Proposed Components (+ Explanations of our Development Strategies) for CalCars' First Two PRIUS+ Prototypes

Updated 8/26/04, RDG + FK

Phase I – An NiMH Prototype PRIUS+ PHEV

1. **Charger:** Brusa NLG513-SA (already purchased) – $3,900
   Metric Mind engineering, Portland, Oregon; for more information, see:
   http://www.metricmind.com/ac_honda/main2.htm (click on link to Charger)
   http://www.brusa.biz/e_welcome.html

   This Swiss charger can be programmed for output voltages from 260-520V and any desired charging profile sequence. Though expensive and higher powered than necessary, it saves us from having to buy and/or build new charging hardware whenever our needs change, which may be often during prototyping.

   This charger also doubles as an energy injection device to help uncover the secrets of Toyota's THS control system, and thereby how to inject energy from the traction battery in such a way that it goes to the desired purpose without deleterious side effects such as running THS components outside their limits (especially the hybrid battery's state-of-charge limits) or causing the control system to stop working correctly. We plan a set of experiments using this charger, the instrumentation below, and UC Davis' chassis dynamometer.

   Subsequent units should be able to use a cheaper charger – either off-the-shelf or custom-designed – at an estimated cost of around $2,000. Unless their cost is greater, we will plan for a 110-240 volt charger.

2. **Temporary experimental battery:** 19 EVP-20, 12V 20Ah sealed batteries – $900
   http://www.electricrider.com/batteries/specsheets/evp20-12.pdf

   An NiMH battery pack will require the assembly of custom modules. This is both time consuming and – until we know our needs quite well – financially risky, as the modules might have to be torn apart, redesigned, and rebuilt.

   Therefore, to reduce financial risk and potential lost time, we think it's worth the extra cost for a lead-acid (PbA) battery pack for our initial experimentation. This pack will be too heavy (260 lb) and have inadequate range (est.10 mi) and life (est. 3500 EV miles) for an effective PRIUS+, but is quick to buy, easy to package and wire, and very rugged. It will be a quick and inexpensive way to experiment with battery configurations – and validate one – before we order an NiMH pack. This PbA battery pack will also allow us to demonstrate a preliminary PRIUS+ "Prototype 0.5" very rapidly, in time for our current goal of unveiling the vehicle at the Air Resources Board hearing on implementation of AB1493 (the Greenhouse Gas or "Pavley legislation) in Los Angeles Sept 23.

   This price includes shipping and cables. As theses batteries are commonly used for electric bicycles and other common applications, we anticipate being able to sell them for as much as half price, once we have replaced them with an NiMH pack for what we might call PRIUS+ "Prototype 0.9".

3. **NiMH battery:** 528 9Ah NiMH "D" cells (incl. spares), in custom modules – est. $5,400

   e.g. Powerthat PWRNM9,000D, 44 12-cell modules @ $122 each = $5,368

   We believe NiMH batteries have the most immediate potential for PHEVs. They have sufficient specific energy for a 15-20 EV-mile PRIUS+ without vehicle chassis modifications, and for factory-designed PHEVs with up to 40 miles EV range. They are mature enough, have good power handling capabilities, are easy to work with, and – as shown in studies by the Electric Power Research Institute (EPRI) and the performance of Southern California Edison's RAV4E fleet – have cycle lives that could result in total lower lifetime cost of ownership for PHEVs compared to hybrids or gasoline vehicles.

   "D" cells are a safe and cost-saving choice of NiMH batteries. They are mature and in high volume production. However, this price is double that shown in our August 5 components list, as BatteriesPlus's quote for custom modules is double their initial estimate. We believe this new price *is* realistic, as we are currently talking as well with two distributors of other brands. We expect competitive pricing, as cell prices (not in modules, but in 500's quantities) are around $5.50-8.00 each ($2,900-4200 for 528). However, we wish to complete experiments with the inexpensive PbA pack before finalizing custom module specifications.

4. **Electronics** – $3,200.

   These items represent a shift in strategy. We intend to capitalize on the experience and tools developed by Energy Control Systems Engineering http://www.energycs.com/, a Monrovia-based consulting, design and prototyping group focused on system integration, management and monitoring of electrochemical energy systems, especially EV and HEV systems.

   Its principals, well known in EV circles, include Greg Hanssen, who came out of McDonnell Douglas Aerospace, then started a successful digital audio business, and Pete Nortman, P.Eng, MScEE, formerly of US Electricar and AeroVironment. They were involved in the conversion of a 2002 Prius to a hydrogen-electric PHEV (this vehicle was shown at Bibendum last fall), and have already completed much of the development work we intended to begin, or we were hoping to gain from the Mini-Scanner project (which appears to be moving at a rate such that its work will be completed long after we need it). EnergyCS has already successfully demonstrated that with the Toyota battery ECU disconnected, its BMS unit can talk directly to the Hybrid System.

   Making this "buy not build" decision is the other piece of the plan to use PbA batteries for Prototype 0.5, and have a chance of meeting our mid-September goal.

   a. **EnergyCS "CDU (Control and Display Unit) + VTC Node" (Voltage/Temperature/Current) CAN-bus monitor/BMS (Battery Management System) + CAN-bus multi-channel input card** (already purchased) – $500

b. **Customization of CDU and VTC Node for the PRIUS+** (already purchased) – $2,000

These devices and their customization will jump-start PRIUS+ development by building on EnergyCS's completed hardware development and Prius experimentation. This should allow us to get a preliminary PRIUS+ up and running, and gathering data, in weeks.

The CAN-bus multi-channel input card is being customized to read PRIUS+ battery current, voltage, and temperature data and put it on the CAN-bus where it can be read by the EnergyCS CDU and any other CAN device we use.

The EnergyCS CDU/BMS has an 8-line display that can be used as a monitor of THS state. It can also be used to replace Toyota's battery ECU messages to the rest of the THS with ones appropriate to PHEV operation and the PHEV battery pack. Additionally, this monitor can integrate battery current, and therefore take the place of the previously specified Xantrex Link-10 Ah meter ($450).

This contracted customization gives us manual control, for experimentation purposes, of battery ECU output parameters such as SOC (state of charge) and battery voltage. Once we have settled on an operational scheme, EnergyCS can provide a program update implementing that scheme. Note, however, that the hardware and software is proprietary, and we will not be able to change or update the software ourselves. Also, data can be logged only via realtime RS-232 output to a laptop.

c. **CAN bus connection: CAN dongle + RS-232 to USB adapter** – $200
http://www.can232.com/index.htm

This is an inexpensive way for us to experiment with battery management profiles that would otherwise require EnergyCS to repeatedly reprogram its software for us, an expensive and time-consuming process. It can also provide us with a much better data logging system. Once we get this equipment and a laptop or a PDA/PocketPC computer with an appropriate programming language running together, we can program BMS schemes and quickly change them until we discover how to maximize the PRIUS+'s potential.

Though the ease and rapidity of initial setup is currently unknown, once it is operational, this system will be invaluable for actually trying out various BMS schemes before deciding on one to be hard-coded into the EnergyCS monitor/BMS. It can also provide for invaluable instantly customizable monitoring and logging – so when we suddenly need to watch the relationship between two parameters, we can immediately do so.

This system does not replace the EnergyCS CDU/BMS, as it will allow us to emulate BMS schemes at will, but only after booting the attached computer and starting the application software – not an operation ordinary drivers will be willing to do each time they drive!

For subsequent conversions by CalCars or other parties, we can specify the use of the EnergyCS CDU/BMS or we can begin a parallel effort to enlist a group of engineers to design and produce a BMS whose hardware design and source code *is* in the public domain.

d. **Mini-scanner III –contribution to non-profit group** – data not dollars (as previously planned) http://autos.groups.yahoo.com/group/Prius_Miniscanner_MarkIII

An independent collaborative group is working on a mini-scanner for the 2004 Prius, based on the one currently available for the Classic Prius. It will be available for around $200 sometime in 2005. Given the timetable, this tool will not be usable by us in our early stages. We expect our findings will help them, and we plan to help them fill in the holes for parameters and data that they are examining by reporting to them our findings from using the EnergyCS module and the Vetronix tool (see Phase III below).

e. **Existing equipment:** laptop computer, PocketPC PDA, oscilloscope, misc. meters, use of UC Davis' chassis dynamometer – $0

5. **Miscellaneous** – est. $1,000

a. Hardware for battery box, electrical connections, etc

b. Possible fabrications for battery box and other parts of installation

c. Battery box fan with AC power supply and air ducts

d. Sales tax, shipping costs, etc, on components listed above

e. Other unknowns

Phase 1 Total: $13,900

$400 of this price may be recoverable by selling the used lead-acid batteries once they are no longer necessary. The major changes from the August 5 budget of $12,150 are: $3,000 saved by eliminating the DC:DC controller, unnecessary for the currently-anticipated configurations. This was largely offset by a doubling of the expected price for the NiMH battery pack. Other hardware was switched around. The higher total reflects the proposed purchase of a temporary PbA battery pack, and the cost of the hardware customization by EnergyCS – much higher than the previously proposed donation to the mini-scanner group. This is the tradeoff for taking advantage of EnergyCS's existing specialized hardware and Prius experimentation.

Phase II: Li-ion Battery Experimentation for Second PRIUS+ Prototype

We believe Li-ion batteries (currently in widespread use in phones, cameras and laptops) have the best long-term potential for PHEVs and full EVs, as they already have twice the specific energy of NiMH cells. (Daimler's Sprinter PHEV development project uses Li-ion batteries.) But they are immature and hard to work with, usually do not yet have sufficient cycle life, and require additional safeguards against overheating and fires. Only tiny 18650 cells are in volume production, with proven reliability and safety (these are the type of cells AC Propulsion used in its air-cooled version of the tZero with 250-300 mile range).

Currently, all Li-ion cells need protection circuitry for each cell or set of paralleled cells. We believe a Li-ion PRIUS+ can show the potential of this up-and-coming battery technology, but we don't yet know enough about the protection electronics, charging, heat dissipation, and necessary safety precautions to commit to a full PRIUS+ battery pack. We are therefore proposing temporarily installing a small, much less expensive, battery pack on an electric bicycle to gain the necessary experience with these cells. If these parts work out, they will become part of the second, Li-ion, PRIUS+ prototype.

Valence offers 18650 cell batteries with protection circuitry. They claim improved cycle life and safety due to an unusual cathode material. If true, the lifetime cost could rival the cost of gasoline savings, even at current gasoline prices! Though we need to investigate them and other suppliers extensively, they are currently our first choice.

We hope to obtain the Valence quantity price even for these first two units. We will determine if the Soneil charger indicated below can be made to work with them; if not, we will have to look further and probably pay more.

1. **Battery:** 2 Valence U-charge VU1 13.2V, 46.4 Ah Li-ion batteries – $1,200
   http://www.valence.com/ucharge.asp
2. **Li-ion Battery Protection:** Valence U-charge controller – $500
3. **Charger:** Soneil 3610SRF, 42V@5A, or similar – $140
   http://www.electricrider.com/accessories/soneil.htm
4. **Data input card:** EnergyCS CAN-bus multi-input card – est. $100
5. **Misc:** $60
6. **Instrumentation:** existing CAN dongle, PDA/PocketPC, etc. – $0

Phase II Total: $2,000 (phase II components are expected to be transferable to phase III)

Phase III – A Li-ion Prototype PRIUS+ PHEV

Assuming that the parts in phase II work out, they are expected to be incorporated into phase III. The parts below are additional.

1. **Li-Ion battery:** 12 *additional* Valence VU1 – $7,200
   http://www.valence.com/ucharge.asp
2. **Charger:** Simpler replacement destined for the NiMH PRIUS+ so the Brusa can be moved to this project) – est. $2,000
3. **Electronics** – est. $1,000
   a. **EnergyCS "CDU + VTC Node" CAN-bus monitor/BMS + CAN-bus multi-channel input card** – $500

   b. **Unknown additional electronics expected to be required** – est. $500

4. **Miscellaneous** (see Phase I for details) – est. $1,000

5. **Sharing of Vetronix CAN-bus scanner with EnergyCS** – $500
   http://www.vetronix.com/diagnostics/mts3100/index.html

   EnergyCS has extended us an offer: we pay for the $1,200 extension of their $5,000 Vetronix scanner to handle the CAN bus and the '04 Toyota Prius, and we can share use of the instrument with them (by shipping it back and forth). This is an invaluable opportunity, as it will enable us to discover essential THS (Toyota Hybrid System) information available in CAN bus messages not guessed at by Prius owners and enthusiasts. It can also initiate Prius test modes invaluable for understanding and working with the THS. We plan to propose a cost-sharing and access arrangement between CalCars, the Mini-Scanner Group and EnergyCS, since all will benefit from this tool. Placing it in Phase III gives us time to do these negotiations.

   Although the Vetronix' diagnostic modes could be valuable right away, the tool's greatest value will come in the stages of optimizing the PRIUS+ and verifying that what we are doing is not going to cause some sort of long term stress, or failure during unusual conditions. The following are what the scanner can do for us that reverse engineering can't:

   a. Find codes and scale factors that we haven't been able to discern, such as MG1 & MG2 speed, power, and temperature, any commands to the DC:DC upconverter and/or the MG inverters, etc. We will be able to reverse engineer some of these parameters and factors, but are unlikely to find them all, especially since there may be some that we don't even suspect, based on our lack of understanding of the THS.

   b. Verify the codes and scale factors we have reverse engineered, as opposed to depending on our educated guesses for critical information we use in improving and refining PRIUS+ performance.

   c. Provide the codes to be sent on the CAN bus, as well as the documentation, for various diagnostic modes provided by Toyota, from which we can learn how the THS really works and how to fool it in various helpful ways without causing problems.

   Examples of issues where the above apply are:

   - If we combine the Prius' existing hybrid battery with an additional traction battery pack (any configuration other than our configuration #2), assuring that the existing hybrid battery remains accurately measured and stays within Toyota's predefined SOC limits.

   - If we find we can extend EV mode beyond 35 mph, we will need to ensure that MG1 does not overspeed.

   - If we find we can extend EV-only acceleration to higher levels before the ICE kicks in, we will need to avoid overstressing or overheating the DC:DC upconverter, MG2's inverter, and MG2 itself.

- If we do any fancy manipulation of the THS – as simple as using configuration #3, #4, or #5 instead of #1 or #2 – we will eventually need to verify as best we can that we aren't also causing hidden problems.

Phase III Total: $11,700

Grand Total for Li-ion Prototype (Phases II and III): $13,700

Grand Total, all Phases: $27,600 for two complete conversions.