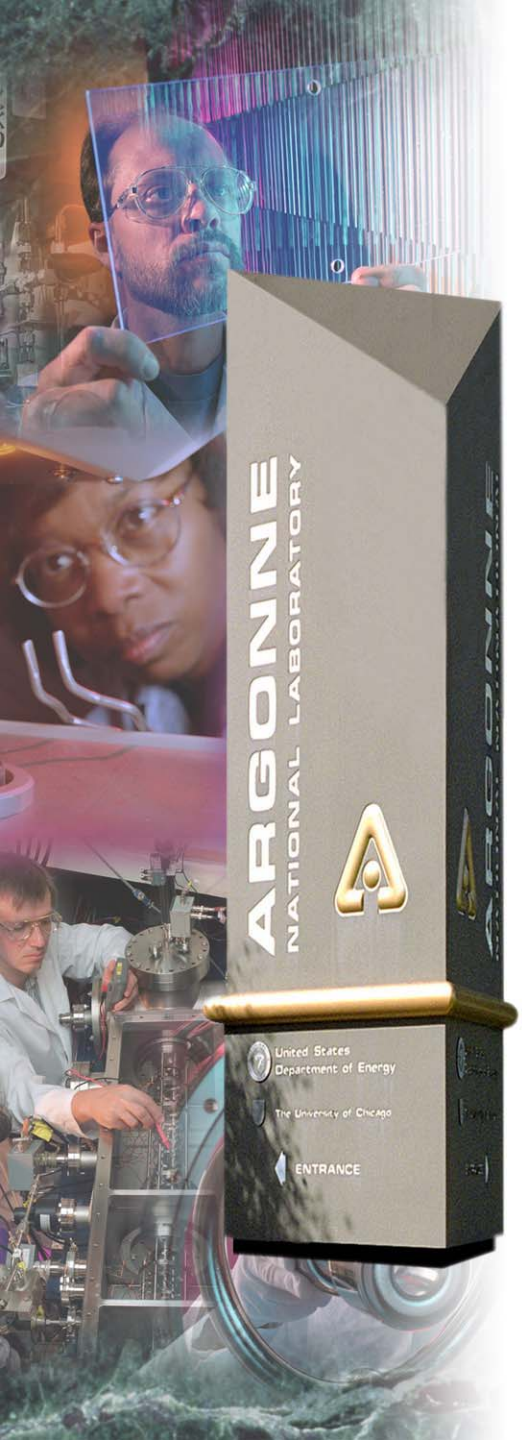

CENTER FOR
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Hybrid Electric Powertrain Fuel Consumption Reduction Cost Effectiveness Trade-Offs

Presentation at the
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U.S. Department of Energy

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

We Conducted a "Study of Studies" of Cost Effectiveness of ICE and FC HEVs vs. Conventional ICEVs

- **Studies that simulate energy economy on U.S. driving cycles were used to assess energy savings/km for comparable vehicles**
  - **Fuel consumption measured in km/L of gasoline energy equivalent**
  - **U.S. "Combined" weighted FTP and Highway cycles**
  - **Focus - CV, CI ICE, SI ICE HEV, CI ICE HEV**
  - **Degree of hybridization**
- **Studies also examining vehicle cost are used to examine cost effectiveness**
  - **Cost effectiveness metrics used in U.S. were criticized**
  - **After investigation, liters saved per 10,000 km driven per $1000 of incremental cost was selected as reliable cost effectiveness metric**
  - **Incremental cost = lower km/L vehicle price less higher km/L vehicle price**

Several "Degrees" of ICE Hybridization were Examined

Charge-sustaining hybrids, no grid charging option

- **Minimal hybrid = idle off, perhaps some degree of regenerative braking (ISG), no grid connection**
- **Mild hybrid = between minimal (or nothing) and full, in any given study, no grid connection**
- **Full hybrid = idle off, considerable regenerative braking, electric launch, no grid connection**

Hybrids capable of both grid charging with charge depleting strategy *and* charge sustaining operation.

(***Operation examined here is only for the charge sustaining mode)***.

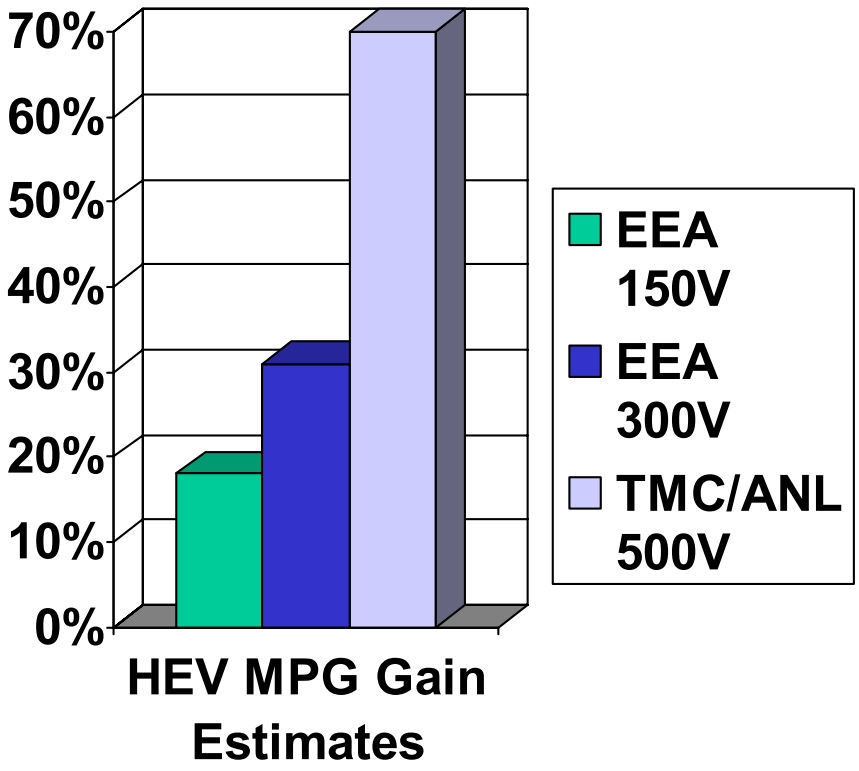
- **HEV## = a grid connectable hybrid with ## miles of electric range**

Note: No single study included all of the above HEV types

Incremental Cost/Benefit Factors

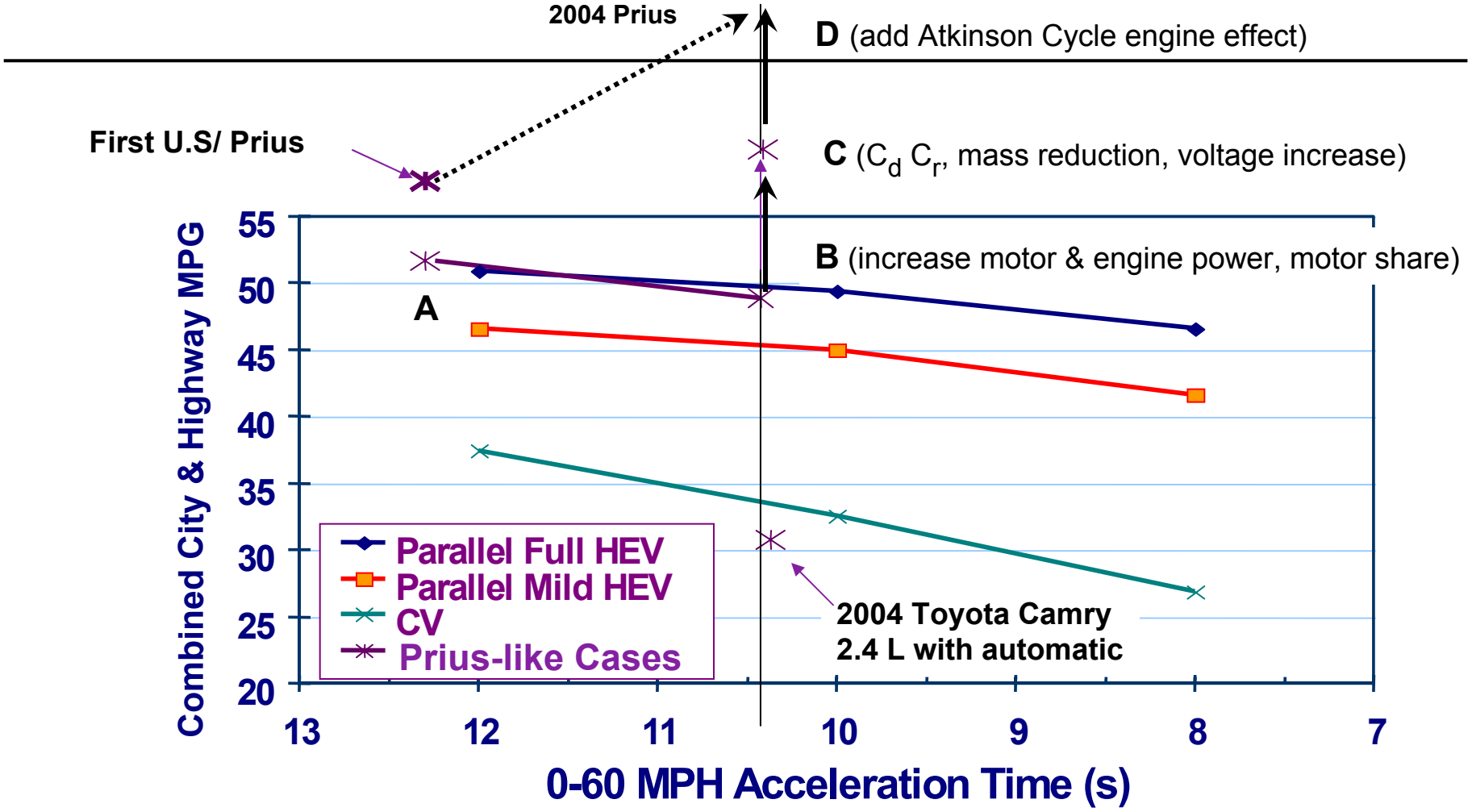
- Control optimization
- Emissions control cost
- **Diesel vs. gasoline engine**
- **Diesel vs. gasoline HEV**
- **"Mild" vs. "Full" HEV**
- **12 to 8 sec 0-60 (pack and motor size, regeneration %)**
- **Engine technology level choice**
- Effectiveness vs. order of adoption (C_d, A, C_r, mass)
- Transmission/motor interaction
- Ex factory gate RPE multiple
- Belly pan value in HEV vs. CV
- **Driving patterns vs. fuel savings**
- Engine, pack life vs. driving patterns
- 2wd vs. 4wd
- Gear & final drive ratios
- No. of electric machines, voltage levels
- Battery materials, subtypes
- Pack size increments
  - Benefits ?
    - Pack life = car life
    - All electric range option
  - Cost - $ to add kWh, kW

"Constant Glider" MPG Gain Approximation for the '04 Prius Showed One Year Old Estimates Were Obsolete



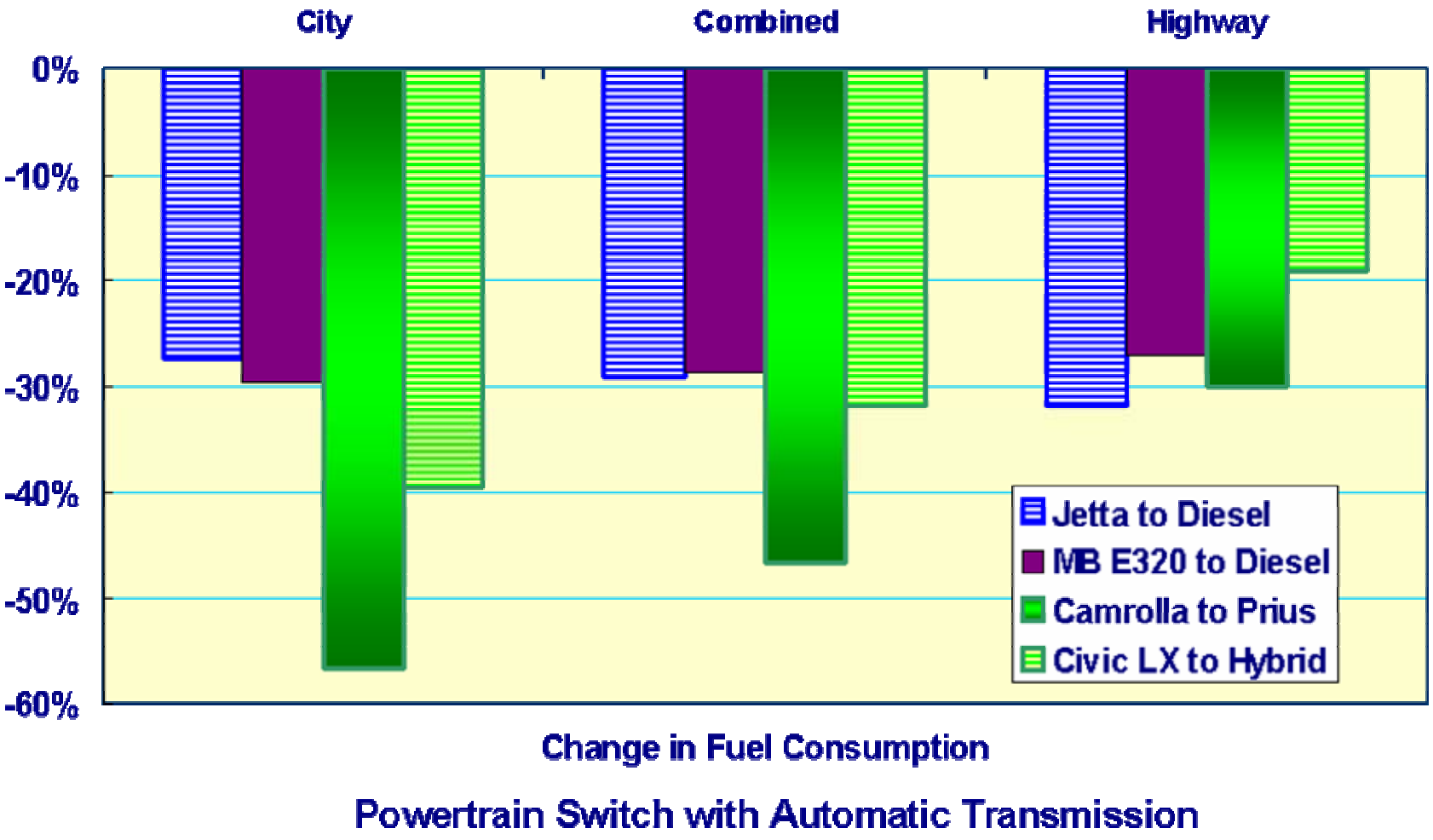
- EEA estimates from 2002 study for California, ANL for actual 2004 Prius
- Lower drag and rolling resistance (than '04 Prius) in the EEA cases
- EEA estimates greater increase in mass of HEV
- All are "mid-size" cars

Prius HEV MPG Gains Exceed "ANL 1" For Several Reasons



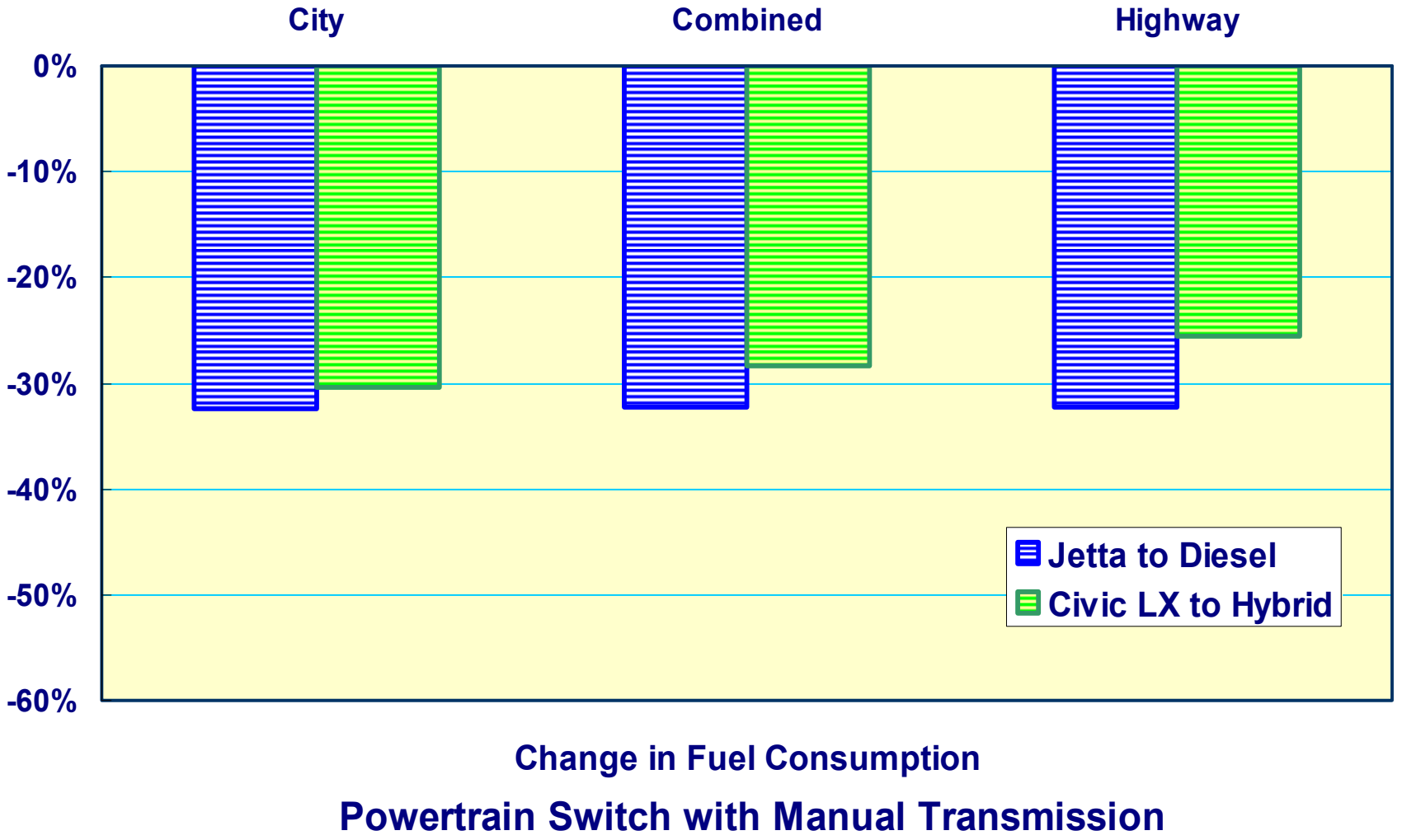
ANL 1 Estimates of HEV Fuel Economy Potential Compared to Actual Prius Results

'04 Actual Consumption Drops of "Full" HEV & Diesel are Relatively Consistent w/ Earlier Estimates, But Better!



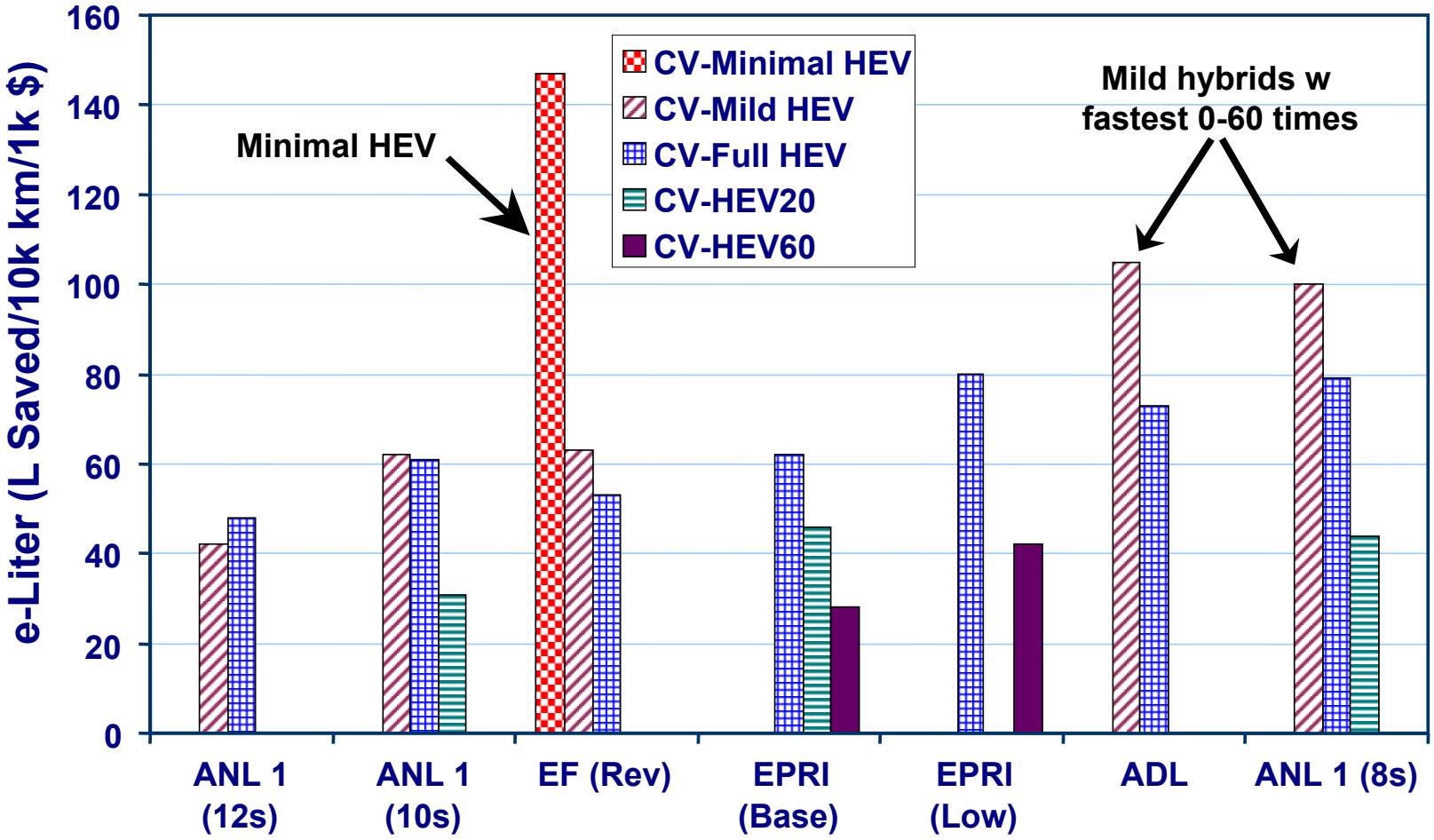
Note: The "Camrolla" is a straight average of a Camry and Corolla. The Prius is exactly midway on EPA interior volume.

Civic MT "Mild" Hybrid is ~ Diesel, and Patterns For City vs Highway Differences are Similar, but Weak



What About Cost Effectiveness to Achieve Such Fuel Use Reductions?

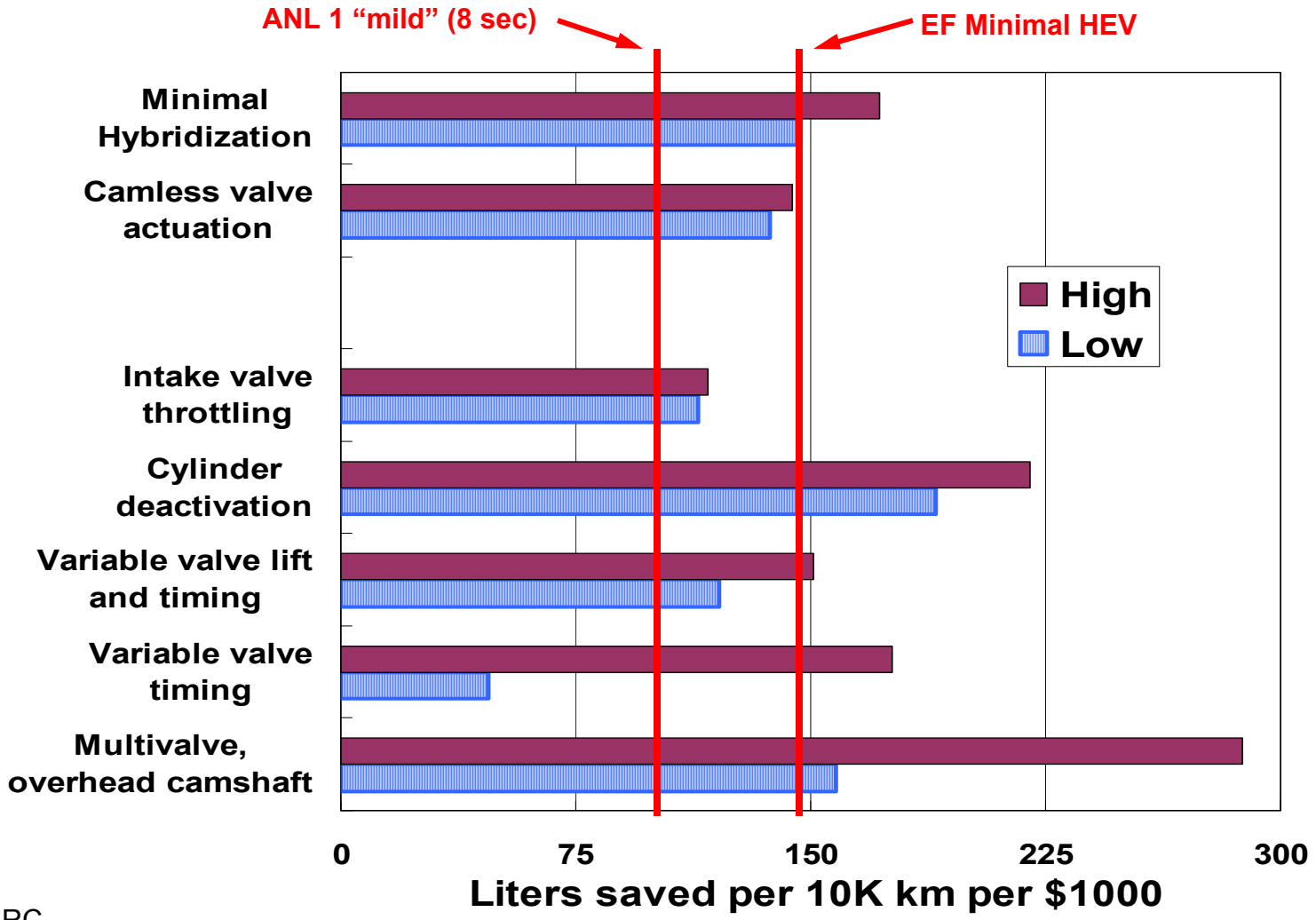
Among Gasoline HEVs, Minimal and Mild Hybrids With 8-9 Sec 0-60 Time Were Estimated to be Most Cost Effective



Sequentially ordered HEV cost effectiveness estimates – L to R = minimal to full HEV, slow to fast 0-60

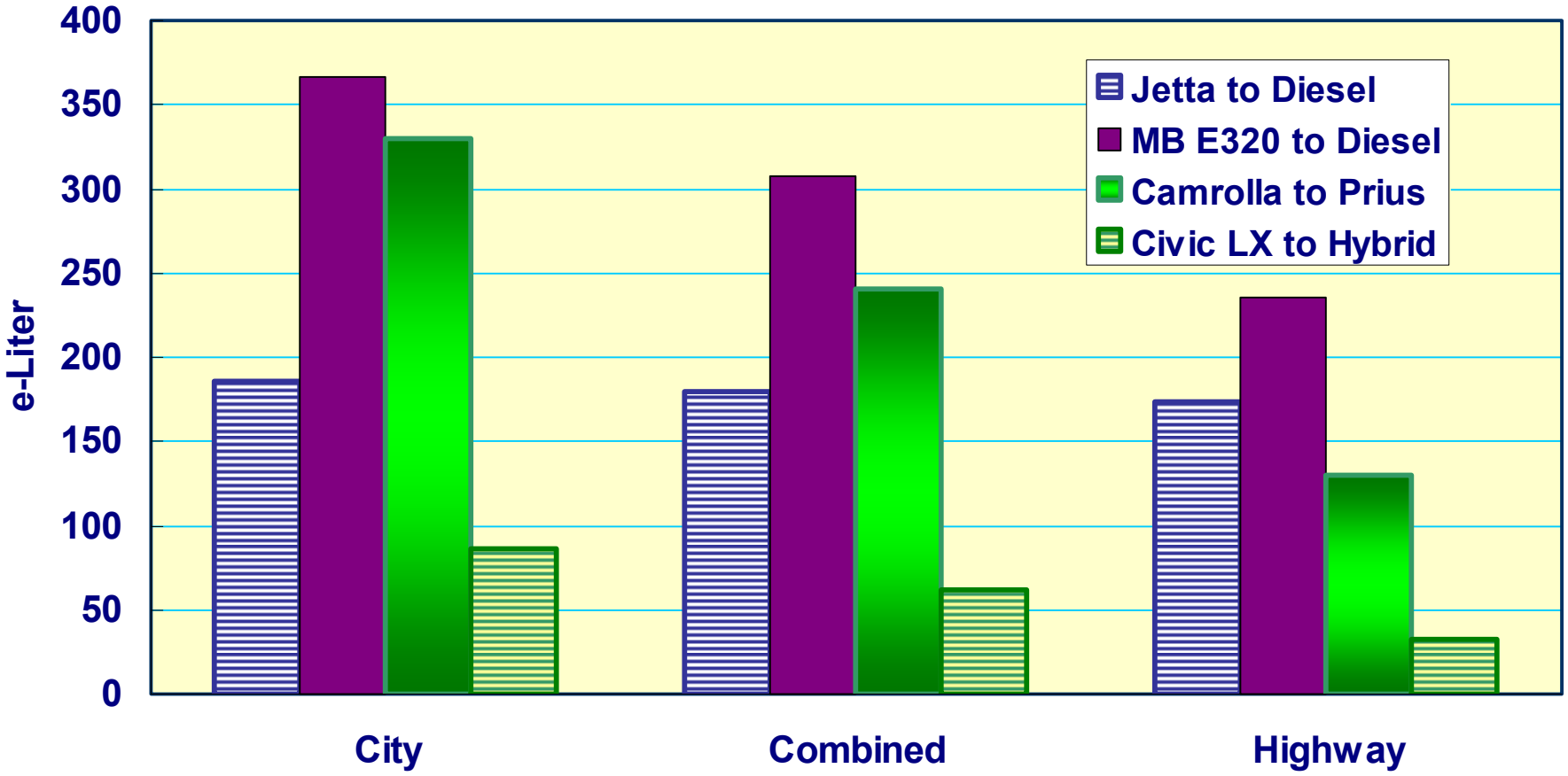
Note: By ANL 1 definition, the 2004 Toyota Prius is "Mild"

NRC Cost-effectiveness: Only Minimal Hybridization Competes w/ High-Tech SI ICE Valve Actuation



Source: NRC

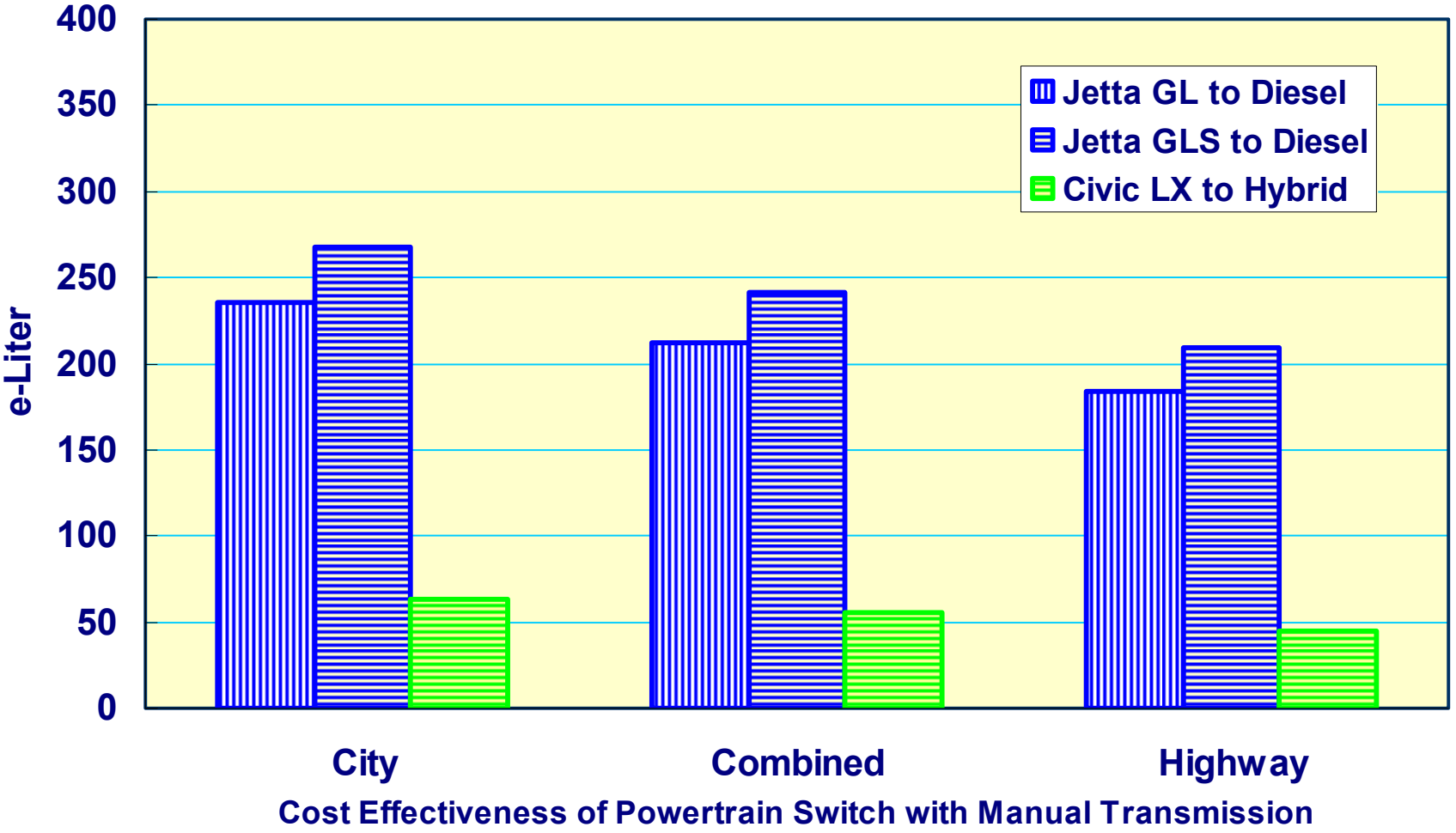
At Present U.S. Sales Prices, the Prius and 2 Diesels Have Much Better "e-liter" Values than Study Results!!



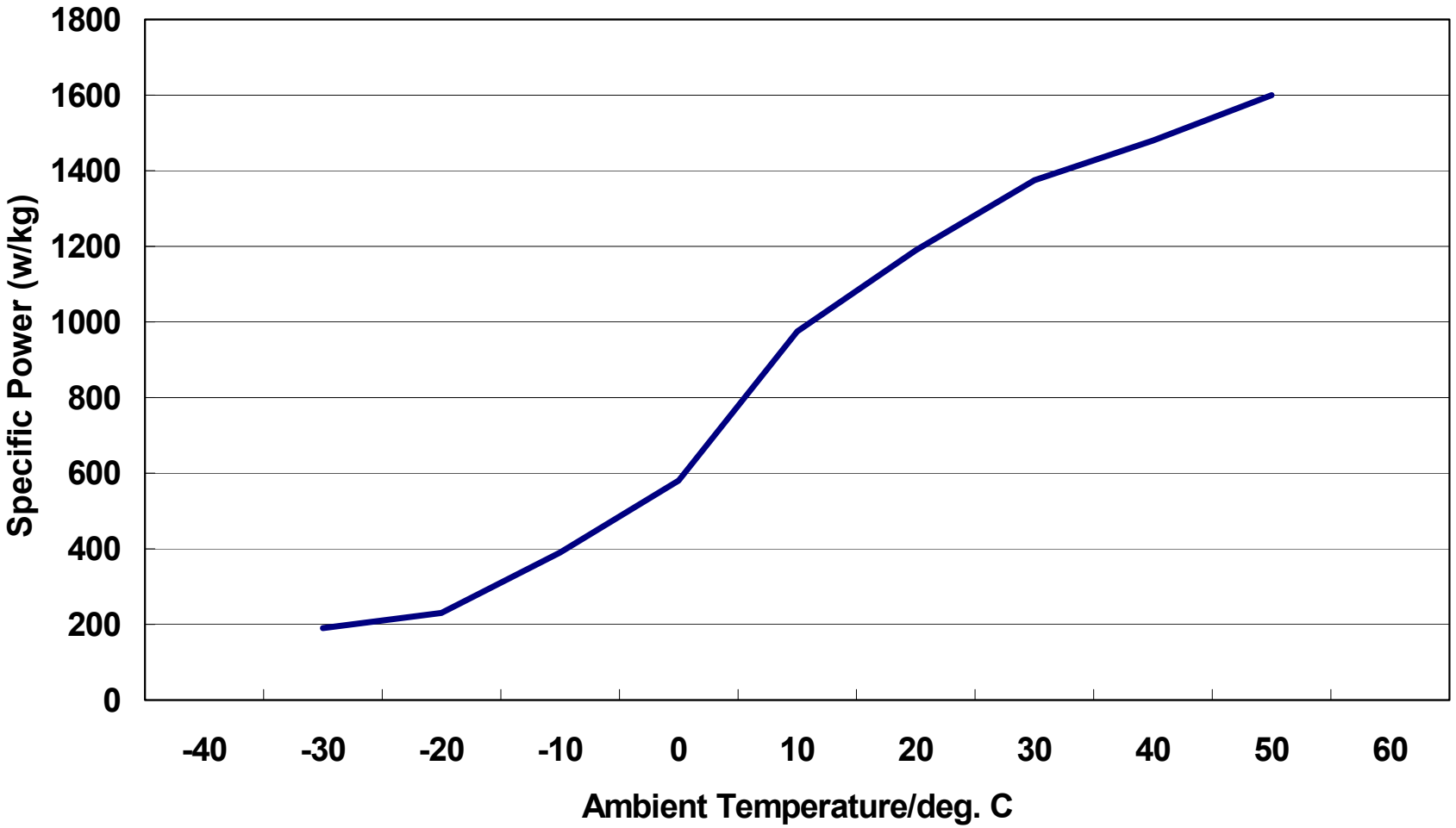
Cost Effectiveness of Powertrain Switch with Automatic Transmission

Note: The "Camrolla" is a straight average of a Camry and Corolla. The Prius is exactly midway on EPA interior volume.

A For Manual Transmissions (Rare in U.S.), Jetta Diesels are More Cost Effective, Civic Hybrids Less



Do Not Get Too Enthusiastic About Hybrids Yet – Cold Weather May Penalize Hybrids Significantly



Specific Power as Function of Ambient Temperature, Panasonic HEV Battery

Conclusion

The Omission of Detailed Examination of Diesel and Hybrid Powertrains in the Recent NRC Study of Cost vs. Benefit of Technologies to Reduce Fuel Consumption Should be Corrected