HighMag

The Magnesium Charge

Magnesium–Sulfur Batteries: Building a Sustainable Path to Next-Generation Energy Storage

Introduction.

The impact of Li-ion batteries has been transformational for portable electronics and electric vehicles. However, there are growing concerns surrounding the long-term availability, supply chain accessibility, and cost of critical raw materials which are currently being used in Li-ion batteries including cobalt, nickel, lithium and natural graphite. There is an increasing demand for alternative battery chemistries that reduce dependence on imported critical raw materials and strengthen Europe's battery supply chain. Among the most promising candidates are magnesium–sulfur (Mg–S) batteries. By combining magnesium metal with sulfur, Mg–S batteries have the potential to deliver high energy density using abundant, low-cost and widely available materials. If successfully developed, Mg–S batteries could provide a safer and more sustainable option for applications ranging from renewable energy storage to electric mobility. In the Department of Physics and Bernal Institute at the University of Limerick (UL) Ireland, researchers within the HighMag project are

"Using biomass and waste plastics as carbon precursors not only diverts waste from landfills but also provides a low-cost route to producing tailored porous carbons with properties that can be optimised for magnesium–sulfur batteries. "

David McNulty
Associate Professor of Energy Materials and Devices, Department of Physics & Bernal Institute, University of Limerick

Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

developing innovative materials and advanced characterisation techniques to overcome the scientific challenges that currently limit Mg–S battery performance.

Why Magnesium?

Magnesium offers several important advantages over lithium. It is the eighth most abundant element in the Earth's crust and is significantly more plentiful than lithium. This greater abundance improves long-term resource security and reduces concerns regarding supply chain resilience. Magnesium is also inexpensive, readily recyclable and already produced at industrial scale. Unlike lithium, magnesium metal can be handled with a lower risk of dendrite formation during battery operation. Dendrites are needle-like metallic deposits that can grow during repeated charging and potentially cause short circuits. Reducing this risk could improve both the safety and lifetime of future batteries. Another attractive feature of magnesium is that each magnesium ion carries two positive charges (Mg2+), compared with the single positive charge carried by lithium ions (Li+). In principle, this enables magnesium to transfer more charge per ion, offering the possibility of increased battery capacity compared to Li-ion batteries. When magnesium is coupled with sulfur, which is a naturally abundant and inexpensive by-product of the petroleum industry, the resulting battery chemistry has the potential to deliver high performance while significantly reducing reliance on critical raw materials.

The Challenges Facing Mg–S Batteries.

Despite their considerable promise, Mg–S batteries remain at a relatively early stage of development. Several scientific challenges must be addressed before they can become commercially viable. One of the main obstacles is the behaviour of sulfur during battery cycling. Sulfur is electrically insulating and undergoes a series of complex electrochemical reactions, producing intermediate magnesium polysulfides. These species can dissolve into the electrolyte and migrate between the electrodes, resulting in the so-called polysulfide shuttle effect. This process reduces efficiency, causes capacity loss and shortens battery lifetime. Magnesium itself also presents unique challenges. Magnesium ions interact much more strongly with surrounding electrolyte molecules than lithium ions, making them slower to transport through electrolytes and

Funded by
the European Union

electrode materials. Developing electrolytes that simultaneously provide high ionic conductivity, electrochemical stability and compatibility with magnesium metal remains one of the most active research areas in the field. In addition, the reversible plating and stripping of magnesium at the metal anode requires carefully designed electrolytes that prevent the formation of passivating surface layers which block ion transport.

Advanced Carbon Materials from Sustainable Sources.

The main contribution from the McNulty Group in UL focuses on the development sustainable carbon materials that can act as sulfur hosts within Mg–S cathodes. These porous carbon structures perform several important functions. They provide electrical conductivity for sulfur, physically confine soluble polysulfides, accommodate volume changes that occur during cycling, and improve electrolyte infiltration throughout the electrode. Rather than relying solely on conventional synthetic carbons, UL researchers are investigating carbons derived from different waste streams including biomass and waste plastic feedstocks. Using biomass and waste plastics as carbon precursors not only diverts waste from landfills but also provides a low-cost route to producing tailored porous carbons with properties that can be optimised for magnesium–sulfur batteries. Converting waste products into advanced battery materials supports the principles of the circular economy while simultaneously reducing waste and lowering the environmental footprint of battery production. By carefully controlling carbon structure, porosity and surface chemistry, these materials can significantly improve sulfur utilisation and enhance long-term cycling stability.

Catalysts and Operando Characterisation.

Researchers from UL are also investigating the incorporation of electrocatalytic nanoparticles within sulfur host materials. These catalysts accelerate the electrochemical conversion between sulfur and magnesium polysulfides, improving reaction kinetics and increasing rate capability. Understanding precisely how these reactions occur requires advanced structural characterisation methods capable of observing batteries while they are operating. Researchers at UL employ a range of operando techniques, including X-ray diffraction (XRD), Raman spectroscopy, and small-angle X-ray scattering (SAXS). These complementary techniques provide real-time

Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

insight into structural changes, reaction pathways, and degradation mechanisms throughout battery cycling. Combining advanced materials development with operando characterisation enables researchers to understand not only whether a material performs well, but also why it performs well, providing the knowledge required to rationally design improved battery materials.

HighMag: Developing the Next Generation of Magnesium Batteries.

These research activities form part of HighMag, a Horizon Europe collaborative research project bringing together leading academic and industrial partners from across Europe to accelerate the development of next-generation magnesium batteries. Within HighMag, UL is leading research on advanced sulfur cathodes, sustainable carbon materials, electrocatalyst development and operando battery characterisation. The project also investigates magnesium metal anodes, electrolyte optimisation, sustainability assessment and future manufacturing strategies. By combining expertise across materials science, electrochemistry, and industrial development, HighMag aims to establish the scientific foundations required to bring magnesium battery technology closer to practical applications while supporting Europe's transition towards a more resilient and sustainable battery value chain.

Conclusion.

Magnesium–sulfur batteries represent one of the most exciting emerging battery technologies. Their use of abundant, low-cost materials offers the possibility of reducing dependence on critical raw materials while delivering safe, high-energy density and environmentally sustainable energy storage. Although significant scientific challenges remain, continued advances in electrolyte design, sulfur host materials, electrocatalysts and operando characterisation are steadily improving their performance. Through the HighMag project, researchers at the University of Limerick are contributing to these developments by combining sustainable material design with cutting-edge analytical techniques. The knowledge generated will help shape the next generation of rechargeable batteries, supporting cleaner energy systems and Europe's ambition to build a more sustainable and secure battery future.

Follow us!

Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.