## Reality check

Electric motors are replacing combustion engines in vehicles thanks to the tremendous progress in battery development, but issues remain in navigating transportation with battery technologies.

e are at the dawn of a new era of electric mobility. Governments in nations such as France, the Netherlands and the United Kingdom have all announced plans to ban the sale of internal combustion engine vehicles (ICVs) between 2030 and 2040<sup>1</sup>. China, the world's largest auto market, is also considering implementing such a ban<sup>2</sup>. Meanwhile, automakers are embracing electric mobility, showcasing dazzling ranges of electrified vehicles (EVs) including hybrid, plug-in hybrid and all-electric models. In 2017, worldwide sales of new EVs rose to a record high of more than one million<sup>3</sup>.

Vehicle electrification is largely driven by the need to reduce greenhouse gas emissions. Subsidies, as well as government EV sales mandates, have been vital in building EV markets, while improvements in charging infrastructure are making things easier for EV owners than in the past<sup>4</sup>. Last but certainly not least, advancements in battery technologies over recent decades, along with their substantial cost reductions, have been a major driver in transforming the automotive industry.

The last time that EVs experienced a significant market share was over 100 years ago. In 1900, EVs accounted for around one-third of all vehicles on the road<sup>5</sup>, in sharp contrast to today's meagre 1% market share. The success was short-lived, however, primarily due to the rise of ICVs in the 1920s. Battery technological limitations and mass production of ICVs were largely responsible for the eventual decline in usage of EVs. The first batteries used in EVs were not rechargeable. The oldest rechargeable battery — lead-acid — has a low energy density, making it suitable only for low-range driving or assistive roles such as starting and lighting. Another rechargeable type with a long history is the nickel-metal hydride battery, which was invented in the 1970s and is still finding uses in today's EVs, especially in hybrid models. More recently, since its commercialization in the early 1990s, the Li-ion battery (LIB) has gradually become the mainstream power solution, with the best combination of properties such as energy density, cycling stability, safety and cost. Today, it is the world's best-selling EV battery technology.

Yet, despite tremendous improvements over recent decades, LIBs still fall short of industrial requirements and customer

expectations. Current LIB packs have an energy density of about 130 Wh kg-1 (or 210 Wh l-1), but this is a lot lower than the 235 Wh kg<sup>-1</sup> (or 500 Wh l<sup>-1</sup>) required for a drive range of 500 km in a single charge, a typical requirement considered to ease range anxiety and achieve mass market penetration<sup>6</sup>. LIB-powered EVs also remain expensive largely due to the battery material cost compared to ICVs, even with their remarkable cost reductions in recent years. Meanwhile, battery accidents such as fires and explosions make the headlines from time to time, continuing to affect people's perceptions of battery safety. In the meantime, research labs have been reporting promising results, especially on batteries beyond Li-ion — the so-called nextgeneration batteries. Though breakthroughs are often hailed by the media, little progress has yet been made for real applications because of the transformational gap in taking advancements from labs to market<sup>7</sup>.

In this context, we present this Insight as a reality check on the current status of existing LIB technologies for EVs and to explore challenges and realistic solutions in moving the technologies forward. This is particularly relevant when considering that the current LIBs are unlikely to be replaced by any nextgeneration technologies for automotive applications anytime soon. "We cannot expect a quantum leap", notes Stan Whittingham in our Q&A with him and Kent Snyder. The two interviewees, from academia and industry, highlight that there is a lot of room for improvement, especially in going from cell level to pack level and call for innovation in both fundamental chemistry and practical implementation in existing LIB technologies. In addition to the Q&A, this Insight covers several important aspects of the state-of-theart of EV batteries including battery materials, production processes, safety and market needs.

Battery materials are at the heart of battery performance. In their Review, Tobias Placke, Martin Winter and colleagues present a comprehensive survey of electrodes and electrolytes used in EV batteries. They also discuss the cost and production aspects of battery materials.

Battery safety is a primary concern. In their Perspective, Jie Deng and colleagues at Ford emphasize the importance of combining electrochemical, electrical, mechanical and thermal behaviours of batteries and propose a framework based on large-scale multi-physics modelling and experimental data to address safety issues of EV batteries.

For automotive applications, batteries come in the form of modules and packs, not the single cells that are often used in research labs. Arno Kwade and colleagues provide an overview of production technologies for automotive batteries, and discuss the relationships between manufacturing process, product quality and performance, as well as challenges in scale-up processes.

Though they are currently the dominant technology, LIBs are only one of many available technologies for powering EVs. Due to their inherent storage ability limits, safety and cost, it is unlikely that LIBs will be suitable for all automotive needs. Zhongwei Chen and colleagues analyse the emerging EV markets — categorized into long-range, low-cost and high-utilization transportation sectors — and discuss the suitability of various technologies, including fuel cells, for different markets.

Despite the current small market share, belief in full electrification of the future automotive industry is growing strong. Though LIB technologies dominate today, it is hard to imagine that the future power system will remain the same as now. In the end, how significantly EVs will penetrate the market and what technologies will become mainstream in the future largely depends on how much performance advancement and cost reduction a technology can offer. We hope that this issue offers some insights into how that may play out.

Published online: 12 April 2018 https://doi.org/10.1038/s41560-018-0143-y

## References

- Countries are announcing plans to phase out petrol and diesel cars. Is yours on the list? World Economic Forum (26 September 2017); https://go.nature.com/2Ge9WnG
- China is looking at banning the sale of petrol and diesel cars. World Economic Forum (11 September 2017); https://go.nature. com/2pj5FNM
- Monthly plug-in sales scorecard. InsideEVs https://insideevs.com/ monthly-plug-in-sales-scorecard/ (2017).
- 4. An infrastructure for charging electric vehicles takes shape. *The Economist* (7 September 2017).
- 5. The History of the Electric Car (DOE, 2014); https://energy.gov/articles/history-electric-car
- Schmuch, R., Wagner, R., Hörpel, G., Placke, T. & Winter, M. Nat. Energy https://doi.org/10.1038/s41560-018-0107-2 (2018).
- 7. Nat. Energy 2, 17126 (2017).