Energy Quarterly

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MRS Bulletin

Energy safety

Energy transitions have historically required careful evaluation of the safety hazards surrounding emerging technologies. Electrical lines in the 19th century were initially not insulated, leading to unexpected encounters of electricity with people and animals. Gasoline-driven cars in the early 20th century presented very different hazards from those of the horse-drawn wagons they replaced. The advent of nuclear energy in the 1960s created safety hazards that remain unresolved for many stakeholders.

We face a similar situation today as renewable wind and solar energy replace fossil fuels, electric cars replace gasoline cars, and large-scale battery storage begins to penetrate the grid. The safety of lithium-ion and next-generation batteries holds a special place in these transitions. Batteries are required across the board, for firming wind and solar generation, for powering electric cars, and for decoupling generation from demand on the grid.

A comparison of the safety hazards of gasoline and batteries illuminates some of the challenges. Gasoline has 30–50 times higher energy density than today's batteries, and 5–10 times higher energy density than the most optimistic projections for next-generation batteries. We are in equally close contact with the gasoline in the tanks of our cars as with the batteries beneath the seats of our electric cars. The hazards, however, are quite different. The hazard of gasoline is fire or explosion from accidental combustion—the same combustion that, in controlled conditions within the engine, supplies the mechanical power to drive the vehicle.

In batteries, the greatest hazard is a side reaction not related to the chemical reactions that provide electrical power. At elevated temperatures (above approximately 160°C for lithium-cobalt-oxide cathodes and higher for other cathodes), the cathode releases oxygen that reacts with the liquid-organic-electrolyte exothermally, releasing energy as heat that drives the temperature higher and the reaction faster. This thermal runaway side reaction has nothing to do with the oxidation and reduction of the cathode by lithium that stores and releases energy, so the safety hazard can be addressed without compromising battery function.

The simplest way to address this hazard is to cool the battery below the thermal runaway temperature, quenching the side reaction and its hazards. Another is to find organic electrolytes, such as ionic liquids, that do not react readily with oxygen released from the cathode. A third and very desirable approach is to design into the battery a self-healing shutoff mechanism that interrupts battery operation above a predetermined temperature and automatically resumes operation when the temperature falls below the trigger point. Promising approaches to such a self-healing safety mechanism based on smart materials have been published recently (Chen et al., *Nat. Energy* **1**, 15009 [2016]; Amine, *Nat. Energy* **1**, 15018 [2016]).

The safety hazards for low energy devices (10–100 Wh) are very different from those for high energy electric cars (15–80 kWh) and the grid (up to MWh). Besides greater energy, these battery uses pose qualitatively different kinds of accidents and potentially harmful consequences, requiring different sets of safety mechanisms and procedures. Next-generation beyond lithium-ion batteries will undoubtedly have a different set of safety concerns based on energy-storing chemistries and undesirable side reactions. We are fortunate that these emerging safety issues can be identified and addressed at the R&D stage, where safety mitigation features can be designed into the battery from the start, rather than discovering safety issues at the product stage requiring potentially inefficient and awkward aftermarket redesigns. The R&D community is well aware of the need for present and future battery safety (Kalhoff et al., *ChemSusChem* **8**, 2154 [2015]; Wen et al., *Mater. Express* **2**, 197 [2012]). It is incumbent on the community to search aggressively and proactively for innovative safety solutions.

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