Emerging Technology Analysis: Supercapacitors

What is this technology?

Supercapacitors are **energy-storing devices** that use high surface area electrode materials (such as a carbon powder) and liquid electrolytes which act as dielectrics (electrical insulators). Supercapacitors can be broken down into three main categories: double-layer capacitors (store charge electrostatically), pseudocapacitors (store charge electrochemically), and hybrid capacitors, which are a combination of double-layer capacitors and pseudocapacitors. Compared to conventional capacitors, supercapacitors have a **higher capacitance** (electric charge-storing capability. When compared to batteries, supercapacitors have a **higher power density, lower energy density** and a **longer cycle life.**

What is its readiness level?

Technology readiness level is estimated to be 9. Supercapacitors are already used in industrial and operational contexts. However, alternative supercapacitor materials are being researched and these have a lower readiness level.

Rail Industry Readiness Level is estimated to be 1-3. The industry is aware of the opportunity and is gathering ideas about implementation on-board rolling stock, but there is not currently a clear route to market for this technology.

What industries use it and why?

In the **automotive industry,** General Motors uses Continental's supercapacitor-based voltage stabilisation system (VSS) for start-stop technology in its Cadillac ATS and CTS sedans. Due to the supercapacitor's fast discharge time and extended cyclability, the system can start an engine within 0.4 seconds - twice as fast as conventional systems. The VSS can extend battery life by reducing stress, stabilise the vehicle's electrical system during periods of high demand and minimise electrical noise. Instead of storing surplus energy from regenerative braking in batteries, Mazda's i-ELOOP system stores it in a supercapacitor. The system can be charged in 7 seconds.

Supercapacitors have been adopted in **public transport systems.** For example, CSR trams in China are powered by onboard supercapacitors which have a 4km range and charge for 30 seconds at stations. With a projected lifespan of one million charging cycles, the supercapacitor provides power to the traction system and draws current from the regenerative braking system, recovering up to 85% of braking energy.

In the energy sector, Maxwell uses supercapacitors for its wind pitch control system on wind turbines. The technology provides backup power in the event of a power loss to orient the rotor blades in a safe position. By using a simpler pitch system, the operating costs, failure rate and maintenance costs can be reduced, thus decreasing the levelised cost of energy.

In the **aviation industry,** supercapacitors are used on the Airbus A380 to operate the aircraft's doors and, in emergency situations, work independently of the aircraft's central power system.

How will it impact the rail industry?

Like the automotive industry, the rail industry can use supercapacitors onboard rolling stock for regenerative braking and start-stop systems. The supercapacitor can use surplus energy from braking to **provide energy for acceleration,** while a battery can provide range and recharge the supercapacitor between surges. Excess energy could be used to **power train stations via reverse-supply power substations.** Consequently, this could **reduce operational costs, maintenance costs**, **energy dependence**, improve **voltage stability** and **increase energy efficiency.** In addition, supercapacitors with load levelling control can be used in conjunction with fuel cells, which could result in hybrid rolling stock with a fast and dynamic response. Results from simulations carried out by the Institute of Transportation Studies have suggested that automotive vehicles could achieve **greater fuel efficiency** and **reduce** the electrical and mechanical **stress on fuel cells** through the use of supercapacitors.

What uncertainties remain?

Although charging is fast, the quick self-discharge means that supercapacitors **need fast but frequent charging,** which may not be suitable for long journeys. Unlike batteries, the **voltage** of supercapacitors **varies over the course of the cycle,** which is mainly due to current leakage. This can be compensated by using **auxiliary components**, such as electronic control and switching converters, but this could **lower the overall efficiency** and **increase the cost** of the system. The **higher cost per unit of energy**, **lower technology readiness level** and **less media attention** means that supercapacitors **may receive lower investment than battery technology.** Potentially as a result of lower investment in R&D compared to similar technologies, the production and use of supercapacitors is relatively low.

What is the state of the current R&D?

As current supercapacitors are expensive and difficult to manufacture, **alternative electrode materials are being researched and developed** for use in the technology. Researchers at MIT have developed a supercapacitor that uses a class of materials called metal-organic frameworks (MOFs) instead of conductive carbon and can produce more power than current technology. Researchers from the City University of Hong Kong have **developed a supercapacitor which combines a polyelectrolyte (polymer electrolyte) with carbon nanotube paper composite electrodes.** The polyelectrolyte can be stretched without breaking or cracking, meaning that the supercapacitor can be stretched by more than ten times its length and compressed to half its thickness without reducing the device's energy-storing capacity. The supercapacitor has the potential to be used as a power source for electronic devices that require flexibility. SuperCapacitor Materials Ltd has **researched and developed crosslinked gel electrolytes** that can provide capacitance values over 100 times greater than those of conventional electrolytes, enhancing the specific energy storage capacities.

What should the rail industry do?

The rail industry could **implement supercapacitors** on-board **hybrid rolling stock,** particularly with **fuel cells** and **battery technology.** By using supercapacitors for **auxiliary purposes,** specifically to store energy from regenerative braking, the technology can minimise voltage drops caused by a high-current load, thus extending battery life. **Research programmes investigating** the development of supercapacitors, focusing on improving energy density, reducing voltage variation over the charge/discharge cycle and extending the discharge time for use in longer journeys should be monitored. **Associated technologies** could also be **developed to reduce voltage variation.** For example, **improving** or **developing new converter electronics** would reduce the associated efficiency loss and reduce the cost of the system.