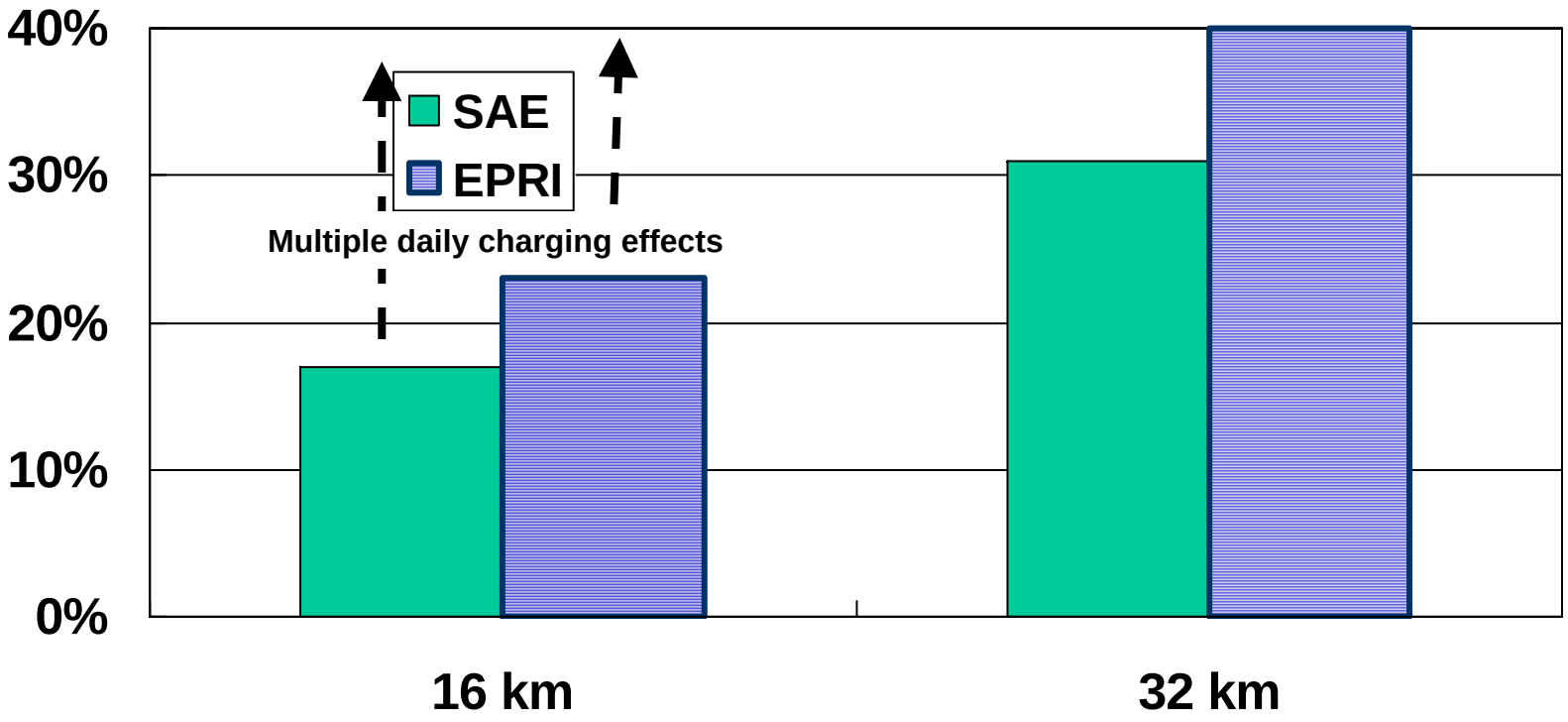
Mean EPA Air Pollution Score, Rated Vehicles in Fuel Economy Guide (10 is Best, 0 Worst)

Even With No Infrastructure Investment, P-HEVs w 32 km Electric Equivalent Charge Overnight



EPRI Estimate of In-House Infrastructure Cost vs. Charge Time

Plug-in Hybrids With Up to 32 km of All-Electric Range Can Cut Own Gasoline Use Up to 40%

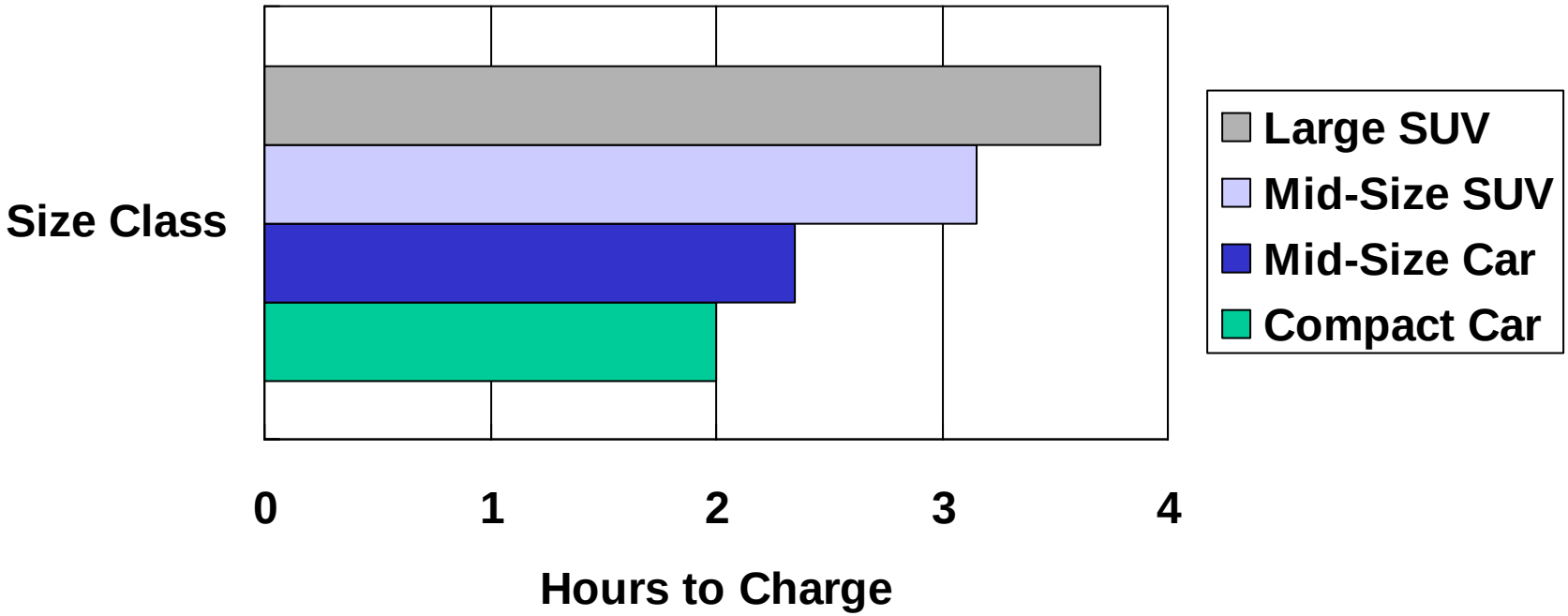


Estimated Percent of Gasoline Use Replaced by Electricity

(<u>If Plugged In With a Full Charge Once a Day</u>)

Note: This is in addition to the fact that these hybrids will use less oil than comparable conventional vehicles even if they never plug in.

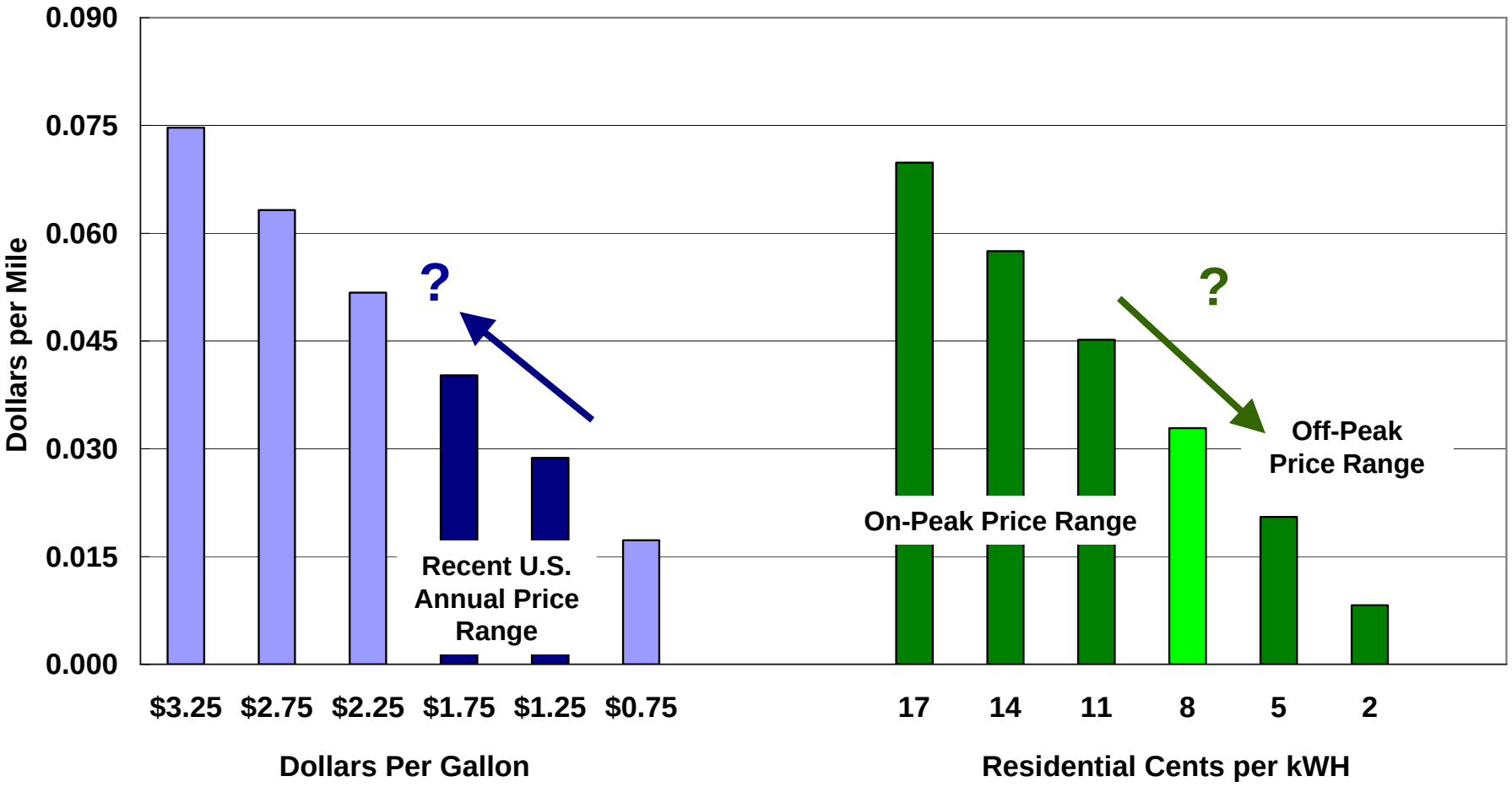
For a P-HEV with 16 km of EV Range "Equivalent" 2 - Even 3 - Charges Day Would be Possible



Charging Times of Hypothetical P-HEVs With 16km of Electric-Equivalent Range, for the "No Infrastructure Cost" Case

(Assumes half of time of EPRI HEV20)

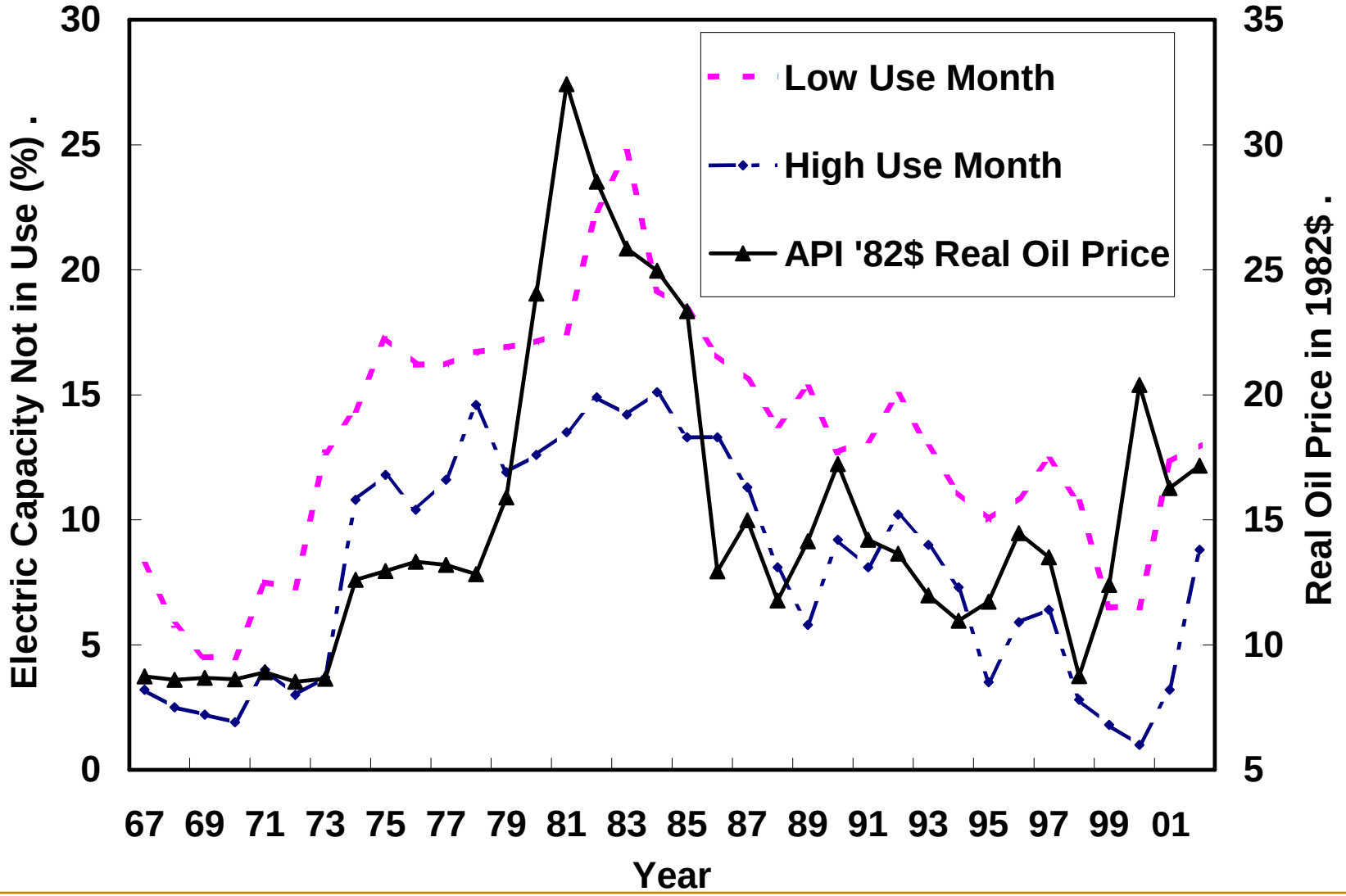
Suppose Excess Electric Capacity Opened Up and Prices Dropped when Oil Prices Increased



Estimated Fuel Costs Per Mile of Operation of the EPRI Mid-Size HEV20 on Gasoline or Electricity

(HEV20 is a plug-in hybrid with 20 miles [32km] of AE range)

With Past Oil Price Shocks and Recessions, Electric Capacity Opened Up – A Lot With Sustained High Prices



P-HEVs Plus Electric Infrastructure to Augment International Petroleum Reserves -- Goals :

- **If subsidy is to be used, adopt the least expensive P-HEVs possible to do the job**
- **Adopt P-HEVs whose electric use can readily expand**
- **Minimize infrastructure investments**
- **Adopt P-HEVs whose capabilities are largely held in reserve, for use in the event of declines of electric output following an oil supply crisis, with increases in electric utility excess capacity.**
- **Adopt P-HEVs to increase capacity utilization in the electric sector, making long-term investments in more capital intensive and efficient powerplants a bit more desirable.**
- **Encourage "full" hybridization, such that greater reductions in oil use from each individual hybrid powertrain sold is achieved**
- **Develop a technology base for high voltage electric drive, allowing easier conversion of future powertrains to fuel cell power, with a large portion of adaptation of the system already accomplished**

A Plug-In Hybrid Does Not Have to Operate All-Electrically to Substitute Electricity for Gasoline

- **If a plug-in hybrid (P-HEV) is in all-electric (AE) mode, it will have lower performance than when operating in "HEV" mode.**
- **The key to substituting electricity for gasoline by a P-HEV is to start travel with a fully charged battery and return with an empty battery, and recharge from the grid when parked.**
- **With modern computer software and carefully developed algorithms, managed charge depletion is possible in a P-HEV without switching to AE mode, with uniform performance.**

- **Nevertheless, all electric capability in P-HEVs could greatly enhance their marketability.**
- **CARB now gives credit to low performance electric vehicles.**
- **Neighborhood electric vehicles (NEV), with maximum 40 km/h speed are legal (if < 56 km/h posted speed) in 37 U.S. states.**
- **Full-function light duty vehicles also capable of low performance AE mode operation would be much safer than NEVs.**

The U.S. SPR is Exhaustible. P-HEVs Could Displace As Much Oil in a Multi-Year Oil Crisis, and Continue

- **600+ million barrels in the SPR**
- **U.S. consumes 20 million barrels/day of petroleum products, 7300 million barrels per year (3200 gasoline)**
- **SPR represents ~ 8% of normal annual needs, but ~ 19% of gasoline market.**
- **Part of SPR purpose would be to support military uses, so less than 8% of commercial petroleum use is "covered"**
- **Before/after crisis electric utilization rates, electric substitution capability, and number of adopted P-HEVs would have a bearing on the capability of the EEPR**
- **From slide 9 assume 20% miles substitution *capability* if 16 km P-HEVs are adopted, ~ 10% off-peak utilization before crisis. If two charges per day average, potential rises to 40%, assuming prior on-peak charging periods are now utilized (reduced rates may be granted after utility capacity opens up). Thus, assume about 25-30% gasoline cuts possible per P-HEV in the fleet, during a supply crisis.**
- **If about 1/6 of the entire fleet of LDVs were P-HEVs with 16 km per charge gasoline displacement capability, six years in use would = SPR**
- **This would require roughly 14% of electric generation capacity.**
- **Note that it would take several years to build up the EEPR capacity**
- **Note also that this is a "first cut" analysis, for perspective. R&D needed.**

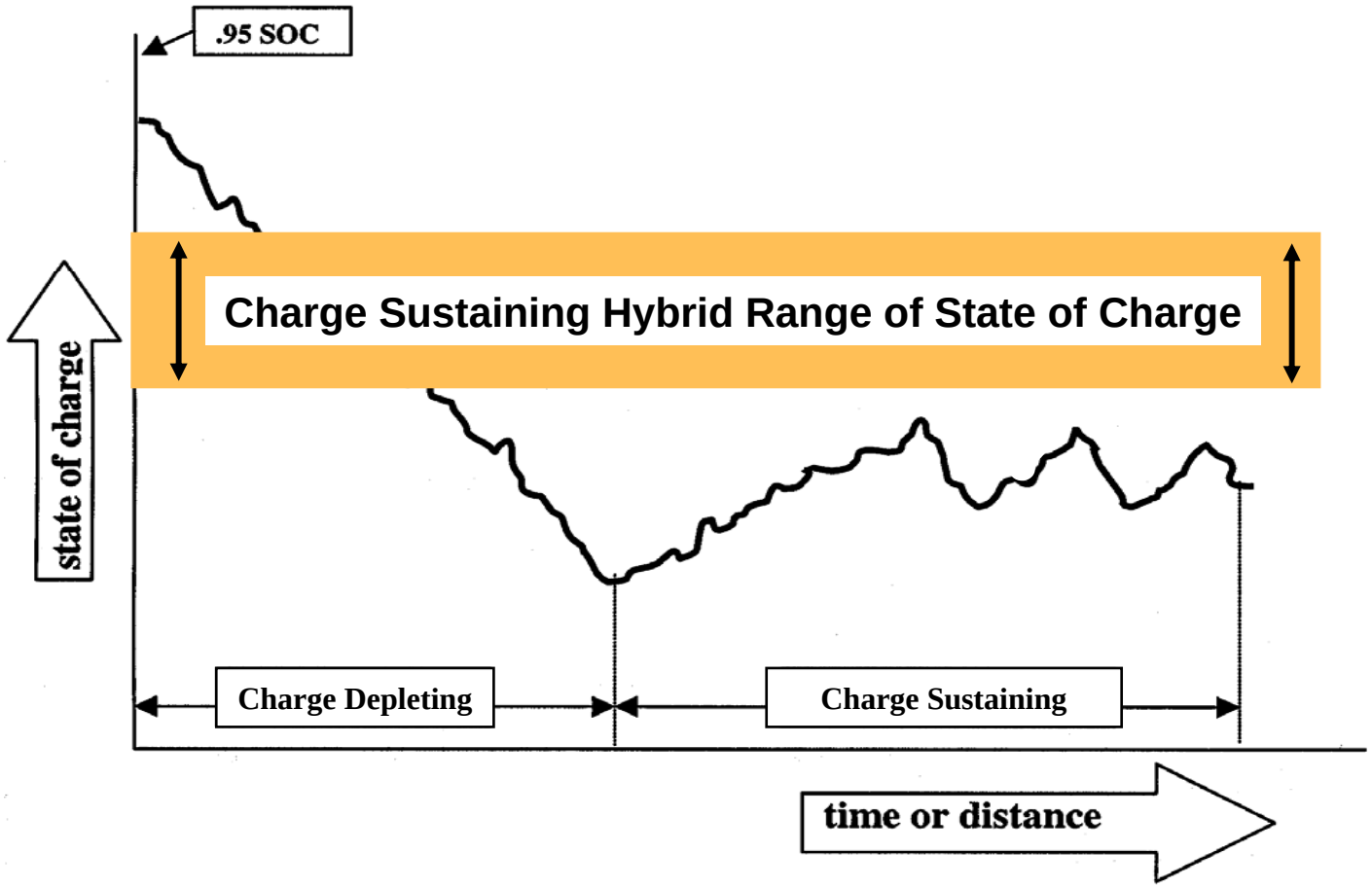
Study of Merits, Costs, Marketability of P-HEVs with Varying Charge Options is Desirable

- **P-HEVs with 16 km instead of 32 km of range would be cheaper, perhaps marketable without government subsidy.**
- **Exactly what value consumers would place on different degrees of charge capability (between 12 and 32 km) is desirable to know.**
- **Marketability of P-HEV in present times vs. 98-99 (when EPRI study was conducted) is desirable to re-evaluate.**
- **Charge depletion strategies and their effects on battery life for CALEV and rest of U.S. purposes should be examined.**
- **If AE operation is to be allowed, minimum U.S. (international?) capability specifications must be developed (harmonized?), and legislation on allowable AE use developed (federal instead of 37 separate states as for NEV legislation – or multi-national?).**
- **Effects on electric utility economics, probable powerplant investment choices, on-peak charging modification strategies (during oil supply shortfalls), etc. would be desirable.**
- **<u>If needed</u>, for frame of reference, $1500/vehicle subsidy for 1/6 of 17 million vehicle market could be funded by a gasoline tax of .03 $/gln.**

The More Demanding are Electric Mode Performance Requirements, the Higher the Likely Cost of P-HEVs

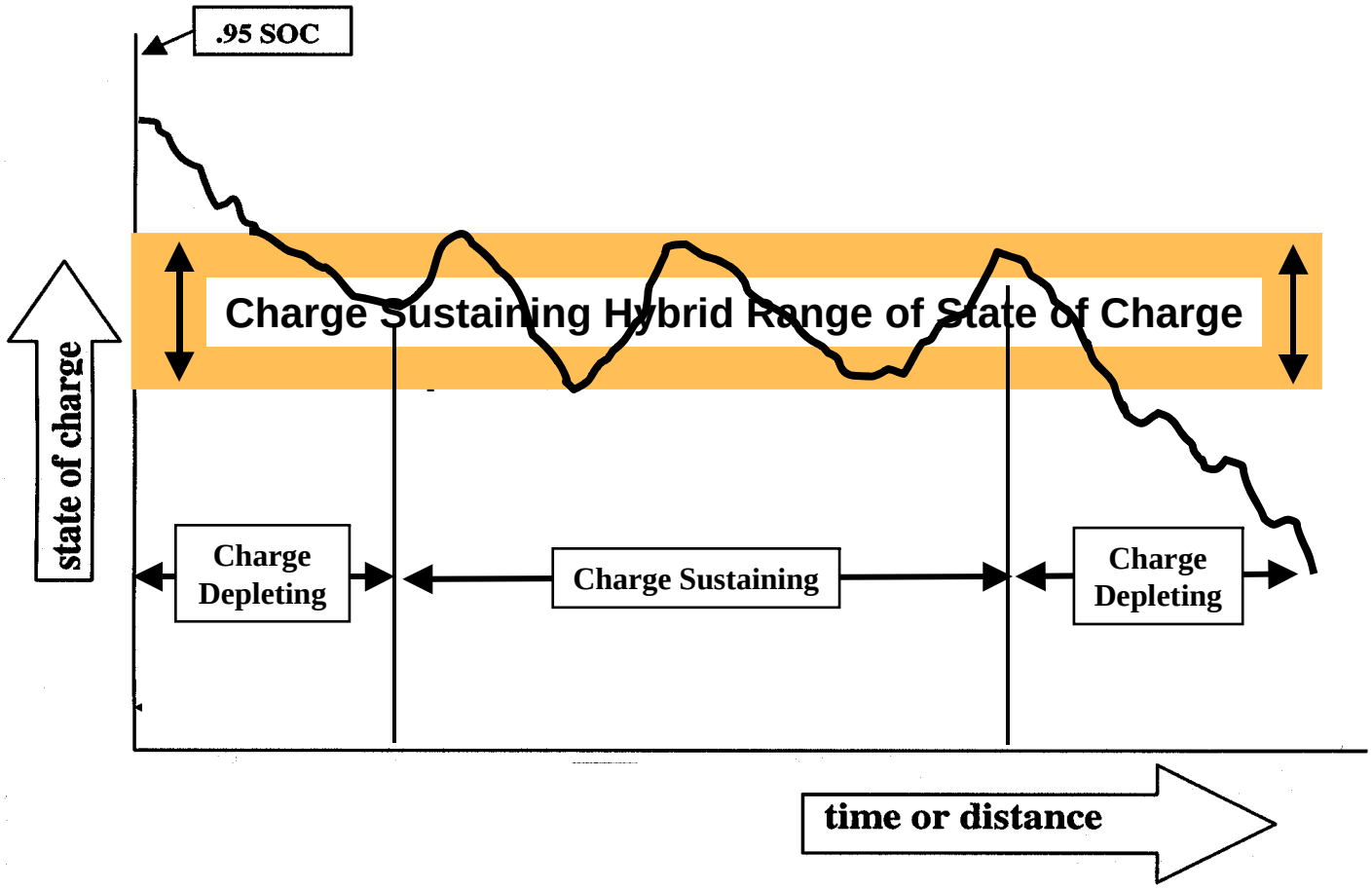
- **CALEV P-HEVs would likely be required to operate all-electrically for as long as possible in the morning after an overnight charge (this would give best air quality benefit)**
- **Rest of the world's P-HEVs could possibly be less capable than CALEV P-HEVs for their AE operation**
- **Rest of world P-HEVs could charge deplete flexibly, at any time during a trip or day's use, just so long as the discharge occurs by the time the P-HEV returns home.**
- **Different charge depletion strategies (illustrated in next two slides) may affect battery life, replacement frequency, and cost.**
- **P-HEVs would logically be more marketable to homeowners with a plug near the parking spot.**
- **In a truly long term multi-year oil supply crisis, however, inexpensive charging stations could be set up in parking lots at shops, apartment complexes, and other places of business.**

Deeper DOD for High All-Electric Miles for CA HEVs Could Reduce Battery Life, Shorten OEM Warranties



A Day's Driving for a Charge Depleting CALEV Hybrid Vehicle

For "Rest of the World P-HEVs", Intelligent Charge Depletion Could Enhance Battery Life



A Day's Driving for a Charge Depleting Hybrid Vehicle for the Rest of the World, With Trip End Forecasting

- **Appendix: The California Perspective**

- **Benefits of P-HEVs depend on the mix of powerplant types and fuels. California is one of the more favorable U.S. locations, as following slides illustrate.**

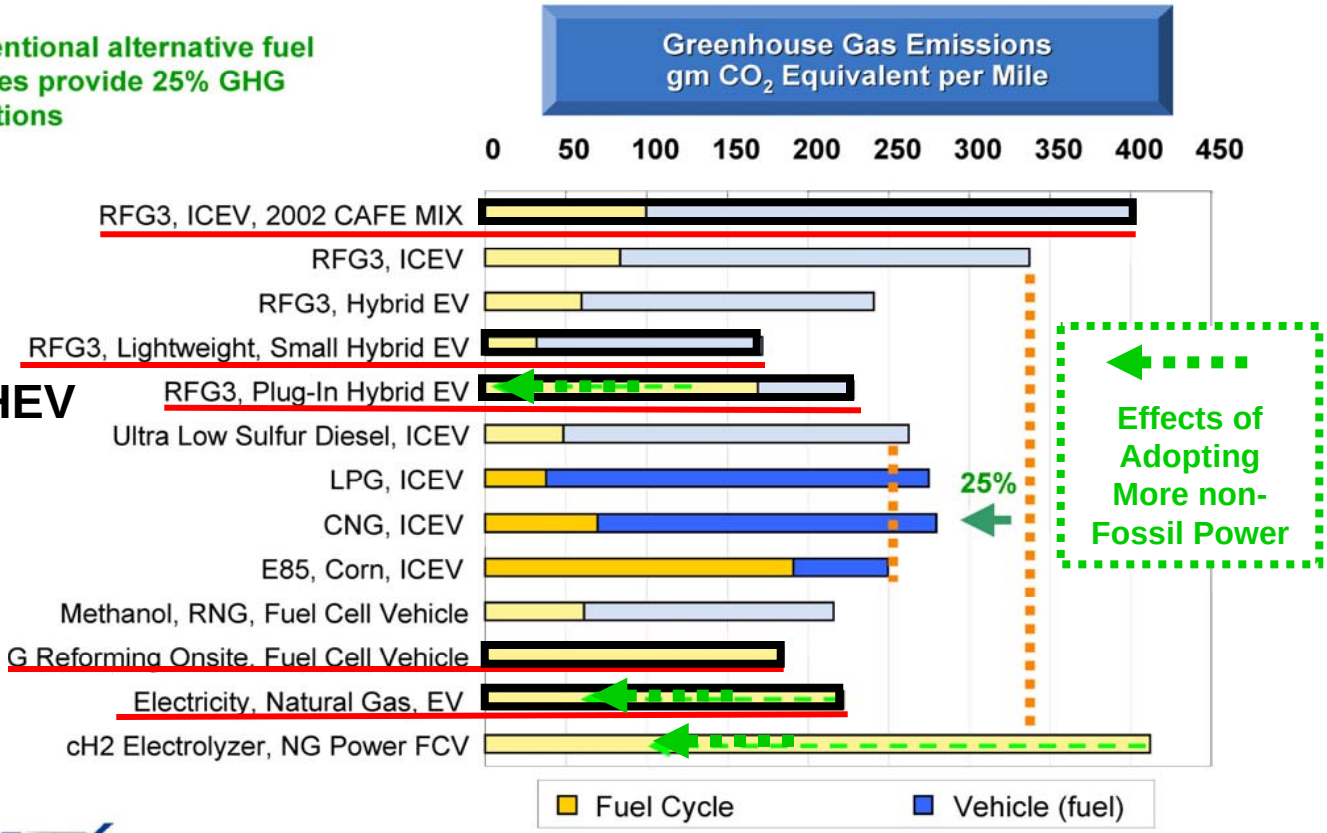
- **Note: Following slides did not consider declining crude quality**

TIAX Reminded California that Rank of PHEV vs. EV & FCV Depends on Generation Mix, Vehicle Size

The Impact of Alternative Fuels on Greenhouse Gas Emissions *Results*

"Well-to-Wheels" GHG Emissions

Conventional alternative fuel vehicles provide 25% GHG reductions



Current Vehicle

Light, Small HEV

Plug-in HEV

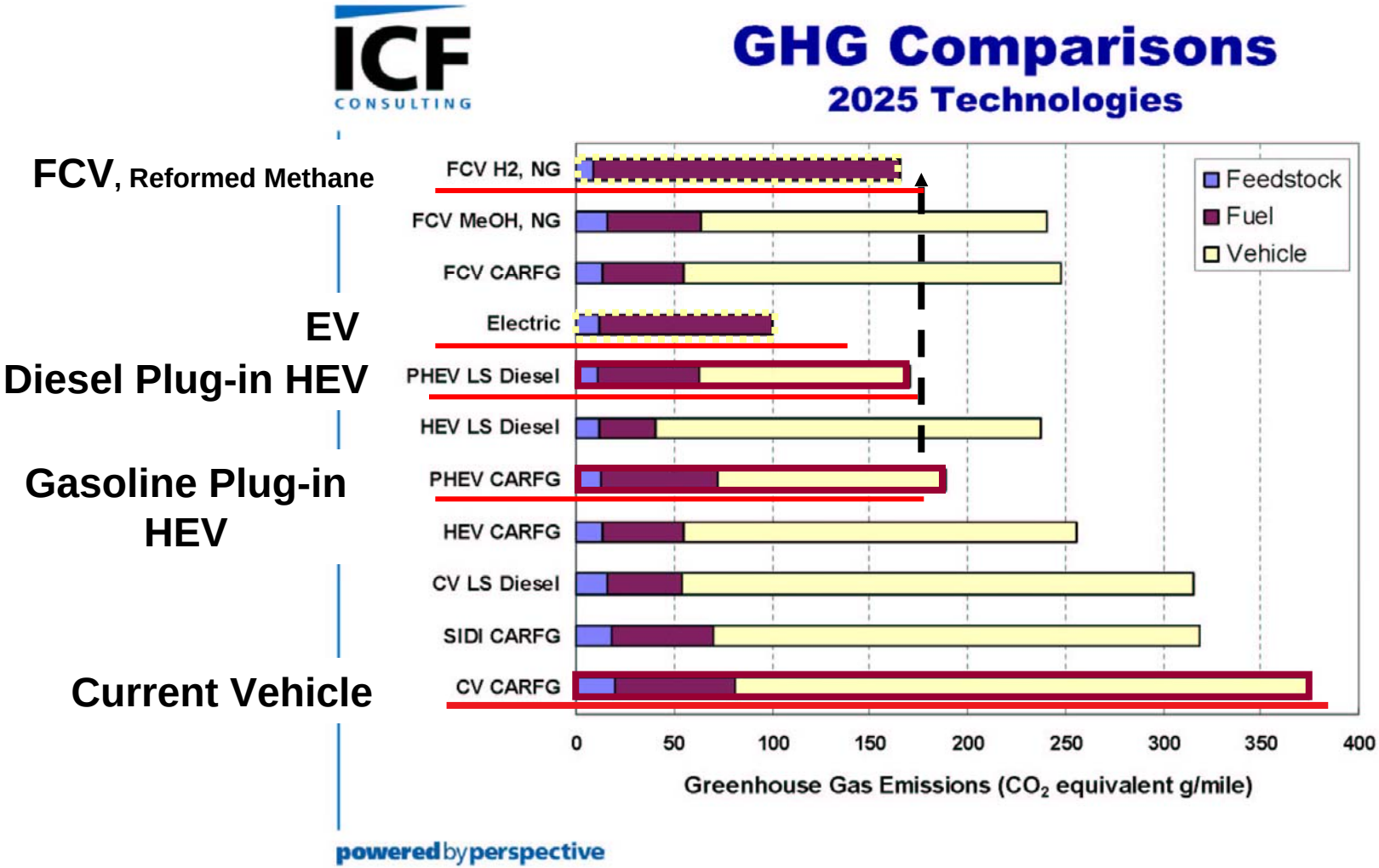
FCV, On-site Reformed Methane

EV, Electricity from Methane

Effects of Adopting More non-Fossil Power

M7100 7640

ICF Consulting has Advised California a Plug-in Hybrid (P-HEV) There Can Reduce GHGs ~ as Much as a FCV



Multiple Plug-in Hybrid Issues are Suggested by Slide 6/14

- **Off-peak residential rates appear to make overnight (off-peak) charging of plug-in hybrids desirable, once purchased.**
- **On-peak residential rates are high, and imply that gasoline costs would have to rise to $2.25/gallon and more to cause plug-in hybrid customers to use on-peak (daytime) charging**
- **Gasoline prices would have to be sustained above $2.25/gallon to cause power plants to be built to serve plug-in hybrids**
- **Absent a long-term crisis (years of high gasoline prices), the capacity that could be devoted to plug-in hybrids is "excess", or off-peak capacity.**
- **A program designed to encourage plug-in hybrids should be planned to first exhaust excess generating capacity.**
- **However – as the next slide will illustrate – excess capacity availability is not a constant.**