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Retired Electric Vehicle (EV) Batteries: Integrated Waste Management and Research Needs

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To reduce the carbon footprint and environmental impact of internal combustion engine (ICE) vehicles, governments and industry have made significant efforts to promote electric vehicles (EVs) worldwide over the past decade.[1] Due to the much higher efficiency of electric motors compared to conventional ICEs, EVs have lower emissions of CO_2 and air pollutants per kilometer driven, which occur at the sources of electricity generation instead of vehicle tailpipes, and can be even free of CO_2 emissions if the batteries are charged by renewable energy. A key component of EVs is the traction battery, which loses some of its storage capacity over time and needs to be replaced, typically after 8−10 years.[2,3] Although not classified as a hazardous waste in the United States (except California), European Union, China, and many other countries, decomposition of dumped EV batteries could release a range of heavy metals and other toxic chemicals. To be ready for handling the millions of batteries soon to be retired from EVs, an integrated management system should be established based on the three R's of environmental protection, that is, reduce, reuse, and recycle. Additionally, substantial research efforts are needed to lower the contents of toxic materials in EV batteries and to develop advanced recycling technologies.

Global adoption of EVs, spearheaded by the United States and China, has experienced explosive growth in the past several years (Figure 1). This has resulted primarily from the significant reduction in their prices due to technological progress and economies of scale, as well as the various policy supports, such as purchase, use, and circulation incentives, provided in many countries.[1] The cost of EV battery in the United States has declined from over USD 1000 to 268 per kWh over the period of 2008−2015 (Figure 1), and is expected to be lowered further to USD 125/kWh or less by 2022, which will make plug-in hybrid EVs cost-competitive with ICE vehicles.[1] Although the global stock of EVs was only ∼1 million in 2015, their market share had expanded quickly from 0.1% in 2011 to 0.9% in 2015.[1] Realizing their important contributions to the three major objectives of energy sustainability (energy security, climate change mitigation, and air pollution reduction), 14 major EV markets have committed to deploy up to 13 million EVs (e.g., 4.6, 2.0, 1.6, and 1.2 million in China, France, UK, and the United States, respectively) by 2020.[1]

The service life of a battery in EV application typically ends when approximately 80% of its maximum storage capacity is left due to the significant driving range loss with battery degradation.[2,3] The lifespan of EV batteries could range from 4 to 14 years (mean: 8−10 years), and is compromised by factors such as high temperature and rapid discharge.[2] As traditional vehicles last 10−16 years, battery replacement is typically necessary during the lifespan of EVs. Thus, the recent fast growth in global stock of EVs means waves of retired batteries will arrive in the near future. A material flow analysis indicates that lithium-ion battery wastes generated from EV deployment in the United States could reach 1 to 23 thousand tonnes in 2020,[2] while it is estimated that the cumulative waste outflow of EV batteries in China would be 120−170 thousand tonnes by 2020.[4]

Although EVs are considered to be more environment- and climate-friendly than ICE vehicles, disposal of the batteries at the end of their automotive lifecycle has emerged as a growing environmental concern. While the nickel−metal-hydrate (NiMH) and lithium-ion batteries commonly used in EVs are much less hazardous compared to the lead-acid batteries used in ICE vehicles, they still contain large quantities of metals, rare earth elements, and toxic materials (e.g., electrolyte salts and solvents), which can adversely affect the environment and pose potential risk to human health.[2,3] They could also pose fire, explosion, and electric shock hazards, if disposed of improperly.[2,3]

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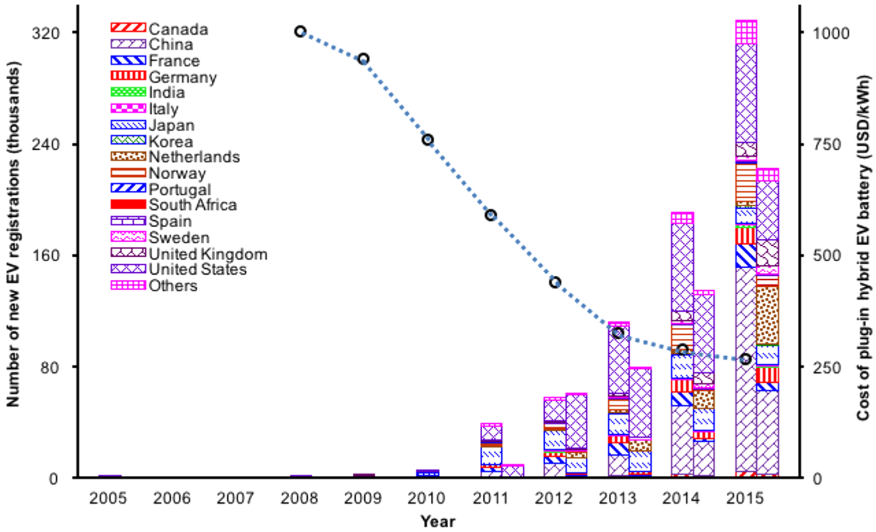

Figure 1. Global evolution of new registrations of battery EVs (left bar) and plug-in hybrid EVs (right bar) between 2005 and 2015, along with the estimated cost of plug-in hybrid EV battery (open circle) based on the observed industry-wide trend in the United States (all data reported by the IEA[1]).

Reducing the production of EVs is not an option if air pollution and climate change goals are to be met, but the production of NiMH batteries, which contain toxic nickel and rare earth elements (e.g., lanthanum), can be reduced and replaced with more environmentally benign lithium-ion batteries (made of lithium, graphite, and electrolytes).[2,3] For cost reasons, battery manufacturers have been working on lowering the contents of nickel and cobalt in lithium-ion batteries, which also reduces their risk of environmental pollution. While NiMH batteries contain an alkaline electrolyte (typically KOH), most electrolyte salts used in lithium-ion batteries are halogen-based (e.g., $LiPF_6$), which are toxic and release HF upon hydrolysis.[2,3] Research on developing halogen-free electrolytes (e.g., $Li(CB_{11}H_{12})$[5]) can significantly improve the safety of EV batteries and facilitate their recycling. Furthermore, technological advances that extend the lifespan of EV batteries are expected to lower their cost and ecological footprint by reducing or even eliminating the need of battery replacement.

Reuse markets should be established for batteries retired from EVs, which still retain 70–80% of their original storage capacity, even though no longer fit for the demanding application of driving vehicles.[2,3] The large volume of retired EV batteries can be reused for a "second life" by being integrated into stationary energy storage systems of various scales, such as residence, commercial facility, or power grid. With useful life of around a decade, they provide far cheaper energy storage than available options, and can accelerate the grid penetration of intermittent renewables. Their reuse also partially offsets the need for production of energy storage batteries. To foster EV battery reuse programs, quality standards and certification protocols should be developed to ensure the retired batteries can function safely and effectively. Furthermore, manufacturers of EVs and batteries need to work together on standardizing battery components and models to ensure cross-manufacturer compatibility,[4] and establishing identification and tracking systems for batteries. These efforts will facilitate the development of key reuse avenues for retired batteries, which can help improve the economic viability of EVs, whose market growth still depends significantly on policy supports.[1]

Scrap EV batteries without reuse value should be recycled at dedicated facilities to recover valuable materials efficiently and safely, although not all types of batteries are economically beneficial to recycle.[3] Due to the high price of nickel, NiMH batteries have been actively recycled by many companies. In contrast, extracting nickel, cobalt, copper, lithium, and iron from lithium-ion batteries (used by most EVs today) costs more than mining of new metals, although recycling them could help enhance the stability of supply chain and prevent future shortages.[2,3] Significant investment should be made in the research and development of advanced technologies to improve the material recovery and cost effectiveness of lithium-ion battery recycling.

Along with the push for consumer demand of EVs, governments and industry should put management of retired EV batteries on the top of their agenda. Besides reduction in the use of toxic materials in the production of EV batteries, reuse markets need to be established, while recycling capacity should be developed to reclaim valuable metals from them at the end of useful life. These measures, along with the ultimate disposal options (e.g., landfilling) for the materials not worth or suitable for recycling (e.g., mixed plastics and graphite), which constitute approximately half of the EV battery waste stream,[2] can maximize the climate benefits of retired EV batteries while minimizing their risk to the environment and human health.

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Notes

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