Argonne’s HEV Energy and Cost Analyses: Scoping Out the Potential Energy Cycle Impacts and Monetary Costs

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ANL'S HEV ANALYSES EVALUATE

- HEV drivetrain requirements (engine, motor, and battery power) for different vehicle configurations, performance requirements (models: Argonne's hevcost, NREL's ADVISOR)
- Vehicle costs (hevcost model)
- Vehicle fuel economy and emissions for different driving cycles (ADVISOR model)
- Total energy cycle energy use and emissions including emissions and energy use from vehicle manufacture and recycle (Argonne's GREET model)

WE'RE EXAMINING THE FOLLOWING TRADE-OFFS:

- Hybrid vs. conventional vehicles
- Parallel vs. series hybrids
- Varying stringency of performance requirements (e.g., 0-60 mph, gradeability)
- Grid independent vs. grid dependent
- Effect of changing/improving drivetrain components
- Different design approaches
  - Different power balance among engine, motor, and battery
  - Different battery designs (e.g., high power or high energy)

WE'RE EXAMINING THE FOLLOWING 2010 VEHICLES:

- Family car, ~Malibu exterior size
- Same body with different drivetrains
- Uultralight steel (ULS) or aluminum body (ULS results described here)
- For 2010.....
  - 2.06 m^2 frontal area
  - 0.26 c_d (aero drag coefficient)
  - 0.0075 c_r (rolling resistance coefficient)
- Baseline performance requirements
  - 12 sec 0-60 mph, 55 mph@ 6.5% gradeability (e.g., PNGV requirements) for hybrid operation
  - 16 sec 0-60 mph for electric-only operation

PHASE I ANALYSIS: KEY ASSUMPTIONS

- Conventional SI engine, federal RFG
- Engine downsized by linear scaling of torque/rpm map
- Three NIMH battery types: high power "Prius-type," intermediate, EV-like high energy
- Key cost assumption: drivetrain component production rates <25,000/yr in 2005, up to >250,000 in 2020 (with learning and volume effects)
- Initial design criterion: engine sized for gradeability, battery/motor for 0-60 mph boost and/or all-electric 0-60 mph (for grid-connected)

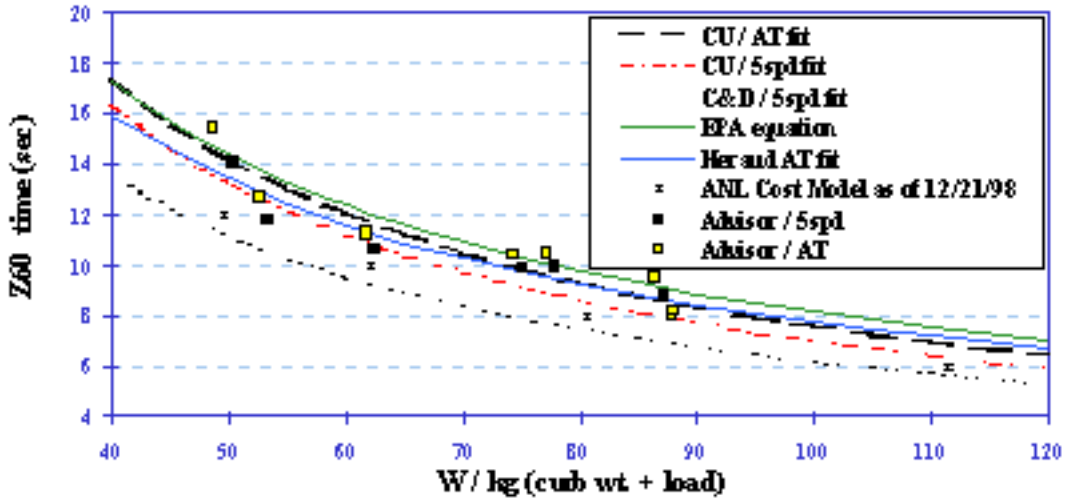
ANALYTICAL CONCERNS

- Avoiding apples & oranges comparisons:
  - Modern vehicles perform better than PNGV performance minima...so a PNGV hybrid won't match up.
  - Hybrids perform *differently* from conventional vehicles (CVs)....and different hybrid configurations perform differently...what's a fair comparison?
  - Zero to 60 mph is a crucial performance indicator...and different testers get different values!
  - We're comparing unoptimized hybrid configurations against optimized CVs.
  - How do we maintain "comparable technology"?
- Modeling issues: engine mapping and scaling, transmission modeling, emissions estimates, tire adhesion, others
- Forecasting future performance, costs involves considerable uncertainty.

A RECENT ANALYTICAL FOCUS: THE "Z60" PERFORMANCE CRITERION

- Equal or better Z60 important to match CVs (along with gradeability, highway passing)
- Also, Z60 analysis determines battery and motor power, heavily influencing cost (also mpg)
- But....no consensus on a testing regimen (so, Consumers Union Z60s slower than C&Ds)
- HEV Z60 analysis issue: Is the engine on or off at start?
- For parallel hybrids, transmission performance is crucial to Z60 estimate....but available transmission models need further development, and transmission behavior is idiosyncratic anyway.

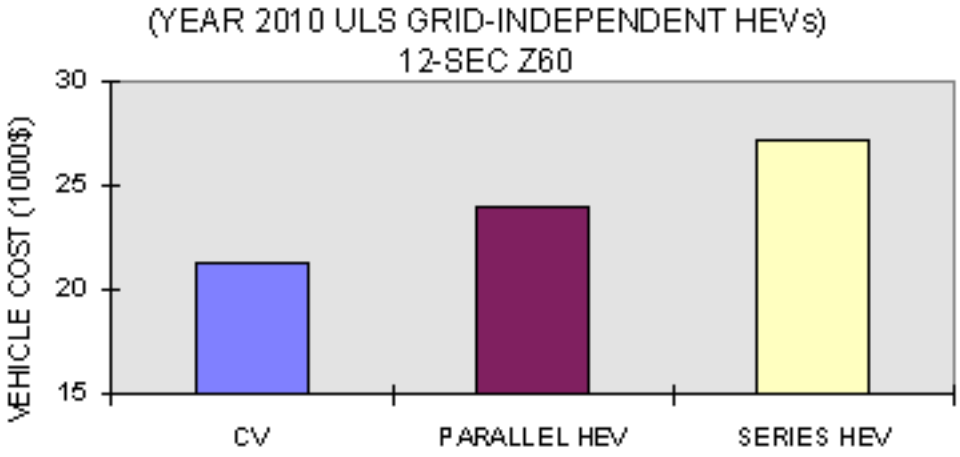
ESTIMATED AND MEASURED 0-60 MPH TIMES (VS. VEHICLE POWER/WEIGHT): *DEPENDS ON WHO'S DOING THE MEASURING!!!!*



WHAT WE'VE LEARNED ABOUT HEV COSTS AND FUEL ECONOMY PERFORMANCE

But remember.....up to this point, we've examined only one configuration for each HEV type and are using one specific design criterion for sizing the powertrain components (that is, engine size determined by gradeability, battery and motor by acceleration power needed)!

PARALLEL HYBRIDS ARE CHEAPER THAN SERIES

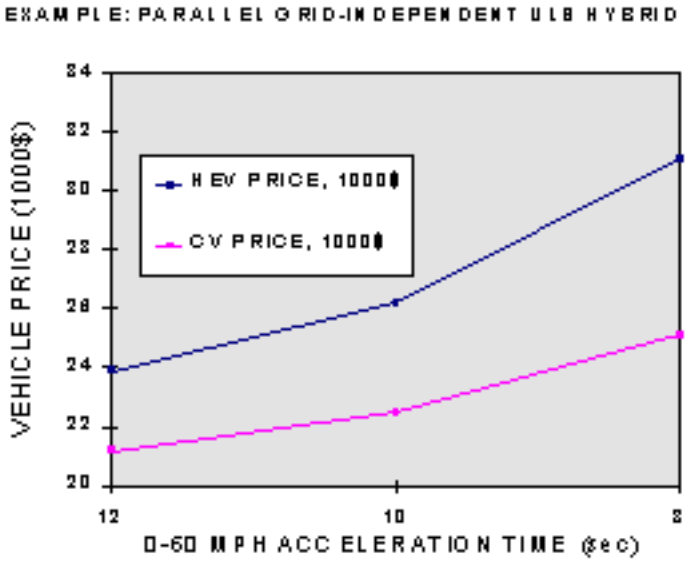


Why?.....look at the components:

	parallel		series
MOTOR SIZE, kW:	15	vs.	76
ENGINE SIZE, kW:	47	vs.	56
BATTERY SIZE, kW:	20	vs.	18

DEMANDING BETTER ACCELERATION PERFORMANCE IS EXPENSIVE

(Note: Powertrain sizing rule yields large, expensive motor and battery for high power; a different design could yield less expensive power, but perhaps at the expense of vehicle efficiency).



GRID CONNECTION INCREASES COSTS
(BUT BE CAREFUL ABOUT APPLES VS. ORANGES COMPARISONS)

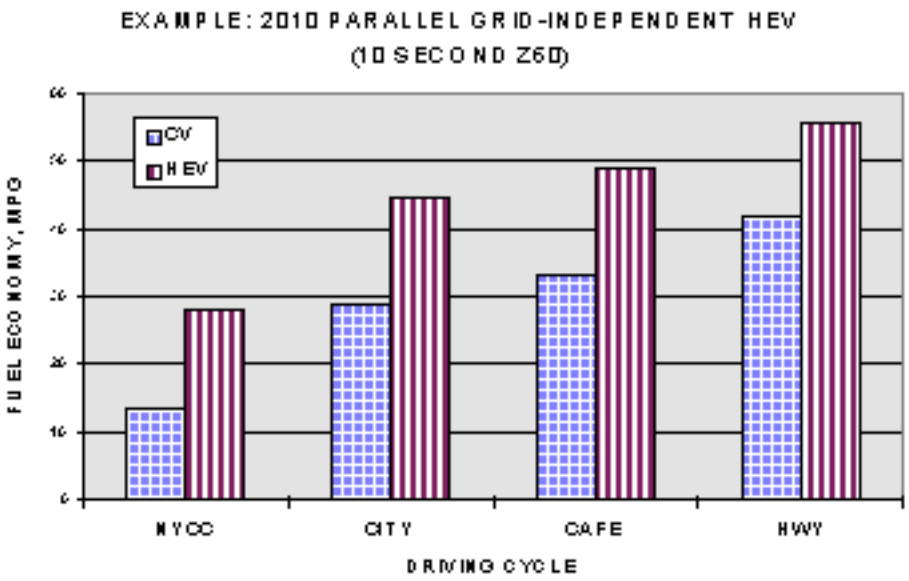
2010 PARALLEL ULS HEVS

INDEPENDENT:	1.	$23,900	12 sec Z60
(Prius-type battery)	2.	$26,200	10 sec Z60

CONNECTED:	1.	$28,900	16 sec Z60 (EV)/
(intermediate battery)		plus charger	9 sec Z60 (HEV)
			19-mile range
	2.	$33,200	12 sec Z60 (EV)/
		plus charger	7 sec Z60 (HEV)
			29-mile range

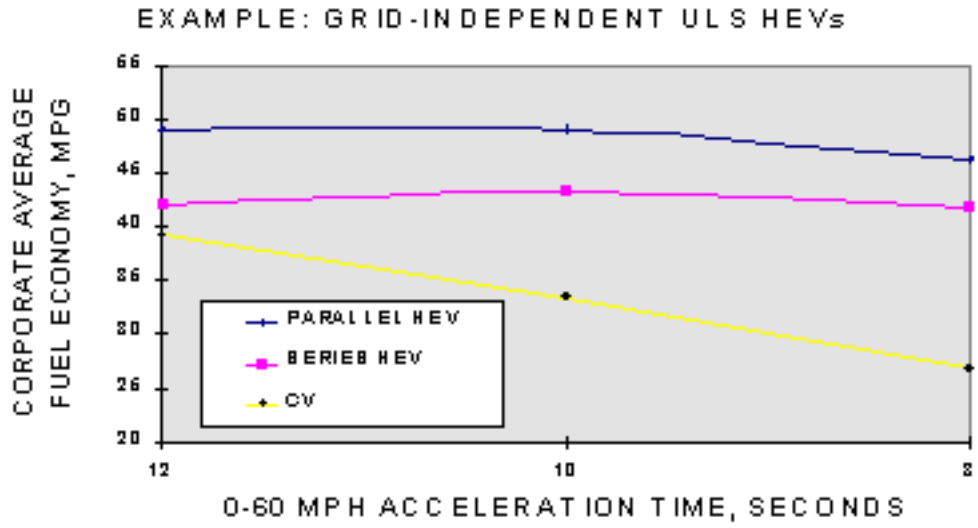
Matching I-1 and C-2 matches a full-time Z60 of 12 sec with a part-time 12-sec, part-time 7-sec Z60; I-2 with C-1 yields a good match for HEV performance, but C-1's EV performance is inferior to I-1's full-time performance. There is no perfect match!

HEVs GAIN THE LARGEST FUEL ECONOMY ADVANTAGE OVER CVs ON THE SLOWEST DRIVING CYCLES

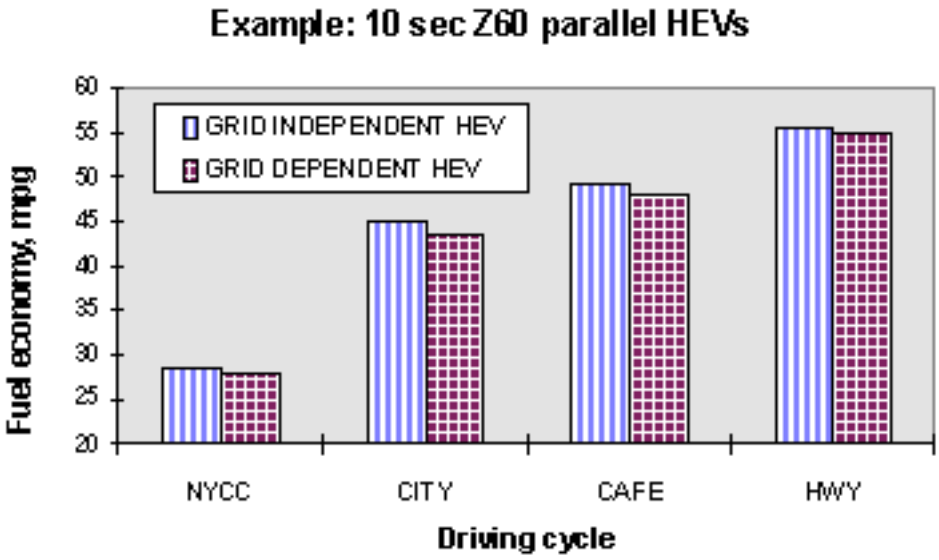


PARALLEL HEVs ARE LIKELY TO BE MORE EFFICIENT THAN SERIES HEVs; *BOTH* HAVE FUEL ECONOMY THAT IS RELATIVELY INSENSITIVE TO PERFORMANCE

(Note: Insensitivity to performance may be due to powertrain sizing rule, which keeps engine relatively constant in size and changes motor and battery to get more power. Another rule might generate another effect.



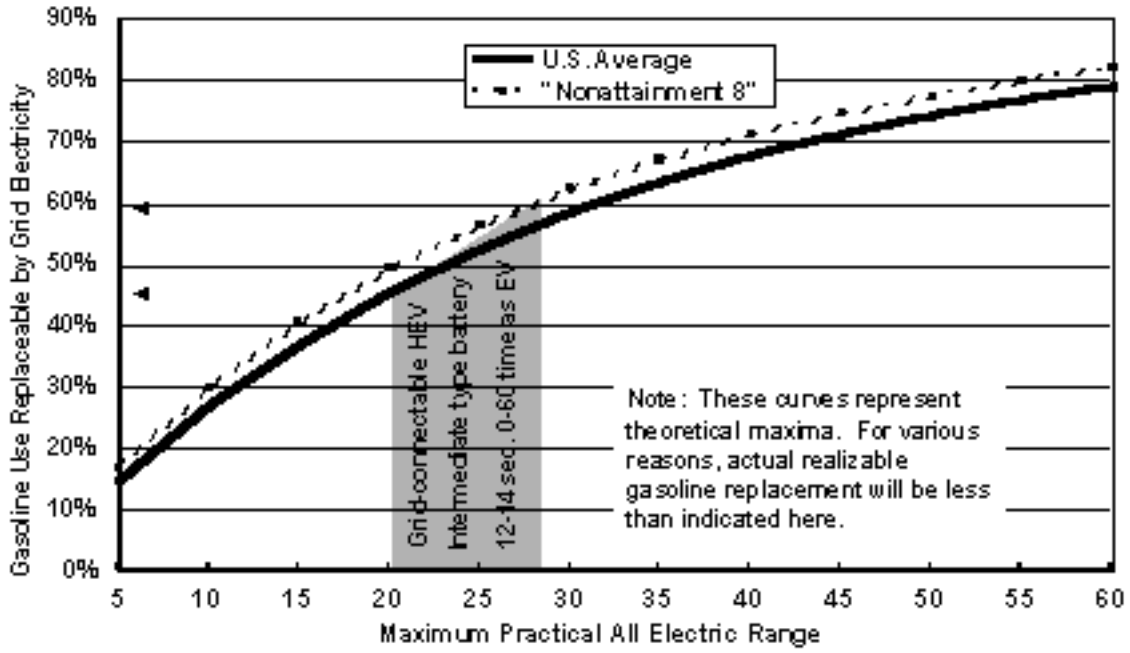
GRID-DEPENDENT HEVS DON'T PAY A SIGNIFICANT FUEL ECONOMY PENALTY



GRID CONNECTION OFFERS SIGNIFICANT GASOLINE SAVINGS ABOVE AND BEYOND THAT OBTAINED BY HEVs' FUEL ECONOMY ADVANTAGE OVER CVs

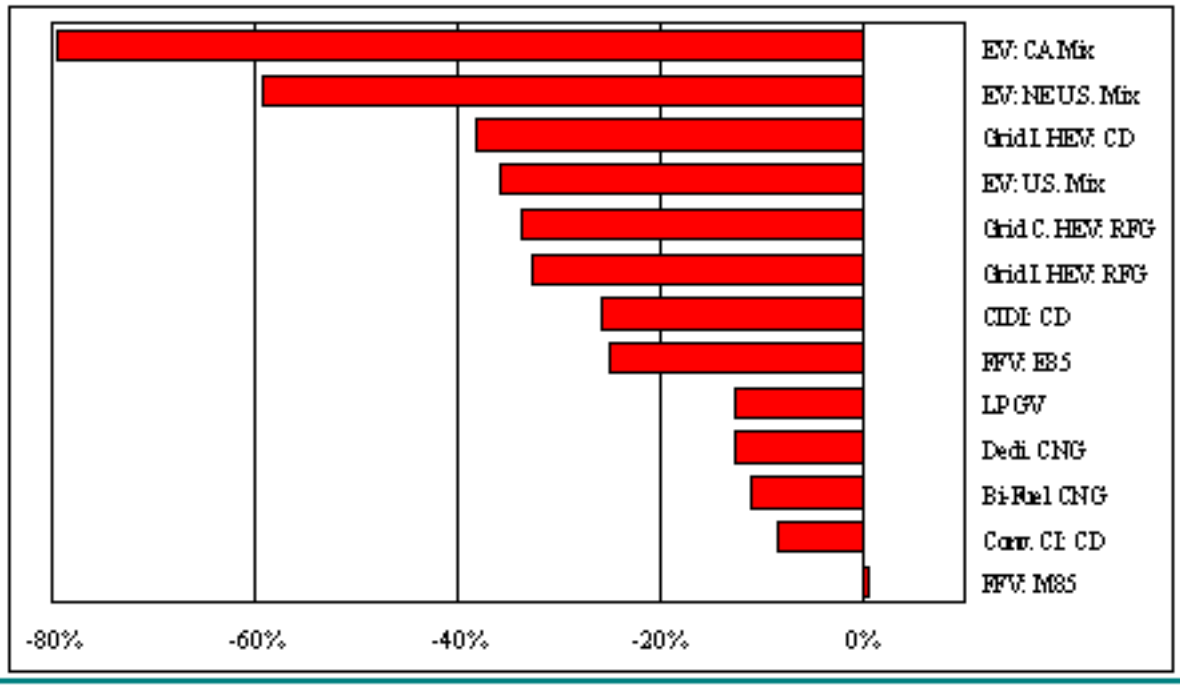
The next viewgraph shows gasoline replacement assuming 100% Recharge by the grid (actual replacement will be lower)

MAXIMIZING GRID CHARGING, AN ULS HEV WITH INTERMEDIATE-TYPE BATTERY & GOOD ZEV PERFORMANCE COULD CUT OIL USE SIGNIFICANTLY



NEXT STEP IS TO APPLY GREET ANALYSIS, WHICH MEASURES PER-MILE GHG EMISSIONS REDUCTIONS

Example: Emissions from Several Near-Term Technologies



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SOME PRELIMINARY CONCLUSIONS

- Fair comparisons of CVs and various HEV types are not easy to make.
- At first glance, parallel HEVs look more attractive.
- HEVs look best in congested driving; under average suburban conditions, fuel economy benefit is moderate.
- HEVs will cost a few thousand dollars more than CVs unless there are extraordinary cost reductions in electric drivetrain components.....or buyers accept lower performance. At U.S. gasoline prices, they may not be cost-effective.
- Grid-connected HEVs are more expensive still...but offer EV range, grid replacement of a portion of vehicle VMT, and high performance in hybrid mode (for parallel vehicles). A potential sticking point: battery longevity.

TO DO

- Refine analysis!
- Revise emissions maps to reflect future (improved) emissions controls.
- Add GREET analyses.
- Examine additional vehicle configurations, explore different design criteria (e.g., different powertrain sizing rules), add different engine and fuel options.