Selected Outcomes

U.S. China Clean Energy Research Center
Clean Vehicle Consortium (CVC)

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1. Advanced Batteries and Energy Conversion [Thrust Area 1]

- ***Characterizing degradation mechanisms to improve battery performance:*** Researchers from Ohio State University examined the thermo-physical properties of electrode materials as battery performance degraded when being charged and discharged in a way representative of actual driving conditions. The team observed the evolution of a non-uniform porosity distribution, believed to be caused by inhomogeneous electrode stacking stresses and/or temperature gradients within the cells. These new findings will assist researchers in formulating design and manufacturing principles to improve battery cycle life. (CERC-AR 2012-2013, page G4, Appendix G: CVC project number 1.1.1)

- ***High energy density batteries:*** Lithium–sulfur batteries (Li-S), which use a sulfur-based cathode, have the potential to exceed the energy density of today's lithium-ion batteries. The cycle life of these batteries is limited due to the so-called "sulfur shuttle," wherein soluble lithium polysulfides migrate from the cathode and damage the anode. Researchers from Tsinghua University, Beijing Institute of Technology, Massachusetts Institute of Technology, and the University of Michigan demonstrated a new cathode design that minimizes this phenomenon by applying a polymer coating to encapsulate nanotube core/sulfur shell cathodes. The new design slows degradation and maintains capacity, a significant step towards making high energy dense lithium-sulfur batteries a reality. (CERC-CVC 2012 4th Quarterly Report, CVC project number 1.2.1)

2. Advanced Biofuels, Clean Combustion and Auxiliary Power Unit (APU) [Thrust Area 2]

- ***Novel materials facilitate conversion of waste heat to electricity:*** Researchers from the University of Michigan and Wuhan University of Technology developed novel thermoelectric materials based on abundant, inexpensive Magnesium-Silicium-Tin solid solutions. In their n-type conduction form, these solutions achieved the thermoelectric figure of merit ZT=1.4 at 800 K, approaching the value achieved by thermoelectric materials that are composed of expensive, toxic, and low- abundant materials such as lead, tellurium, and rare earths. Efforts are underway to develop new forms of the material. Thermoelectric modules based on these compounds could significantly advance the efficient conversion of waste heat into electricity in internal combustion engine vehicles. (CERC-AR 2012-2013, page G28, Appendix G: CVC project number 2.8)

3. Vehicle Electrification [Thrust Area 3]

- ***Power-weighted efficiency analysis for rapid sizing:*** Researchers at Tsinghua University, Shanghai Jiao Tong University, and the University of Michigan are developing key techniques for the modeling, analysis, design, and control of power-split hybrid powertrains. The focus is to extend hybrid powertrains to heavier vehicles, which require multiple planetary gears and multi-mode operation. The project team has developed an optimal design method which is approximately 12,000 times faster than exhaustive optimization methods such as dynamic programming. This method has been used to analyze powertrain configurations with varying constraints on the number of planetary gears and clutches. After thorough topological analysis, researchers identified configurations with multiple clutches, resulting in four operating modes with better launching and fuel economy performance in urban cycles compared to popular production hybrid vehicles. This exhaustive-search design method can be applied to the design of other hybrid powertrains, such as parallel or series hybrids, or electric vehicles. (CERC-AR 2012-2013, page G31, Appendix G: CVC project number 3.3.1)

- ***Computationally efficient finite element algorithms for steady-state simulation of electric machines:*** Researchers at the University of Michigan are developing new algorithms for the analysis and design of electric machines. The new algorithms focus on efficiently calculating an electric machine's torque and power losses under steady-state operating conditions. The models capture important frequency-dependent phenomena such as skin effect and proximity effect. These phenomena are important when trying to accurately calculate losses in conducting regions (e.g., permanent magnets and the machine windings). A MATLAB toolbox has been made available to all CERC members, which provides a stand-alone electric machine modeling and simulation environment. This toolbox is currently in use in a project sponsored by CERC-member DENSO, which involves the design of a high-performance in-wheel electric motor for battery electric vehicles. The algorithms used in this new methodology are substantially faster than the current state-of-the-art used in commercial software, enabling a faster design process for electric machines used in hybrid or electric vehicles.

4. Advanced Light-weight Materials and Structures [Thrust Area 4]

- ***Joining in multi-material structures:*** Researchers at Ohio State University recently developed techniques capable of joining dissimilar materials both by welding and by conformal interference joining. These efficient techniques for joining dissimilar materials are key enablers for further light-weighting of vehicle structures.
    - One collision welding methodology produced strong joints between almost arbitrary pairs of dissimilar metals. Explosive welding has been the dominant method of collision welding, and very thick plates are often joined in this way. The newly developed method vaporizes a thin metal foil using pulsed electrical currents and is readily applicable for the sizes and materials that are relevant for automobile construction. A wide range of dissimilar metals were successfully joined, including

aluminum and stainless steel, with continuous welds up to 5 cm long. Some pairings of materials produced joints stronger than the weaker parent material.
  - A conformal interference joining methodology attached steel nodes to aluminum tubes with no reduction in load-carrying ability. Conformal interference joining has the added benefit of not distorting the metal, which can result in a loss in strength.

(CVC Annual Meeting, Beijing, China, August 2013: Technical Breakout, TA4+OSU.pdf, "Vaporizing Foil Actuator Welding;") (CVC Annual Meeting, Beijing, China, August 2013: Poster Project 4.3.2, "Joining in Multi-Material Structures" and CERC-AR 2012-2013, page G41, Appendix G: CVC project number 4.3.2)

- ***Modeling results optimize design of lightweight vehicle bodies:*** Researchers at Tsinghua University, Shanghai Jiao Tong University, and the University of Michigan developed a model that simulates performance of vehicle bodies made of lightweight materials under crash safety tests. Researchers also used computer-aided engineering models to optimize vehicle aerodynamics and to study the effects of battery layouts on crashworthiness. The newly developed model enables the rapid exploration of thousands of variations in structural and geometrical parameters. This allows an engineer to optimize lightweight body structure for a clean vehicle in terms of safety, cost, manufacturability, and aerodynamics. (CERC-AR 2012-2013, page G44, Appendix G: CVC project number 4.4)

5. Vehicle Grid Integration [Thrust Area 5]

- ***Electric vehicle charging station simulations reveal potential benefits to electricity and transport systems:*** Researchers from Ohio State University and Tsinghua University simulated electric vehicle (EV) charging station location strategies to optimize coordination of the electricity and transport systems. Researchers found that existing methodologies fail to capture some unique challenges in the design of the EV charging infrastructure. The team proposed an alternate evaluation methodology for power systems with high penetration of EVs and renewable power sources. The coordinated EV-wind simulations showed significant reductions in total system operation costs, wind curtailment, and emissions, and also a decrease in EV owners' charging fees. Researchers are expanding this work to study the benefits of charging management and distributed resources (e.g., energy storage, photovoltaic power) in reducing impacts of EV charging on the electricity system. (CERC-AR 2012-2013, page G46, Appendix G: CVC project number 5.1.1)

- ***Wireless charging of electric vehicles with extremely high efficiency:*** Researchers from the University of Michigan-Dearborn developed a high-efficiency wireless power transfer method for the charging of electric vehicles. They adopted a bipolar charging pad, a double sided LCC circuit, and developed a soft switching system for improved efficiency. With the proposed method, the resonance is automatically tuned so the power transfer efficiency no longer deteriorates excessively with the increased distance between and misalignment of the transmitting and receiving coils. The distance between coils now exceeds 300mm and the misalignment tolerance is more than +-300mm. The new wireless charging method

results in a greatly improved overall efficiency, with DC to battery efficiency exceeding 96% at 8kW output power. (CERC-CVC 2012 4th Quarterly Report, CVC project number 5.4)

6. Energy Systems Analysis, Technology Roadmaps and Policy [Thrust Area 6]

- ***Travel pattern studies help focus battery design for EVs:*** Design criteria for battery-sizing of plug-in hybrid vehicles has been guided by the estimated 40-mile daily average for U.S. drivers. Researchers in China, using GPS tracking software on 100 vehicles to monitor the driving behavior of drivers in Beijing, found that 60% of Beijing drivers travel less than 25 miles per day. Based on this information, hybrid, plug-in hybrid, and electric vehicles with more suitable battery storage capacities can be developed for the Beijing market while providing customers with sufficient electric range for their daily commutes. In addition, researchers at the University of Michigan used large-scale travel data for more than 10,000 taxis in Beijing to study their travel behavior and model the adoption and utilization of electric vehicles if introduced to the fleet. The study found the optimal PHEVs battery size and corresponding electric range to maximize fleet vehicle miles traveled (VMT) electrification was approximately 70 miles. The study also developed an integrated modeling framework to utilize general travel data for understanding adoption and utilization of electric vehicles considering important factors such as fuel cost, electricity cost, and subsidies.

- ***Life cycle models guide PHEV deployment and vehicle lightweighting strategies:*** Researchers at the University of Michigan developed new models and methods for evaluating the potential benefits of electrification and vehicle lightweighting; important strategies for improving energy efficiency and reducing greenhouse gas emissions (GHGs). These integrated models aim to capture the life-cycle carbon footprint of clean vehicles more accurately and will be able to guide both vehicle manufacturers and policy makers towards better solutions.
    - Charging PHEVs in coal-intensive regional electrical grids in the United States and the national grid in China indicated elevated life cycle GHG emissions compared to operating the PHEVs in gasoline mode.
    - Material sourcing of aluminum was found to a have a major impact on potential life cycle GHG savings from aluminum lightweighting compared to conventional and high strength steel.
    - A methodology was developed to allocate GHG emissions from electricity generators to electricity consumers; where no standardized protocol was previously available.

  (CERC-AR 2012-2013, page G57, Appendix G: CVC project number 6.3; CERC-AR 2012-2013, page G60, Appendix G: CVC project number 6.5)