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Image courtesy of Loughborough University

Front Cover Image – Water Droplet Erosion

This issue front cover image is water droplet erosion induced surface roughness along the last stage low pressure steam turbine leading edge. The top image is close to the blade root, middle image midway long the blade and the bottom image is close to the blade tip.

Temperatures in the last stage of a steam turbine as usually close to or just below the condensation temperature, i.e. water droplets form in the vapor stream. The last stage blade is typically around 1–1.5 m with moving velocities circa 300ms^{-1} at the tip. At these speeds the water droplet impact energy is large but reduces towards the blade root at the moving velocity reduces.

A curious fact is that as blades get longer the tip velocities may be sufficient for the flow to carry the droplets past the blades without impacting the surface meaning the critical erosion region moves down the blade and away from the tip.

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EMG newsletter lead

Little could we have realised the impact that COVID-19 would have on our working and personal lives this year. However, during these difficult times, we have learned to adapt to the change in circumstances which remain for the foreseeable future. Many beyond the NHS have continued to meet society needs and this includes industries and their support in the energy sectors. In particular electrical power generation, gas production and supply. However there have been others such as transportation where the impacts have been negative and significant. In this context I would like to draw your attention to two articles in the *Bulletin for the UK Forum for Engineering Structural Integrity*, Issue 1, 2020,

www.fesi.org.uk/fesipublishing/bulletin

The first is by Rod A Smith, Imperial College, London, and a former chief scientific advisor to the Government on transport that considers *Notes on the Covid-19 emergency in the UK – statistics, transport, implication*. The second by Elisabeth LeMay addresses *Engineers in the Age of Covid -19*. Both provide thought provoking insights into the impact of the pandemic and how the engineering community in the UK has responded to the challenge.

However, amid these complex, uncertain and confusing times there have been some positive steps announced by Government to support and develop the UK nuclear power generation industry. The Government has invested £40m to develop the next generation of nuclear energy technology to supply low carbon heat, hydrogen and other clean energy. A significant part of the funding (£30m) will support developments for three Advanced Modular Reactors which are smaller than traditional nuclear plants, such as that being built at Hinkley, and these can be constructed at remote locations supplying electricity or heat. This is to be supported with further investment in advanced manufacturing for materials, for example developing additive manufacturing methods and applications for pressure components and parts.

The Government is committing a further £220m to developing a conceptual design for a fusion power station called, the Spherical Tokamak for Energy Production (STEP). This is an innovative approach for constructing a power plant by 2040. The first stage is to produce a conceptual design by 2024. It builds upon the UKAEA, Culham expertise in this area where the UK are world leading. It is hoped that it will create jobs in the sector and in the associated supply chain organisations. However, this does potentially bring this technology to market in what appears to be a realistic timeframe.

These announcements are supported by other investments to reinvigorate the civil nuclear programme in the UK such as significant funding to supply advance, state of the art equipment to support research in UK universities. Overall, these initiatives will enable the UK to maintain a place at the civil nuclear power generation international community table. Moreover, it recognises the importance that nuclear power can contribute to the future clean energy demands and requirements for the UK.

Please stay alert and well.

Professor Peter Flewitt
Vice Chair of Energy Materials Group

Energy Materials Information Streams

The EMG microsite is a mine of information relating to Energy Materials with links to various sources of information, including funding sources for collaborative research/development. The EMG microsite is actively managed and regularly updated at –

www.iom3.org/energy-materials-group/energy-materials-links

MaterialsTodayEnergy, vol 14, December 2019

- Synthesis of $\text{LiMg}_{1-x}\text{Zn}_x\text{VO}_4$ with $0 \leq x \leq 1$ for application to the negative electrode of lithium-ion batteries
- 13.5% flexible organic solar cells achieved by robust composite ITO/PEDOT:PSS electrodes
- Physical shortcut accelerating electron transport of rechargeable zinc-air battery
- Prediction of sunlight-driven CO_2 conversion: Producing methane from photovoltaics, and full system design for single-house application
- Synthesis of PtAg bimetallic material as a multi-fuel tolerant electrocatalyst and spectroelectrochemical analysis of its capability to perform the oxygen reduction
- Highly purified dicobalt phosphide nanodendrites on exfoliated graphene: In situ synthesis and as robust bifunctional electrocatalysts for overall water splitting
- Passivation effect for current collectors enables high-voltage aqueous sodium ion batteries
- Molecular engineering of a conjugated polymer as a hole transporting layer for versatile p-i-n perovskite solar cells
- Constructing a sandwich-structured interlayer with strong polysulfides adsorption ability for high-performance lithium-sulfur batteries
- Tree leaves-derived three-dimensional porous networks as separators for graphene-based supercapacitors
- Biphasic Ag block assisting electron and energy transfer to facilitate photothermal catalytic oxidation of HCHO over manganese oxide
- Bio-oil derived hierarchical porous hard carbon from rubber wood sawdust via a template fabrication process as highly stable anode for sodium-ion batteries
- Supply risks of lithium-ion battery materials: An entire supply chain estimation
- Highly cross-linked carbon sponge enables room-temperature long-life semi-liquid Na/polysulfide battery
- Carbon coated porous SnO_2 nanosheet arrays on carbon cloth towards enhanced lithium storage performance
- Giant bulk photovoltaic effect in solar cell architectures with ultra-wide bandgap Ga_2O_3 transparent conducting electrodes

Organisation Profile

Energy Storage Association

The U.S. Energy Storage Association (ESA) is the national trade association dedicated to energy storage, working toward a more resilient, efficient, sustainable and affordable electricity grid – as is uniquely enabled by energy storage. With around 190 members, ESA represents a diverse group of companies, including independent power producers, electric utilities, energy service companies, financiers, insurers, law firms, installers, manufacturers, component suppliers and integrators involved in deploying energy storage systems around the globe.

ESA's mission is to accelerate the widespread use of competitive and reliable energy storage systems in North America. Energy storage systems revolves around 5 key technologies, Batteries, Thermal Storage, Mechanical Storage, Hydrogen and Pumped Hydropower. Batteries include Lithium Ion (Li-Ion), Lead, Redox Flow, Vanadium Redox (VRB) Flow, Nickel-Cadmium (NI-CD), Sodium Sulphur (NaS), Electrochemical Capacitors, Iron-Chromium (ICB) Flow and Zinc-Bromine (ZNBR) Flow. Thermal Storage includes Pumped Heat Electrical and Liquid Air Energy; Mechanical Storage includes Flywheel Energy, Compressed Air Energy (CAES) and Isothermal Compressed Air Energy. Hydrogen includes production, storage and fuel cells.

The purpose of energy storage is to save money, improve reliability & resilience, integrate diverse resources and reduce environmental impacts. By storing energy when supply is plentiful, i.e. exceeds demand, and feeding back when supply is below demand all four of these purposes can be met. By operating plant at optimal efficiency at all times operational costs are reduced – stored energy can be brought on line quickly to counteract any outages improving the system reliability; integrating diverse energy sources allows capture of intermittent supplies all of which reduces the need for surplus energy systems to meet peak demand and by capturing the intermittent renewable energy sources environmental impacts are reduced.

Whilst primarily a US organisation focused on US related policy and infrastructure many companies outside the US are members through US subsidiaries. Much of the work of the organisation entails lobbying and policy making at both local and national level. The ESA produces an extensive webinar series on a range of topics of interest and relevance to members. Topics include – current events impacting the storage sector, market updates, technical issues facing the industry, and primers introducing energy storage topics to those new to the technologies – among others. Some webinars are exclusive to members, some are available for a fee to non-members, and some are completely free. Some examples being *End of Life and Recycling: Advanced Energy Storage Systems*, *Long Duration Storage: Where are We Now and Where are We Headed?* and *Storage 101: End Uses*.

ESA also holds an annual conference 'The ESA Energy Storage Annual Conference & Expo' usually in August each year, which this year will be a virtual four-day conference. While, the conference and ESA is mainly commercial biased therefore not 100% relevant to the materials community it points the way to exploitation of technologies and where research should be focused.

More information at energystorage.org

Editor's Titbits Section

Can a hydrogen boom fuel a green recovery for Britain?

Norwegian energy company, Equinor, (formerly Statoil), unveiled proposals to install the biggest facility in the world for making hydrogen from natural gas, using capture and storage technology to extract and bury the resulting carbon under the North Sea, which could create up to 5,000 local jobs.

'Blue' hydrogen – the kind Equinor hopes to produce in Hull – can be made almost carbon-free from natural gas, by using capture and storage technology. Green hydrogen, on the other hand, which is made from renewable sources, bypasses fossil fuels altogether.

Astronauts replace ageing nickel-hydrogen batteries with new lithium-ion batteries

NASA broadcasted spacewalks conducted by its astronauts 16–16 July as they upgrade the power system on the International Space Station. The spacewalks, which lasted some 5 hours, are meant to be the finishing touches of an almost four-year effort to replace ageing nickel-hydrogen batteries with new lithium-ion batteries.

The space agency says since 2017, there have been 12 spacewalks performed to change out batteries for eight power channels used to supply electricity to the station. When the astronauts finish their work, they plan to remove lifting equipment used for the ground processing of the station's solar panels.

UK Government to encourage larger battery storage projects

The UK Government has changed planning legislation to encourage the development of larger batteries to store renewable energy from solar and wind farms. The relaxation of legislation will enable storage projects above 50MW to be developed in England, while batteries with capacity more than 350MW will be given the go-ahead in Wales.

Although the UK has the largest installed capacity of offshore wind in the world, a significant volume of energy can be lost due to harsh weather conditions affecting transmission – this legislative change will prevent this happening and is expected to help increase the overall use of green electricity and support the reliability of the grid.

Offshore wind investments grow soaring

Investments in the offshore wind sector experienced 'colossal' growth in the first 6 months of the year according to the latest report by research company Bloomberg New Energy Finance (BNEF), which suggests offshore wind financings in the first half of 2020 totalled US\$35 billion (£27.8bn), up 319% year-on-year and higher than 2019's record full-year figure of almost \$32 billion (£25.4bn). This includes the 'largest ever' wind farm the 1.5GW Vattenfall Hollandse Zuid project off the coast of the Netherlands, costing US\$3.9 billion (£3.1bn).

UK Government invests to develop next-gen nuclear tech

The UK Government is investing £40 million to help speed up the development of the next generation of nuclear energy technologies, including £30 million for three Advanced Modular Reactor (AMR) projects in Oxfordshire, Cheshire and Lancashire, bringing them closer towards supplying low carbon heat and hydrogen across the country. AMRs can be used at remote

locations because they are much smaller than traditional nuclear energy power plants and they use intense heat generated in nuclear reactions to produce low carbon electricity.

Global methane emissions hit record heights in 2020

Worldwide emissions of methane, a potent greenhouse gas, have hit the highest levels on record. That's one of the findings from the latest report by *Global Methane Budget 2020*, which says by the end of 2019, methane concentrations reached around 1,875 parts per billion, more than two and a half times pre-industrial levels.

The report suggests that agriculture, livestock farming, waste and fossil fuel sectors are likely the dominant cause of this global increase. The largest methane concentrations globally can be observed in South America, Africa, South-East Asia and China, which combined make up half of the global emissions, according to the report.

Note: methane could have a global warming potential 28 times larger than carbon dioxide.

Facebook data centre provides heat for nearly 7K Danish households

Facebook's data centre, powered by renewable energy provided by wind turbines. in Odense, Denmark, is successfully capturing heat generated by its servers via heat pumps for delivery to a local district heating system. The project produces 100,000MWh of heat energy every year, enough to warm around 6,900 homes in the neighbouring area.

Johnnie Walker whiskey to be sold in paper bottles in 2021

British beverages company Diageo has announced plans to launch a new bottle made of paper for its whiskey brand Johnnie Walker in early 2021. The bottle would be 'world's first-ever 100% plastic-free paper-based spirits bottle', made entirely from sustainably-sourced wood.

The new bottle, developed in partnership with the venture management company Pilot Lite, will be made from wood pulp and will be fully recyclable.

World's longest electricity interconnector

The first phase of Viking Link's construction will see Siemens Energy developing the UK and Denmark converter stations on both ends of the link – the new infrastructure will allow the UK and Denmark to share renewable energy through a 765 kilometre-long high-voltage cable,

Once completed in 2023, the £1.7 billion cable will have the capacity to be able to supply renewable energy to power 1.5 million British homes.

Plans for the world's largest green hydrogen plant

A consortium is planning to build what is claimed to be the 'world's largest green hydrogen plant' in Saudi Arabia. The \$5 billion (£3.9bn) hydrogen-based ammonia production plant will be built at a site in north-west Saudi Arabia and is expected to supply 650 tonnes of hydrogen for global transportation. The facility, which is scheduled to start operations in 2025.

Mini Feature

End-of-Life Management of Lithium-ion Energy Storage Systems

(abridged from report issued by ESA, April 22, 2020)

Energy storage is experiencing a period of rapid deployment growth in both the power and transport sectors. Both grid-connected energy storage systems (ESS) and electric vehicles (EVs) rely on Li-ion batteries, and the phenomenal growth in Li-ion applications creates stress along the entire value chain—from mining raw material inputs, such as lithium and rarer elements, to manufacturing and disposition of the batteries once they reach the end of their useful lives.

The primary objective of a circular economy framework is to promote a sustainable economic system by minimizing material and energy used to provide economic goods and services, as per the shorthand slogan, 'reduce, reuse, recycle.' However, given current technology and markets, not all production and waste can be brought into a circular economy with beneficial results. For some goods, more energy would be used in collecting and recycling activities than is used to produce virgin materials, or the costs of reuse or recycling are prohibitive compared with relatively benign disposal options. Current constraints and limitations to beneficial reuse or recycling within the Li-ion battery value chain have already prompted recent initiatives and new programs to address these barriers.

As with any other asset within the power sector, the decommissioning process involves dismantling the ESS and removing it from the site in compliance with applicable federal and local rules. Once a used battery is removed from service and diverted toward end-of-life management, it is designated as 'Universal Waste,' a special category of hazardous waste under Environmental Protection Agency (EPA) regulations. A battery intended for refurbishment and reuse is not considered 'waste' under Resource Conservation and Recovery Act (RCRA), because it is not discarded.

Where economically feasible, reusing battery systems and other components is more environmentally sound than recycling constituent materials. As batteries degrade over time, they may be less useful for their originally intended purpose, but still valuable for other applications. For example, backup power systems or batteries coupled with renewables to power remote irrigation systems may not need the same performance characteristics as commercial grid systems. These 'second life' applications can substitute for newly-manufactured battery energy storage systems and in some cases expand the role of stationary energy storage, such as when new systems may be prohibitively expensive, but a lower cost refurbished system can meet the desired performance requirements. EV batteries are typically retired when they reach 70-80% of their original rated capacity. By 2018, China had redeployed almost 1GW of used batteries, primarily as back-up power at telecommunication facilities.

The primary loop for spent Li-ion batteries to re-enter the economy remains some form of recycling. Ultimately, this becomes the only alternative to disposal for all batteries: even if second life applications become prevalent, at some point batteries can no longer perform useful service. Therefore, recycling is currently the only viable long-term path to manage spent Li-ion battery waste consistent with circular economy principles.

The recycling process begins with dismantling electrically discharged batteries. The current diversity of Li-ion battery types, sizes, and chemistries makes this process difficult to automate, so it must largely be done manually. The steps consist of removing the battery casings, separating the connectors, disassembling modules from packs, separating cells from modules, and removing the electrolyte. In addition to manual separation, some recyclers employ ultrasound and/or mechanical agitation to remove cathode material. After shredding, or milling and pre-treatment, the cells undergo the recycling process. Today, there are two primary commercial pathways for recycling batteries – the most common being pyrometallurgical processes (i.e., smelting), and emerging hydrometallurgical processes that include chemical methods such as precipitation, solvent extraction, ion exchange and electrowinning.

Pyrometallurgy is based on 100-year old technology – the primary advantage of pyrometallurgy is that the smelters can easily handle battery cells of mixed chemistries. Hydrometallurgical recycling processes reduce cells to elemental products using leaching techniques, which dissolve the metallic fraction and recycled metal solutions for separation and recovery. Leaching agents include organic and inorganic acids, and ammonia-ammonium salt systems. The main advantage for hydrometallurgy is the ability to recover transition metals and lithium from the cathode.

A major new research and development effort is focused on a third process called ‘direct cathode recycling.’ Direct cathode recycling aims to recover relatively intact cathode materials for easier reinsertion into the battery manufacturing process and may provide a method to recover significant value from lithium iron phosphate (LFP) and lithium manganese oxide (LMO) cathodes. This direct recycling is expected to have lower energy costs than other processes and produce more reclaimed and readily reusable material when scaled commercially.

Recycling methods that reintroduce raw materials into cell production can also reduce overall environmental impacts of battery production – life cycle analysis generally finds that upstream raw material extraction and processing creates more environment and energy burdens than cell production and pack assembly. For example, since cobalt, nickel and copper are produced from sulfide ores, their virgin production is not just energy-intensive but also results in high sulphur oxide (SO_x) emissions, which are avoided by recycling. Hence recycling or reclamation can be an efficient strategy to reduce overall environmental impacts from using Li-ion batteries.

Currently, high processing costs and insufficient demand (related to low market prices for some of the constituent materials such as battery-grade lithium carbonate) impede recycling. For recycling to be economically viable the recovered materials must have more market value than the costs of the obtaining and recycling the batteries. Economies of scale in recycling processes and automation are key to reducing recycling costs. The primary element working in favour of recycling economics is that the concentration of metals in scrap is much higher than in virgin ores. The cost of materials comprises more than 50% of new cell cost, of which cathode materials comprise the most significant portion, so Li-ion recycling depends heavily on cost-effectively recovering cathode material.

Where recycling facilities are unavailable or the recovered materials are uneconomic, batteries are disposed as waste. Once rendered inert from fire risk (mechanically or chemically), non-hazardous materials can be disposed of through municipal waste streams. While some lithium

chemistries are considered non-hazardous, many batteries have toxic constituents that require treatment as hazardous materials. The potential toxicity of Li-ion battery materials varies widely by chemistry – for example, where nickel, cobalt, or lead are present in battery chemistries in significant quantities, precautions must be taken at disposal or incineration sites in line with the hazards of those individual materials. For the full report please refer to link below.

www.energystorage.org/wp/wp-content/uploads/2020/04/ESA-End-of-Life-White-Paper-CRI.pdf

NEXT COMMITTEE MEETINGS

09:00-11:00 26 Nov, EMG Board meeting, via zoom

09:00-16:00 11 Feb 2021, University of Bristol

EMG SPONSORED WORKSHOPS/CONFERENCES

ECCC2021, 13–15 September 2021, Edinburgh, UK

OTHER WORKSHOPS/CONFERENCES/COURSES OF INTEREST

Energy Materials 2020 International Conference on Advanced Energy Materials, 17–18 August 2020, Venice, IT. (Additional webinar covering conference August 26-27 Aug 2020)

The ESA Energy Storage Annual Conference & Expo, 24–27 August, 2020, virtual event

21st European Annual Conference on Advanced and Energy Materials, 28–29 September 2020, Amsterdam, NL

NANO4EV's - Energy Storage, 17 November 2020, London, UK

Advanced and Energy Materials, 22–23 December 2020, Webinar

The 4th International Conference on Advanced Energy Materials (ICAEM 2021), 21–24 January, 2021, Singapore, SG

CF-8 8th International Conference on Creep, Fatigue & Creep-Fatigue Interaction, 9–12 February 2021, Mamallapuram, IN.

ALTA 2021 Nickel-Cobalt-Copper, Uranium-REE, Gold-PM, in Situ Recovery, Lithium & Battery Technology Conference & Exhibition, 22–30 May 2021, Perth, AU

Editor's Note: Date for the above events were correct at the time of going to print. Revisions to the events are likely to occur in the coming weeks, so please refer to the events website.