

Enabling Long-Duration Energy Storage: Heat Transfer and Flow Physics in Near-Isothermal CAES

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Abstract

This plenary talk addresses the critical role of heat transfer and fluid flow in enabling next-generation energy storage solutions to support net-zero power systems. As the global transitions toward a highly decentralised energy landscape dominated by intermittent renewable sources such as wind and solar, maintaining grid stability requires scalable and long-duration energy storage technologies. Compressed Air Energy Storage (CAES) offers a promising pathway for medium- to long-duration storage, capable of balancing supply and demand over timescales ranging from hours to weeks. However, conventional CAES systems suffer from significant thermal inefficiencies due to heat losses during compression and expansion processes. This talk focuses on recent advances in near-isothermal CAES systems, where enhanced heat transfer and flow control are leveraged to minimise thermal losses and improve round-trip efficiency. Fundamental aspects of fluid dynamics and heat transfer governing near-isothermal compression and expansion processes will be discussed, including multiphase flow behaviour, interfacial heat exchange, and system-scale thermal management. The presentation will highlight novel design concepts and technologies developed within our research group, supported by a combination of high-fidelity numerical modelling, experimental validation, and thermodynamic analysis. In addition, the talk will present insights into the economic viability and environmental impact of near-isothermal CAES systems, demonstrating their potential as a competitive and sustainable solution for long-duration energy storage. The findings underscore the importance of coupling advanced fluid flow and heat transfer engineering with system-level optimisation to unlock the full potential of CAES in future low-carbon energy systems.