Advanced Battery Management for Transportation

Making batteries last longer and work better

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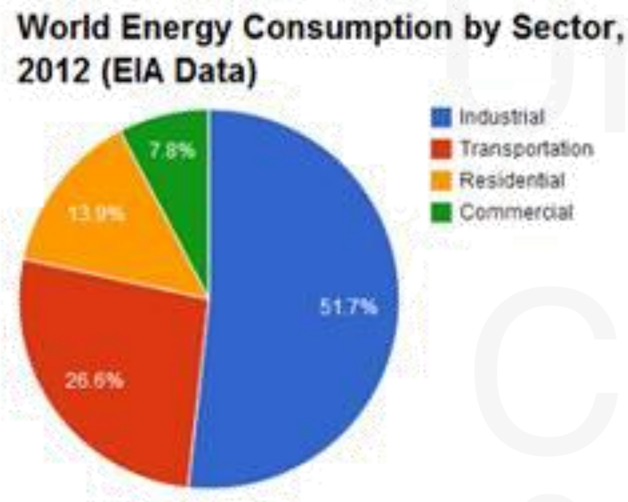
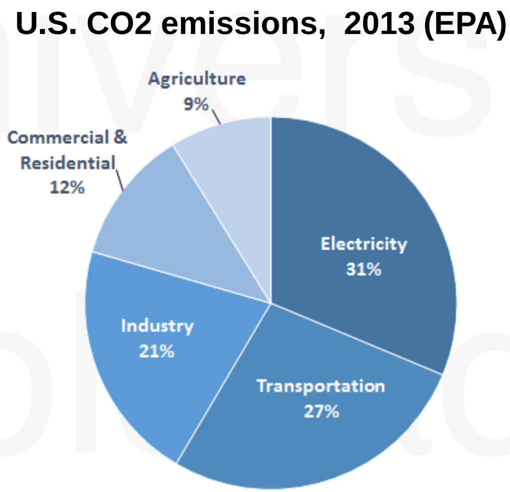
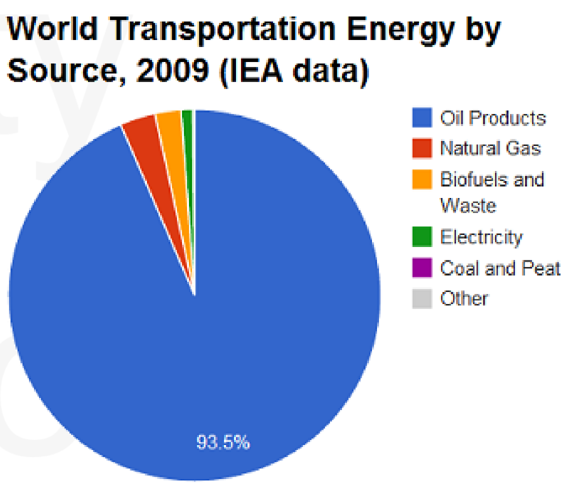
The global problem (and opportunity)

- Transportation accounts for about 27% of worldwide energy consumption
- Is responsible for 27% of CO_2 emissions produced by the US
- More than 93% of transport is oil-powered, achieves only 21% efficiency





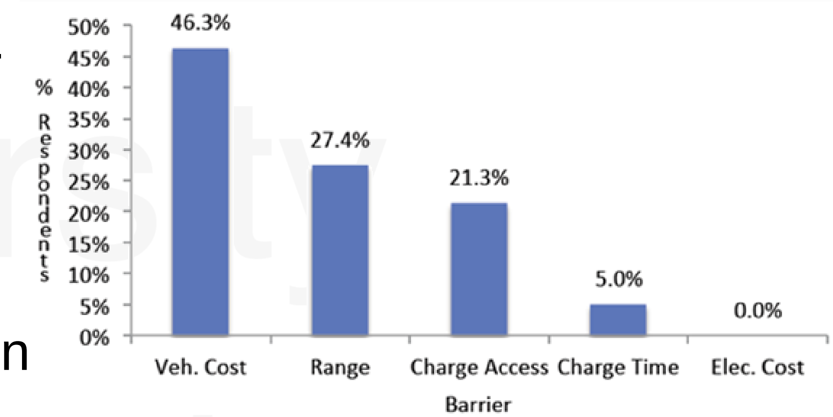


- Plug-in hybrid and electric vehicles (xEVs) reduce fossil-fuel use, boast ≈80% on-board energy efficiency, almost no point-in-use emissions.
- xEV energy source can include renewables (e.g. solar, wind, hydro, etc.).
- Increased market penetration of xEVs will have an enormous impact on global sustainability

Consumer reluctance but UCCS leadership

- About 80% of consumer reluctance to adopt xEV relate to vehicle cost, range, plug-in charge time
- All are battery related: Battery is single-most expensive xEV component; battery size determines range, cost; required longevity drives charge time

Main Barrier to Purchasing EV (EV WORLD)



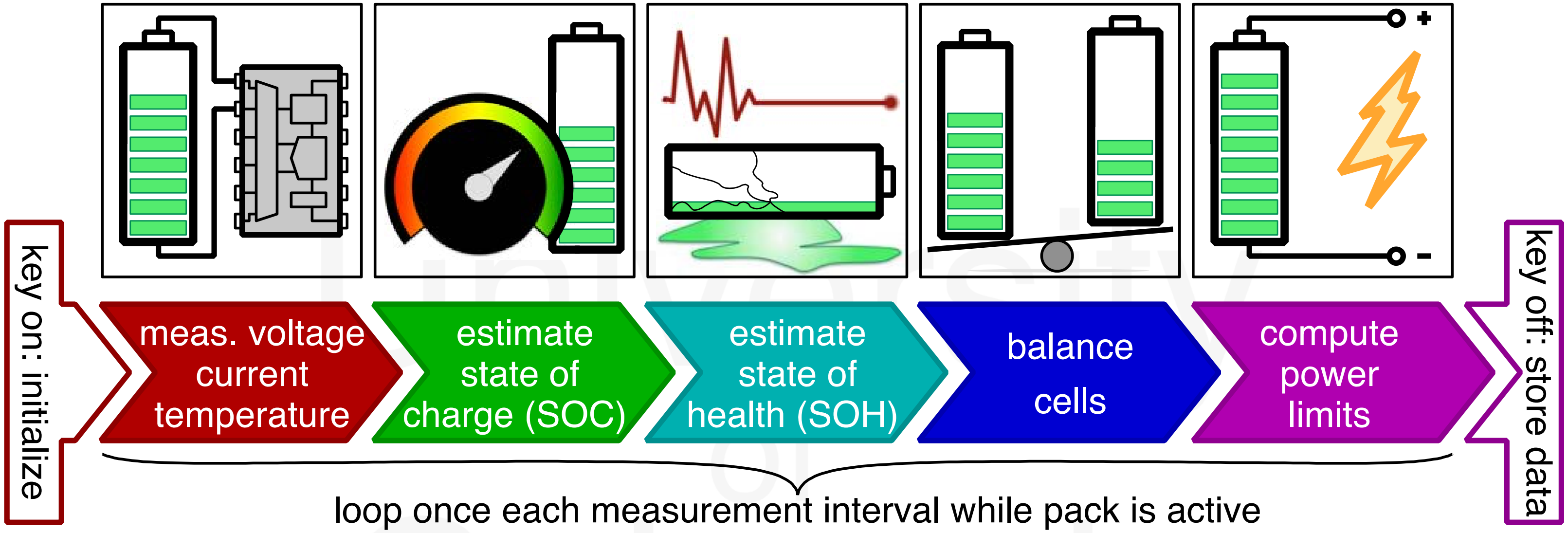
- We are working on this: UCCS has been fortunate to be able to contribute to this field over the past 15 years
- Our UCCS research team builds controls that maximize *performance* and *lifetime* – extending range, reducing size, cost, and charge times
- We lead DOE's *GATE Center of Excellence in Innovative Drivetrains in Electric Automotive Technology Education*: certificate + MS programs
- Applications of our work have had an impact on the trajectory of xEV design and on broader interest of reducing use of fossil fuels for transport

How can we make a difference?

- Battery management systems (BMS) implement the battery controls
- xEVs (i.e., EV, HEV, PHEV, E-REV…) need to know two battery quantities:
  - How much **energy** is available in the battery pack
  - How much **power** is available in the immediate future
- An estimate of energy is most important for **EV**
- An estimate of power is most important for **HEV**
- Both are important for **E-REV/PHEV**

Photos from http://teslamotors.com, http://www.autocartechno.com/, and http://autoblog.com/

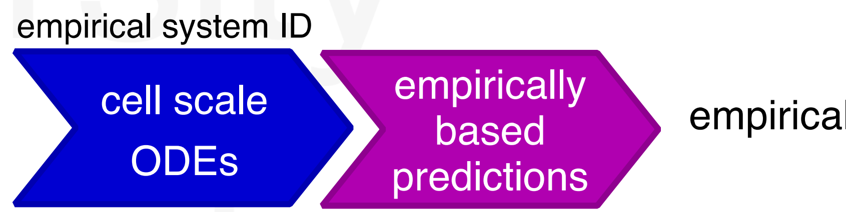
Value of accurate estimates

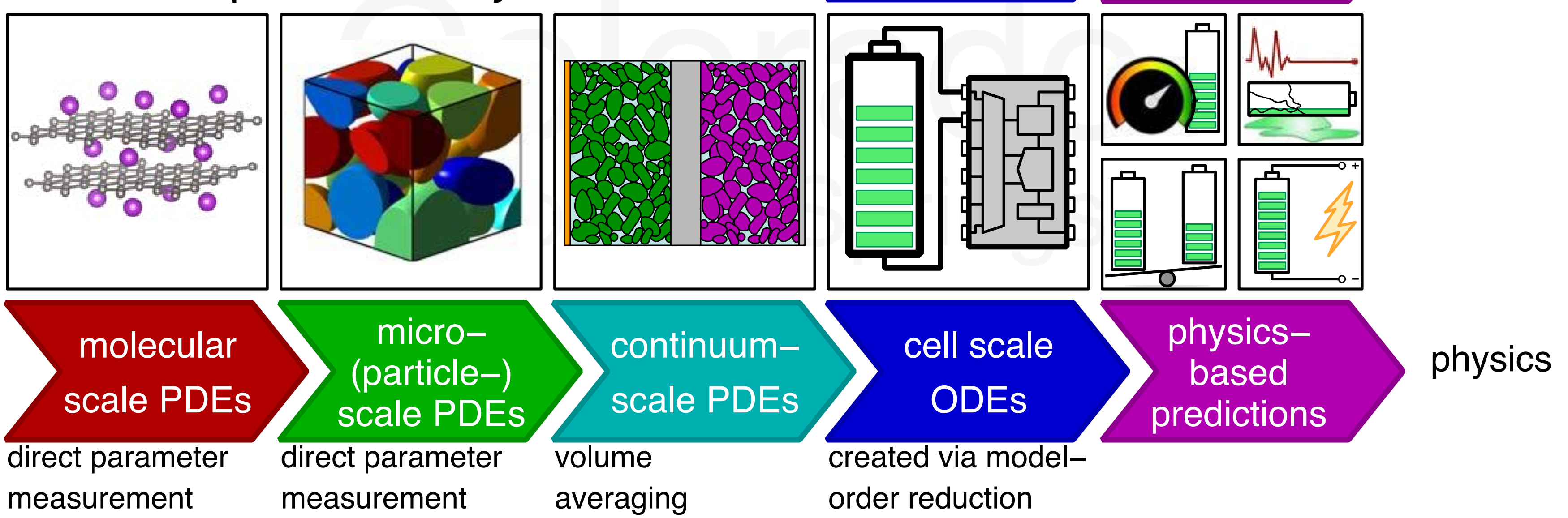


- Neither energy nor available power can be measured: must be estimated
- Poor estimation methods yield poor estimates:
  - Abrupt corrections when voltage/current limits exceeded
  - Over-charge or over-discharge
- To compensate for uncertainty, products are often over-designed
- **Premise: Investing $ in good estimation algorithms and a capable BMS processor can reduce pack size, save $$**

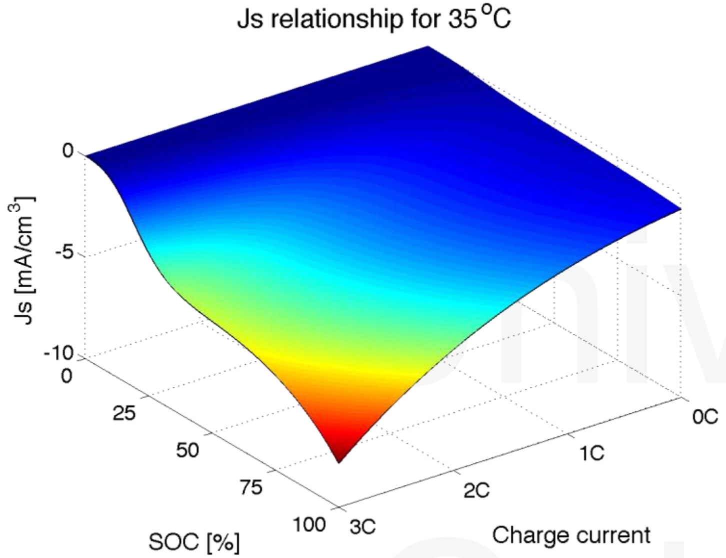
Model-based controls are required

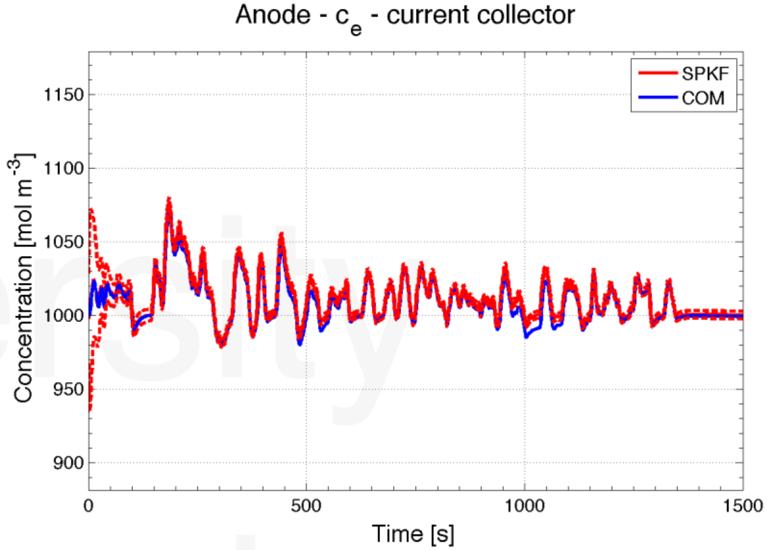
- To control a battery pack, we must understand how it works: need models
- **Empirical models** can match cell input-output and track aging behavior well, but give limited predictions
- **Physics-based models** more difficult to formulate, but allow enhanced monitoring and prediction of individual mechanisms
- Our research focuses on using reduced-order physics-based models to derive optimal battery controls



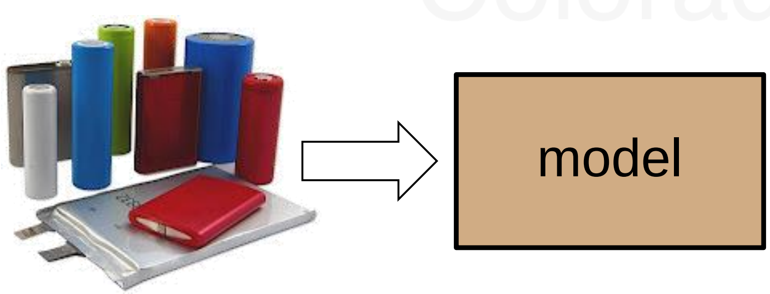


Present/recent research directions





1. Reduced-order degradation models for lithium-ion cells [Lukas Aldrich]
2. Model-based estimation of battery state [Kirk Stetzel]
3. System identification of parameters of physics-based reduced-order model using cell-test data [Ryan Jobman]



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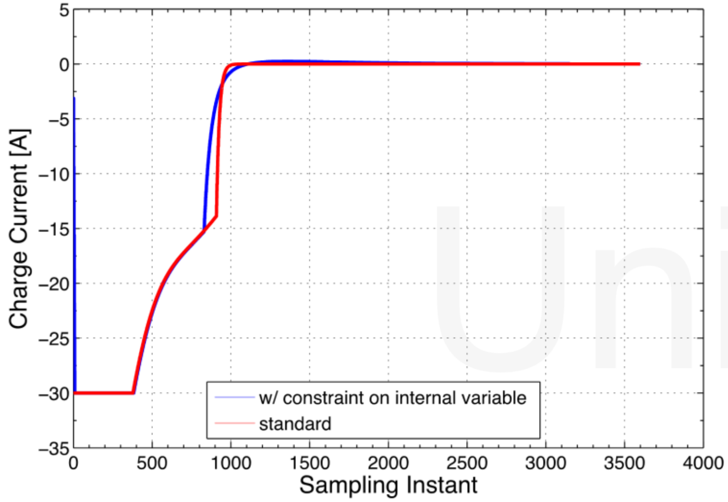
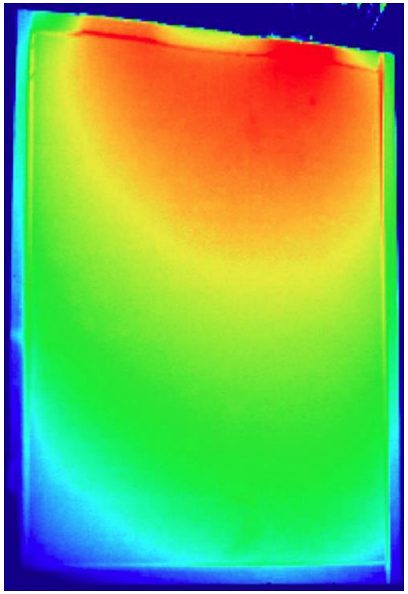


4. Model-predictive control with hard constraints on internal physics states [Marcelo Xavier]

5. Thermal modeling of cell incorporated into physics-based reduced-order ideal-cell model [Matt Aldrich]

6. Efficient computation of reduced-order models of lithium-ion cells [Dante DePalma, Albert Rodríguez]



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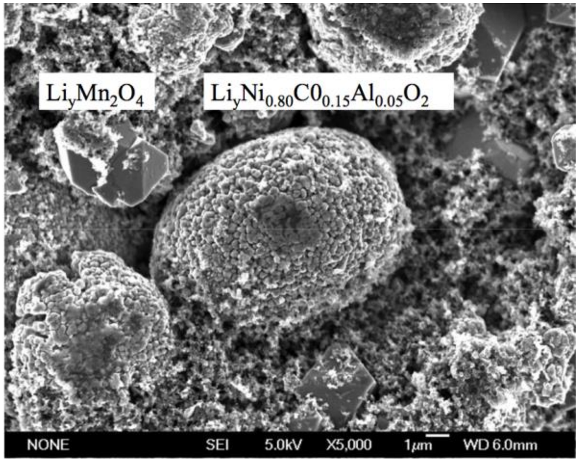
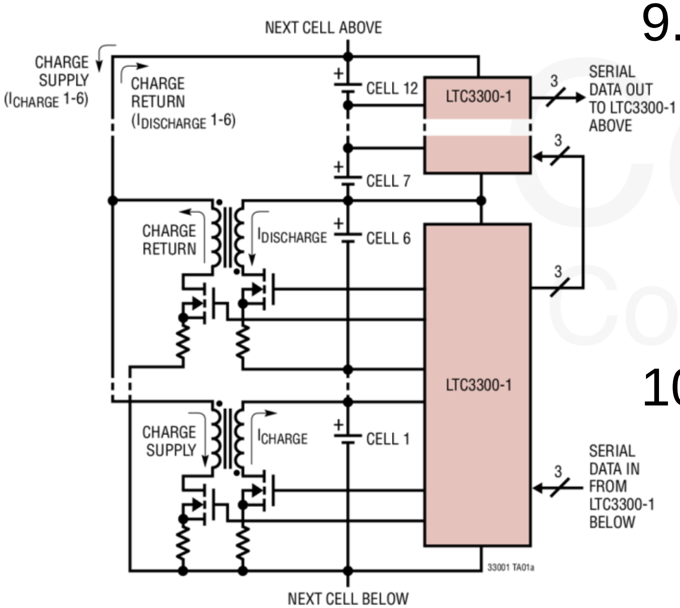
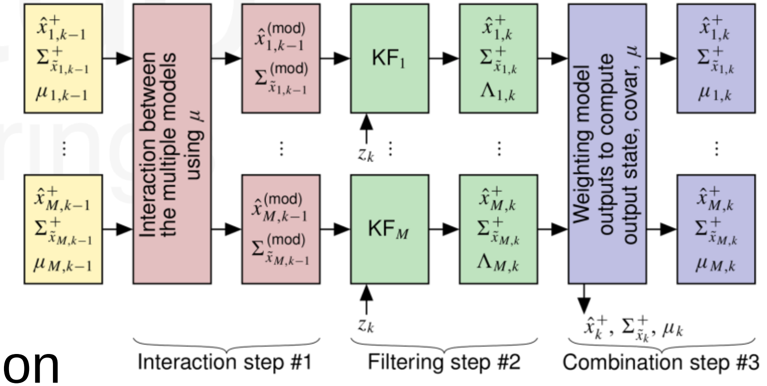


7. Reduced-order models of lithium ion cells having blended electrode materials [Albert Rodríguez]

8. Physics-based models of ultracapacitors [Al Mundy]

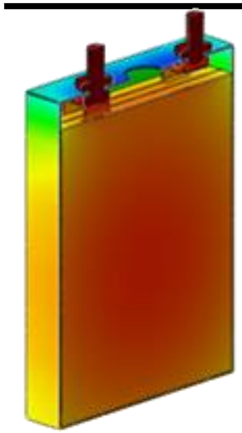


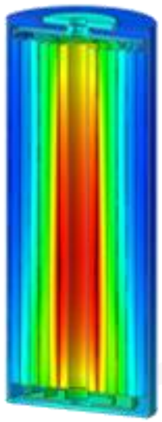
9. Algorithms for optimally balancing battery pack using bidirectional active balancers [Joshua Moore]



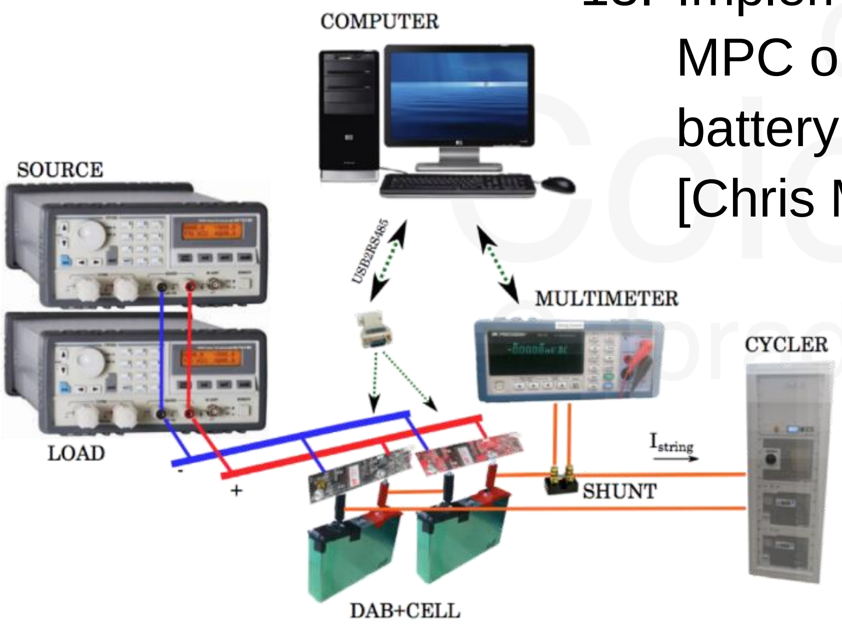
10. Adaptive determination of present degradation status of a battery [Adam Smiley]

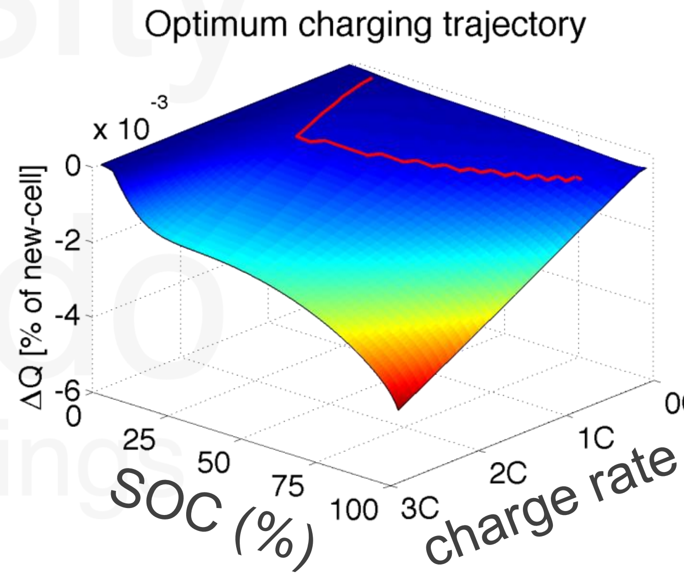
Present/recent research directions





11. System identification of blended-material cells; thermal properties [Jackie Cromer]
12. Model-predictive controls incorporating Kalman-filter state estimation [Gustavo Florentino]
13. Implementing MPC on lab battery pack [Chris Macklen]





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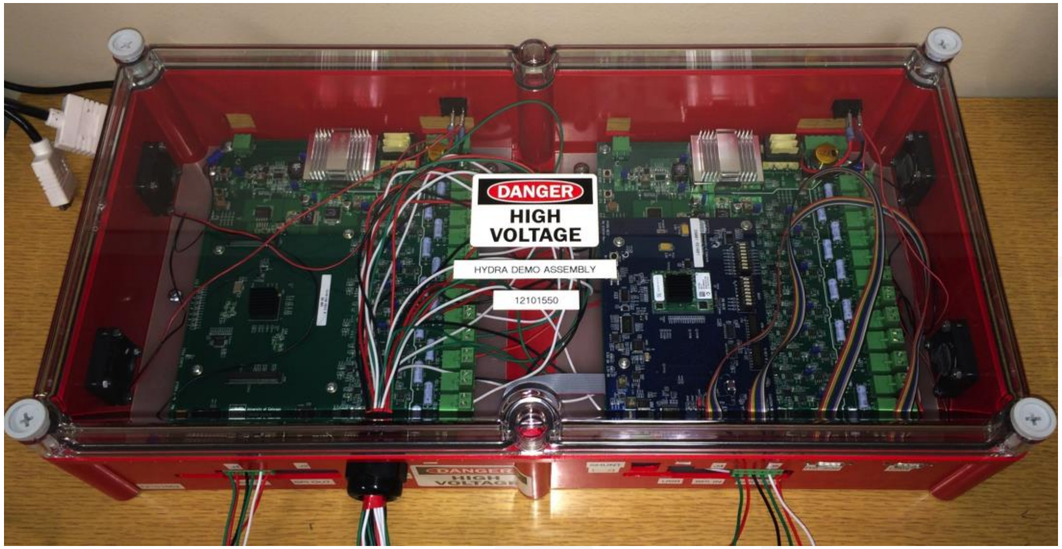

14. Hardware battery pack simulator [Mark Kraska, Katrina Brandau, Jonathan McIver]

15. Hardware/software battery management system testbed [Mark Kraska, Katrina Brandau, Wesley Hileman, Bobby Wilson]

Summary and next steps

- Advanced battery controls can extend battery life while still maximizing the performance that it delivers
- UCCS battery research team is fully involved in improving battery controls for sustainable transportation
- Next steps include implementing theoretic results on our two purpose-built electric vehicles: key platforms to enable implementing, testing, and validating battery-pack control electronics and algorithms
- Lessons learned will continue to improve our results

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