FACT SHEET: PHEV Conversions (April 20, 2006)

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This summary of conversions brings you up to speed on what we've done—and where we're heading. This is a work in progress—check at http://www.priusplus.org to for the latest. For technical discussions, see the **EAA Conversion Group** URL below**.** Subscribe to the CalCars-News newsletter to keep up with the latest PHEV coverage and milestones. See How to Get page at CalCars for latest information on availability, warranty information, and links to other resources.

Note that all MPG reports also include electricity use – no free lunch!

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SPECIFICATIONS FOR PRIUS+ (FIRST PRIUS CONVERSION)

- **Conversion platform** is Ron Gremban's stock 2004 Prius hybrid (HEV).
- **Stock Prius hybrid battery pack** (Panasonic nickel-metal hydride [NiMH] 6.5 Ah, 201.6 Volt, 99 lb/45kg) remains unused during PHEV operation and can be used in normal hybrid mode as needed, e.g., for comparison (in future conversions, this battery will probably be removed).
- **CalCars' initial battery pack** (for our first prototype, we used low-performance, short-life but resilient lead acid (PbA) for testing purposes and to obtain design criteria for higher-performance packs): 18 electric bicycle B&B 20Ah 12Volt SLA batteries from ElectricRider.com. Pack replaced with new PbA batteries Oct 2005, after 11 months and approx. 200 charging cycles; unable to handle 120A peak discharges beyond 70% of its capacity.
- **Batteries positioned** in empty well below hatchback deck, with independent manually switchable air cooling system.
- **Batteries recharged** via 120-volt outlet in 3 hours with Brusa NLG5 charger from MetricMind.com (cheaper charger; longer for larger packs).
- **Battery Management System, Controller/Display Unit** (CDU) by Energy Control Systems Engineering (EnergyCS.com) of Monrovia, CA, replaced Toyota's Battery ECU. No other changes to Hybrid Synergy Drive (HSD).
- **Data from battery and CAN (Controller Area Network) bus interface:** Dashboard analog meters display battery voltage and current. EnergyCS digital display includes battery voltage and current, Amp-hours used from the battery, vehicle power requested (e.g. via throttle position), state-of-charge (SOC) reported to THS, and gas used/trip (1000ths of gallons).
- **Simulated State of Charge** information sent to THS is set semi-automatically to force energy use and regenerative braking regimen (automation has been fine-tuned in later iterations of EnergyCS controller).
- **Configuration** permits rapid reversion to standard hybrid operation using the Prius's Battery Management System and the retained original battery.
- **Operation** permits electric-only mode at up to 34 mph (using reverse-engineered "EV" button available on European and Asian Priuses; above 34 mph, battery energy continues to assist the engine, contributing to lower gasoline consumption. The PbA battery is good for 10 all-electric miles, 20 miles of doubled gasoline mileage, or mixes of the two. Then operation reverts to normal HEV mode, still using the new battery pack.

ADDITIONAL PROTOTYPES AND CONVERSIONS FOR CONSUMERS

For battery specifics, please see the Battery Comparison chart.

- **EDrive Systems:** The EnergyCS prototype and impending EDrive Systems commercial Prius conversions provide 25-30 miles of all-electric range using Li-Ion. Improved performance and additional electric range can be expected from the above batteries, due to significantly lower internal resistance losses. EDrive's partner for distribution in Europe is **AmberJac Projects**.
- **Hymotion:** In early 2006 Hymotion announced Li-Ion conversions for the Prius and, later this year, the Ford Escape Hybrid. These conversions will initially be sold initially to fleets (100 units minimum), with consumer conversions available in late 2006/2007.
- **"Do-It Yourself" project** for advanced experimenters with experience in high-voltage projects initiated by the **Electric Auto Association** (EAA). CalCars and the EAA are developing an **"open-source"-style** effort to enable anyone with access to a qualified engineer to retrofit their Prius. Full documentation, as well as recommended materials and batteries, will be made available at the EAA-PHEV web site.
- **New efforts by CalCars** continue on other platforms, including Ford Escape Hybrid, and in exploration of new batteries. In 2005, CalCars announced a development program with Electro Energy Inc. (NASDAQ EEEI) to test bi-polar Nickel-Metal Hydride (NiMH) batteries. This has resulted in a current prototype vehicle and a timeline for high-volume manufacturing of batteries in 2007.

We estimate automakers could sell small, 30-mile (any speed) range PHEVs for $3,000 more than hybrids, $5,000 more than a non-hybrids.

PHEV Battery Comparison Chart

Maker	Battery	Description	Weight	Ah/kWhr	Range*	Notes
CalCars PRIUS+	Lead-acid	CalCars prototype lead-acid.	300lbs	12Ah, 2.4kWhr	20miles	Original pack replaced at 11 mos. Degraded perf. at moderately low temps.
Electro Energy (EEEI) / CalCars	NiMH	First-generation prototype NiMH proof-of-concept.	400lbs	14-20Ah, 3-4kWhr	20-30mi	Present prototype, non-optimized battery used for integration and demonstration.
EEEI / CalCars	NiMH	Second-generation prototype and production-ready (2007) NiMH.	200-220lbs†	30Ah, 6.5kWhr	40-50mi	Prototype optimized for reduced weight, improved performance. Build and testing est. 3Q 2006, volume production in 2007.
EnergyCS / Amberjac (UK)	Lithium-ion	Prototypes including CalCars vehicle.	180lbs†	35-40Ah, 9kWhr	50-60mi	Uses off-the-shelf Valence Technology Saphion U batteries.
EDrive Systems	Lithium-ion	Consumer production-ready (late 2006).	80lbs†	35-40Ah, 9kWhr	50-60mi	Uses standard lithium cells.
Hymotion	Lithium-ion	Fleet production-ready (late 2006).	160lbs	5kWhr	50-60mi	Integrates with original Prius battery.
CalCars Proposed	Lithium-ion	Prototype lithium-ion, possible advanced lead-acid. Not yet started.	100-150lbs	40Ah, 9kWhr	55mi	Calculated performance for batteries by Saft, Worley-Parsons, or Enax.

* mixed-mode driving (50% EV) range at double normal Prius gasoline mileage † after removal of original Prius battery and controls (99lbs)

ANECDOTAL PHEV CONVERSIONS PERFORMANCE DATA

Equivalent mpg numbers and operation costs depend on patterns of use (total miles driven/day, speeds driven, etc.).

CalCars' lead-acid PRIUS+: The following performance is expected to be better with lighter, more efficient batteries. **Important:** low PHEV and HEV mileage due to short runs, hilly Marin County terrain and other local factors.

Heavy lead-acid batteries add approx. **300 lb (10%) total**, reducing mileage by approx. 5 mpg (10%) in standard HEV operation on city streets (due to acceleration losses), but by little or nothing at highway speeds (where wind resistance is the main factor). Lower weight from removing original pack and lower internal resistance of future batteries is expected to increase the efficiency of standard HEV operation to restore original HEV city mileage even when grid-charging energy is not involved.

- **Under 10-mile** all-electric propulsion (at < 34 mph): **infinite mpg** plus 262 grid Watt-hours/mile vs. 40-45 mpg as normal HEV.
- **14 mile round trips**, including approx. 10 miles on hilly freeways: **80 mpg** + 200 grid Wh/mi, compared to 36 actual HEV mpg on the same course, driving with the extra battery weight -- otherwise maybe 40 mpg.
- **26-28 mile trips** with many surface streets: **60 mpg** +144 grid Wh/mi.
- **Beyond 20 miles/day** (40 miles/day with NiMH or 60 miles/day with Li-Ion batteries): normal HEV mileage—except better mileage on long descents due to more recovered energy storage—and no further electricity use.
- ***All-electric miles****: power cost, approx. 1.3 cents/mile (assumption of 260 grid Wh/mi and 5 cents/kWh on California off-peak EV "E-9" (PG&E) rate, and not amortizing battery cost), vs. approx. 5.6 cents/gasoline mile ($2.50/gallon, 45 mpg). (2.5 cents for 10 cents/kWh rate)*

EnergyCS Li-Ion: EnergyCS's version of PRIUS+, completed Feb. 2005, uses off-the-shelf Valence Technology Saphion U Li-Ion batteries, plus specialized monitoring and control circuits. These automatically select EV operation at low speeds during low power usage, and provide electric motor benefits at all speeds. This vehicle is the starting point for **retrofits for sale in mid-2006 from EDrive Systems**.

(Unverified data reported by EnergyCS)

- Under 35-mile trip all-electric propulsion (at under 34 mph): **infinite mpg** (i.e., no gasoline) plus 200 Watt-hours/mile.
- 70 mile trip, 80% 55 mph freeway, 20% city: **120-180 mpg** + 115-150 grid Wh/mi, compared to est. 55 mpg as a normal HEV.
- Beyond 50-60 miles/day: normal HEV mileage—except better mileage on long descents due to more recovered energy storage—and no further electricity use.
- *All-electric miles: power cost approx. 1.0 cents/mile (assumption of 200 Wh/mi and 5 cents/kWh on California off-peak EV "E-9" (PG&E) rate, or 2 cents/mile at 10 cents/kWh electricity, not amortizing battery cost), vs. approx. 5.6 cents/gasoline mile ($2.50/gallon, 45 mpg)*