2nd WORLD ENERGY STORAGE CONFERENCE

Jointly with the 7th UK Energy Storage Conference

Programme & Abstract

October 12 - 14, 2022

UNIVERSITY OF BIRMINGHAM | BIRMINGHAM ENERGY INSTITUTE

BIRMINGHAM CENTRE FOR ENERGY STORAGE

Supergen Energy Storage

WORLD ENERGY STORAGE CONFERENCE

12th – 14th OCTOBER 2022

Jointly with the 7th UK Energy Storage Conference

2^{nd} WORLD ENERGY STORAGE CONFERENCE

Jointly with the 7^{th} UK Energy Storage Conference

October 12 - 14, 2022

Conference Chair

Prof Yulong Ding

Organizing Committee

(Birmingham Centre for Energy Storage, University of Birmingham, UK)

Dr Adriano Sciacovelli (Chair)

Prof Yongliang Li

Dr Helena Navarro

Dr Shivangi Sharma

Dr Yi Wang

Dr Tongtong Zhang

Ms Lada Zimina

Dr Antzela Fivga

Day-1 (12 October, Wednesday)

***All timings are in British Summer Time (BST)**

Session 1: Opening plenary (public): 16:00-18:00	
16:00-16:20	**Welcome and introduction:** Yulong Ding & Stephen Jarvis & Martin Freer
16:20-17:10	**Plenary 1.1:** Recent advances in hydrogen storage - science & technology **Speaker:** Nigel Brandon (Imperial College London)
17:10-18:00	**Plenary 1.2:** Recent advances in Carnot batteries – science & technology **Speaker:** Andre Thess (DLR)

Day-2 (13 October, Thursday)

10:00-10:50	**Online platform opens** **Poster session**
10:50-11:00	**Welcome:** Yulong Ding
11:00 – 13:00	**Session 2: Recent Advances in Energy Storage** (Keynote presentation: 30min presentation + 10min Q&A) (Oral presentation: 10min presentation + 5min Q&A)
13:00-13:30	**Lunch Break & Poster session**
13:30-15:30	**Session 3: Application Through Integration** (Keynote presentation: 30min presentation + 10min Q&A) (Oral presentation: 10min presentation + 5min Q&A)

Session 2: Recent Advances in Energy Storage (11:00 – 13:00)

Parallel session 2.1: Recent advances in electrochemical energy storage science & technology (focusing on lithium-ion, sodium-ion and sodium-sulphur batteries) **Chairs:** Paul Shearing & Clare Grey	
11:00-11:40	**Keynote speaker:** Claire Villevieille **Title:** Multiscale investigation of solid state batteries using advanced operando

	techniques
11:40	**Presenter:** Bo Dong **Title:** New Ni based layered/disordered rock salt cathode materials for lithium ion batteries
11:55	**Presenter:** Peter Brugryniec **Title:** Predicting Li-Ion battery hazards during thermal runaway using micro-kinetic modelling
12:10	**Presenter:** Seyed Saeed Madani **Title:** An Optimization-based technique for modelling lithium-ion batteries
12:25	**Presenter:** Jiahuan Xu **Title:** Nitrogen-doped spongy-like hierarchical porous carbon derived from biomass tar: a sustainable energy material for supercapacitor

Parallel session 2.2: Recent advances in electrochemical energy storage science & technology (focusing on flow batteries) **Chairs:** Sara Walker & Xianfeng Li	
11:00-11:40	**Keynote speaker:** Qing Wang **Title:** From Electrochemistry to Electrified Chemistry: Electrochemical Energy Storage and Conversion beyond the Electrode-electrolyte Interface
11:40	**Presenter:** Qilei Song **Title:** Innovation in Membrane Materials for Flow Battery Energy Storage
11:55	**Presenter:** David Trudgeon **Title:** Enhanced surface area carbon cathodes for the hydrogen-bromine redox flow battery
12:10	**Presenter:** Ethan Williams **Title:** Synergistic doping and surface coating of NMC 9.5.5 for structural and electrochemical stabilisation
12:25	**Presenter:** Carl Reynolds **Title:** Metrology for the Electrode Coating Process

Parallel session 2.3: Recent advances in thermo-mechanical energy storage science & technology (focusing on thermal energy storage) **Chairs:** Christos Markides & Wenjin Ding	
11:00-11:40	**Keynote speaker:** Desideri Umberto **Title:** Challenges and perspectives of heat storage
11:40	**Presenter:** Klarissa Niedermeier **Title:** High temperature heat storage with liquid metals as heat transfer fluids – status and challenges
11:55	**Presenter:** Yang Tian **Title:** Bionic triply periodic minimal surfaces metal foam phase change material for fast latent heat storage
12:10	**Presenter:** Oguzhan Kazaz **Title:** Enhanced Thermal Energy Storage Capacity of Solar Systems Using Nano-encapsulated Nano Size of n-Octadecane Phase Change Material as an Inorganic Shell
12:25	**Presenter:** Yanping Du **Title:** Enhancement of thermal energy storage with carbon nano tubes (CNTs) additives
12:40	**Presenter:** Julian Steinbrecher **Title:** Status on thermal energy storage with molten nitrate salt up to 620 °C

Parallel session 2.4: Recent advances in thermo-mechanical energy storage science & technology **Chairs:** Seamus Garvey & Haisheng Chen	
11:00-11:40	**Keynote speaker:** Toru Okazaki **Title:** Electric Thermal Energy Storage (ETES) for Economic De-carbonized Society

11:40	**Presenter:** Danlei Yang **Title:** Dynamic operation principles for the compressed carbon dioxide energy storage system
11:55	**Presenter:** Yan Yang **Title:** Analysis on off-peak power synergy of liquid air energy storage system coupled hydrogen liquefaction process
12:10	**Presenter:** Silas Heim **Title:** Metal-based high-temperature energy storage systems for flexible steam generation in power plants
12:25	**Presenter:** Pengfei Li **Title:** Numerical Research on Off-design Characteristics of Multistage Axial Flow Compressor in Compressed Air Energy Storage System
12:40	**Presenter:** Yaroslav Grosu **Title:** Intrusion-extrusion of non-wetting liquids into-from nanopores for thermomechanical and thermoelectrical energy storage/conversion

Parallel session 2.5: Recent advances in chemical and thermochemical energy storage **Chairs:** Adriano Sciacovelli & Jihong Wang	
11:00-11:40	**Keynote speaker:** Xianglei Liu Title: Thermochemical energy storage under direct solar irradiation
11:40	**Presenter:** Mingxi Ji **Title:** Thermochemical energy storage using a packed bed reactor – experimental study and system level efficiency evaluation
11:55	**Presenter:** Roza Yazdani **Title:** Green sorption materials for thermochemical energy storage
12:10	**Presenter:** Feng Gong **Title:** Composite nitrogen carrier based chemical looping ammonia synthesis for thermochemical hydrogen storage
12:25	**Presenter:** Gabriele Humbert

	Title: Performance maximization of thermochemical energy storage reactors through topology optimization
12:40	**Presenter:** Bahaa Abbas **Title:** Study of $CaCl_2$ charge cycle investigating the interaction between the charging temperature and the flow rate for thermochemical heat battery applications

Session 3: Application Through Integration (13:30-15:30)

Parallel session 3.1: Renewable generation with storage (including wind, solar, wave, tidal, bioenergy, geothermal) **Chairs:** Deborah Greaves & Josh McTigue	
13:30-14:10	**Keynote speaker:** Paul Denholm **Title:** The Role of Storage in the Decarbonized Power Grid
14:10	**Presenter:** Julien Mouli-Castillo **Title:** Mine water geothermal heat storage: building upon a legacy
14:25	**Presenter:** Oguzhan Kazaz **Title:** Nanoencapsulation of Phase Change Materials with Metallic Shell Materials for Solar Thermal Energy Harvesting and Conversion Applications
14:40	**Presenter:** Andrew Lyden **Title:** Decarbonising heat by storing curtailed wind energy in long-term thermal energy storage
14:55	**Presenter:** Enock Ebbah **Title:** Modelling solar-powered diffusion absorption machines to meet building cooling and heating demand
15:10	**Presenter:** Robin Fisher **Title:** Coupling Thermochemical Energy Storage with Power-to-Heat to Increase Domestic PV Utilisation

<u>Parallel session 3.2:</u> Base load generation and network with storage (including nuclear, centralised energy grids, localised networks e.g. districted heating/cooling) **Chairs:** Xiaohong Li & Xiaoze Du	
13:30-14:10	**Keynote speaker:** Rao Martand Singh **Title:** Thermal energy storage in Geothermal Energy Piles incorporated with Phase Change Material
14:10	**Presenter:** Alberto Grimaldi **Title:** Ageing and energy analysis of a utility-scale grid-connected lithium-ion battery energy storage system for power grid applications with a data-driven modelling approach
14:25	**Presenter:** Ivan De la Cruz **Title:** Dimensionless numbers for the characterisation of thermal stratification and their application in 1-D models of hot water tanks
14:40	**Presenter:** Saman Nikkhah **Title:** Increasing the Penetration Level of Renewable Energy Sources Using Battery Energy Storage and Heat Pump
14:55	**Presenter:** David Greenwood **Title:** Capacity value of integrated energy storage-soft open point devices in distribution networks

<u>Parallel session 3.3:</u> Applications of AI to energy storage (including materials discovery, management, control and emulation of storage, reliability, predictive maintenance, digital twinning, as well as AI driven life cycle analysis) **Chairs:** Haris Patsios & Alfonso Capozzoli	
13:30-14:10	**Keynote speaker:** Parisa Akaber **Title:** Digitalisation, a Key Enabler for Smart Decision Making for Distributed Energy Storage Systems: E-fleet Case Study
14:10	**Presenter:** Ze Sun **Title:** Accelerated multivariate high performance molten salt design with

	machine learning methods
14:25	**Presenter:** Ma'd El-Dalahmeh **Title:** A Machine Learning and Empirical Wavelet Transform- based Framework for Online Capacity Estimation of Lithium-ion Batteries under Generalized Operating Conditions
14:40	**Presenter:** Dacheng Li **Title:** Study on the dynamic modelling framework for the solid-gas sorption energy storage system
14:55	**Presenter:** Kavita Joshi **Title:** Solid state hydrogen storage: Decoding the path through machine learning
15:10	**Presenter:** Giovanni Trezza **Title:** A machine learning optimization of MOFs for thermal energy storage applications

Parallel session 3.4: Cold storage and sustainable cooling **Chairs:** Yongliang Li & Wenji Song	
13:30-14:10	**Keynote speaker:** Kai Wang **Title:** Gas Compression Process Enhancement via Self-utilization of Compression Heat
14:10	**Presenter:** Donghao Fan **Title:** Study on thermophysical properties and application in cold storage of the C9-C11 alkane phase change material
14:25	**Presenter:** Tiejun Lu **Title:** Experimentally study on carbon dioxide hydrate formation for a new partial cold storage two-stage carbon dioxide (CO_2) hydrate-based vapor-compression refrigeration system
14:40	**Presenter:** Mingbiao Chen **Title:** Performance of ice source heat pump based on supercooled water method

14:55	**Presenter:** Sambhaji Kadam **Title:** An Adsorption-Compression Cold Thermal Energy Storage System
15:10	**Presenter:** Vincenza Brancato **Title:** Sorption composites for sustainable cooling: a comparison among different salts and host matrices

Parallel session 3.5: Energy storage for transport infrastructure **Chairs:** Andrew Cruden & Roberto Lot	
13:30-14:10	**Keynote speaker:** Chris Cox **Title:** The role of energy storage in supporting the deployment of EV charging infrastructure
14:10	**Presenter:** Peng Xie **Title:** Numerical simulation and optimization of a compact thermal energy storage device for electric vehicles
14:25	**Presenter:** Jinqi Liu **Title:** Planning and Optimal Operation of Battery Replacement Hub Integrating with a Local Energy System
14:40	**Presenter:** Andrei Dascalu **Title:** Experimental Investigations of DC-Linked Hybrid Lead-Acid and Li-Ion Battery Energy Storage Systems
14:55	**Presenter:** Ilias Sarantakos **Title:** Energy storage for port decarbonization
15:10	**Presenter:** Ze Sun **Title:** Thermal Management Simulation of Automotive Supercapacitors

Day-3 (14 October, Friday)

10:15-11:00	**Online platform opens** **Poster session**
11:00 – 13:00	**Session 4: Whole system approach & Policy**

	(Keynote presentation: 30min presentation + 10min Q&A) (Oral presentation: 10min presentation + 5min Q&A)
13:00-13:30	**Lunch Break & Poster session**
13:30-14:30	**Session 5: Closing Plenary**

Session 4: Whole system approach & Policy (11:00 – 13:00)

Parallel session 4.1: Role, value and policy of energy storage

Chairs: Grant Wilson

11:00-11:40	**Keynote speaker:** Steve Griffiths **Title:** The Role and Value of Energy Storage in a Net Zero World
11:40	**Presenter:** Xinfang Wang **Title:** Assessing the innovation process for energy storage
11:55	**Presenter:** Bruno Cardenas **Title:** Renewables + storage vs. nuclear power: An analysis of the UK's electricity grid
12:10	**Presenter:** Timur Saifutdinov **Title:** Role and value of energy storage in future market-driven distribution systems
12:25	**Presenter:** Joseph Day **Title:** Estimate of the cost of overnight storage in natural gas linepack in the Great Britain
12:40	**Presenter:** Christopher Harrison **Title:** Assessing impacts of energy storage policy on deployment in the UK

Parallel session 4.2: Techno-economics and sustainability of energy storage

Chairs: Jacquetta Lee & Wei Wu

11:00-11:30	**Keynote speaker:** Manuel Baumann **Title:** Life cycle oriented sustainability assessment of energy storage

	technologies - use cases from a lab to market level
11:30-12:00	**Keynote speaker:** Yingru Zhao **Title:** Integrated Energy Systems Incorporating Storage: R&D in China
12:00	**Presenter:** Diarmid Roberts **Title:** Assessing the economic viability of iron based flow batteries as long duration energy storage
12:15	**Presenter:** Amruta Joshi **Title:** Exploring energy storage supply chains for energy security and sustainability
12:30	**Presenter:** Paula Mendoza-Moreno **Title:** Impact of controlled ortho- to para-hydrogen conversion on liquid hydrogen production for energy storage
12:45	**Presenter:** Daniel Murrant & Corentin Jankowiak **Title:** Offshore wind integration – storage and flexibility modelling

Parallel session 4.3: Medium & long duration energy storage **Chairs:** Asegun Henry & Chunping Xie	
11:00-11:40	**Keynote speaker:** Jeremy Twitchell **Title:** TBC
11:40	**Presenter:** Wenwen Du **Title:** Study on the simulation of storage tank for long-term storage of liquid air
11:55	**Presenter:** Aitonglu Zhang **Title:** A mini review on building phase-change thermal storage wall
12:10	**Presenter:** Audrius Bagdanavicius **Title:** The value of heat in thermomechanical energy storage
12:25	**Presenter:** Abu Kasim **Title:** Hydrogen production via thermochemical water splitting, utilising industrial waste streams

12:40	**Presenter:** Andrea Vecchi **Title:** Thermo-mechanical energy storage options for long-duration storage: present and future techno-economic competitiveness
12:55	**Presenter:** Diarmid Roberts **Title:** An analysis of the optimal long duration storage deployment in a net-zero UK electrical grid

Session 5: Closing Plenary 13:30-14:30

13:30-14:15	**Plenary 5.1: Royal Society large scale energy storage study** **Speaker:** Chris Llewellyn Smith
14:15-14:30	**Closing remarks & Announcement for next WESC:** Yulong Ding & Josh McTigue

Biography

Chairing Committee

Prof Paul Shearing

I am a Professor in Chemical Engineering at University College London where I hold The Royal Academy of Engineering Chair in Emerging Battery Technologies. My research interests cover a broad range of electrochemical engineering themes with a particular interest in the relationship between performance and microstructure for energy materials.

I co-direct UCL's Electrochemical Innovation lab and lead the UK STFC Global Challenge Network in Batteries and Electrochemical Devices. I was a founding investigator of the UK's Faraday Institution, where I chair the Training & Diversity Panel and am PI of the LiSTAR programme investigating Li-Sulfur battery technologies, and the SAFEBATT programme exploring the Science of Battery Safety. I am involved in the foundation of The Advanced Propulsion Lab at UCL East.

In 2006, I graduated with the top first in Chemical Engineering at Birmingham University and in the same year was awarded the university's Sir John Cadman Prize and the Salter's Institute Graduate Prize. From 2006-09 I completed a PhD in Dept. Earth Science and Engineering, Imperial College under the supervision of Prof Nigel Brandon. My thesis "Characterisation of Solid Oxide Fuel Cells in Three-Dimensions" was awarded the Imperial College, Janet Watson Memorial Prize for Research Excellence.

After a short post-doctoral appointment at Imperial, I joined Dept. Chemical Engineering at UCL as a lecturer in July 2011 – shortly after I won a RAEng Research Fellowship from 2012-16. I was promoted to senior lecturer in 2014, Reader in 2016, and in 2018 was appointed Professor of Chemical Engineering, and Royal Academy of Engineering Chair in Emergin Battery Technology. which I will hold until 2016. As a co-director of the Electrochemical Innovation Lab, my research portfolio is supported by national and international research councils, as well as through extensive interaction with industry. In 2014 I was named the Institute of Chemical Engineers, Young Chemical Engineer of the Year in Academia and in 2016 the RAEng Engineers Trust Young Engineer of the Year.

Prof Clare Grey

Clare P. Grey, FRS is the Geoffrey Moorhouse-Gibson Professor of Chemistry at Cambridge University and a Fellow of Pembroke College Cambridge. She holds a Royal Society Professorship. She received a BA and D. Phil. (1991) in Chemistry from Oxford University. After post-doctoral fellowships in the Netherlands and at DuPont CR&D in Wilmington, DE, she joined the faculty at Stony Brook University (SBU) as an Assistant (1994), Associate (1997) and then Full Professor (2001-2015). She moved to Cambridge in 2009, maintaining an adjunct position at SBU. She was the founding director of the Northeastern Chemical Energy Storage Center, a Department of Energy, Energy Frontier Research Center (2009-2010) and then Associate director (2011-2014). She is currently director of the EPSRC Centre for Advanced Materials for Integrated Energy Systems (CAM-IES) and a member of the Expert Panel of the Faraday Institution. Recent honours and awards include the Richard R. Ernst Prize in Magnetic Resonance (2020), the RS Hughes Award (2020) and the Körber European Science Prize 2021. Her current research interests include the use of solid-state NMR and diffraction-based methods to determine structure-function relationships in materials for energy storage (batteries and supercapacitors), conversion (fuel cells) and carbon capture. She is a co-founder of the company Nyobolt, which seeks to develop batteries for fast-charge applications.

Prof Sara Walker

Prof. Walker spent eight years at De Montfort University, where her research and teaching focussed on renewable energy and energy efficiency technologies, and where she also completed a PhD part time. This PhD investigated the impact of electricity sector deregulation on renewable energy market share. During that period with De Montfort University, Prof. Walker worked on a number of research projects around renewable energy and energy efficiency, primarily funded by the European Commission.

Prof. Walker then moved out of academia and into industry, with a five-year period in energy related consultancies. This consultancy work for Econnect and IT Power included contribution to the influential report "Potential for micro-generation: study and analysis" published by Energy Saving Trust for the DTI. Prof. Walker also worked on high profile projects for commercial clients, such as London Array.

In 2007, Prof. Walker joined Northumbria University and continued her research on renewable energy and energy efficiency. She also developed new programmes, including the MEng Building Services Engineering, and successfully ran programmes, managed staff and developed research and business outreach. Her first role was as Subject Director for the Building Services team. Following a restructure, she took on the role of Director of Research and Engagement for the Department of Architecture, Construction and Engineering. Later she was promoted to a Faculty role, as Director of Business and Engagement for the Faculty of Engineering and Computing.

In September 2015 Prof. Walker joined Newcastle University in the School of Mechanical and Systems Engineering. She was Degree Programme Director for the MSc Renewable Energy Flexible Training Programme (REFLEX) and MSc Renewable Energy and Enterprise Management (REEM) until 2017. In 2017 she became Director of Expertise for Infrastructure research and member of the School of Engineering Executive Board.

In September 2019 Prof. Walker became Director of the Newcastle University Centre of Research Excellence for Energy, known as The Centre for Energy. In 2021 she was promoted to Professor. Her research continues to focus on renewable energy and energy efficiency in buildings, energy policy, energy resilience, and whole energy systems.

Prof Xianfeng Li

Dr. Xianfeng Li is a Full Professor at Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences (CAS). He currently serves as the Deputy Director and the head of energy storage division at DICP. His research interests focus on electrochemical energy storages (Flow batteries, lithium-ion batteries, sodium ion batteries etc), including key materials (membranes, electrode, bipolar plate, electrolytes), device and system integration. Up to now, he is Co-author of more than 250 peer-reviewed papers with more than 10000 citations and filled more than 150 patents. Currently, he serves as Associate Editor of Chinese Chemical Letters, Advanced Membranes and the editorial board member of Science Bulletin, Sustainable Energy & Fuels (RSC), Journal of Energy Chemistry (Elsevier) and Sustainability.

Prof Christos Markides

Christos Markides is Professor of Clean Energy Technologies and Head of the Clean Energy Processes Laboratory at Imperial College London. He is also, amongst other, Editor-in-Chief of 'Applied Thermal Engineering', a member of the UK National Heat Transfer Committee, on the Editorial Board of the UK National Heat Transfer Committee, and the Scientific Board of the UK Energy Storage SUPERGEN Hub. He specialises in applied thermodynamics, fluid flow and heat/mass transfer processes as applied to high-performance devices, technologies and systems for thermal-energy recovery, utilization, conversion and storage. He has published >300 journal papers and >350 conference papers on these topics. He won IMechE's 'Donald J. Groen' outstanding paper prize in 2016, IChemE's 'Global Award for Best Research Project' in 2018, the Engineers without Borders 'Chill Challenge' in 2020 and received Imperial College President's Awards for Teaching in 2016 and Research Excellence in 2017.

Dr Wenjin Ding

Dr. Wenjin Ding received his Bachelor degree of Biochemical Engineering from Zhejiang University in China, then Diploma and PhD degree of Chemical Engineering from Karlsruhe Institute of Technology (KIT) in Germany. He works within KIT from 2011 to 2016 in the field of synthetic fuels technology. Since 2016 Dr. Ding works in German Aerospace Center (DLR) on development of molten halide salt technologies for energy storage applications. His current research interests are on next-generation molten chloride thermal energy storage (TES), concentrated solar power (CSP), Carnot batteries and molten salt batteries using molten halide salt electrolytes. As the project manager and PI researcher of DLR, he has managed a number of R&D projects funded by the EU or the German federal government, such as the EU Horizon 2020 project and the NSFC-DFG Sino-German cooperative research project. He is awarded the International Award for Outstanding Young Chemical Engineer in 2021, DAAD-DLR Postdoc Scholarship in 2016, Chinese National Outstanding Self-financed International Student Award in 2015, etc. In the part-time, Dr. Ding is currently the chairman of the Society of Chinese Scholars of Chemistry and Chemical Engineering in Germany (GCCCD, e.V.), guest editor of the SCI journal "Energies", etc.

Prof Seamus Garvey

Graduated in 1984 from University College Dublin with a 1st Class Hons Degree in Mech. Eng. Worked for GEC Large Electrical Machines Ltd., Rugby from 1984-1990. Then joined Aston University as a lecturer in Mechanical Engineering. By 1998, I was promoted to Reader in Mechanical Engineering. I left Aston University to join Nottingham University in 2000 as Professor of Dynamics. I am a member of the Gas Turbine and Transmissions Research Centre (G2TRC) research group.

Prof Haisheng Chen

Professor Haisheng CHEN, BEng, PhD, born in 1977, is currently the deputy Director of Institute of Engineering Thermophysics (IET), Chinese Academy of Sciences (CAS). He received his bachelor from University of Xi'an Jiaotong University in 1997 and Ph.D from IET-CAS in 2002. He joined IET-CAS in 2009 as a "100-Talents" professor after previous employments at University of Leeds, IET-CAS, Vrije University of Brussels and Beihang University. He is now also the Director of China National Research Centre of Physical Energy Storage and the President of Energy Storage Alliance, China Energy Research Society.

He has been working on design, experiment and numerical simulation of fluid dynamics, heat transfer and chemical systems related to energy storage and power engineering. More specifically, his research includes energy storage material and system, micro/ nano scale flow & heat transfer, fluid dynamics of internal flow of turbomachinery. He has been involved with 50+ research projects with 30+ of which being the principal investigator. His research has led to 300+ peer-reviewed papers, 2 books, 9 book chapters, 150+ patents and 11 provincial level awards. Among the papers, 130+ have been indexed by SCI database and received 5000+ citations according to the Thomson ISI Web of Science Database (SCI). He also acts as the chair/co-chair of 7 international conferences and editorial board member for 8 peer reviewed journals. He is currently the deputy editor-in-chief of 5 peer reviewed Journals including Journal of Thermal Science, Energy Storage, Journal of Energy Storage Science and Technology, Journal of Smart Grid etc.

Dr Adriano Sciacovelli

Adriano Sciacovelli is an Associate Professor in the School of Chemical Engineering and a member of the Birmingham Centre for Energy Storage where he leads his MODES research group. His research is in the field Energy Process Engineering and Process Intensification; he is specialist in in thermal, thermo-mechanical and thermo-chemical processes and systems for storage, generation and upgrade of zero-carbon thermal energy (heat and cold). The ability to undertake combined thermo-fluid computational modelling and heat transfer experimental research is a distinct feature of Dr Sciacovelli's research and of the capabilities in his team. He has been supported by EPSRC, EU, Royal Society, Innovate UK and industry.

Prof Jihong Wang

Professor Wang is Head of Power and Control Systems Research Laboratory, the University of Warwick. Her research interests include power system modelling and control, energy storage (mainly in compressed air energy storage) and grid integration, energy efficient actuators and optimal control methods. She has published over 100 journal papers and gained several best paper awards. She led the EPSRC Grand Challenge Programme in Energy Storage "Integrated Market-fit and Affordable Grid-scale Energy Storage (IMAGES)" (EP/K002228/1). Through the project, an open-source software tool has been developed for compressed air and thermal energy storage (http://estoolbox.org). Her research group has established a Campus Energy System Living Laboratory which uses live data via an IoT platform for study of local energy system optimisation strategies in supporting future low carbon energy system planning and design. She is Co-I for Supergen Energy Storage Hub (EP/L019469/1) and Deputy Director of Supergen Energy Storage Network+ 2019 (EP/S032622/1).

Prof Deborah Greaves

I am Head of the School of Engineering, Computing and Mathematics and Professor of Ocean Engineering at the University of Plymouth. Alongside this, I am also the Director of the COAST Laboratory, Board Member and Inaugural Chair for PRIMaRE, Director of the Supergen ORE Hub, and Non-Executive Director of Wave Hub Plc.

Prior to joining the University, I was a lecturer at the University of Bath in the Department of Architecture and Civil Engineering, and University College London in the Department of Mechanical Engineering. I also held a Royal Society University Research Fellowship for six years and have worked in industry as a Civil Engineer.

I have made contributions to industry and society in engineering and offshore renewable energy through media and outreach activities and being a strong advocate for women in STEM. In 2018 I was awarded an OBE in the Queen's Birthday Honours List for services to marine renewable energy, equalities and higher education, was shortlisted for the 2014 WISE Research Award, and in 2020 was voted as one of the Top 50 Women in Engineering.

My research expertise is in the areas of marine renewable energy, physical and numerical modelling of violent free surface flow and wave-structure interaction, have published over 200 peer-reviewed papers and secured over £20 million in research funding from EPSRC, GWR, EU Interreg, IEE, Horizon 2020, SWRDA and Innovate UK, working with industrial and academic collaborators.

Since its inception in 2017, I have been Director of the £9m the Supergen Offshore Renewable Energy (ORE) Hub. I was appointed to develop the strategy and consortium for the new Supergen ORE Hub that brings together offshore wind with marine energy sectors. I am also leading the Collaborative Computational Project on Wave Structure Interaction (CCP-WSI), and the University of Plymouth's involvement with MARINET2, a project working towards its vision of unlocking the energy potential of our oceans and providing trans-national access to the COAST Laboratory.

I led the multi-partner EU project, Streamlining of Ocean Wave Farm Impacts Assessment (SOWFIA) on wave energy impact assessment. I also recently led EPSRC projects A Zonal CFD Approach for Fully Nonlinear Simulations of Two Vessels in Launch and Recovery

Operations (EP/N008847/1), The Hydrodynamics of Deformable Flexible Fabric Structures (EP/K012177/1) and the five partner project Fundamentals and Reliability of Offshore Structure Hydrodynamics (EP/J012866/1).

Dr Josh McTigue

Josh McTigue is a research engineer in the Thermal Sciences Group at NREL. Currently, his research concentrates on an electricity storage system known as Pumped Thermal Electricity Storage (PTES) or a Carnot Battery. He is also interested in developing techno-economic models of hybrid energy systems which integrate geothermal power, concentrating solar power and thermal energy storage.

For his graduate work, Josh researched PTES and packed-bed thermal storage with an emphasis on exergy analysis and system design and optimization. His expertise lies in heat transfer, thermodynamics, and optimization techniques.

Josh received his PhD and M.Eng in Mechanical Engineering from the University of Cambridge, UK.

Prof Xiaohong Li

Prof Xiaohong Li is Professor and Chair of Energy Storage in Renewable Energy Group at University of Exeter (UoE). Xiaohong holds a BSc in Organic Chemistry, an MSc in Analytical Chemistry, and PhD in Physical Chemistry. She has also worked as the Director of Global Development in Engineering Department at Faculty of Enviroment, Science and Economy in UoE. Her research interests focus on energy conversion and storage, with an emphasis on battery electrode materials, redox flow battery (RFB), anion exchange membrane water electrolysers for hydrogen production, and nanoscale materials for electrocatalysis. She has been involved in eight large research projects (EPSRC, Innovate UK, FP7, H2020), in which she is the principal investigator at UoE side for Horizon 2020 MELODY RFB project, EPSRC zinc-nickel RFB project, and Interreg E2C project. Xiaohong is the author of over 100 peer-reviewed journal papers, including two book chapters and six invited review papers.

Prof Xiaoze Du

Professor Xiaoze Du is the head of School of Energy, Power and Mechanical Engineering, North China Electric Power University, Beijing. His main research interests: solar thermal power generation, energy storage technology and energy storage materials, efficient and flexible thermal power generation, etc. He is undertaking 4 projects of the National Natural Science Foundation of China; his published papers have been cited more than 9000 times with an h-index of 49; he has received 1 National Science and Technology Progress Second Prize and 2 Provincial and Ministerial Science and Technology Awards First Prize. He is also the director and deputy secretary-general of the Chinese Electrical Engineering Society, executive director of the Chinese Renewable Energy Society, director of the Special Committee on Energy Storage, member of the Committee on Heat and Mass Transfer of the Chinese Society of Engineering Thermophysics, and editorial board member of the Journal of Power Engineering.

Dr Haris Patsios

Dr Haris Patsios is a Reader in Smart Energy Systems with significant experience in the design, modelling and control of power systems including renewables. He is a Co-director and WP leader for the Supergen Energy Storage Network, and Work Package Leader for the £5m EPSRC's National Centre for Energy Systems Integration (CESI). He is also a co-investigator in relevant projects such as the £5m EPSRC project 'Multi-scale ANalysis for Facilities for Energy Storage' (EP/N032888/1) linking energy storage facilities across the UK.

Dr Patsios's research focuses on the development of integrated models and control techniques for energy storage as well as decentralized control in future power networks, working closely with UK industry and academia.

Dr Alfonso Capozzoli

Alfonso Capozzoli is a Mechanical Engineer and received his PhD in Engineering of Mechanical Systems from University of Naples Federico II (Italy). Currently he is Associate Professor in building physics and building energy systems at the Department of Energy of Politecnico di Torino where he leads the Building Automation and Energy Data Analytics lab (www.baeda.polito.it). He chairs courses on HVAC systems and building physics, energy management and automation in buildings, and energy transition and low carbon architecture. His research activity focuses on grid-interactive efficient buildings, data analytics-based energy management, and thermal management in data centers. He was general chair of the International Conference on Sustainability in Energy and Buildings (SEB 2016) and chair in various technical sessions in international conferences on building energy performance. He has been member of the Scientific or Organizing Committee of several conferences. He has been involved as investigator in International Research Projects and in various research groups of the International Energy Agency (IEA-EBC) on building energy performance and data-driven smart buildings. He has been responsible of different research contracts with industries in the field of data-driven energy management and of research projects financed by Italian National Energy Agency (ENEA). In 2017 and in 2018 he was appointed as visiting principal fellow at the Sustainable Buildings Research Centre (SBRC) of the University of Wollongong (Australia).

Prof Yongliang Li

Professor Yongliang Li was trained as a thermal engineer first at Beijing University of Aeronautics & Astronautics and the University of Chinese Academy of Sciences in China, and then as a process engineer at the University of Leeds. Following the completion of his PhD in 2011, Professor Li took a postdoctoral position at the same institution until the end of 2013 when he was appointed as a lecturer in the School of Chemical Engineering at the University of Birmingham.

Professor Li has been working on thermal energy processes and systems since 2007 with extensive research experience in cryogenic fluids, flow and heat transfer, carbon capture, process intensification and integration, systematic analysis and optimisation. He has published over 30 peer-reviewed journals and book chapters as well as 2 patents. He has won several prestigious awards including the Dorothy Hodgkin Postgraduate Award (EPSRC/Highview, 2007), China National Award for a Self-Financed Chinese Scholar (China Scholarship Council, 2011), and Collaborative Development Award (British Council, 2014). His current research interests cover a wide range including thermal energy (heat and cold) storage, refrigeration and air conditioning, carbon capture and storage, process and system simulation and optimization. He receives funding from the EPSRC and British Council in these fields as well as from major industrial companies including Air Products, SGRI and CSR. He has received over £2.5M in funding over since he joined Birmingham in 2014.

Prof Wenji Song

Prof. Wenji Song received his PhD degree from University of Chinese Academy Sciences (UCAS, 2009, China). After that, SONG has been working in Guangzhou Institute of Energy Conversion (GIEC) as Senior Research Assistant (2009), Associate Professor (2012) and Professor (2017)., SONG was a senior visiting scholar to University of Birmingham (UK) during 2016 and awarded Newton Fellow funded by NSFC& Royal Society UK from 2016 to 2018.

His current research interests focus into large-scale cold energy storage technologies, distributed energy system and optimization strategy, lithium-ion battery energy & thermal management, etc. In these areas, SONG took charge in more than 10 funded R&D projects. Over 60 papers in refereed journals and conference proceedings were published, and over 30 Chinese patents were patented. He serves as a reviewer of international journals such as Energy, AE, JPS, IJER, energies, etc. He was invited to serve as organizing committee members and session chairs for several international conferences.

SONG is a professional member of National Technical Committee for Standardization of China (Committee for SAC/TC575), and member of Youth Innovation Promotion Association, Chinese Academy of Sciences (YIPA, CAS).

Prof Andrew Cruden

Andrew Cruden received the B.Eng., M.Sc., and Ph.D. degrees in electronic and electrical engineering from the University of Strathclyde, Glasgow, U.K., in 1989, 1990, and 1998, respectively. He is currently the Associate Dean (Infrastructure) of the Faculty of Engineering and Physical Sciences (FEPS) and a Professor of energy technology with the University of Southampton, U.K. He has significant experience in the field of energy storage and electric vehicles, covering vehicle-to-grid (V2G), new battery technologies, such as aluminium-ion cells, and flow cells, such as soluble lead flow battery. He has previously worked in fuel cell technology and condition monitoring of wind turbines. He is a member of the Training and Diversity Panel of the U.K.'s Faraday Institution and the Co-Director of the EPSRC Centre for Doctoral Training (CDT) in energy storage and its applications.

Dr Roberto Lot

Dr Roberto Lot is associate Professor of Mechanics of Machines at Università degli. He has over twenty years of experience in dynamics and control of road and race vehicles, and still the intellectual curiosity and enthusiasm of early days. His research contributes to make our vehicles safer, faster, and eco-friendlier. He has directed several National and International research projects and published more than hundred scientific papers and several patents. He has been teaching and implementing a wide range of topics in Automotive Engineering and Mechanics of Machines.

Dr Grant Wilson

Grant Wilson is a Lecturer in Chemical Engineering with research interests in multi-vector, multi-scale data analytics, and a particular focus on the comparison of energy vectors over similar timeframes. Grant has published 14 research papers in scientific journals as well several online pieces in The Conversation. He is focussed on the decarbonisation of heat as a significant challenge for the UK's energy systems underpinning a net-zero society. Digging deeper into the challenges of the decarbonisation of heat – it is the flexibility of energy systems to deliver energy in space and time that defines the greatest challenges. How do we provide energy system flexibility in a low-carbon manner? How do we do this over different timescales? The Birmingham Centre for Energy Storage is researching answers to these critical questions, and the Energy Informatics Group continues to focus on bringing wider attention to this looming problem. He is also interested in innovations in teaching and learning, and passionate about the benefits of using empirical energy data in teaching and wider outreach on the challenges of the energy transition.

Dr Jacquetta Lee

Dr Lee has a MEng in Mechanical Engineering and Materials and holds a PhD in Environmental Systems Analysis from Cranfield University. Prior to joining the Centre for Environment and Sustainability at the University of Surrey, she worked for Rolls-Royce plc in their Environmental Strategy Department, specialising in Life Cycle Assessment and Design for Environment.

On joining academia in 2003, she spent two years as a Leverhulme Special Research Fellow, investigating the potential for television to influence environmental behaviour of consumers. Dr Lee has a holistic approach to sustainability systems analysis, incorporating environmental and social aspects from both academic and industrial perspectives. She has over 25 years of experience across a diverse range of industrial sectors including aerospace, electronics, construction, agriculture, fast moving consumer goods market, automotive, nanotechnology, architecture, and nuclear energy.

As Director of the Practitioner Doctorate in Sustainability Programme and Reader in Sustainable Systems Analysis at the at the University of Surrey, Dr Lee is responsible for engaging major industry leaders and high calibre postgraduate researchers to work collaboratively on specific research briefs designed to resolve current sustainability issues within industry. This innovative programme offers an unparalleled opportunity, uniting academia and industry to develop solutions that will have enduring value for individual organisations, industry and governance.

Dr Wei Wu

Wei Wu is an Assistant Professor of Energy Economics at Xiamen University. He received his PhD from the School of Economics, Xiamen University. His research interest covers broad areas of Energy Policy, Energy Economics, Energy Storage Commercialization, Energy Transformation and General Equilibrium Model. He has published 16 articles in peer-reviewed journals, including Energy Economics, Energy Policy, Energy, Social Science in China (Chinese) etc. He has served as a member of the 14th Five-Year Energy Technology Forecast Expert Group of the Ministry of Science and Technology and has repeatedly reported research results to the National Energy Administration, the China Electricity Council and the Coal Industry Association. His researches have also won many awards such as the first prize of Fujian Social Science Outstanding Achievement Award.

Dr Asegun Henry

Dr. Asegun Henry started as an Associate Professor in the Department of Mechanical Engineering at MIT in 2018, where he directs the Atomistic Simulation & Energy (ASE) Research Group. Prior to MIT, he was an Assistant professor in the Woodruff school of Mechanical Engineering at Georgia Tech from 2012 to 2018. He holds a B.S. degree in Mechanical Engineering from Florida A & M University as well as a M.S. and Ph.D. in Mechanical Engineering from MIT. Professor Henry's primary research is in heat transfer, with an emphasis on understanding the science of energy transport, storage and conversion at the atomic level, along with the development of new industrial scale energy technologies to mitigate climate change. After finishing his Ph.D. he worked as a postdoc in the Materials Theory group at Oak Ridge National Laboratory (ORNL) and then as postdoc in the Materials Science Department at Northwestern University. After Northwestern, he worked as a fellow in the Advanced Research Projects Agency – Energy (ARPA-E), where he focused on identifying new program areas, such as higher efficiency and lower cost energy capture, conversion and storage.

Prof Henry has made significant advances and contributions to several fields within energy and heat transfer, namely: solar fuels and thermochemistry, phonon transport in disordered materials, phonon transport at interfaces, and he has developed the highest temperature pump on record, which used an all-ceramic mechanical pump, to pump liquid metal above 1400°C. This technological breakthrough, which is now in the Guinness Book of World Records, has opened the door for new high temperature energy systems concepts, such as methane cracking for CO2 free hydrogen production and a new grid level energy storage approach affectionately known as "Sun in a Box", that is slated to be cheaper than pumped hydro.

Prof Henry has also been the recipient of a number of awards including: the National Science Foundation Career Award, the Lockheed Inspirational Young Faculty Award, the Georgia Power Professor of Excellence Award, the ASME Bergles-Rohsenow Young Investigator Award in Heat Transfer and he was the winner of the 2018 World Technology Award for Energy. He has also been awarded a number of fellowships including an MIT Lemelson Presidential Fellowship, a Department of Energy Computational Science Graduate Fellowship, a UNCF-Merck Postdoctoral Fellowship and a Ford Foundation postdoctoral Fellowship.

Dr Chunping Xie

Chunping Xie is a Policy Fellow at the Grantham Research Institute at the London School of Economics and Political Science (LSE). In her current role, she leads a programme to inform decision-making about China's policies on climate change, energy, economics and development, working with Professor Lord Nicholas Stern. She has published more than 30 academic papers in a range of high-impact multidisciplinary journals in the field of energy/environmental economics and climate change. She has also published a series of policy briefs, and she gives expert opinion and writes commentary articles to various media outlets including China Daily, Reuters, and Carbon Brief. She is currently an Editorial Board Member of the Elsevier journal Energy Storage and Saving (ENSS), and a recognised outstanding reviewer for various journals. Prior to that, she worked at the Birmingham Centre for Energy Storage (BCES), University of Birmingham, focusing on developing techno-economic models for the integration of energy storage technology into energy systems.

Biography

Keynote Session

Prof Nigel Brandon

Presentation title: Longer term energy storage – opportunities and progress

Professor Nigel Brandon OBE FREng FRS is an electrochemical engineer whose research is focused on electrochemical devices for low carbon energy applications, with a particular focus on fuel cells, electrolysers, and flow batteries. He is Director of the UK Hydrogen and Fuel Cells SUPERGEN Hub (www.h2fcsupergen.com), and Chair of Imperials Sustainable Gas Institute (www.imperial.ac.uk/sustainable-gas-institute). He is a founder of Ceres Power (www.cerespower.com), spun out from Imperial College in 2000, and a founder and Director of RFC Power (www.rfcpower.com), a flow battery company spun out from Imperial College in 2018. He was awarded the Royal Academy Silver Medal in 2007, the ASME Francis Bacon Medal in 2014, and elected an International member of the US Academy of Engineering in 2022.

Prof André D. Thess

Presentation title: Recent advances in Carnot batteries – science & technology

André Thess (born 22. Februar 1964) is the Director of the Institute of Engineering Thermodynamics at the German Aerospace Center (DLR) and Professor of Mechanical Engineering at the University of Stuttgart. His research fields are high-temperature technologies, thermochemical energy storage, and electrochemical energy storage. His particular interests are simulation of energystorage systems from the microscaleto the macroscale, the development of Carnot-Batteriesand electric flight. Professor Thess's book "The Entropy Principle –Thermodynamics for the Unsatisfied" has contributed to the improvement of teaching methods in undergraduate Engineering Thermodynamics.

Professor Thess is currently teaching “Thermodynamics of Energy Storage Systems” (in the winter term) and “Culinary Thermodynamics” (in the summer term). Culinary Thermodynamics is the first course at a German University that gives an evidence-based scientific proof of the superiority of home-made food over convenience food.André Thess received his PhD (summa cum laude) in Theoretical Physics from DresdenUniversity of Technology in 1991. From 1991 to 1993 he carried out post-doctoral research at Ecole Normale Superieure de Lyon(France), atInstitut de Mécanique de Grenoble(France)and was a post-doctoral fellow of the German Science Foundation (DFG) at Princeton University (USA). At the age of 34 years he was appointed as a Professor of Engineering Thermdynamics in 1998 at Ilmenau University of Technology. André Thess was visiting Professor at the University of Nagoya (Japan), at Stanford University (USA) and at Northeastern University Shenyang (China) and was awarded the Research Prize of the State of Thuringia in 2007. Professor Thess is a member of Verein Deutscher Ingenieure (VDI), of the German Aerospace Society (DGLR), of the German Physics Society (DPG) andlifetime member of the American Physical Society (APS). He served as a member of the bureau of the International Union of Theoretical and Applied Mechanics (IUTAM) and as a board memberof the GAMM. He has been member of the scientific board (Fachkollegium) of the German Science FoundationDFG from 2008 to 2016 and has served as a Chairman of the Research Training Group “Lorentz Force Velocimetry and Lorentz Force Eddy Current Testing” at Ilmenau Unviersity of Technology from 2010 to 2013.

Dr. Claire Villevieille

Presentation title: Multiscale investigation of solid state batteries using advanced operando techniques

Claire Villevieille is currently CNRS research director (i.e. Full Prof) at the LEPMI laboratory in Grenoble, France. Her research is dedicated to the investigation of complex reaction mechanisms of battery systems such as Li-ion batteries and post Li-ion batteries by means of various operando techniques. Her research involves both, in-house devices as well as large facilities in France ERSF (Grenoble) and ILL (Grenoble). Her primary interests include solid state synthesis, electrochemical properties, and bulk–surface relationship of the various electrode/electrolyte materials.

Prof Qing Wang

Presentation title: From Electrochemistry to Electrified Chemistry: Electrochemical Energy Storage and Conversion beyond the Electrode-electrolyte Interface

Dr. Qing Wang is a Dean’s Chair Associate Professor at the Department of Materials Science and Engineering, National University of Singapore. He obtained his PhD in Physics at Institute of Physics, Chinese Academy of Sciences in 2002. Before he moved to Singapore, he had worked in École Polytechnique Fédérale de Lausanne (EPFL), Switzerland, and National Renewable Energy Laboratory (NREL), USA, on mesoscopic photoelectrochemical cells. His research interest is “Charge Transport in Mesoscopic Energy Conversion and Storage Systems”. Currently his group is extensively working on a new research platform — redox-mediated energy storage and conversion, with the implementation of the redox-targeting concept to a wide variety of battery chemistries and energy materials for advanced energy related applications.

Prof Umberto Desideri

Presentation title: Challenges and perspectives of heat storage

Umberto Desideri is Professor in the Department of Engineering for Energy, Systems, Territory and Construction of the University of Pisa, Italy. He was formerly professor at the Department of Engineering of the University of Perugia. He received a PhD in Energy Engineering at the University of Florence. He sits on the editorial boards of a number of energy journals and is active in research in the field of renewable energy systems, advanced power plants, hydrogen and fuel cells, carbon capture and storage and innovation in energy systems. He is a fellow of the ASME. He has founded two spin-off companies.

Dr Toru Okazaki

Presentation title: Electric Thermal Energy Storage (ETES) for Economic De-carbonized Society

Dr. Toru Okazaki was born in Osaka, Japan in 1961. He graduated Kyoto University and joined Sumitomo Electric Industries in 1987. He engaged with the development of superconducting magnets. He got his Ph.D. from the University of Birmingham in 1995. He changed his research theme to renewable energy in 2009. He began to advocate the wind heat power. He was temporary transferred to International Superconducting Technology Center in 2012 as an international relation division director. He also moved to The Institute of Applied Energy (IAE) in 2016. He generalized the idea of wind heat power to an electric thermal energy storage in IAE.

Prof Xianglei Liu

Presentation title: Thermochemical energy storage under direct solar irradiation

Xianglei Liu is a full professor and associate dean of School of Energy and Power Engineering in Nanjing University of Aeronautics and Astronautics. Prof. Liu obtained Ph.D. degree from Georgia Institute of Technology in 2016. Prof. Liu mainly focuses on the researches of micro/nanoscale heat transfer, solar fuel production, and thermal energy storage. He has authored and coauthored 3 book chapters, more than 110 peer reviewed journal papers, and 40 conference papers/presentations. He received Elsevier/JASRT Raymond Viskanta Awards and the Sigma Xi Best Ph.D. Thesis Award.

Dr Paul Denholm

Presentation title: The Role of Storage in the Decarbonized Power Grid

Paul Denholm is a Principal Energy Analyst at the National Renewable Energy Laboratory. His research focuses on examining the technical and economic impacts of large-scale deployment of renewable electricity generation, and the role of energy storage. He holds a Ph.D. in energy analysis from the University of Wisconsin-Madison.

Prof Rao Martand Singh

Presentation title: Thermal energy storage in Geothermal Energy Piles incorporated with Phase Change Material

Rao Martand Singh is a Professor of Geotechnical Engineering at the Department of Civil and Environmental Engineering, NTNU, Norway. He is mainly carrying out his research in the field of Energy and Environmental Geotechnics doing physical and numerical modelling of heat, moisture and gas transport in porous media. Currently, he is leading a project related to

Geothermal Driven Energy Pile investigating potential of Energy Piles for heating buildings in Norwegian conditions. He has received funding from EPSRC, UK; NFR, Norway and EU in the field of Geothermal Energy for Heating/Cooling. He is leading working groups in two EU Cost Action projects viz. Geothermal DHC and FOLIAGE. Previously he worked in various academic roles at the University of Surrey, UK, Monash University, Australia and Cardiff University, UK. Prof Singh has got 15 years of international experience in the area of geothermal energy pile foundations, energy tunnels, energy walls, soil-structure interaction, and thermo-hydro-mechanical (THM) behaviour of unsaturated clays and geosynthetics. His research has been awarded in the form of best paper awards in 2013, 2016 and 2017 from prestigious international journals including ICE.

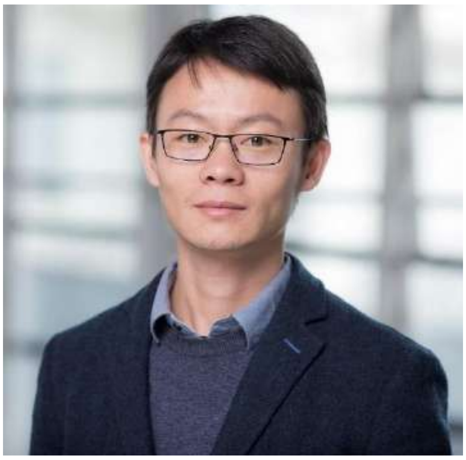
Parisa Akaber

Presentation title: Digitalisation, a Key Enabler for Smart Decision Making for Distributed Energy Storage Systems: E-fleet Case Study

I am an Operational Technology (OT) Cybersecurity Specialist within the Siemens Smart Infrastructure business. I have 7 years of international research and technical experience in Energy Automation domain specifically Smart EV Charging Scheduling Applications, Smart Grid Operational Resilience, and Cascading Failure Modelling and Simulation in Smart Power Systems. In my current role, I am leading the implementation/integration of processes that are designed to make sure that our products, solutions, and services are following highest cybersecurity standards. In addition, I have been recently selected as one of the 12 members of the "Siemens Smart Infrastructure Challenger Committee" which has been introduced with the aim of supporting the Siemens leadership team by bringing new perspectives and innovative ideas to the Siemens GB&I business and challenge the status quo!

I have received my MSc in Information Systems Security from Concordia University, Montreal, Canada in 2017 and currently while working full-time at Siemens, I am pursuing my PhD at Newcastle University in Power Systems on the topic of “A Data informed Customer-Oriented E-fleet Smart Charging and Load Management Platform.

Prof Kai Wang



Presentation title: Gas Compression Process Enhancement via Self-utilization of Compression Heat

Dr. Kai Wang is a research professor at Zhejiang University. He received his B.Eng. degree in Energy and Environment Systems Engineering and Ph.D. degree in Power Engineering and Engineering Thermophysics from Zhejiang University in 2009 and 2014, respectively. After his PhD, he worked as a postdoctoral researcher in the Energy Research Institute at Nanyang Technological University from 2014 to 2017 and then in the Clean Energy Processes (CEP) Laboratory at Imperial College London before he returned to Zhejiang University as a faculty member in 2019. His research interests focus on high-performance energy technologies, components and systems for liquid-hydrogen production, storage and refuelling, heat-to-power conversion, co-/trigeneration systems and solar thermal technologies. He is the recipient of the Sadi Carnot Award from the International Institute of Refrigeration (IIR), one of the IIR Scientific Awards for young researchers working on thermodynamics. To date (September 2022), he has published 1 book, 2 book chapters, more than 60 peer-reviewed journal papers, more than 20 conference presentations/papers and owns more than 10 patents.

Chris Cox

Presentation title: The role of energy storage in supporting the deployment of EV charging infrastructure

Chris Cox, Head of Energy Systems & Infrastructure, Cenex (Centre of Excellence for Low Carbon & Fuel Cell Technologies). Chris joined Cenex in early 2018 leading Cenex' activities relating to energy and infrastructure for transport. This includes innovative R&D projects in areas such as vehicle-to-grid, wireless charging and microgrids as well as strategic and technical consultancy. He is a Chartered Engineer and member of the Institution of Mechanical

Engineers (IMechE) with over a decade's experience in the energy and utilities industry. Chris has had a varied career, also working in areas such as tidal/wave generation, virtual power plants, energy storage and smart homes; and he is passionate about reducing emissions relating to energy and transport.

Dr Steven Griffiths

Presentation title: The Role and Value of Energy Storage in a Net Zero World

Dr. Steven Griffiths is Senior Vice President for Research and Development and Professor of Practice at the Khalifa University of Science and Technology. At Khalifa University, his responsibilities include development and implementation of the university's research strategy, management of the university's research institutes and centers and management of the departments that are accountable for research partnerships, research services, technology management and innovation, research computing and research laboratories.

In addition to his executive management role at Khalifa University, Dr. Griffiths is a member of the Emirates Research and Development Council, advisor to the UAE Research Program for Rain Enhancement Science, a Zayed Sustainability Prize Selection Committee member, a member of the Dubai Future Council on Energy, a member of the Artificial Intelligence (AI) Expert Group Subcommittee of the UAE Council for AI & Blockchain, an elected member of the Global Energy Prize International Award Committee, a Governing Board member of the Graphene Engineering Innovation Center at the University of Manchester, a board member of the Microsoft Energy Core and a Board member of Human CorpMission established by the Rosatom Corporate Academy and the Higher School of Economics National Research University. He advised the government of Alberta, Canada on provincial innovation system structuring throughout 2014 and continues to support the global advancement of research and innovation via evaluator and mentor roles in regional and international research and innovation competitions and programs.

Dr. Griffiths is Associate Editor and Editorial Board member of Elsevier's international journal

Energy Strategy Reviews and Editorial Board member of Elsevier's international journal Smart Energy. He further is a non-resident Fellow of the Payne Institute for Public Policy at the Colorado School of Mines, which is a leading Institute focused on energy, natural resource and environmental policy. Dr. Griffiths' international research engagements further include an appointment as research affiliate at the Laboratory for Atmospheric and Space Physics at the University of Colorado-Boulder.

Prior to his position at KU, Dr. Griffiths was Vice President for Research and Associate Provost at the Masdar Institute of Science and Technology. Dr. Griffiths transitioned to the Masdar Institute from his role as Executive Director of the Technology and Development Program at the Massachusetts Institute of Technology (MIT), which is a position he undertook while simultaneously serving as the Founding Executive Vice President and Chief Technologist of Light Pharma Incorporated.

Dr. Griffiths holds a PhD in Chemical Engineering from MIT and an MBA from the MIT Sloan School of Management.

Dr Manuel Baumann

Presentation title: Life cycle oriented sustainability assessment of energy storage technologies - use cases from a lab to market level

Dr. Manuel Baumann is a researcher at the Institute for Technology Assessment and Systems Analysis of the Karlsruhe Institute and lecturer for energy systems at Aalen University. He has a Bachelor degree in energy economics and a master in energy and environmental management. His PhD topic was about the sustainability assessment of energy storage technologies. He is coordinator of the sub-program 6 "Energy storage: Techno-economics and sustainability" of the Joint Program Energy Storage of the European Energy Research Alliance (EERA), affiliate of Post Lithium Storage Cluster of Excellence (Polis), part of the EU-Project Storage Research Infrastructure Eco-System (StoRIES) and other European and national projects. His research interests are technology assessment, decision-making methods, techno-economics, and life cycle assessment of energy storage technologies.

Prof Yingru Zhao

Presentation title: Integrated Energy Systems Incorporating Storage: R&D in China

Dr. Yingru Zhao is Professor in Energy Efficiency Engineering at College of Energy, Xiamen University. She holds a PhD in Theoretical Physics and a Bachelor's degree in Physics both from Xiamen University. Between 2008 and 2011 she worked as a Research Associate at Imperial College London. She has a comprehensive experience in integrated modelling, simulation and optimization of complex energy systems, with particular focus on integrated energy systems, micro-grid and poly-generation, with links to economic and environmental sustainability analyses, etc.

Prof. Zhao was nominated in the Program for New Century Excellent Talents in University by China Ministry of Education in 2011. She is also winner of Fujian Province Outstanding Youth Fund. She serves as Associate Editor for Renewable and Sustainable Energy Transition (Elsevier Journal), Assistant Editor for Applied Energy (Elsevier Journal), Editor for Smart Energy (Elsevier Journal), Editor for Scientific Reports (Nature Journal), Editor for Progress in Energy (IOP Journal), Review Editor for Frontiers in Chemical Engineering, Guest Editor for Frontiers in Energy Research, Guest Editor for Energies (MDPI Journal), and Editor-in-Chief of the Special Issue of an Chinese journal Global Energy Interconnection. She is the Vice Chairman of Fujian Society for Electrical Engineering. She is a Lindau alumnus who has received the award for participation in the 58th Meeting of Nobel Laureates (Physics) in Germany.

Prof. Zhao has authored/co-authored over 100 peer-reviewed journal papers and 7 books on model-based methods & applications, organized and chaired a number of international and national conferences. Her current research focus is on how to introduce the mutli-scale modeling and mathematical/systems engineering techniques to analyze and optimize energy networks and complex, spatially- and temporally-explicit energy systems.

Jeremy Twitchell

Jeremy Twitchell is an energy research analyst at the Pacific Northwest National Laboratory, where he leads the equitable regulatory environment area of the PNNL Energy Storage Program and assists in distribution system planning research. In those roles, he is responsible for reaching out to states to provide technical assistance in analyzing energy storage and other developing energy resources and incorporating them into utility planning and procurement activities.

Abstract

Parallel Session

New Ni based layered/disordered rocksalt cathode materials for lithium ion batteries

Bo Dong[1,2], Javier Castells-Gil[1,2], Jaime-Marie Price[1,2], Laura Driscoll[1,2], Phoebe Allan[1], Emma Kendrick[2], Peter Slater[1]
[1]School of Chemistry, University of Birmingham, Birmingham B15 2TT, U.K.
[2]School of Metallurgy and Materials, University of Birmingham, Birmingham, B15 2TT, U.K.
Keywords: High Ni cathode; Lithium ion batteries; Oxyfluoride;

To meet the demand in the growing electrical energy storage, such as electric vehicles and grid storage applications, novel cathode materials with large storage capacity and high energy density are required. Over the past decade, cation disordered rocksalt materials have attracted much attention as they can delivery capacities higher than 250 $mAhg^{-1}$ based on both cationic and anionic redox. Ni-Rich cathode materials are attracting a great deal of attention as cathodes for the next generation of Li-ion batteries.[1-3] This provides a useful platform for decreasing the use of Co in the common cathode materials, like NMC cathodes, thus reducing drastically the production costs while maintaining a high working voltage alongside a high capacity and energy density.[4]

Anion doping is an unconventional and alternative way in improving the electrochemical stability and enhancing the energy density of next generation cathode materials for lithium ion batteries. Such work can potentially enable lithium ion batteries with higher energy and free of expensive transition elements, such as cobalt. In this work, new layered/ disordered rocksalt Li-Ni-Mo-Mg-O-F material are reported, which shows both cationic and anionic redox behaviours, and can be potentially used for next generation lithium ion batteries.

References:

1 R.A. House, J.-J. Marie , M.A. Pérez-Osorio , G.J. Rees , E. Boivin , P.G. Bruce. Nat. Energy, 2021, 6, 781-789.
2 G. Assat, J.-M. Tarascon, Nat. Energy, 2018, 3, 373-386.
3 J.P. Huang , P.C. Zhong , Y. Ha , D.-H. Kwon, M.J. Crafton, Y.S. Tian , M. Balasubramanian , B.D. McCloskey , W.L. Yang , G. Ceder. Nat. Energy, 2021, 6, 706-714.
4 M. Bianchini, M. Roca-Ayats, P. Hartmann, T. Brezesinski, J. Janek, Angew. Chem. Int. Ed. 2019, 58, 10434-10458.

CONFERENCE TOPIC
Recent advances and breakthroughs in energy storage.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Predicting Li-Ion battery hazards during thermal runaway using micro-kinetic modelling

Dr. Peter Bugryniec[1], Dr. Sergio Vernuccio[1], Prof. Solomon Brown[1]

1 Department of Chemical & Biological Engineering, University of Sheffield, Sheffield, S1 3JD, England, UK.
p.bugryniec@sheffield.ac.uk

Keywords: battery safety, risk assessment, computational chemistry, electrolyte decomposition, reaction network analysis

1. ABSTRACT

The extensive use of Li-Ion batteries (LIBs) in electric vehicles and stationary applications is facilitating a reduction in carbon emissions and helping to mitigate climate change. The use of LIBs is driven by their benefits of high energy density and low cost. However, LIBs can suffer from the hazard of thermal runaway. Thermal runaway is a catastrophic event during which a battery cell, followed by the whole battery, decomposes exothermically ultimately leading to fire and explosion. As such, improving our understanding of thermal runaway is key to improving LIB safety. To achieve this, we aim to develop a more detailed model of LIB thermal runaway.

Computational modelling is a proven tool to better understand and predict the thermal runaway behaviour of a LIB under various scenarios. However, classical models are largely based on empirical data and as such can limit the scope over which a model is accurate. Further, these models can be considered simplified as they do not consider the real reaction species generated nor do they include the interactions between battery materials or their decomposition products.

To overcome these issues, we aim to develop a mechanistic model of the decomposition process of the battery materials during thermal runaway. This mechanistic model utilises micro-kinetic modelling and reaction theory to describe the reaction pathways, elementary steps and intermediates. This allows us to build a model without a prior assumption on the rate determining steps and also allows us to predict off gas species.

This work is a novel application of micro-kinetic modelling and reaction network analysis. It shows how one can apply these methods to thermal runaway analysis and predict quantities of flammable gases. Case studies examining electrolyte thermal decomposition analyse the products produced under various conditions. This method can be applied across multiple length scale to inform hazard assessments of LIBs from cell to grid scale level.

2. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

An Optimization-based technique for modeling lithium-ion batteries

Seyed Saeed Madani

Institute of Applied Materials-Applied Materials Physics, Karlsruhe Institute of Technology Karlsruhe, Germany

seyed.madani@kit.edu

Lithium-ion batteries are being used as electrochemical storage in different appliances, via which energy could be saved in the configuration of potential chemical diversity and utilized on every occasion required. Electric vehicles employ the electrical power of lithium-ion batteries to work motors effectively. Lithium-ion batteries have many applications, especially in portable electronics, including laptops, mobile phones, and other electronic appliances. Besides, they have potential implementations for automobile goals. In order to study the behavior of lithium-ion batteries for different applications, battery models are required. This study used an optimization-based technique for modeling lithium-ion batteries. Experimental outcomes were compared with the simulation data. The exactness of the recommended and parameterized model for the researched lithium-ion battery cell was assessed by fulfilling a verification experiment.

Introduction

Global warming is a specific outcome of the aggregation of greenhouse gases. Internal combustion engines release a significant amount of carbon dioxide and, consequently, substituting energy supplies for automotive propulsion is one of the main motivations of green energy research worldwide. Lithium-ion batteries are currently the most promising storage technology to reduce the greenhouse gas emissions of the transport sector.

Over the last few years, there has been growing attention from authorities, universities, manufacturers, and the scientific community on the environmental consequences of greenhouse issues. In addition, significant developments have been happening for energy storage, which is recognized among the technologies, which can lead to a more eco-friendly and sustainable society and is also crucial in the future energy markets where power generation will be based on renewables. In addition, they received increasing interest in backup energy supply applications, including renewable grid integration and grid support.

Electric vehicles can be an excellent alternative to vehicles that use conventional internal combustion engines and are harmful to the environment. The extensive use of these devices depends on the development of rechargeable batteries. Lithium-ion batteries have been used for this purpose due to their excellent performance characteristics, such as high energy density, high life span, and low self-discharge.

Due to their significant power and energy densities, lithium-ion batteries are an appropriate nominee for an extensive assortment of renewable energy storage utilization. Lithium-ion battery technology is appropriate for vast utilization, and every application has different necessities. Lithium-ion batteries are also applicable for military, aerospace, and residential utilization, attributable to their safety and reliability, significant power potential, and life span.

Electrical models are separated into two classifications based on the parameterization approach. Thévenin-based electrical models are parametrized utilizing discharging and charging current pulses, which are used in the time domain [1], [2]. Impedance-based electrical models are parameterized employing the electrochemical impedance spectroscopy approach, which is used in the frequency domain [3]. Both two techniques could be employed for the dynamic modeling of lithium-ion batteries [4]. Modeling the dynamic behavior of lithium-ion batteries is not straightforward [5]. An electrical equivalent circuit model was used for modeling lithium-ion batteries [6,7]. In this study, a nonlinear least square method using the Levenberg-Marquardt algorithm was used for modeling lithium-ion batteries.

Results

The current pulse methodology was applied to the lithium-ion battery to parameterize the lithium-ion battery cell model. Specific discharging and charging current pulse profiles were applied to the lithium-ion battery. Besides, the equivalent circuit model parameters of the lithium-ion battery were determined. In addition, numerous simulations were done to determine the parameters of the lithium-ion battery.

The equivalent circuit model parameters were optimized by employing the Levenberg-Marquardt optimization algorithm in Matlab to reduce the voltage estimation error. The investigated model approximated the lithium-ion battery cell voltage for a broad scope of working situations. The open-circuit voltage, internal resistance, and capacity of the lithium-ion battery cell were determined at various temperatures, state of charges, and load currents. Experimental outcomes were compared with the simulation data. The exactness of the recommended and parameterized model for the researched lithium-ion battery cell was assessed by fulfilling a verification experiment.

This research employed a second-order equivalent electrical circuit lithium-ion battery model. The equivalent circuit model parameters were specified from multi-pulse discharge and charge data. Different tests were done to support the recommended modelling approach. The current pulse methodology was applied to the lithium-ion battery to parameterize the lithium-ion battery cell model. Specific discharging and charging current pulse profiles were applied to the lithium-ion battery. Besides, the equivalent circuit model parameters of the lithium-ion battery were determined.

The parameter estimation technique is described in Figure 1. Experimental data is used to fit model parameters. This approach uses an optimization-based approach where the goal is to improve the design parameters to reduce estimation errors. Figure 2 demonstrates a comparison between estimated and measured lithium-ion battery voltage for a dynamic profile. The model was shown by employing a dynamic current profile, illustrating satisfactory preciseness for the considered load current.

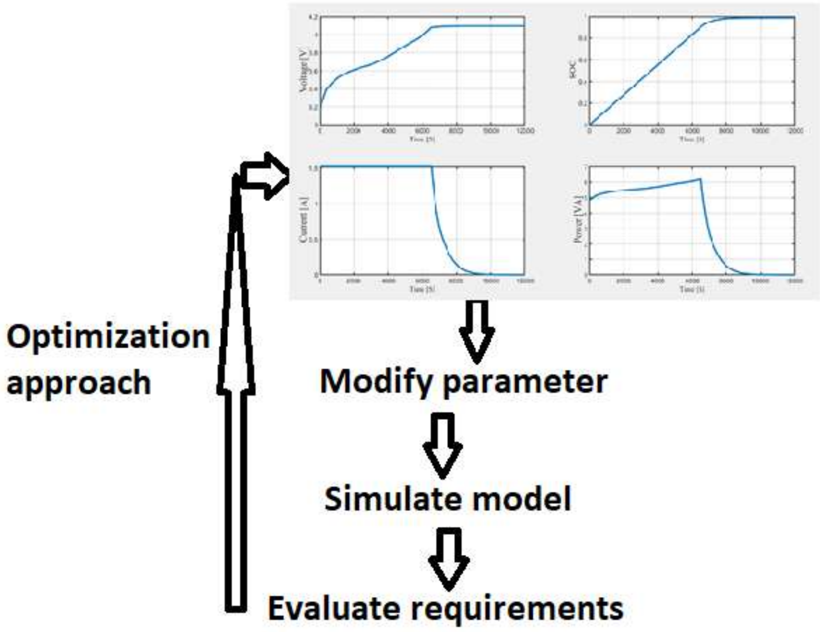
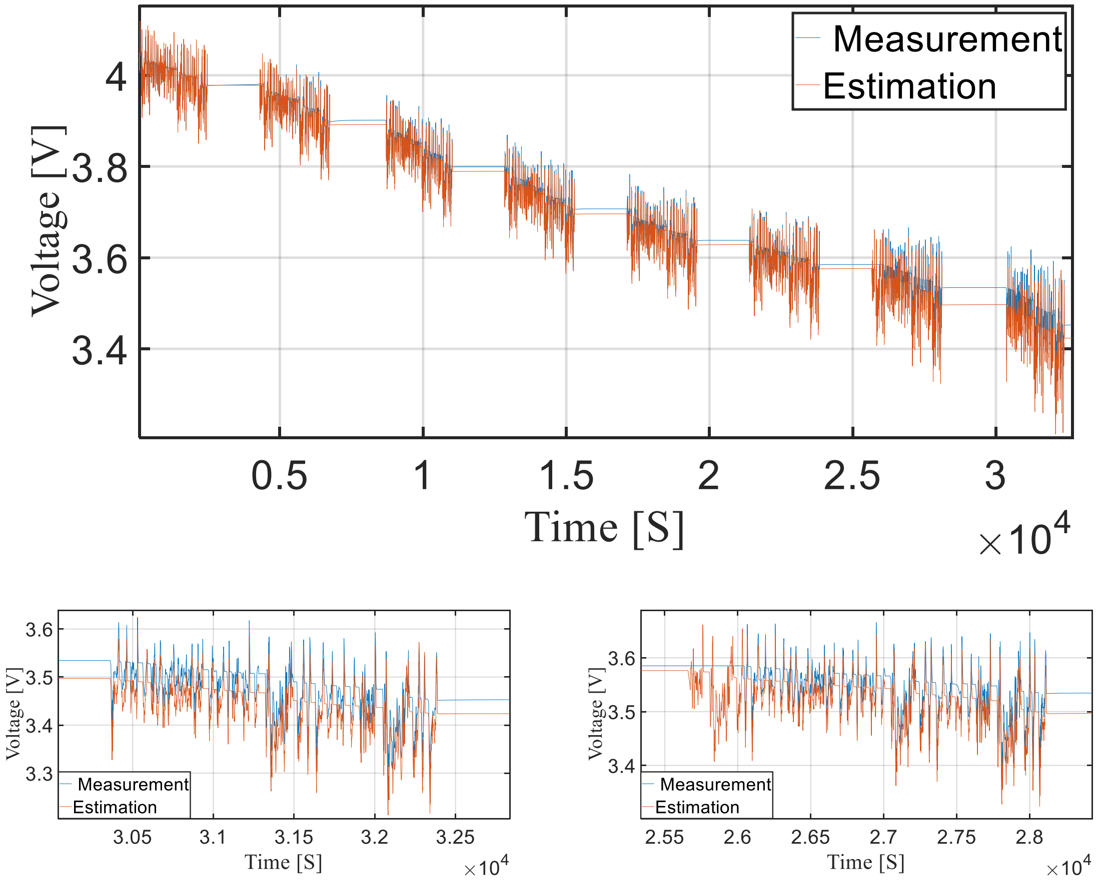


Figure 1. Parameter estimation technique



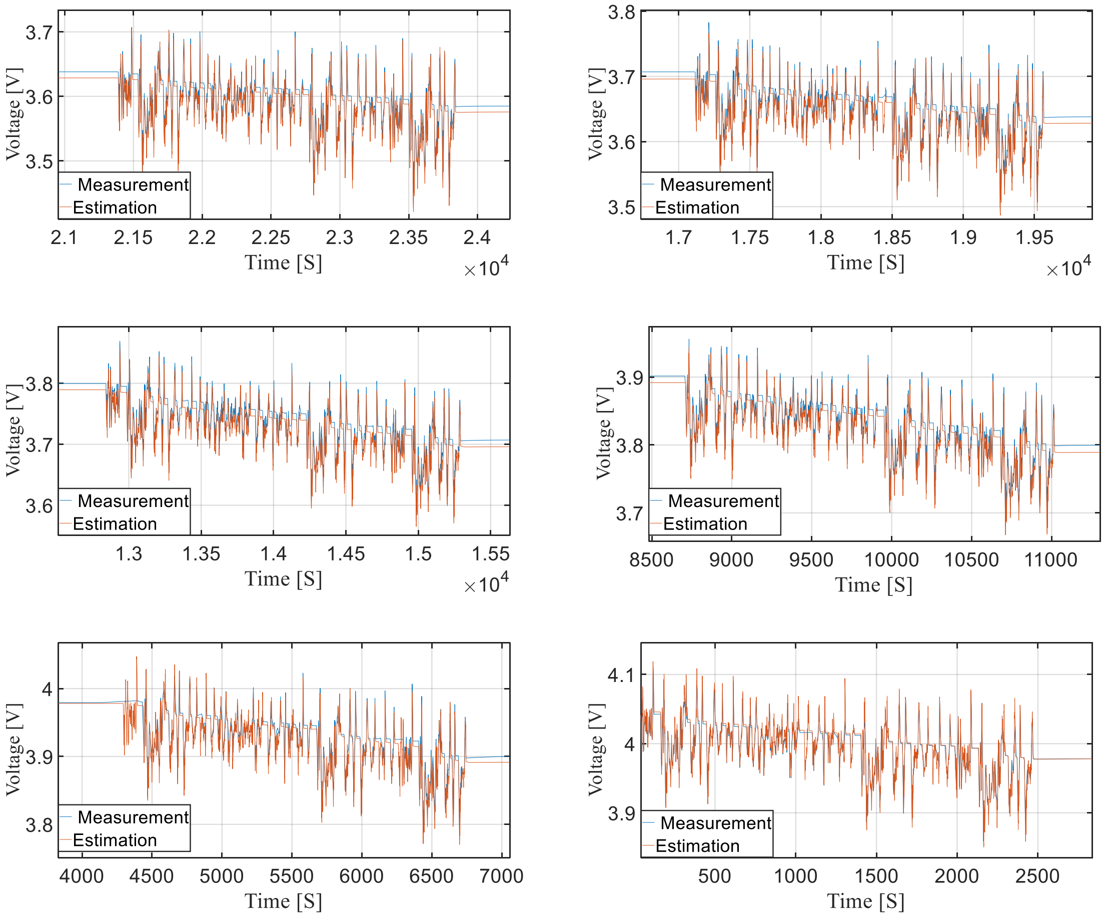


Figure 2. Comparison between estimated and measured lithium-ion battery voltage for a dynamic profile.

Conclusion

An electrical equivalent circuit model of a lithium-ion battery was used. The lithium-ion battery model must foresee the lithium-ion battery cell's voltage behaviour for small and large currents. The lithium-ion battery cell's voltage as a function of time at different temperatures and current rates was determined. Therefore, several tests were done to understand the lithium-ion battery's behaviour. In addition, numerous simulations were done to determine the parameters of the lithium-ion battery. Besides, it was demonstrated how estimation influences voltage variation. The number of capacitances, resistances and open-circuit voltage of the equivalent circuit model may influence the estimation results which will be studied in future investigations. The presented model was demonstrated by employing a dynamic current profile, demonstrating acceptable accurateness for all the considered load current levels. The lithium-ion battery model could accurately forecast the battery voltage throughout the transients.

Reference

[1] Min Chen and G. A. Rincon-Mora, "Accurate electrical battery model capable of predicting runtime and I-V performance," in *IEEE Transactions on Energy Conversion*, vol. 21, no. 2, pp. 504-511, June

2006.
[2] A. Hentunen, T. Lehmuspelto and J. Suomela, "Time-Domain Parameter Extraction Method for Thévenin-Equivalent Circuit Battery Models," in *IEEE Transactions on Energy Conversion*, vol. 29, no. 3,
pp. 558-566, Sept. 2014.

[3] D. Andre, et al., Characterization of high-power lithium-ion batteries by electrochemical impedance spectroscopy. II: Modelling, *Journal of Power Sources*, vol. 196, no. 12, pp. 5349 – 5356, 2011.
[4] D.-I. Stroe, M. Swierczynski, A.-I. Stroe, S. K. Kær, ”Generalized Characterization Methodology for Performance Modelling of Lithium-Ion Batteries,” *Batteries*, vol. 2, no. 4, pp. 37-58, 2016.
[5] N. Omar et al., "Assessment of performance of lithium iron phosphate oxide, nickel manganese cobalt oxide and nickel cobalt aluminum oxide based cells for using in plug-in battery electric vehicle applications," 2011 IEEE Vehicle Power and Propulsion Conference, Chicago, IL, 2011, pp. 1-7.
[6] S. S. Madani, E. Schaltz, and S. Knudsen Kær, “An Electrical Equivalent Circuit Model of a Lithium Titanate Oxide Battery,” Batteries, Vol. 5, No. 1, PP. 1-14, 2019.

[7] Madani, S. S., Soghrati, R., & Ziebert, C. (2022). A Regression-Based Technique for Capacity Estimation of Lithium-Ion Batteries. Batteries, 8(4), 31.

Nitrogen-doped spongy-like hierarchical porous carbon derived from biomass tar: a sustainable energy material for supercapacitor

Jiahuan Xu, Beichen Xue, Chao Liu, Ming Li, Rui Xiao

Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, Jiangsu, China

Keywords: Biomass tar; Hierarchical porous carbon; Nitrogen-doped; Supercapacitor

1. INTRODUCTION

The supercapacitor is widely regarded as one of the most important energy storage devices with obvious advantages of excellent power output, long lifespan, and short charge time. Recently, biomass-derived porous carbon electrode materials have attracted extensive attention by virtue of their high surface area and low cost. However, the carbons exclusively rely on the biostructures and the pore structure is difficult to regulate. Therefore, it is urgent to develop suitable raw materials and facile methods to synthesize high-quality carbon materials for the large-scale practical application of supercapacitor.

2. MATERIALS AND METHODS

Biomass tar, the liquid by-product of pyrolysis of rice husk, was employed as carbon precursor. It possessed high carbon content and good thermoplastic properties. The liquid form is beneficial for the regulation of the porous structure. Urea was chosen as nitrogen supplement. The target carbons were synthesized through a one-step MgO template method in combination with K_2CO_3 activation at 800 ºC. The structural and chemical properties were investigated extensively by using SEM, TEM, BET, Raman, and XPS. Then the electrochemical performance was evaluated systematically in 6 M KOH solution.

3. RESULTS AND DISCUSSION

The obtained carbons possessed large surface area (SSA; 979.91-1286.54 $m^2\ g^{-1}$) and exhibited a spongy-like hierarchical porous structure with well-interconnected micro-, meso- and macropores. Especially, the pore size concentrated in a range of less than 5 nm. The adjustment of the mass ratio of MgO and K_2CO_3 can effectively achieve the regulation of the porous structure. Besides, the relatively high graphitization degree led to benign conductivity. It showed that the carbons contained abundant oxygen species (8.29-16.92 at%) and the nitrogen was successfully introduced into the carbons (2.26-2.93 at%), which facilitated the surface wettability and the generation of pseudocapacitance. PMg_6K_8-800 displayed a high specific capacity of 242.40 F g^{-1} at 0.5 A g^{-1} and favorable cycle stability.

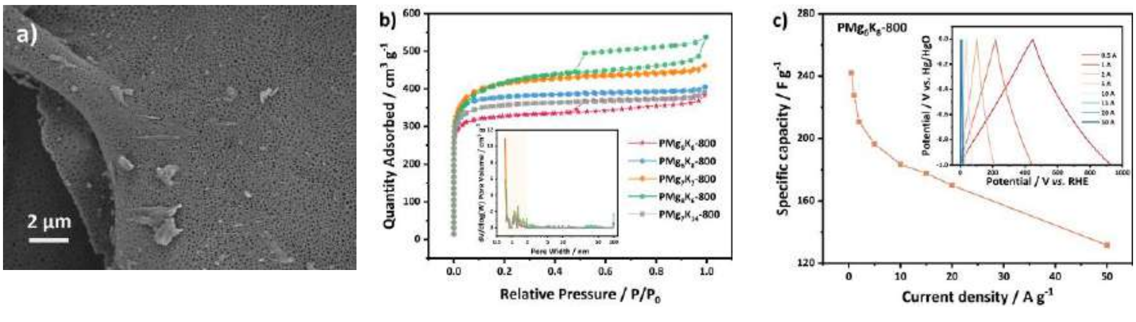


Fig. 1. (a) SEM image of PMg_6K_8-800; (b) N_2 adsorption-desorption isotherms and the insert is pore size distribution curves; (c) Specific capacitance values at different current densities and the insert is gravimetric capacitance at a current density from 0.5 to 50 A g^{-1}.

4. CONCLUSIONS

This work verified the great potential of biomass tar as a sustainable and low-cost precursor for advanced functional carbons and was conducive to the large-scale production of efficient energy storage material for supercapacitor.

5. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Innovation in Membrane Materials for Flow Battery Energy Storage

Qilei Song[1]*, Anqi Wang[1], Rui Tan[1], Charlotte Breakwell[1], Kim E. Jelfs[1], Chunchun Ye[2], Neil McKeown[2]
1 Imperial College London, UK. Email: q.song@imperial.ac.uk
2 School of Chemistry, University of Edinburgh, UK.

Keywords: energy storage, redox flow batteries, membrane materials, ion exchange membranes

1. ABSTRACT

Redox flow batteries (RFBs) based on aqueous organic electrolytes are a promising technology for safe and cost-effective large-scale electrical energy storage. Membrane materials for electrochemical energy conversion and storage devices play important roles in low-carbon technologies for net-zero emissions. Next-generation ion-selective polymer membranes with low-cost production, high ionic conductivity and selectivity, and durability are required for large scale applications of electrochemical energy conversion and storage devices. We will present our recent work in the development of a new generation of ion-selective membranes and their applications in redox flow batteries for energy storage. A series of ion-selective membranes were developed from polymers of intrinsic microporosity (PIMs) by incorporating ion-conductive groups into the polymers. Owing to their microporosity and ion-conducting functionality, PIM membranes present fast ion transport and high selectivity towards electrochemical active materials. The versatile chemistry of polymer membranes can be tailored on the molecular level to precisely tune the pore size and ion-conducting functionality to match the batteries with different redox chemistries. The new PIM membranes significantly boost battery energy efficiency and peak power density and enable stable operations of RFBs over several thousand of charge and discharge cycles. Our membrane design strategy may inspire the development of a new generation of ion-selective membranes for a wide range of electrochemical processes for energy applications.

2. FIGURES

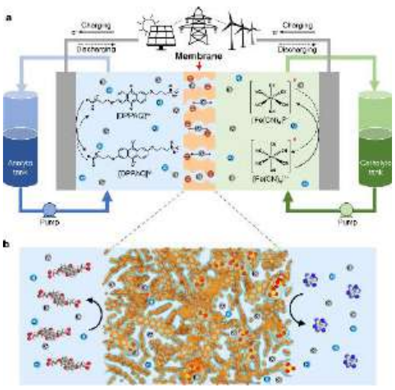


Figure 1. Aqueous organic redox flow battery for energy storage, using ion-sieving membrane with subnanometer pores that enable fast transport of charge-carrying ions while limiting the crossover of redox active species.

3. REFERENCES

[1] Tan, et al, Hydrophilic microporous membranes for selective ion separation and flow-battery energy storage. **Nature Materials**, 19, 195–202(2020).
[1] Ye, C., Wang, A., Breakwell, C. et al. Development of efficient aqueous organic redox flow batteries using ion-sieving sulfonated polymer membranes. **Nat Commun** 13, 3184 (2022). https://doi.org/10.1038/s41467-022-30943-y
[3] Ye, C., Tan, R., Wang, A., et al, Long-Life Aqueous Organic Redox Flow Batteries enabled by Amidoxime-Functionalized Ion-Selective Polymer Membranes. **Angewandte Chemie International Edition**. 2022. In press.

Conference Topic

Recent advances and breakthroughs in electrochemical energy storage, focusing on flow batteries.

Enhanced surface area carbon cathodes for the hydrogen-bromine redox flow battery

David P. Trudgeon[1], Xiaohong Li [1]

1 Renewable Energy Group, Faculty of Science, Environment and Economy, University of Exeter, Penryn Campus, Cornwall, TR10 9FE

Keywords: Redox flow batteries, Carbon electrodes, Nanomaterials

1. INTRODUCTION

The hydrogen-bromine system has been under development since 1980 [1]. The low cost of hydrogen and bromine leads to system capital costs as low as 220 $KWh^{-1} [2] with levelized costs of storage potentially as low as 0.034 $KWh^{-1} [3]. Due to rapid hydrogen and bromine reaction kinetics, high current densities are achievable, with power densities up to 1.4 Wcm^{-2} reported [4,5]. Here, carbon paper (SGL Carbon, 29AA) and carbon cloth (AvCarb, HCB1071) are modified with carbon black (Cabot Corp., PBX51) or graphene nanoplatelets (Sigma-Aldrich, 900407) using a simple drop casting method to achieve a loading of 0.3 mgcm^{-2}. Employing a three-electrode bromine half-cell, comparative electrode performance is assessed using linear sweep voltammetry (LSV), galvanodynamic polarisation and galvanostatic oxidation/reduction cycling. Electrochemically active surface areas (ECSA) are estimated using cycling voltammetry (CV).

2. RESULTS AND DISCUSSION

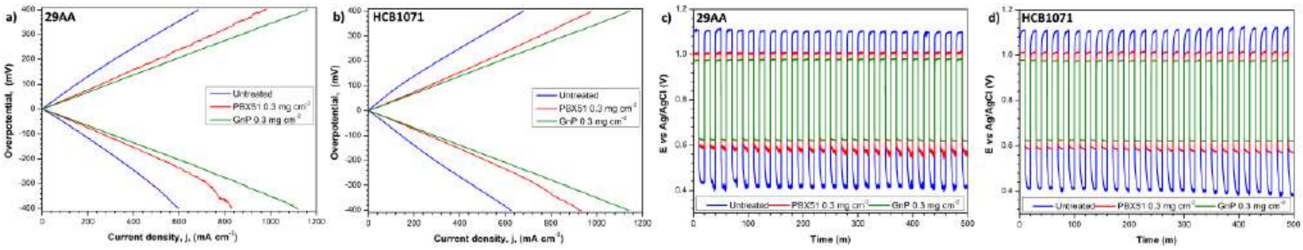


Figure 1: *(a,b) polarisation curves (c,d) oxidation/reduction cycling potential responses at +/- 500mAcm^{-2} on as received, carbon black and GnP modified electrodes.*

Fig. 1 provides polarisation and oxidation/reduction cycling results. During polarisation tests, current densities at overpotentials of +/- 400 mV are increased by 39-49% by the application of carbon black and 69-87% with the addition of GnP, while overpotentials at +/- 500 mAcm^{-2} are reduced by 31-39% in the case of carbon black electrodes and 39-47% for GnP modified electrodes (***Fig. 1 a-b***). Oxidation/reduction cyling yields reduction/oxidation potential ratios 46-48% higher than unmodified materials in the case of carbon black electrodes and 61-63% increases for GnP electrodes (***Fig.1 b-c***). Increases in ECSA are observed, with surface areas ~11 times and ~8 times larger than the as received materials for carbon black and GnP modified electrodes, respectively. In highly concentrated electrolytes, oxidation/reduction cycling at +/- 1.5 A cm^{-2} on enhanced surface area electrode produces overpotentials <400 mV for both oxidation and reduction, demonstrating the capability of enhanced surface area materials to facilitate high current density operation.

3. REFERENCES

[1] Yeo RS, Chin D-T. A hydrogen-bromine cell for energy storage applciations. J. Electrochem. Soc. 1980; 127;549-555.
[2] Singh N, McFarland EW. Levelized cost of energy and sensitivity analysis for the hydrogen-bromine flow battery. J. Power Sources 2015; 288;187-198.
[3] Hugo YA, Kout W, Dalessi G, Forner-Cuenca A, Borneman Z, Nijmeijer K. Techno-economic analysis of a kilo-watt scale hydrogen-bromine flow battery system for sustainable energy storage. Processes 2020; 8;1-22.
[4] Cho KT, Ridgway P, Weber AZ, Haussener S, Battaglia V, Srinivasan V. High performanc hydrogen/bromine redox flow battery for grid scale energy storage. J. Electrochem. Soc. 2012; 159;A1806-A1815.
[5] Tucker MC, Cho KT, Weber AZ, Lin G, Van Nguyen T. Optimization of electrode characteristics for the Br_2/H_2 redox flow cell. J Appl. Electrochem. 2015; 45;11-19.

4. CONFERENCE TOPIC

2.2 – Recent advances in electrochemical energy storage science and technology focusing on flow batteries

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Synergistic doping and surface coating of NMC 9.5.5 for structural and electrochemical stabilisation

Ethan Williams[1*], Chenglong Wu [1], Peter Slater [2], Emma Kendrick [1]

1 School of Metallurgy and Materials, University of Birmingham
2 School of Chemistry, University of Birmingham
* etw078@student.bham.ac.uk

Keywords: NMC, Lithium-ion, doping, high-energy, synthesis

1. INTRODUCTION

Ni-rich Li-ion cathode materials like NMC-9.5.5 ($LiNi_{0.9}Mn_{0.05}Co_{0.05}O_2$) are of interest as they have a higher energy density and limit the cobalt content, aiding the transition away from questionably sourced raw materials, when compared to materials like NMC111 - 622. This has the advantage of reducing production costs while maintaining a high working voltage and capacity. However, the high nickel content of these materials can be detrimental due to disorder brought by Li^+/Ni^{2+} cation mixing, lithium residuals, and irreversible phase changes during operation.[1] Similarly, the different synthesis methods and treatments drastically affect the morphological, structural, and electrochemical properties.

2. METHOD AND RESULTS

We present a study of the coprecipitation synthesis of NMC-9.5.5 precursor prepared at scale in a 5 L continuous stirred reactor tank (CSTR) and the optimisation of the firing process to provide synergistic coating and doping of the active material. In this work a range of metal cations are investigated with a simple and scalable method to achieve mixed metal and mixed valence synergistically coated and doped NMC-9.5.5 with the aim to further improve cycle life and stability.

The initial doping study showed the choice and amount of dopant has an effect upon the particle size and aids sintering of the primary particles, as well as improving the structural and electrochemical properties of the NMC material. Electrochemical results show that increasing the molar content of the dopant results in increased capacity retention during cycling which is reflected in the dq/dv plot which shows the stabilisation of the H2-H3 phase transition at higher voltage. This is also reflected in the XRD characterisation which shows that the introduction of metal cations acts to stabilise and inhibit the Li/Ni cation mixing. The XRD also shows splitting of the (108)/(110) peaks, indicating the retention of the layered crystalline structure. Additionally, surface coated NMC materials were produced by wet or dry mixing methods with an additional annealing step to encourage doping into the bulk. The SEM characterisation reveals the formation of halo-type spherical coatings, whilst XRD patterns show a slight increase in the lattice constant suggesting some doping into the structure, leading to partial transition metal reduction. The wet coated materials in particular show higher cycling capacity and stability compared to that of the doped only and baseline materials. Our results illustrate that tuning the doping ion and content can improve cycling capacity stability, whilst the addition of a surface coating on these materials can further improve performance.

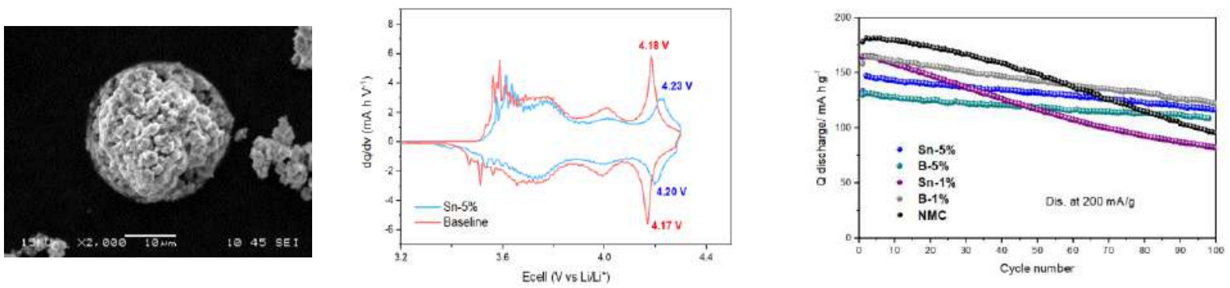


Figure 1: (L-R) SEM micrograph of coated-doped NMC 9.5.5 material, dq/dv plots showing stabilisation of the high voltage phase transition, and the cycling performance comparison of the doped materials.

3. REFERENCES

[1] Fikadu Takele G et al. Identifying surface degradation, mechanical failure, and thermal instability phenomena of high energy density Ni-rich NCM cathode materials for lithium-ion batteries. RSC advances. 2022; 12(1): p.5891-5990.

4. CONFERENCE TOPIC

Energy storage for decarbonisation of transport, Recent advances and breakthroughs in energy storage.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Metrology for the Electrode Coating Process

Carl Reynolds[1], Emma Kendrick[1]

1 School of Metallurgy and Materials, University of Birmingham, Elms Rd, Birmingham B15 2SE
c.d.reynolds@bham.ac.uk, e.kendrick@bham.ac.uk

Keywords: Battery Manufacturing, Metrology, Coating, Rheology

1. ABSTRACT

Slurry casting is the most common method of electrode manufacture, and with the rapid development of new gigafactories, this technology is currently the focus of heavy investment. It is therefore vital to optimise slurry casting lines for best performance and to allow rapid adoption of novel, more sustainable, drop-in technologies, ensuring they do not become obsolete in the near future. In slurry casting, active materials are mixed into a slurry and coated onto a current collector which is then dried, calendared, and assembled into a cell. Currently, these stages are optimised by trial and error and there is a need for advanced metrology and process understanding to enable in-line control, rapid optimisation, and reduction of wastage in time and materials.[1,2]

Metrology is key at each stage of the electrode manufacturing process, and by capturing more information earlier in this sequence, changes can be detected earlier, and adjustments made to maintain quality. Collecting parameters at each stage will also improve understanding of the links between physical properties and final coating microstructure, enabling next generation modelling and the production of digital twins of the process.[3]

We will discuss the metrology possible during the electrode manufacturing process, and the novel metrology options that have been introduced on the mini reel to reel scale up line at Birmingham. This includes slurry and coating characterisation, through rheology (shear, extension and in-line capillary flow), surface tension, contact angles, imaging coating flows, measuring coating properties (thickness, coatweight) and detection of defects. We will detail how the data extracted can be used for process control, including physical and data-driven models, and the opportunities in the future for advanced metrology.

2. CONFERENCE TOPIC

This abstract lies within the following topics:

- Recent advances and breakthroughs in energy storage

- 2.1 Recent advances in electrochemical energy storage science & technology focusing on lithium-ion, sodium-ion and sodium-sulphur batteries

3. REFERENCES

[1] C.D. Reynolds, P.R. Slater, S.D. Hare, M.J.H. Simmons, E. Kendrick, A review of metrology in lithium-ion electrode coating processes, Mater. Des. 209 (2021) 109971. https://doi.org/10.1016/j.matdes.2021.109971.

[2] E. Kendrick, Advancements in Manufacturing, in: Futur. Lithium-Ion Batter., 2019: pp. 262–289.

[3] M. Faraji, C. Reynolds, L. Roman Ramírez, J. Marco, E. Kendrick, Systematic analysis of the impact of slurry coating on manufacture of Li-ion battery electrodes via explainable machine learning, 51 (2022) 223–238. https://doi.org/10.1016/j.ensm.2022.06.036.

High temperature heat storage with liquid metals as heat transfer fluids – status and challenges

K. Niedermeier[1], Franziska Müller-Trefzer[2], Thomas Wetzel[3]

1 Karlsruhe Institute of Technology (KIT), Institute for Thermal Energy Technology and Safety (ITES), klarissa.niedermeier@kit.edu
2 KIT, ITES, franziska.mueller-trefzer@kit.edu
3 KIT, Institute for Thermal Process Engineering, thomas.wetzel@kit.edu

Keywords: Thermal energy storage, liquid metals, high temperature, packed bed

1. INTRODUCTION

In 2020, the total gross production of heat in the EU was 599 TWh with 38.2% being produced from natural or manufactured gases, 31.6% from renewables and 19.6% from solid fossil fuels [1]. With an increasing amount of fossil sources being replaced by renewable energies, heat storage capacities are necessary to guarantee thermal energy supply on demand. Especially in the manufacturing industry of iron, steel, non-metallic minerals and non-ferrous metals, high temperature thermal energy at above 500°C is necessary. For these temperatures, liquid metal-based heat storage can be used due to the wide liquid state operating temperature range combined with excellent heat transport capabilities. This contribution will present the status of research regarding liquid-metal based heat storage, current work of the Karlsruhe Liquid Metal Laboratory on packed-bed storage configuration and the main challenges of this technology.

2. STATUS OF RESEARCH ON LIQUID METAL BASED HEAT STORAGE

Different storage concepts using liquid metal as heat transfer fluid have been published in the past years. Pomeroy [2] published the concepts of using a packed bed of iron spheres in direct contact with liquid sodium in 1979. More recently, a structure of hexagonal rods [3] and a brick-type storage system [4] have been proposed. Moreover, latent heat storage concepts with liquid metals as the heat transfer fluid have been proposed, e.g. Refs [5,6].

3. CURRENT WORK ON PACKED-BED HEAT STORAGE WITH LIQUID METAL

At the Karlsruhe Liquid Metal Laboratory, a lab-scale prototype of a packed-bed heat storage with liquid metal as the heat transfer fluid was successfully tested [7]. Currently, a pilot-scale storage of 100 kWh is under construction. The main challenges for high-temperature (>500°C) heat storage using liquid metal as heat transfer fluid are 1) corrosion issues, 2) keeping the temperature stratification during standby after partial (dis)charge and 3) reducing the storage material cost.

4. CONCLUSIONS

Liquid metal-based heat storage systems are a promising technology due to their broad liquid due to their broad liquid state temperature range and outstanding heat transfer capabilities. This contribution will give an overview of the research on liquid-metal based heat storage and will discuss the current experiments of a packed-bed thermal energy storage system and the associated findings and challenges.

5. REFERENCES

[1] Eurostat 2020; https://ec.europa.eu/eurostat; accessed 15.7.22
[2] Pomeroy BD. Thermal energy storage in a packed bed of iron spheres with liquid sodium coolant. Sol Energy 1979; 23:513–515
[3] Forsberg C. Separating Nuclear Reactors from the Power Block with Heat Storage to Improve Economics with Dispatchable Heat and Electricity. Nucl Technol 2021; 1-23.
[4] Coventry J, Torres JF, Kee Zebeedee, Bozorg MV, Taheri M, Mojiri A, Pye J, Bell S, Will G, Steinberg T. Packed bed thermal energy storage with sodium as the heat transfer fluid, Asia-Pacific Solar Research Conference 2021
[5] Kotzé J. Thermal energy storage in metallic phase change materials. PhD thesis, Stellenbosch University, 2014.
[6] Kee Z, Coventry J, Pye J. A dynamic model of a sodium/salt PCM energy storage system, MATHMOD 2018
[7] Müller-Trefzer F, Niedermeier K, Daubner M, Wetzel, T. Experimental investigations on the design of a dual-media thermal energy storage with liquid metal. Appl Therm Eng 2022; 213:118619.

6. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage.

Bionic triply periodic minimal surfaces metal foam phase change material for fast latent heat storage

Yang Tian[1], Xianglei Liu [1,2] *

1 School of Energy and Power, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu Province, 210016, China
2 Integrated Energy Institute, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu Province, 210016, China
*Corresponding author email: xliu@nuaa.edu.cn

Keywords: Triply periodic minimal surfaces; Metal Foam; Latent heat storage

1. INTRODUCTION

The latent heat storage technology has been widely used in various thermal energy storage and management fields, but its extensive application is limited due to the slow thermal storage rate of phase change material (PCM) [1]. Here, inspired by the microstructure butterfly wings, four different triply periodic minimal surface (TPMS) based metal foam skeletons are introduced to enhance latent heat storage performances [2], which are evaluated by both experiment and numerical simulation. The Primitive-based metal foam-PCM (MFPCM) has the best thermal storage performance and highest effective thermal conductivity with melting time obviously decreased by 20% compared to the traditional structure (Net) as shown in Fig. 1. The underlying mechanism can be attributed to a more continuous and compact internal structure than that of traditional MFPCM, which significantly improves the heat transfer performance. This work guides the design of MFPCM and paves the way for the application of bionics in high-performance latent thermal energy storage.

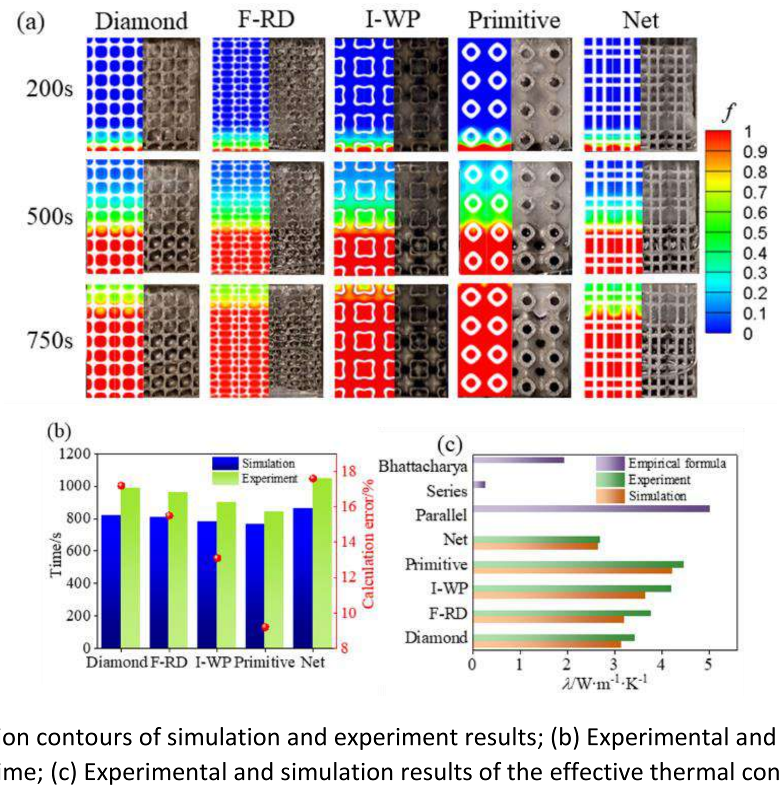


Fig. 1 (a) Liquid fraction contours of simulation and experiment results; (b) Experimental and simulation results of melting time; (c) Experimental and simulation results of the effective thermal conductivity.

2. REFERENCES

[1] A. G. Olabi, C. Onumaegbu, T. Wilberforce, M. Ramadan, M. A. Abdelkareem, A. H. Al-Alami. Critical review of energy storage systems, Energy, 2021, 214:118987. https://doi.org/10.1016/j.energy.2020.118987.

[2] O. Al-Ketan, R. K. Abu Al-Rub. MSLattice: A free software for generating uniform and graded lattices based on triply periodic minimal surfaces, Material Design & Processing Communications, 2021, 3:e205 (10 pp.)-e205 (10 pp.). https://doi.org/10.1002/mdp2.205.

3. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage.

Enhanced Thermal Energy Storage Capacity of Solar Systems Using Nano-encapsulated Nano Size of n-Octadecane Phase Change Material as an Inorganic Shell

Oguzhan Kazaz[1], Nader Karimi[1, 2], Shanmugam Kumar [1], Gioia Falcone[1], Manosh C. Paul[1*]

[1]Systems, Power & Energy Research Division, James Watt School of Engineering, University of Glasgow, Glasgow, G12 8QQ, UK, o.kazaz.1@research.gla.ac.uk, Msv.Kumar@glasgow.ac.uk, Gioia.Falcone@glasgow.ac.uk
[2]School of Engineering and Materials Science, Queen Mary University of London, London, E1 4NS, United Kingdom, n.karimi@qmul.ac.uk
*Corresponding author: Manosh.Paul@glasgow.ac.uk

Keywords: Nano encapsulated phase change material, solar energy, thermal energy storage, heat transfer enhancement, conjugate heat transfer

Increasing use of renewable energy contributes to sustainable energy production by reducing the negative effects of greenhouse gases and carbon emissions. Due to the ease of use and ubiquity of solar energy, it is attractive among renewable energy sources. The biggest problem of solar energy applications, however, is not being able to benefit from sunlight for 24 hours. Hence, this problem can be eliminated thanks to the storage of solar energy. Therefore, the high latent heat of the phase change materials (PCMs) can be released during the phase changes, and the thermal energy can be stored. Due to these advantages of PCMs, their usage in solar collectors is increasing. On the other hand, PCMs need to be improved since they have low thermal conductivity and cannot interact directly with the heat transfer fluids (HTFs) due to leakage during phase changes. Encapsulation techniques can be used to prevent these drawbacks, which can improve the thermal performance of PCMs by being surrounded by a shell, keeping their shape, and preventing leaks. Thus, the encapsulated PCM can be easily incorporated into the HTF.

In this study, nanoencapsulation of PCM with inorganic shell materials dispersed in base fluid is novelty of this study, and this is the first example of the use of this material as a HTF in volumetrically heated solar collectors. Since the optical properties of encapsulated phase change slurries (PCSs) depend on both the PCM, the base fluid, and the shell material, the effects of them should be investigated. The effect of encapsulated PCM on the phase change process because of the mass fraction and size change of the PCM, as well as the radiation heating, still needs to be studied. Because the heat transfer medium is a translucent medium, therefore, a 2D fluid flow and heat transfer model is developed using the Discrete Ordinate method for radiative transport equation. The results show that the surface plasmon resonance, which is activated due to the interaction of the electrons in the inorganic shell materials with the irradiation, creates the absorption peak positions and shifted these peak waves to larger wavelengths with the increase of the core diameter. It is found that the use of encapsulated PCS and the increase in PCM mass concentration improve the temperature and storage gain by increasing the solar energy absorption capacity of HTF. Increasing the size of the core/shell structure reduces the surface area of the capsule, causing aggregation of the particles, and this situation increases the thermal resistance and causes a decrease in the heat transfer between the capsule and the host fluid, so it is observed that the temperature gain decreases. Besides, it is discovered that the mono and hybrid nanoparticles added to the water augment the thermal performance of the encapsulated PCS. Furthermore, it is seen that since the encapsulated PCS increases the sunlight absorption capacity, it can be evaluated both as a HTF and as a storage medium in solar energy applications.

Conference topic: Recent advances and breakthroughs in energy storage

APPENDIX A

Enhancement of thermal energy stoage with carbon nano tubes (CNTs) additives

Yanping Du[1,2], Tao Zhou[2]

1 Renewable Energy Group, School of Engineering, University of Exeter, y.du2@exeter.ac.uk
2 China-UK Low Carbon College, Shanghai Jiao Tong University, tzhou1203@sjtu.edu.cn

Abstract: In the study, CNTs based nanocomposite phase change materials (NPCMs) is considered for breaking through the constraint of the low thermal conductivity of conventional PCMs for thermal energy storage. A conceptual pathway for the evaluating the effective thermal performance of NPCMs is newly demonstrated, which is validated by comparisons with Monte Carlo method and experiments. The results show that by forming effective conduction paths composed of backbones in the NPCMs, the average thermal conductivity can be significantly improved. A molecular dynamics simulation is conducted to interpret the structural, diffusive and thermal properties of CNTs based PCMs from the microscopic perspective. It is found that the PCMs is preferentially distributed as either one or two ring-shaped layers that discretely separated from the CNTs wall with a distance of 3.8 A˚ and 8.0 A˚, respectively. The mean square displacement (MSD) and the self-diffusion coefficient are characterized for featuring the molecule mobility and predicting the melting temperature of the composite PCMs. Interestingly, the dense phase existing between the CNTs wall and the PCMs is proven to be the dominant factor that negates the phase change enthalpy of the composite system. In realistic experiments using the CNTs with a radius of 10∼15 A˚, the thermal conductivity is highly potential to be improved to 5∼15 W/m · K, indicating an augmentation of the thermal conductivity by approximate 32∼100 times compared to pure PCMs. The formation of efficient heat conduction paths explains for the intrinsic mechanism of the tremendous improvement in the CNTs based NPCMs, which could be achieved in the premise of strong binding effect of materials and reduced contact thermal resistance among CNTs in macroscopic PCM modules.

Keywords: Nanocomposite phase change materials (NPCMs); Carbon nano tubes (CNTs); Molecular dynamics (MD); Thermal conductivity

Conference Topic: Recent advances and breakthroughs in energy storage (thermal energy storage)

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Status on thermal energy storage with molten nitrate salt up to 620 °C

Julian Steinbrecher[1], Alexander Bonk[1], Thomas Bauer [2]

1 Institute of Engineering Thermodynamics, German Aerospace Center (DLR). Pfaffenwaldring 38, 70569 Stuttgart, Germany.
2 Institute of Engineering Thermodynamics, DLR. Linder Höhe, 51147 Cologne, Germany.

Keywords: Keywords number should not exceed 5. Text Calibri 10pt

1. INTRODUCTION

Molten nitrate salts are state-of-the-art heat transfer fluids (HTF) and thermal energy storage (TES) in Concentrating Solar Power (CSP) plants. Only recently, the authors of this work demonstrated that higher operating temperatures of at least 620°C can be realized, compared to state-of-the-art temperatures of 565 °C.[1] The development principally enables the transformation of conventional power plants (e.g. coal) into Storage Power Plants that can absorb peak currents from fluctuating renewable sources. The presentation outlines the potential of nitrate salts in these new fields of application with a particular view on the material research level. In the last years the scientific community has made important progress in understanding the fundamental reaction mechanisms in nitrate salts at temperatures as high as 620 °C (Some accepted reaction schemes from different literature sources are presented in Figure 1).[2] Yet, the schematic description is far from complete and in the presentation we will outline the recent for the successful implementation of Molten Salt storage up to 620 °C.

2. ENHANCED THERMAL STABILITY OF MOLTEN NITRATE SALTS

Enhancing the thermal stability of nitrate salts has been an obvious target over decades, given that energy conversion efficiency and storage capacity both amplify with higher operating temperatures. Yet, with higher operating temperatures come new challenges. The molten salts become increasingly corrosive at higher temperatures if thermal decomposition reactions are not controlled carefully. We have demonstrated that the corrosivity of a nitrate salt melt directly relates to the degree of aging recently.[3] Most importantly, the formation of nitrites and oxide ions in the melt is responsible for the corrosion process and accordingly, reducing the concentration of both anions is key for the realization of nitrate salt storage up to 620 °C. The formation of these anions can be suppressed, e.g. by using a reactive gas atmosphere on top of the melt and this effect has been demonstrated recently.[4] This methodology is currently investigated in-depth from the salt's chemistry perspective. The contribution provides an overview on the topic, the state of knowledge and outlines the latest progress in this field of research.

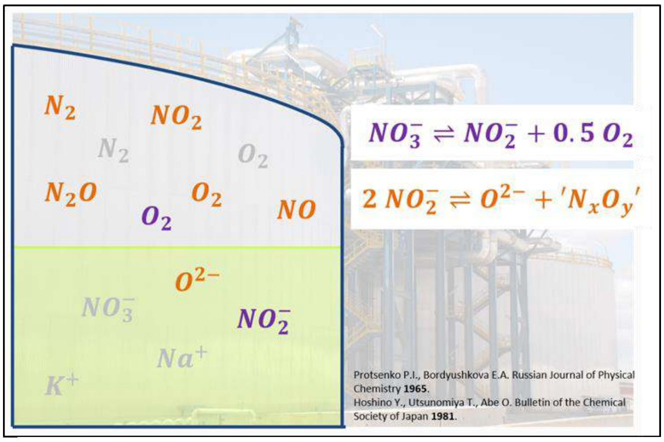


Figure 1: Complex reaction mechanisms proposed for molten nitrate salts at temperatures at >560 °C.

3. REFERENCES

[1] V. A. Sötz, A. Bonk, J. Steinbrecher and T. Bauer, *Solar Energy* **2020**, *211*, 453-462.
[2] a) Y. Hoshino, T. Utsunomiya and O. Abe, *Bulletin of the Chemical Society of Japan* **1981**, *54*, 1385-1391; b) P. I. Protsenko, *Russian journal of physical chemistry* **1965**, *39*.
[3] A. Bonk, D. Rückle, S. Kaesche, M. Braun and T. Bauer, *Solar Energy Materials and Solar Cells* **2019**, *203*, 110162.
[4] a) A. Bonk, M. Braun, V. A. Sötz and T. Bauer, *Applied Energy* **2020**, *262*, 114535; b) J. Steinbrecher, A. Bonk, V. A. Sötz and T. Bauer, *Materials* **2021**, *14*.

4. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

Dynamic operation principles for the compressed carbon dioxide energy storage system

D L Yang[1,2], G H Tang[1,*], K H Luo[2,*], Y H Fan[1], X L Li[1]

1 MOE Key Laboratory of Thermo-Fluid Science and Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China
2 Dept of Mechanical Engineering, University College London, London WC1E 7JE, United Kingdom

1, * Corresponding author. Tel: +86(0)29-82665319 E-mail: ghtang@mail.xjtu.edu.cn

2, * Corresponding author. Tel: +44(0)20-76793916 E-mail: k.luo@ucl.ac.uk

Keywords: compressed carbon dioxide energy storage, dynamic, operation principle

1. INTRODUCTION

The energy storage system has drawn attention since it can shave peaks and fill valleys of the grid, which enables the integration of unstable and intermittent renewable energy into the grid. The compressed carbon dioxide energy storage (CCES) system was proposed and regarded as a promising technology due to its improved performance by using CO_2 as the working fluid. However, there are few works about the dynamic characteristics of the CCES system [1, 2], and the existing analysis is only focused on the one round-trip process. In fact, the CCES system may have different working conditions during multiple round-trip processes to accomplish the peak-shaving. For example, the system can be filled completely but emptied half in some round-trip processes, while be filled half and emptied completely in others. Therefore, these complex dynamic operation processes need to be investigated and the operation principles for the system are to be revealed.

2. DYNAMIC MODELLING

The dynamic model of CO_2 energy storage tank of the CCES system is,

$$\frac{d(mu)}{dt} = \dot{m}(t)h(t) \qquad \text{(eq. 1)}$$

where m is the CO_2 mass, u is the specific internal energy, t is the time, $\dot{m}$ is the mass flow rate, and h is the enthalpy.

3. RESULTS AND DISCUSSION

The complex dynamic operation processes are discussed according to four cases: 1) One round-trip process, which has a single charge and a single discharge processes. The results show that when the storage tank is charged completely, the system can get the highest round-trip efficiency of 59.66%. 2) Two symmetry round-trip processes, which has the same occupation volume of the tank at the end of the two charge processes. The highest round-trip efficiency of 59.18% is achieved when the storage tank reaches the least occupation volume at the end of the first discharge process. 3) Two non-symmetry round-trip processes, which has different occupation volumes of the tank at the end of the two charge processes. The highest round-trip efficiency of 58.35% is achieved when the difference between the CO_2 reserves in the storage tank is the smallest after the two charge processes are completed.

4. CONCLUSIONS

Three dynamic operation principles are suggested: 1) charge the tank as full as possible, 2) empty the tank as much as possible, and 3) keep all the round-trip processes similar.

5. REFERENCES

[1] Zhao P, Xu W, Zhang S, Gou F, Wang J, Dai Y. Components design and performance analysis of a novel compressed carbon dioxide energy storage system: a pathway towards realizability. Energ Convers Manag 2021;229:113679.

[2] Zhang Y, Wu YT, Yang K. Dynamic characteristics of a two-stage compression and two-stage expansion Compressed Carbon dioxide energy storage system under sliding pressure operation. Energy Convers Manag 2022; 254: 115218.

6. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Analysis on off-peak power synergy of liquid air energy storage system coupled hydrogen liquefaction process

Yan Yang [1], Lige Tong [1,2,*], Shaowu Yin [1,2], Chuanping Liu [1,2], Peikun Zhang [1,2], Wei Guo [1,2], Li Wang [1,2], Yinan Qiu [3]

1 School of Energy and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China; g20208241@xs.ustb.edu.cn (Yang Y.); yinsw@ustb.edu.cn (Yin S.); cpliu@ustb.edu.cn (Liu C.); pkzhang@ustb.edu.cn (Zhang P.); guowei@ustb.edu.cn (Guo W.); liwang@me.ustb.edu.cn (Wang L.)
2 Beijing Key Laboratory of Energy Saving and Emission Reduction for Metallurgical Industry, University of Science and Technology Beijing, Beijing 100083, China
3 State Key Laboratory of technologies in Space Cryogenic Propellants, Beijing 100028, China; qyn@wingspanchina.com
* Correspondence: tonglige@me.ustb.edu.cn

Keywords: Hydrogen liquefaction; Liquid air; Energy storage; Energy analysis; Exergy analysis

1. ABSTRACT

Due to the severe challenges posed by climate change, hydrogen has become one of the powerful options to help achieve carbon neutrality goals and the United Nations Sustainable Development Goals (SDGs). In order to continuously optimize the global hydrogen supply network, hydrogen storage with high efficiency and low energy consumption is an important part. Liquid hydrogen storage has advantageous gravimetric density (100 wt%) and volumetric density (70.6 kgH_2/m^3), so it is expected to become the main way of large-scale hydrogen storage in the future. However, the main problem with liquid hydrogen storage is the high cost associated with higher energy consumption (12.5–15 $kWh/kgLH_2$). The researchers have focused on optimizing the hydrogen liquefaction process in a various ways. In this paper, a hydrogen liquefaction process with an integrated air liquefied energy storage system is proposed based on the above problems. A schematic diagram of the process flow is shown in Figure 1. During the off-peak time, the air is divided into two parts after the charge process and sent to the air liquefaction process and the refrigeration process. The refrigeration process is a modified Heylandt cycle, which together with the cold storage medium in the cold tank provides cold energy for the air liquefaction process. During the peak period, after the liquid air passes through the pump and the diverter, it exchanges heat with the hydrogen and the cold storage medium respectively to recover the cold energy. The reheated high-pressure air releases electricity through the discharge process. When the hydrogen flow rate is 2052 kg/h and the liquid-air split ratio of #1 and #2 is 8:1, the overall round-trip efficiency is 58.9% and the overall exergy efficiency is 53.15% according to the simulation calculation. Therefore, the proposed process has a good performance.

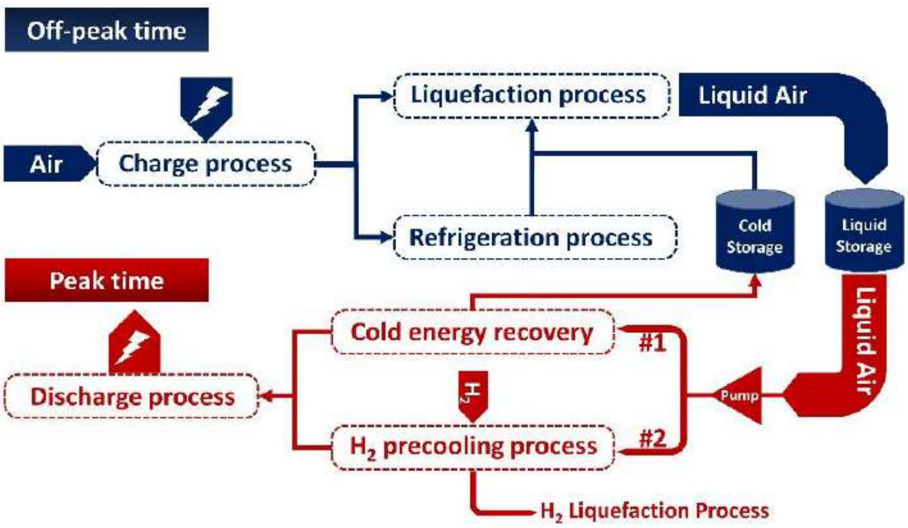


Figure 1: Concise schematic diagram of the proposed process.

2. CONFERENCE TOPIC

· Application of energy storage through integration with renewable generation and energy networks

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Metal-based high-temperature energy storage systems for flexible steam generation in power plants

Silas Heim[1], Robert Daschner[2], Matthias Franke[3]

1 silas.heim@umsicht.fraunhofer.de
2 robert.daschner@umsicht.fraunhofer.de
3 matthias.franke@umsicht.fraunhofer.de
1,2,3 Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Institute Branch Sulzbach-Rosenberg, An der Maxhütte 1, 92237 Sulzbach-Rosenberg, Germany

Keywords: Latent heat storage, Metallic phase change materials, Cogeneration plants, Process steam generation

1. INTRODUCTION

A metal-based high temperature latent heat storage has been developed for the application of flexible operation of combined heat and power plants [1]. Metals as PCM provide high power levels and fast dynamics, which makes them suitable for power plant requirements. Conventional power plants are in need of flexible operation due to the ongoing integration of renewable energy sources: Fossil-fired plants shut down up to 50 times per year while renewable plants may also shut down for maintenance and unforeseeable incidents.

2. IDENTIFICATION OF APPLICATIONS

Applications outside the steam power cycle have been investigated for easy integration of thermal energy storage (TES) and were assessed using the analytical hierarchy process. These are i) process steam backup, ii) auxiliary boiler replacement and iii) mill preheating, with the former being the most promising application: Process steam back up boilers are most often kept running at minimum load to rapidly ramp up during shutdown in order to provide non-interruptible steam supply. This operation causes high fuel consumption and an increase in steam generation costs. The developed TES may allow these auxiliary boilers to go into warm load where no steam is actively produced. The TES then bridges the gap between plant shutdown and auxiliary boiler start up by supplying the process steam.

3. MATERIAL SELECTION AND DEMONSTRATION PLANT

Various metals and alloys in the range of 250 – 550 °C for direct steam generation have been characterized and tested against three steel types in regards to cyclic stability. Ten suitable alloys were found with proven cyclic stability for at least 1,000 cycles.

A demonstration plant has been built using a PCM with a phase change temperature of 381 °C and 1 ton of storage material. The TES is designed to supply superheated steam above 296 °C at 44 bar for 20 minutes. The plant has been characterized using Design of Experiment (DOE) methodology.

4. PROCESS SIMULATION AND ANALYSIS OF TECHNOLOGY POTENTIAL [2]

Process simulations were carried out in Aspen Plus Dynamics to investigate the integration of the TES into actual steam grids the implications thereof. Research was conducted on industrial parks in Germany to gain a representative database. It has been found that the TES improves process stability and the steam disruption caused by the shutdown can be compensated by 75 to 92 %.

In the analysis of potential a profitability analysis was carried out, taking fuel types into account as well as commodity price trends, CO_2 costs and capital-bound power plant costs. Savings are generated mostly by an increase in cogenerative operation of the power plant. On the contrary side are material, manufacturing and integration costs. The difference in levelized costs of energy with and without TES integration gives the achieved savings. It has been found that for all fuel types the amortization period is less than three years (apart from non-feasible oil plants with gas-fired auxiliary boilers).

The results of the material investigations, demonstration plant test executions, process simulation and analysis of potential are to be shown in this presentation.

5. REFERENCES

[1] Komogowski L, Faust E, Beer S, Hummel D, Behrens D, Riedl K, Wolf G, Prabhu SD. Metallischer Latentwärmespeicher zur Flexibilisierung industrieller Heizkraftwerke. VGB PowerTech 2019; 11, 48-54

[2] Heim S, Komogowski L. Analysis of Technology Potential of a Metal‐based Latent Heat Storage for Backup Process Steam Supply. Chemie Ingenieur Technik 2021; 93(4), 605-617

6. CONFERENCE TOPIC

- Recent advances and breakthroughs in energy storage
- Application of energy storage through integration with renewable generation and energy networks

Numerical Research on Off-design Characteristics of Multistage Axial Flow Compressor in Compressed Air Energy Storage System

Pengfei Li[1,2], Zhitao Zuo[1,2,3], Jingxin Li[1], Wenbin Guo[1], Haisheng Chen[1,2,3]

[1] Institute of Engineering Thermophysics, Chinese Academy of Sciences;
[2] University of Chinese Academy of Sciences;
[3] National Energy Large Scale Physical Energy Storage Technologies R&D Center of Bijie High-tech Industrial Development Zone;

lipengfei@iet.cn; zuozhitao@iet.cn; lijingxin@iet.cn; guowenbin@iet.cn; chen_hs@mail.etp.ac.cn

Keywords: Multistage axial flow compressor; Variable rotational speeds; Overall aerodynamic performance; Inlet parameters; Energy conversion

Abstract: Axial flow compressors in compressed air energy storage (CAES) system often operate in variable working conditions and need to ensure stable and efficient operation. The rotational speed adjustment can effectively expand the stable working range and improve the performance under variable working conditions. In this study, a five-stage axial flow compressor for certain CAES system is taken as the research object, and the numerical calculation of variable rotational speed characteristics is carried out by NUMECA three-dimensional calculation software. The effect of rotational speed change on overall aerodynamic performance is first investigated, and the results show that rotational speed adjustment increases the working flow range from 11.5% to 54%, and the pressure ratio and efficient working range are effectively widened; the maximum efficiency operation curve of the compressor with variable rotational speeds gives the highest efficiency value of the compressor under different discharge pressures, which provides a practical guidance for the efficient operation of the compressor. Then, the influence of rotational speed change on the inlet parameters is studied. The results show that the relative Mach number and relative airflow angle at the inlet of the first stage rotor increase uniformly with the rotational speed increasing; the comprehensive map of the inlet parameters gives the reasonable distribution range of the inlet parameters and the distribution of the inlet parameters at near-highest efficiency point, which provides a practical guidance for the stable operation of the compressor. Finally, the changing laws of compressor blade surfaces normalized static pressure, meridional view entropy and rotor blade surfaces limiting streamlines are studied under different rotational speeds. The results show that with rotational speed increasing, the pressurization ability of the blades gradually improves, the reverse pressure gradient of the main channel enhances; the boundary layer in the end wall area thickens, and the entropy value increases; the leakage flow at the tip of R3 gradually intensifies, the flow at trailing edge of the suction surface gradually separates, and the angular vortex intensity near the hub area gradually increases. By analysing the variable rotational speed characteristics of the compressor, this study can provide a practical guidance for the stable and efficient operation of the axial compressor in CAES system.

APPENDIX A

Intrusion-extrusion of non-wetting liquids into-from nanopores for thermomechanical and thermoelectrical energy storage/conversion

Mehdi Hashemi-Tilehnoee [1], Nikolay Tsirin [2], Victor Stoudenets [2], Yuriy G. Bushuev [3], Mirosław Chorążewski [3], Mian Li [4], Dan Li [5], Juscelino B Leão [6], Markus Bleuel [6,7], Paweł Zajdel [8], Elena Palomo Del Barrio[1,9], Yaroslav Grosu [1,3,*]

1 Centre for Cooperative Research on Alternative Energies (CIC energiGUNE), Basque Research and Technology Alliance (BRTA), Alava Technology Park, Albert Einstein 48, 01510 Vitoria-Gasteiz, Spain. ygrosu@cicenergigune.com
2 Laboratory of Thermomolecular Energetics, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Pr. Peremogy 37, 03056 Kyiv, Ukraine
3 Institute of Chemistry, University of Silesia, Szkolna 9, 40-006 Katowice, Poland
4 Department of Chemistry, Shantou University, Guangdong 515063, China
5 College of Chemistry and Materials Science, Jinan University, Guangzhou 510632, China
6 NIST Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA
7 Department of Materials Science and Engineering, University of Maryland, College Park, Maryland 20742-2115, USA
8 Institute of Physics, University of Silesia, 75 Pułku Piechoty 1, 41-500, Chorzów, Poland
9 Ikerbasque, Basque Foundation for Science, 48013 Bilbao, Spain

Keywords: Liquid Piston, Molecular Spring, Compressed Air Energy Storage, Intrusion-Extrusion, MOFs

1. INTRODUCTION

Intrusion(wetting)/extrusion(drying) of liquids in/from lyophobic nanoporous systems is key in many fields, including thermomechanical-to-electrical energy conversion [1], thermal actuation [2], negative compressibility [3] and sensing [4]. Here we study intrusion-extrusion for thermomechanical energy storage within the liquid piston technology.

2. MATERIALS AND METHODS

{Cu_2(tebpz) + H_2O} system was explored *via* high-pressure intrusion-extrusion cycling, *in situ* neutrons scattering, MD and CFD simulations.

3. RESULTS AND DISCUSSION

Liquid piston is a method for pressure transmission used in a wide range of technologies. Currently, liquid piston is a passive element solely used to apply pressure to a working body. In this work, we propose the concept of liquid piston based on intrusion-extrusion – an active element, which can store a considerable amount of mechanical energy, apart from its main function, which is pressure transmission. Using compressed air energy storage (CAES) as a case study, we demonstrate that energy density for this technology can be enhanced more than 3 times by replacing water with a water-based molecular spring – Fig 1. Additionally, intrusion-extrusion liquid piston improves thermal management of CAES systems, enables narrow operational pressure ranges and provides an anti-vibration capability. The intrusion-extrusion liquid piston concept can be useful for a broad range of technologies, where pressure transmission is implemented through fluids.

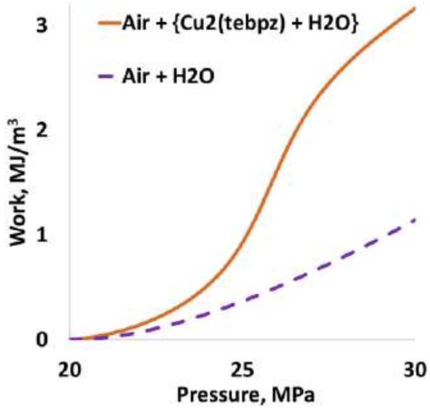


Fig. 1. Work stored in CAES system where H_2O or {Cu_2(tebpz) + H_2O} is used as a liquid piston

4. REFERENCES

[1] www.electro-intrusion.eu

[2] Chorążewski M et al. Compact Thermal Actuation by Water and Flexible Hydrophobic Nanopore ACS Nano 2021; 15: 9048-56.

[3] Tortora M et al. Giant Negative Compressibility by Liquid Intrusion into Superhydrophobic Flexible Nanoporous Frameworks ACS Nano Lett 2021; 21:2848-53.

[4] Anagnostopoulos A et al. Giant Effect of Negative Compressibility in a Water–Porous Metal–CO_2 System for Sensing Applications ACS Appl Mater Interfaces 2020; 12:39756-63.

5. CONFERENCE TOPIC

2.4: Recent advances in Thermo-mechanical energy storage science & technology

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Thermochemical energy storage using a packed bed reactor – experimental study and system level efficiency evaluation

Mingxi Ji [1], Yulong Ding [2]

1 Birmingham Centre for Energy Storage & School of Chemical Engineering, University of Birmingham, Birmingham, B15 2TT, UK, email address: mxj164@student.bham.ac.uk
2 Birmingham Centre for Energy Storage & School of Chemical Engineering, University of Birmingham, Birmingham, B15 2TT, UK, email address: y.ding@bham.ac.uk

Keywords: Thermochemical energy storage, packed bed reactor, gas-solid system, coefficient of performance

1. ABSTRACT

The thermochemical energy storage (TCES) technology has attracted more and more attention due to its high energy density and suitability for domestic space heating. TCES is often badged for long-term energy storage, but it can also serve for medium and short-term applications. Although significant efforts have been made over the past decade or so, TCES technology remains at a low level of technology readiness. There are various technological challenges existing across TCES materials, devices, and systems, respectively. Here we report an experimental study on a gas-solid packed-bed based TCES system using water-sorbent pair with a rated capacity of 7.5kWh as shown in Figure 1. Both pure sorbent (silica gel) and a composite thermochemical material (magnesium sulphate salt with silica gel matrix) were studied. Although the experimental system was designed as a closed system, the experiments were mostly done with the system operated as an open cycle due to long charging/discharging processes. Figure 2 shows typical temperature profiles at different positions of the packed bed reactor as a function of time in the charging and discharging process, which provide information on the charging / discharging kinetics. Figure 2 also shows a temperature lift of ~30°C in the discharging process with the outlet temperature suitable for underfloor heating applications. Figure 3 indicates the temperature profiles at the same operating conditions during charging and discharging but using pure sorbent silica gel only. By comparing the results for both pure sorbent and composite materials, composite thermochemical materials illustrated a higher temperature lift during discharging process and shorter charging time during the charging process. Hence, it is more promising and appropriate for further application in space heating or domestic hot water supplement. Besides, one result shows efficiency of over 85% in the charging process, which is significantly higher than the discharging process efficiency of ~40% with the latter likely due to incomplete discharge and experimental system insulation. By using the charging and discharge efficiency data, one works out the overall system efficiency, which is often called the system-level coefficient of performance (COP) of 35%. In addition, we also investigated the effect of varying working fluid flowrate on the system level efficiencies, summarised in Table 1. We concluded that a higher working fluid flowrate indicates a higher system level. Finally, a discussion on the enhancement of the system efficiency is made and further improvement on the system aspect was suggested.

2. TABLES

Table 1: Coefficient of performance variation for various working fluid flowrate

Coefficient of Performance (%)	Working fluid flowrate (litre per min)
35	1650
17	1100
9	550

3. EQUATION

$$\text{Charging efficiency} = \frac{Q_{charging}}{Q_{input-charging}} = \frac{Q_{desorption}}{Q_{heater} + P_{Fan}} = \frac{m(h_{out,cha} - h_{in,cha})}{m(h_{out,heater} - h_{in,heater}) + P_{Fan}} \quad \text{(eq.1)}$$

APPENDIX A

$$\text{Discharging efficiency} = \frac{Q_{discharging}}{Q_{input-discharging}} = \frac{Q_{adsorption}}{Q_{desorption} + P_{Fan}} = \frac{m(h_{out,dis} - h_{in,dis})}{Q_{desorption} + P_{Fan}} \qquad \text{(eq.2)}$$

$$COP = \frac{Q_{adsorption}}{Q_{total\ input}} = \frac{Q_{adsorption}}{Q_{desorption} + P_{Fan,charging} + P_{Fan,discharging}} \qquad \text{(eq.3)}$$

4. FIGURES

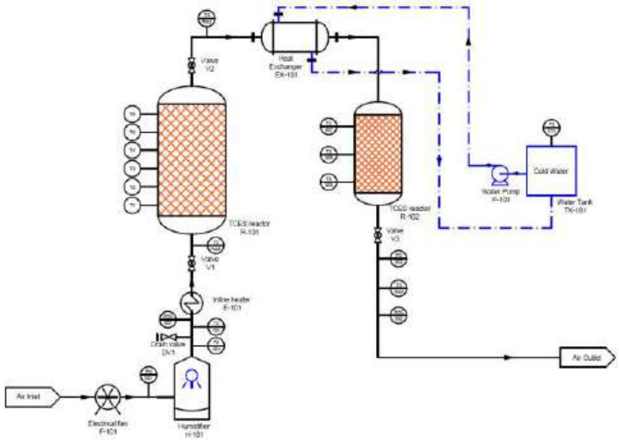
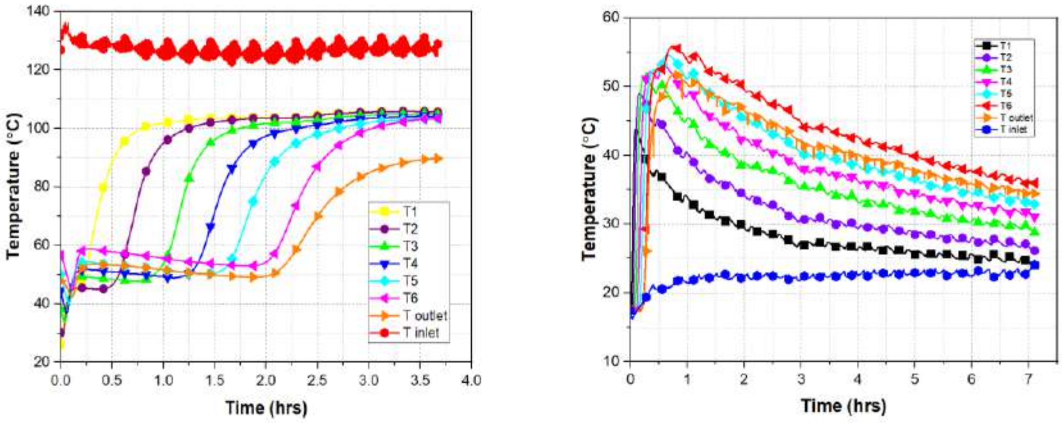
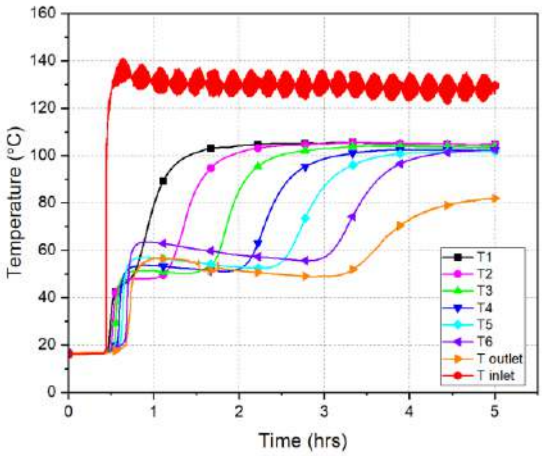


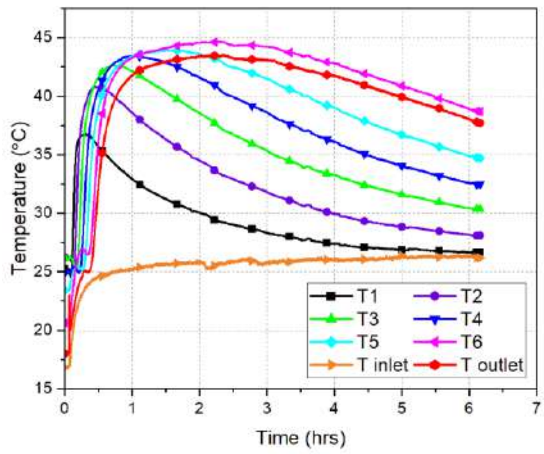
Figure 1: Schematic diagram of gas-solid packed bed TCES system



(a) **(b)**

Fig 2: Experimental results for the TCES system using composite thermochemical material (a) Charging process (b) Discharging process





(a) **(b)**

Fig 3: Experimental results for the TCES system using pure sorbent (a) Charging process (b) Discharging process

5. CONFERENCE TOPIC

Energy storage for decarbonization of heating and cooling

Green sorption materials for thermochemical energy storage

Maryam Roza Yazdani

1 Department of Mechanical Engineering, Aalto University, Espoo 02150, Finland

Keywords: Thermochemical energy storage; hydration-dehydration reaction heat; salt hydrates.

1. INTRODUCTION

Thermochemical energy storage (TES) utilizes sorption-desorption reactions between a sorbent and a sorbate to reversibly store and release energy. TES can store energy approximately 2-10 times higher over sensible or latent thermal energy storage via a more compact system and for a longer time. Heat is charged into the system to separate the sorbate (usually water) from the sorbent via endothermic desorption reactions. The recombination of these components causes a heat discharge via exothermic sorption reactions. Salt hydrates have high energy densities reaching up to 3.12 GJ.m^{-3} for water/space heating (<100 °C), based on reversible hydration-dehydration reactions as follows:

$$Salt.xH_2O\ (s) + Heat \leftrightarrow\ Salt + xH_2O \qquad \text{(eq. 1)}$$

Salts´ high affinity towards water molecules, however, causes deliquescence, the formation of saturated solutions at high relative humilities. Deliquescence and consequent swelling and agglomeration of the salt particles cause severe mass transfer barriers and vapor penetration leading to low levels of energy charging and discharging and low cycling stability for long-term operation of TES. The impregnation of salts within the porous matrices can prevent salts´ dissolution and agglomeration issues. As such, herein, inexpensive $CaCl_2$ has been impregnated in porous carbon for TES.

2. MATERIALS & METHODS

Porous carbon was produced via pyrolysis of wood under nitrogen gas condition. Wood was used as the source biomass because it is a common product of forestry and easily accessible worldwide. The composite was prepared via vacuum impregnation method. Three different ratios of salt to biocarbon as 70/30, 65/35, and 60/40 wt% were prepared and characterized by scanning electron microscopy (SEM) and simultaneous thermal analysis (STA).

3. RESULTS & DISCUSSION

SEM (Fig 1) confirmed a successful impregnation through pore filling mechanism. The surface area of the pure biocarbon was 600 m^2/g that was reduced to around 60 m^2/g after salt impregnation into the pores. The compositions showed no leakage or agglomeration of the salt while still providing high energy storage density. STA recorded the storage capacity of hydration-dehydration reactions, which reached up to 1 kJ/g of charging and discharging heat. These results show the potential of salt-impregnated biocarbon as a green energy storage material.

4. REFERENCES

[1] Aydin, D., Casey, S. P., Riffat, S., The latest advancements on thermochemical heat storage systems, Renew. Sustain. Energy Rev. 41, 2015, 356-367.

5. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

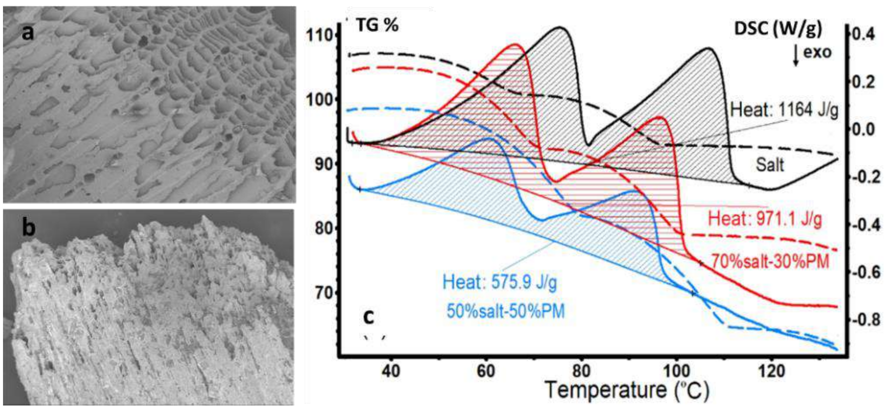


Fig 1. Microscopic images of a) porous carbon and b) impregnated salt-carbon composite as well as STA plot.

Composite nitrogen carrier based chemical looping ammonia synthesis for thermochemical hydrogen storage

Sijun Wang, Feng Gong*, Rui Xiao

Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, 2# Sipailou, Nanjing, China
Email: gongfeng@seu.edu.cn (Feng Gong*)

Keywords: Chemical looping; Ammonia synthesis; Composite nitrogen carrier; Density functional theory

ABSTRACT

Ammonia is a safe and efficient energy carrier for the storage and transportation of hydrogen energy. Chemical looping ammonia synthesis (CLAS) is expected to facilitate the utilization of hydrogen energy and achieve decarbonized ammonia synthesis under mild conditions. However, the competition reactions between N_2 activation and NHx (x=0 to 2) conversion on single active site during ammonia synthesis still hinder the fast ammonia generation in CLAS. The nitrogen carriers with dual active sites may overcome the above challenge, which has attracted incremental attention. Here, we developed a facile and novel nitrogen carrier based on nickel-loaded chromium nitride (Ni-CrN) with dual active sites for CLAS, which obtained high stability in the atmosphere. The systematic studies indicate that the intrinsic CrN is extremely inert, and the conversion of lattice nitrogen is difficult with an average ammonia generation rate of ~82.1 umol g^{-1} h^{-1} (700 °C, 1 atm). Upon loading nickel, the Ni-CrN carrier achieved the enhanced performance with the ammonia production rate of 611.1 umol g^{-1} h^{-1} under H_2/N_2 atmosphere. Furthermore, when the composite carrier was used for CLAS, an average ammonia generation rate of ~640 umol g^{-1} h^{-1} could be obtained for 10 chemical looping. Density functional theory (DFT) calculations revealed that nitrogen vacancies were easily generated on Ni-CrN with a formation energy of 0.53 eV. It was also found that the doped nickel acted as active sites for H_2 dissociation. The dissociated H atoms were capable of attacking the lattice nitrogen of CrN to generate NH_3 and thus nitrogen vacancies, which play as effective adsorption and activation sites for N_2 fixation through the Mars–van Krevelen mechanism. This work reports a novel avenue for the development of efficient nitrogen carrier for CLAS with synergistic dual active sites.

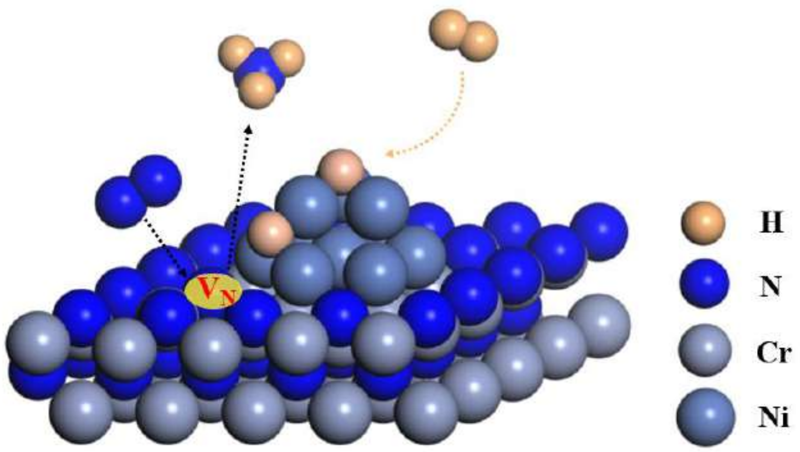


Fig. 1 Structure and reaction mechanism for ammonia synthesis over Nickel-loaded chromium nitride

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Performance maximization of thermochemical energy storage reactors through topology optimization

Gabriele Hubert [1], Adriano Sciacovelli[1]

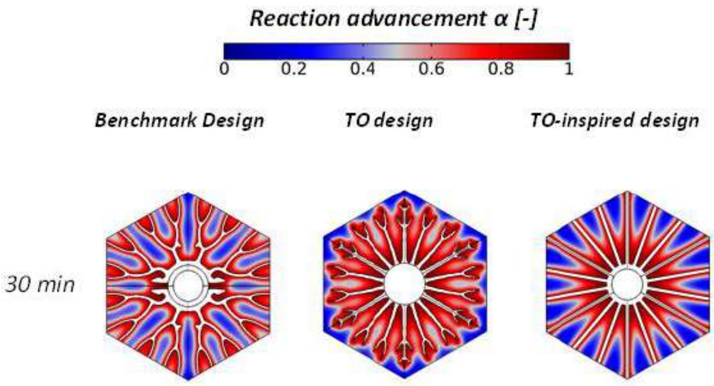
1 Birmingham Centre for Energy Storage, School of Chemical Engineering, University of Birmingham, Birmingham, United Kingdom .

Keywords: thermochemical energy storage; thermal energy storage; optimization

1. INTRODUCTION

Heating and Cooling (H&C) is the single largest source of energy demand and CO_2 emissions in Europe (51% of total EU demand), with residential buildings accounting for 45% of the final H&C consumption (~2500 TWh/y). They still however mainly rely on fossil fuels. Renewable energy sources (RES) utilization in the H&C sector remains marginal (9%). To unlock massive Renewable energy (RES) utilization, studies unequivocally point out that TES needs to be integrated into buildings for various purposes [1]: short-duration peak shifting, long-duration storage of RES, flexible operation of multiple RES sources and coupling of buildings with the wider electricity grid. Thermochemical energy storage system (TCS) is among the most promising TES options to increase the use of renewable energy sources in future energy scenarios. However, the full exploitation of the thermochemical materials' potential is hampered by their poor heat and mass transfer properties and whin remains to be solved through development of novel components, devices and reactors.

2. TOPOLOGY OPTIMIZATION FOR THERMOCHEMICAL ENERGY STORAGE REACTORS



Enhancing performance of TCS reactor has been an obvious target over the last years; However, this has been historically pursued by means of traditional heat exchangers design methods and configuration leading to limited performances. overcome this limitation, our research explores the use of topology optimization as a design tool to identify novel configuration that could intensify heat transfer in TCS reactors beyond what proposed so far. Topology Optimization (TO) is indeed a form-finding methodology that aims at answering the engineering question [2,3] : *'how should we place a material so that the device performance is maximized?'*. Compared to conventional optimization methodologies, TO presents the advantage of design freedom, as no initial design guesses are required and the design is free to evolve towards its optimal configuration along the optimization iterations.

3. NOVELTIES AND CONTRIBUTIONS

Compared to the existing literature, the research reported here presents a radically different approach to discover new design and TCS systems configurations, it allows for the systematic generation of non-intuitive, higher performance reactor configurations that outperform existing solutions. The emerging design trend can be used to derive guidelines for the effective configuration of fit-for-purpose TCS reactors with superior performance, ultimately contributing to technological advancements in the field of TCS systems. Further the contribution provides The contribution provides an overview on the topic, the state of knowledge and outlines the latest progress in this field of research.

4. REFERENCES

[1] Zhang X, et al . Values of latent heat and thermochemical energy storage technologies in low-carbon energy systems: J of Energy Storage. 2022;50:104126.

[2] Pizzolato A, et al Maximization of performance in multi-tube latent heat storage–Optimization of fins topology, effect of materials selection and flow arrangements. Energy. 2020 Jul 15;203:114797.

[3] Humbert G, et al. Combined enhancement of thermal and chemical performance of closed thermochemical energy storage system by optimized tree-like heat exchanger structures. Applied Energy. 2022 Apr 1;311:118633.

Study of $CaCl_2$ charge cycle investigating the interaction between the charging temperature and the flow rate for thermochemical heat battery applications.

Dr. Bahaa Abbas, Dr. Jonathon Elvins, Dr Eifion Jewell, Dr Justin Sealer
1 College of Engineering, Swansea university, B.H.A.Abbas@Swansea.ac.uk
2 College of Engineering, Swansea university, Jonathon.Elvins@Swansea.ac.uk
3 College of Engineering, Swansea university,E.Jewell@Swansea.ac.uk
4 College of Engineering, Swansea university, J.R.Searle@Swansea.ac.uk
Keywords: thermochemical storage; thermal power; heat battery; hydrated salt

1. INTRODUCTION

In the last decade, the demand for heat supplied by renewable energy has significantly increased with a number of technologies providing alternatives to the traditional fossil fuels for the provision of space heating. The new systems are targeting the reduction in CO_2 emissions to combat the ongoing climate change crisis. Thermochemical heat storage is a promising alternative as a new heating source to meet the target set by several nations worldwide to reduce CO_2 emissions within the heating sector. The long-term seasonal heat storage with minimal energy loss are the main aspects for considering the thermochemical heat application as a future replacement for gas heating [1]

The study aimed to evaluate the performance of the composite materials of calcium chloride deposited to vermiculate in 2:1 ratio in a thermochemical storage system. Precisely, it aimed to identify and understand the relationship and interaction between the charging temperature and flow rate applied during the charging process. The findings would help to determine the cycle charging requirement in terms of the amount of usage of material. In this study, a humidity generator combined with computer and data collection software used to create a simulation to the seasonal ambient condition to apply a specific setting for each run and for data collection. The humidifier was set for every run with the parameters present in Table 1.

Table 1

	Discharge Cycle 10 hours	Charge Cycle16, 32 hours
Relative Humidity (%)	65%	5%
Temperature (°C)	20°C	100/70/40 °C
Flow rate (LPM)	30 LPM	30/50 LPM

As volumetric air flow rate, air temperature and relative humidity can be controlled by humidifier, repeatable conditions were delivered to the heat battery and a schematic drawing of the reactor is shown in figure 1

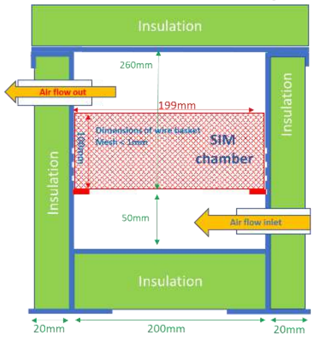


Figure 1

2. REFERENCES

[1] S. Walsh *et al.*, "Assessing the dynamic performance of thermochemical storage materials," *Energies*, vol. 13, no. 9, 2020, doi: 10.3390/en13092202.

Conference Topic

2nd world energy storage conference and 7th uk energy storage conference

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Mine water geothermal heat storage: building upon a legacy

Julien Mouli-Castillo[1], Jeroen van-Hunen [2], Charlotte Adams[3], Tom Sear[4]

1 Durham University Julien.mouli-castillo@durham.ac.uk
2 Durham University Jeroen.van-hunen@durham.ac.uk
3 The Coal Authority
4 Durham University

Keywords: Mine water heat storage, Geothermal, Numerical modelling, Decarbonising heat

1. INTRODUCTION

Worldwide, greenhouse gas (GHG) emissions from energy use in buildings accounts for 17.5% of total emissions. These emissions are mostly linked to the need for heating and cooling. This is compounded by the current rise in the cost of energy has highlighted the value of reliable, endemic sources of energy, and storage. On such form of energy is mine water geothermal heat (MWGH). This resource's sustainability, however, is only as good as its proper management. This includes an important storage element. The poor understanding of the artificial mine working interaction with the natural environment makes the investment in these projects risky compared to other alternatives. Our research addresses this problem by developing a numerical modelling tool designed to provide greater insight and help quantify the risk at a feasibility stage.

2. MATERIAL AND METHODS

Our method combines numerical and analytical approaches with digitised legacy mine data to estimate the variations in the abstraction water temperature over the lifetime of a project. Namely, we couple the heat transfer approximation method originally proposed by Rodriguez and Diaz (2009) to that of flow in a pipe network as described by Todini and Pilati (1987). We refine the original heat transfer approximation by accounting for flow regime specific heat transfer coefficient between the rock mass and the water, as prescribed by Loredo et al. (2017). Finally, we develop a novel weighting function to account for the interference between the galleries, an aspect which is overlooked in previous work, and leads to overestimated abstraction temperatures.

3. RESULTS AND DISCUSSION

Of particular interest to this conference, we have the capacity to simulate periods where the mine is being re-charged with warmth or coolth. We will present what the purpose of the model is, how it is designed, and some preliminary results we have obtained. Specifically, results of a scenario showing thermal breakthrough, compared to one which doesn't due to the storage of heat. The effect of interference will also be presented.

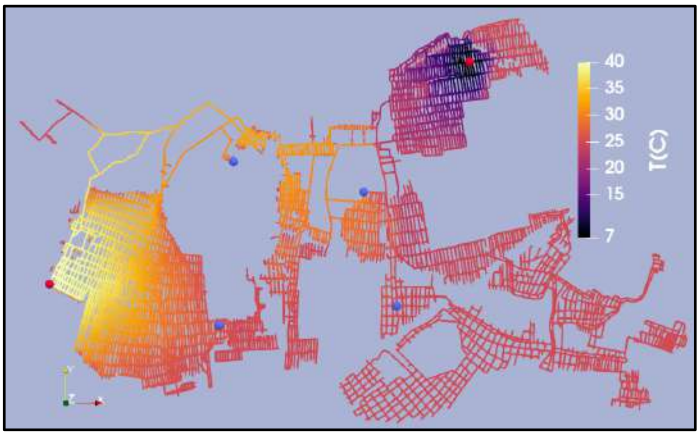


Figure 1: Mine workings beneath Durham University. Red dot represent injection points (one hot, one cold) and the blue dots abstraction points. The model is about 3 km across.

4. REFERENCES

[1] Rodriguez R and Díaz M. Analysis of the utilization of mine galleries as geothermal heat exchangers by means a semi-empirical prediction method. Renewable Energy 2009; 34(7), 1716-1725.

[2] Todini E and Pilati S. A gradient method for the analysis of pipe networks. Computer app. In water supply 1987; 1-20, v1.

[3] Loredo C, Banks D, Roqueñí N. Evaluation of analytical models for heat transfer in mine tunnels. Geothermics 2017; 69; 153-164.

5. CONFERENCE TOPIC

Energy storage for decarbonisation of heating and cooling – Presentation preferred.

APPENDIX A

Nanoencapsulation of Phase Change Materials with Metallic Shell Materials for Solar Thermal Energy Harvesting and Conversion Applications

Oguzhan Kazaz[1], Nader Karimi[1, 2], Shanmugam Kumar [1], Gioia Falcone[1], Manosh C. Paul[1*]

[1]Systems, Power & Energy Research Division, James Watt School of Engineering, University of Glasgow, Glasgow, G12 8QQ, UK, o.kazaz.1@research.gla.ac.uk, Msv.Kumar@glasgow.ac.uk, Gioia.Falcone@glasgow.ac.uk
[2]School of Engineering and Materials Science, Queen Mary University of London, London, E1 4NS, United Kingdom, n.karimi@qmul.ac.uk
[*]Corresponding author: Manosh.Paul@glasgow.ac.uk

Keywords: Nano-encapsulated phase change materials (PCMs), direct absorption solar collector (DASC), heat transfer enhancement, thermal energy conversion, solar energy

As a carbon neutral energy source, solar energy is one of the most effective non-conventional energy sources that can reduce environmental pollution, alleviate the energy crisis, and prevent the fluctuations in fossil fuel prices. In order for solar energy to be used by converting it into useful energy forms, it is necessary to use solar collectors, which act as a heat exchanger in the conversion of solar radiation into thermal energy. Conventional heat transfer fluids (HTFs) such as water or nanofluids are widely used in solar thermal systems. These HTFs, however, store energy as a sensible due to their low specific heat capacities and the absence of phase change, and this storage capacity is limited. Being able to avoid this, the use of latent functional thermal fluids (LFTFs) formed by the PCMs with the base fluid as HTF improves the heat transfer performance of the collector as it provides both sensible and latent heat storage.

In this work, it is the first example of the investigation of LFTF under flow conditions in DASCs using a new type of fluid. The velocity of the HTF is one of the most important factors affecting the photo-thermal conversion performance by being affected by the flow conditions in the solar collectors. The paraffin based PCM is encapsulated in nanoscale with metallic shell structures and dispersed into the water. The analysis of flow and heat transfer in the collector is carried out using Computational Fluid Dynamics. The radiative transport equation including emitting, absorbing, and scattering factors is solved using the Discrete Ordinates (DO) method. The results reveal that the metallic shell materials provide the formation of absorption peak by stimulating the plasmon resonance by creating a vibration frequency with the free electrons they have when exposed to sunlight. The peaks become more pronounced with increasing thickness size. In addition, increasing particle size causes a decrease in the surface area of the core/shell structure by increasing the particle volume, resulting in agglomeration of the capsules dispersed in the HTF and creating larger particles, reducing both the temperature and enthalpy gain of the HTF. Besides, the addition of nanoparticles to the LFTF decreases the thermal performance of the HTF by reducing the outlet temperature of the HTF, as it allows more sunlight to be absorbed by the hybrid LFTF around the upper wall. It is discovered that although the amount of solar radiation collected by the collector enhances by increasing the collector length, the heat loss to the environment increases as the top wall temperature of the collector increases. Furthermore, as the increase in the collector height at a fixed collector length reduces the solar radiation reaching the depths of the collector, the HTF absorbs the radiation more around the top wall, thus decreasing the outlet temperature of the HTF. Moreover, the obtained results clearly indicate that the use of LFTF in this system, where the fluid is used both as energy storage medium and as HTF, increases the photo-thermal conversion performance.

Conference topic: Recent advances and breakthroughs in energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Decarbonising heat by storing curtailed wind energy in long-term thermal energy storage

Andrew Lyden[1], Lukas Franken[2], Thibaut Desguers[3], Daniel Friedrich[4]

1 School of Engineering, Institute of Energy Systems, University of Edinburgh. andrew.lyden@ed.ac.uk
2 School of Engineering, Institute of Energy Systems, University of Edinburgh. lukas.franken@ed.ac.uk
3 School of Engineering, Institute of Energy Systems, University of Edinburgh. thibaut.desguers@ed.ac.uk
4 School of Engineering, Institute of Energy Systems, University of Edinburgh. d.friedrich@ed.ac.uk

Keywords: Long-term thermal energy storage; Smart energy systems; Energy system modelling

1. ABSTRACT

Wind farms are increasingly being curtailed in the UK and offer a potential source of low-cost and low-carbon electricity to technologies which can respond flexibly. Long-term thermal energy storage can act flexibly and use curtailed wind to decarbonise heating networks in conjunction with power-to-heat technologies such as heat pumps and direct electric heaters. This research has modelled a long-term thermal energy storage integrated with both a district heating network and the wider electricity network to investigate the ability of long-term thermal energy storage technologies to respond to curtailment events.

Curtailment of renewable generation occurs due to network constraints and mismatch in generation and demand. The Scotland-England boundary is often constrained due to proportionally high wind production in Scotland and high electrical demand in England. Data from National Grid indicates that this boundary was constrained for 11% of the time over 2021. Taking an average across 10 large-scale wind farms near to the Scotland-England boundary finds that each onshore wind farm was curtailed for around 700 hours over 2019 with a curtailment cost of around £65/MWh with total curtailment of 2.04 TWh. In the near future (2030) and toward net zero pathways (2040, 2050) wind curtailment events will be more common as more wind farms are installed.

Long-term thermal energy storage can utilise this curtailed wind energy. This stored heat can then provide low-carbon heat to a district heating network. Three common types of long-term thermal storage are in use: - borehole thermal energy storage require suitable geological conditions – drillable ground, favourable groundwater, high heat capacity, and thermal conductivity; aquifer thermal energy storage require suitable geological conditions – natural aquifer layer, confining low-permeability layers, no or low groundwater flow, suitable water chemistry; and tank thermal energy storage and pit thermal energy storage have high land requirements, but borehole and aquifer thermal energy storage have lower land requirements.

Analysis is carried out in two steps: - scenario analysis to optimise operation and size of components using historical data; and impact of future wind curtailment using a discount based on the curtailed wind energy output from future energy scenario transmission network modelling. Both linear optimization and a detailed TRNSYS model are used to undertake the modelling and optimization of the long-term thermal energy storage and district heating network and generation units, while a wider electricity transmission network model is used to model curtailment in future years. There is a requirement for access to a market mechanism to enable a discount for responding to wind curtailment events, e.g., participating in the balancing mechanism.

This work shows many benefits of long-term thermal energy storage using curtailed wind:

1) Lower total heating system costs and carbon emissions for the delivery of low-carbon heat in district heating.

2) Network operators can benefit from reduction in constraint payments to wind farms.

3) Lower network upgrade costs, offset by greater flexibility of operating heat pump/direct electric heating due to long-term thermal energy storage.

2. CONFERENCE TOPIC

- Application of energy storage through integration with renewable generation and energy networks
- Energy storage for decarbonisation of heating and cooling

Modelling solar-powered diffusion absorption machines to meet building cooling and heating demand

Ebbah EA[1], Elvins J [2], Jewell EH[3],

1 Swansea University, 853875@swansea.ac.uk; 2 Swansea University, jonathon.elvins@swansea.ac.uk
3 Swansea University, e.jewell@swansea.ac.uk

Keywords: Building energy, TRNSYS, energy storage, Diffusion-absorption machine, solar cooling and heating.

1. INTRODUCTION

The building sector accounts for 30% of global final energy consumption and 28% of global energy-related carbon dioxide emissions [1]. To evaluate using solar thermal collectors for both cooling and heating, building simulations were carried out using TRNSYS to calculate the building cooling and heating demand of a standard building in four climatically verifying locations in India, Tunisia, Russia, and the UK. Annual and hourly building cooling and heating loads were determined and compared to available solar power. Deficits were identified where there was a net daily energy demand and days where there was sufficient net energy. However, a temporal lag existed between the available solar energy and demand. Increased solar collector sizes and storage are explored as remedies to these deficits. Further exploration of the cooling machine material, design, and operational principles is proposed to determine concept feasibility. The work forms the basis of further studies examining the role of dwelling size, occupancy, use of local materials, and building techniques.

2. SIMULATING BUILDING ENERGY PERFORMANCE AND ENERGY STORAGE

TRNSYS is a transient energy system simulation program used to model a standard building with a floor area of 24.75 m^2 (5.5 m x 4.5 m) which complied with UK building standard in terms of wall, roof, and floor U values and 1.8 m^2 glass window opening. 60% of the roof space was allocated to solar collectors operating at 70%. The hot water generated was assumed to be used for direct building heating and as an energy source for a bespoke solar-driven diffusion absorption cooling machine, operating with an effective COP of 0.2. The aim in each instance was to assess the power required to keep the dwelling at 21 °C. Further investigation of the hourly and daily behaviour allows energy deficits to be characterised as those where the net daily energy is insufficient and days where sufficient energy is available. However, there is a lag between the demand and the supply. The number of deficit hours a day throughout the year for Swansea is shown in figure 1. The standard house has 291 days where there is an hourly deficit between the demand and the supply for heating. As expected, the daily deficit is more extensive in the winter and less in the summer. Parametric studies have been carried out to understand which remedies are practicable such that the real-world design envelope of the cooling engines can be estimated.

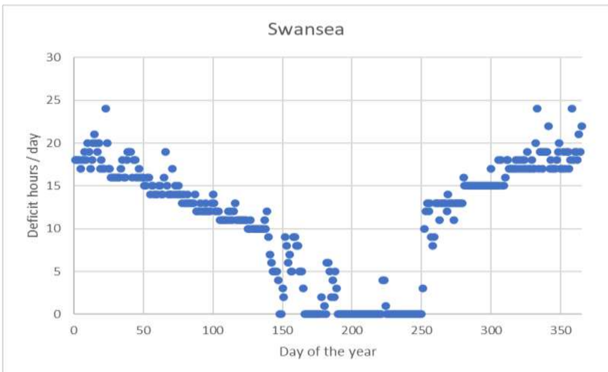


Figure 1. The number of deficit hours in a day through the year for Swansea

3. REFERENCES

[1] IEA. Buildings-Tracking Clean Energy Progress. 2019; https://www.iea.org/tcep/bildings (accessed 2022.09.01)

4. CONFERENCE TOPIC

Energy storage for decarbonisation of heating and cooling.

Coupling Thermochemical Energy Storage with Power-to-Heat to Increase Domestic PV Utilisation

Fisher R[1], Niknam P[2], Sciacovelli A[3]

1 University of Birmingham, Birmingham Centre for Energy Storage, r.fisher@bham.ac.uk
2 University of Birmingham, Birmingham Centre for Energy Storage, p.niknam@bham.ac.uk
3 University of Birmingham, Birmingham Centre for Energy Storage, A.sciacovelli@bham.ac.uk

Keywords: Thermochemical Energy Storage, Domestic PV, Power-to-heat, Inorganic Salts

1. ABSTRACT

Through thermochemical energy storage (TCS), heat can be stored with virtually no losses over the span of months. This feature of TCS makes it a highly promising technology to improve the performance of energy conversion technologies based on renewable energy sources, such as solar thermal or solar PV. TCS is generating interest as a means to increase the penetration of solar energy for domestic heating, by seasonally shifting thermal energy from periods of high solar availability (day time and summer time) to periods of low solar availability (night time and winter).

Many potential reactions are viable candidates to perform TCS. The reversible hydration and dehydration of inorganic salts takes place at a temperature range that makes it suitable for releasing heat for domestic heating. However, the temperatures reached with solar thermal but may not be sufficient to fully exploit the energy storage potential of these salts. Additionally, TCS is restricted to areas with high amounts of solar resources, yet in certain areas there is high demand for space heating combined with low sunlight. Furthermore, there is an increasingly acknowledged need for the electrification of energy systems, which can be achieved through so-called power-to-heat. All of these considerations, coupled to recent advances in electrically heated chemical reactors, could open the door to coupling TCS to power-to-heat, to enable the long-term storage of energy originally converted through solar PV.

In this article is studied the techno-economic potential of a novel PV/TCS system using power-to-heat as the intermediary energy converter. The study is carried out using a simple dynamic process model integrating solar PV, salt-based TCS and power-to-heat to a domestic family-sized building. The TCS in particular is modelled with a system of ordinary differential equations, which account for the thermo-physical properties of the selected thermochemical material (TCM). The overall model accounts for the intrinsic inefficiencies of the TCS related to the time-dependent behaviour of hydration/dehydration of salts, and offers a realistic view of the dynamic integration of the storage into a real system. Results show that while the PV system on its own can cover 17% of the space heating demand, a 10m^3 TCS with a resistance heater as power-to-heat component could enhance this by a further 11%. In a UK detached house, with assumed TCS costs of 20€/kWh, this system could achieve economic viability with levelized costs of energy around 300 €/MWh to 500 €/MWh depending on the overall heat losses of the building and the power rating of the PV system.

2. CONFERENCE TOPIC

Application of energy storage through integration with renewable generation and energy networks

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Ageing and energy analysis of a utility-scale grid-connected lithium-ion battery energy storage system for power grid applications with a data-driven modelling approach

Alberto Grimaldi [1], Francesco Demetrio Minuto [1], Andrea Lanzini [1], Alessandro Perol [2], Silvia Casagrande [2]

1 Politecnico di Torino-Energy Department, alberto_grimaldi@polito.it, francesco.minuto@polito.it, andrea.lanzini@polito.it
2 Edison S.p.A., alessandro.perol@edison.it, silvia.casagrande@edison.it

Keywords: Energy storage; Li-ion BESS; Grid-connected battery; Battery ageing; Battery storage system efficiency.

1. INTRODUCTION

The increasing penetration of Renewable Energy Source (RES) in the national energy mix requires more flexible power distribution networks to manage injections variability. Energy Storage Systems (ESSs) are becoming one of the most relevant technologies to effectively support RES deployment. In this perspective, there is a growing body of literature that recognises the importance in modelling the operation of large-scale battery energy storage systems (BESS) for power grid applications [1,2].

2. MATERIALS AND METHODS

The present paper proposes a detailed ageing and energy analysis based on a data-driven empirical approach of a real large-scale grid-connected Lithium-Ion Battery Energy Storage System (LIBESS) for providing power grid services. A large amount of LIBESS numerical models with different degrees of complexity can be found in literature [3], especially applied at single-cell level, and then scaled up to the complete BESS assuming that all cells behave equally. However, to derive a battery system model that can be of practical use in evaluating the services that a battery could provide in real market context and which remuneration could get in return, it is crucial to extrapolate actual system performance based on different operating conditions. To overcome this gap, this study aims to develop a data-driven model for battery performance and ageing based on real data provided by a LIBESS currently in operation.

The system under investigation is a real utility-scale LIBESS integrated with a multi-PV plant and connected to the Medium Voltage (MV) network, located in Southern-Italy. The ageing and energy analysis has been performed using data measured by the Supervisory Control and Data Acquisition (SCADA) system directly connected with the LIBESS. This large amount of data is collected in a specific cloud database and then elaborated using proper software tools.

3. RESULTS AND DISCUSSION

This experimental campaign applied on a commercial LIBESS covers the impact of degradation mechanisms, such as cycle and calendar ageing, the battery and global system efficiency as well as the role of auxiliaries' power consumption under real and power grid services operations. Thanks to the low complexity of the proposed data-driven model, it could be easily replicated in any other LIBESS facility, operating in both real-world and laboratory context.

The results of this analysis can be used by stakeholders or power plants managers to run the system at its optimal operating conditions to achieve maximum efficiency and minimal losses. Moreover, this data-driven model might help stakeholders to identify the most impacting key performance indicators (KPIs) of large-scale LIBESS during power grid services provision. Table 1 resumes the main topics discussed in each section. Figure 1 and figure 2 show some of the results obtained from ageing and energy analysis, respectively.

4. CONCLUSIONS

In the last section two case studies are presented to demonstrate the effective potential of this novel model. The selected electrical services are primary frequency regulation and energy arbitrage. Here, also economic aspects are considered within technical ones with the aim to understand how running the system and when to buy and sell (charge and discharge) energy while providing power network services. Typically, a LIBESS is often used to provide multiple energy and ancillary services for the electrical grid simultaneously. Thence, the adoption of a prioritization procedure to select the most efficient and remunerative service over a specific time horizon could help stakeholders to opt for the optimal control strategy.

5. TABLES AND FIGURES

Table 1: Article structure.

Section1	Introduction
Section 2	LIBESS Layout
Section 3	Methodology implemented to build the data-driven empirical model and description of applicative case studies
Section 4	Results. Ageing and energy analysis applied on both normal and power grid operations
Section 5	Results of the applicative case study (energy arbitrage and/or primary frequency regulation)
Section 6	Conclusions and foreseen next steps

APPENDIX A

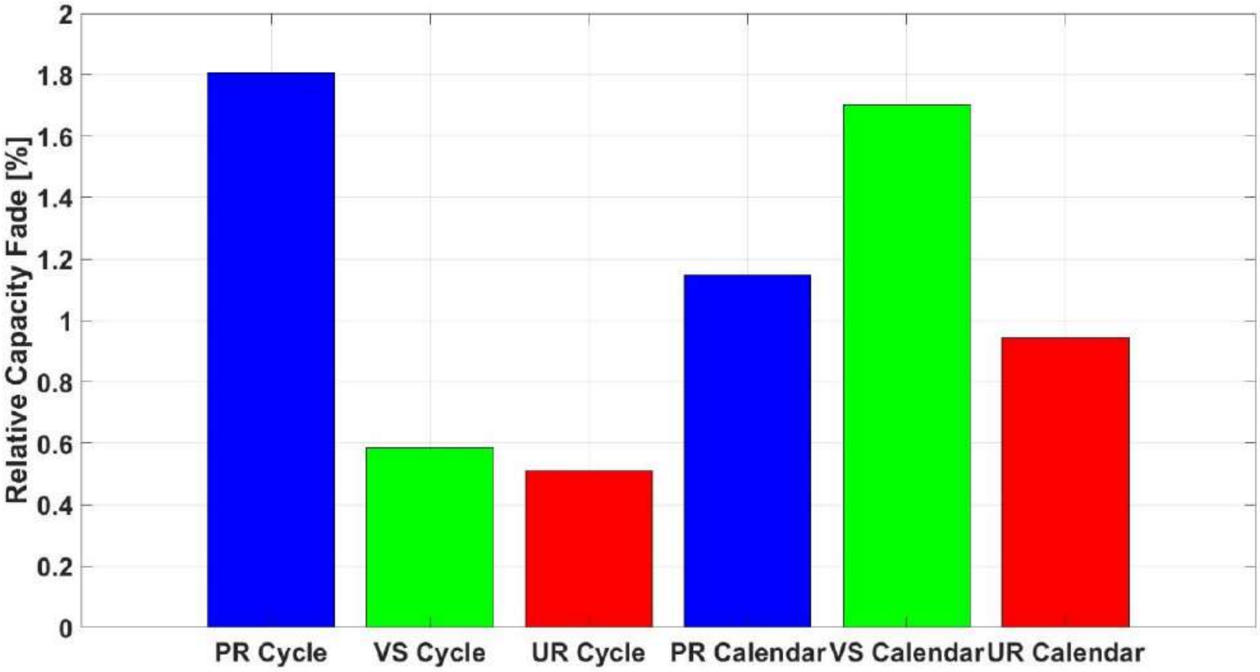


Figure 1: Cycle and Calendar Ageing applied on Primary Regulation (PR, blue bar), Voltage Support (VS, green bar) and Unbalances Reduction (UR, red bar) grid services. Time horizon simulated: 1 year.

Table 2: Numerical results of figure 1.

Electrical Services	Cycle Ageing Capacity Fade [%]	Calendar Ageing Capacity Fade [%]	Total Capacity Fade [%]	Full-Cycles Equivalent [FCE]
Primary Regulation (PR)	1.81	1.15	2.95	671.55
Voltage Support (VS)	0.58	1.70	2.29	144.79
Unbalances Reduction (UR)	0.51	0.94	1.45	159.77

APPENDIX A

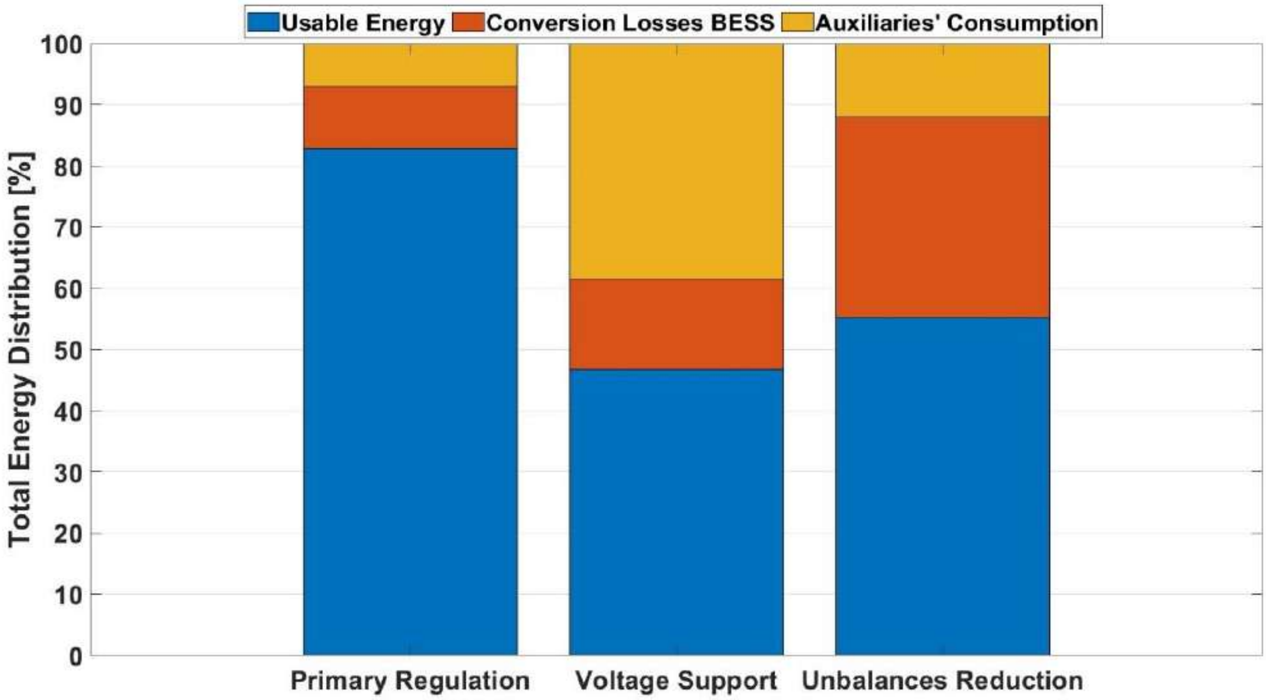


Figure 2: Total energy distribution of Primary Regulation (PR), Voltage Support (VS), Unbalances Reduction (UR) grid services. The total energy is distributed in usable energy (blue bar), conversion losses of BESS (red bar), auxiliaries' consumption (yellow bar).

Table 3: Numerical results of figure 2.

Electrical Services	Elapsed Time [seconds]	Usable Energy [%]	Conversion Losses BESS [%]	Auxiliaries' Consumption [%]
Primary Regulation (PR)	10598	82.72	10.16	7.05
Voltage Support (VS)	114638	46.71	14.82	38.47
Unbalances Reduction (UR)	85763	55.26	32.67	12.08

6. REFERENCES

[1] Rancilio G, Lucas A, Kotsakis E, Fulli G, Merlo M, Delfanti M, Masera M. Modeling a Large-Scale Battery Energy Storage System for Power Grid Application Analysis. Energies **2019**, 12(17), 3312. [CrossRef].

[2] Schimpe M, Naumann M, Truong N, Hesse HC, Santhanagopalan S, Saxon A, Jossen A. Energy efficiency evaluation of a stationary lithium-ion battery container storage system via electro-thermal modeling and detailed component analysis. Applied Energy 210 (**2018**), 211–229. [CrossRef].

[3] Vykhodtsev AV, Jang D, Wang Q, Rosehart W, Zareipour H. A review of modelling approaches to characterize lithium-ion battery energy storage systems in techno-economic analyses of power systems. J. Renewable and Sustainable Energy Reviews 166 (**2022**) 112584. [CrossRef].

7. CONFERENCE TOPIC

Application of energy storage through integration with renewable generation and energy networks.

Dimensionless numbers for the characterisation of thermal stratification and their application in 1-D models of hot water tanks

De la Cruz-Loredo I, Saleem A, Bastida H, Ugalde-Loo CE

School of Engineering, Cardiff University, Wales, UK

Keywords: Thermal energy storage, hot water tanks, thermal stratification, heating systems, dynamic systems modelling

Conference Topics: Energy storage for decarbonisation of heating and cooling.

Abstract

Hot water tanks are an economic solution to provide thermal energy storage (TES) capacity and operational flexibility to domestic heating systems. In turn, this flexibility may be used to support the demand-side management of the local thermal demand, bringing economic and environmental benefits to the end-users and system operators. To this end, the effective design of automatic controllers and energy management systems requires obtaining and simulating mathematical models that accurately reproduce the thermal-hydraulic behaviour of the thermal store. Although three-dimensional (3-D) models based on finite element analysis can be used to accurately simulate the fluid dynamics inside hot water tanks, simple one-dimensional (1-D) dynamic models are preferred due to their simplicity and reduced computational cost.

The conventional 1-D modelling approach for hot water tanks relies on the spatial discretisation of the volume within the TES unit to capture the effect of thermal stratification on the temperature transition of water. Due to the wide range of operating conditions, the extent of thermal stratification in a storage tank can vary during the charging and discharging operations. Therefore, the applicability of a given 1-D model may be restricted. A method to effectively characterise the extent of thermal stratification is required so that a 1-D tank representation can be adapted to a set of operating conditions to maximise its accuracy. Dimensionless numbers can be employed to provide further insight into the thermal performance of the thermal store.

In this work, two dimensionless numbers are compared to determine their suitability for characterising the extent of thermal stratification of hot water tanks. This enables the provision of real-time information on the thermal and hydraulic operating conditions during charging and discharging processes, which in turn allows suitably adapting a 1-D tank model so that the dynamic behaviour of interest is reproduced faithfully. Fundamental properties of the Richardson's number and the stratification number are discussed. For this, transient simulations of a 3-D model of a practical hot water tank (see Figure 1a) are conducted using ANSYS CFX to determine its sensitivity to input temperature and flow conditions. The charging and discharging profiles are simulated using the CFX expression language. Simulation results of the thermal gradient behaviour from the 3-D tank model are compared to those obtained from a 1-D tank model implemented in MATLAB/Simulink to assess the level of agreement of the models. The 1-D tank model (see Figure 1b) is simulated using two calculation methods for high and low extents of thermal stratification, which can be interchanged depending on charging and discharging conditions.

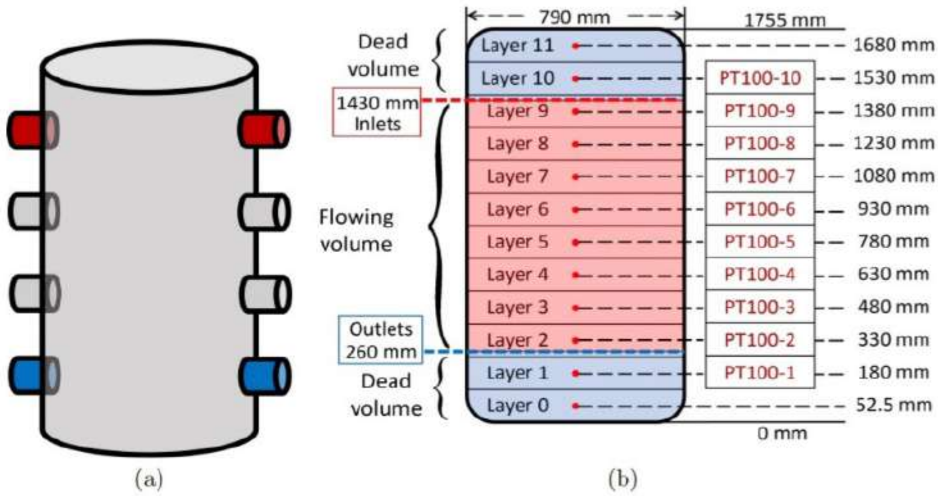


Figure 1: (a) Simplified schematic of the hot water tank, and (b) thermally stratified tank model.

Increasing the Penetration Level of Renewable Energy Sources Using Battery Energy Storage and Heat Pump

Saman Nikkhah[1], Adib Allahham[1], Haris Patsios[1], Sara L. Walker[1], Damian Giaouris[1]

1 School of Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK
Keywords: Renewable energy sources, energy storage, heat pump, active building.

1. INTRODUCTION

Complying with the worldwide targets for decarbonisation will likely require much more active management of buildings as one of the primary end-users of energy networks. With 36% of the global energy consumption [1], buildings are responsible for creating a considerable amount of carbon dioxide emissions worldwide. The proportion of carbon dioxide emission caused by the building sector is about 45% worldwide [2]. It is necessary to improve the energy scheduling strategies for the buildings and the role they can play in the energy network. Enabling the flexibility in the building side can create potential opportunities for the system operators in terms of ancillary services and increasing the penetration level of renewable energy sources.

2. LITERATURE REVIEW

Battery energy storage and heat pump are two important asset of technologically developed buildings which can enable flexibility. Optimal energy management of these assets along with other components of building can bring about multiple advantages. In [3], optimal management of battery energy storage units resulted in efficient utilisation of residential photovoltaic units and decreasing the energy bills of occupants. Reference [4] has shown the role of heat pumps in providing ancillary services for the Danish energy grid and the way optimal management of this assets can result in increasing the utilisation of renewable energy sources. In addition to the economic benefits of battery energy storage in cutting down energy costs, authors in [5] highlighted the social benefits of local markets in increasing the needs for storage unit equipment and indirectly rising the employment demand.

3. CONTRIBUTION

This paper focuses on the optimal energy management of battery energy storage and heat pumps for increasing the utilisation of renewable energy sources. A comprehensive optimisation model is introduced for energy management of building assets, including heat pumps and battery energy storage. The optimisation problem simultaneously minimises the energy bill and carbon emission. The mathematical model considers operational characteristics of building assets and aims at increasing the utilisation of renewable energy sources. A mixed integer non-linear optimisation model is introduced and solved using GAMS software. The model is solved for 100 residential buildings which are clustered into three groups depending on their occupancy profile and the asset possession. The simulation results show that optimal energy management of battery energy storage and heat pumps can reduce energy bills, decrease environmental pollution, and increase the penetration level of renewable energy sources.

4. REFERENCES

[1] S. Nikkhah, A. Allahham, M. Royapoor, J. W. Bialek, and D. Giaouris, “Optimising Building-to-Building and Building-for-Grid Services under Uncertainty: A Robust Rolling Horizon Approach,” IEEE Transactions on Smart Grid, 2021.
[2] M. Royapoor, M. Pazhoohesh, P. J. Davison, C. Patsios, and S. Walker, “Building as a virtual power plant, magnitude and persistence of deferrable loads and human comfort implications,” Energy and Buildings, vol. 213, pp. 109794, 2020.
[3] S. Nikkhah, A. Allahham, M. Royapoor, J.W. Bialek, D. Giaouris, “A Community-Based Building-to-Building Strategy for Multi-Objective Energy Management of Residential Microgrids,” In2021 12th International Renewable Engineering Conference (IREC) 2021 Apr 14 (pp. 1-6). IEEE.
[4] M. Zhang, Q. Wu, T.B. Rasmussen, X. Yang, J. Wen, “Heat pumps in Denmark: Current situation of providing frequency control ancillary services,” CSEE Journal of Power and Energy Systems. 2021 Sep 10.
[5] H. Huang, S. Nie, J. Lin, Y. Wang, and J. Dong, “Optimization of peer-to- peer power trading in a microgrid with distributed pv and battery energy storage systems,” Sustainability, vol. 12, no. 3, p. 923, 2020.

5. CONFERENCE TOPIC

Energy storage for decarbonisation of heating and cooling.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Capacity value of integrated energy storage-soft open point devices in distribution networks

DM Greenwood[1], I Sarantakos[2], M Deakin[3]

1 Newcastle University, UK, David.Greenwood@ncl.ac.uk
2 Newcastle University, UK, Ilias.Sarantakos@ncl.ac.uk
3 Newcastle University, UK, Matthew.Deakin@ncl.ac.uk

Keywords: **Reliability, Optimization, Soft Open Points, Distribution Networks**

1. INTRODUCTION

Energy Storage Systems can enhance the reliability of electricity distribution networks by providing stored energy which can continue customer supplies after an emergency [1]. Power electronic converters are required to connect DC storage devices to the AC power network. These converters can themselves be configured as soft open points (SOPs) [2], which also improve reliability via network flexibility. Combining the SOP topology with an energy storage system creates the Energy Storage Soft Open Point (ES-SOP) [3], which can provide both network flexibility and stored energy at multiple locations within a distribution network. The topologies of these devices are shown in Figure 1. This paper will quantify the reliability benefit of ES-SOP devices in terms of their capacity value (the additional load which the networks can now carry) as a result of both network and storage flexibility.

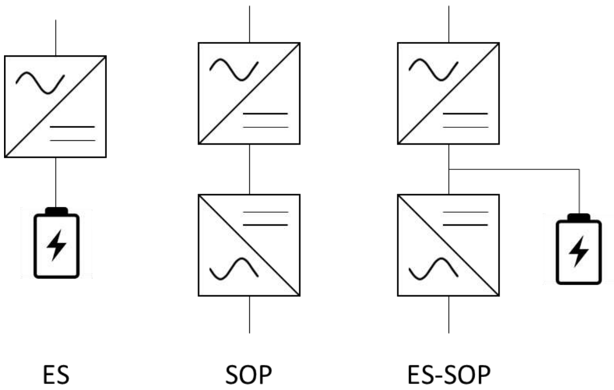


Figure 1: The topology of ES, SOP, and ES-SOP devices

2. METHODOLOGY

This research builds on previous work to simulate the operation of ES-SOP devices and to quantify the capacity value of both ES and SOPs. Convex conic optimization will be used to minimize interruptions to customer supplies during a fault and sequential Monte Carlo simulation will enable meaningful investigation of the impact of the ES-SOP on network reliability. New innovations will be presented which identify how the reliability benefits are shared between the networks connected by the ES-SOP device.

3. REFERENCES

[1] Greenwood, David M., et al. "A probabilistic method combining electrical energy storage and real-time thermal ratings to defer network reinforcement." *IEEE Transactions on Sustainable Energy* 8.1 (2016): 374-384.
[2] Sarantakos, Ilias, et al. "A reliability-based method to quantify the capacity value of soft open points in distribution networks." *IEEE Transactions on Power Systems* 36.6 (2021): 5032-5043.
[3] Sarantakos, Ilias, et al. "A Robust Mixed-Integer Convex Model for Optimal Scheduling of Integrated Energy Storage–Soft Open Point Devices." *IEEE Transactions on Smart Grid* (2022).

4. CONFERENCE TOPIC

· Application of energy storage through integration with renewable generation and energy networks

Accelerated multivariate high performance molten salt design with machine learning methods

Ze Sun[1], Yuxin Luo [1]

1 Engineering Research Center of Resources Process Engineering, Ministry of Education, East China University of Science and Technology, Shanghai 200237, China

Keywords: molten salts, design, machine learning

1. INTRODUCTION

With worldwide energy shortages and concerns about environmental issues and carbon neutrality goals, renewable energy and energy storage have attracted widespread attention. Molten salt energy storage is widely used as an energy storage technology in concentrated solar power plants. Molten salts have many advantages such as high thermal storage capacity, low vapor pressure, non-toxic, low cost, good thermal stability, flexible modification, and wide range of applications. Currently, in order to further enhance the energy storage performance of molten salts, they are required to operate in a wider operating temperature range, which has prompted a large number of researchers to carry out the design of new molten salts.

In recent decades, the development of high-performance molten salts has been characterized by increasingly complex molten salt compositions, with cations including Na^+, K^+, Li^+, Ca^{2+}, Mg^{2+}, and Zn^{2+}, and anions including NO_3^-, Cl^-, CO_3^{2-}, SO_4^{2-}, etc. Moreover, the research on molten salts has shifted from binary salts to ternary salts, quaternary salts, and even more, so the composition design space has become larger. Therefore, it is difficult to quickly and accurately design molten salt compositions that meet the multi-target performance requirements by relying on the traditional empirical trial-and-error method. Using machine learning methods, it is easy to analyze the composition, formation process, structure and properties of eutectic salts, build performance prediction models, discover new materials with huge space, and perform experimental validation.

In this study, many data were compiled based on the composition and melting point, decomposition temperature, density, viscosity, and heat storage density of high-temperature multivariate molten salts from the collected literature. Based on this, an optimization model based on machine learning for the combination of multivariate molten salts is developed, and our study demonstrates the possibility of using machine learning to develop molten salts with good thermophysical properties.

2. METHODS

In this study, we selected k-nearest neighbor regression (KNN), support vector machine (SVM) and artificial neural network (ANN) in constructing the component-performance interrelationship model, and used optimization algorithm (OA) to select and optimize the model with the highest prediction accuracy and the best prediction performance for a given target performance..

3. RESULTS AND DISCUSSION

High temperature and compliant thermophysical properties of molten salts have a wide range of applications in the future, and the development of new multifaceted mixed molten salts is the key to further improve the efficiency of molten salts. The prediction model in this paper provides a new idea and possibility for the design of molten salts trapped in the traditional high-cost trial-and-error method.

4. REFERENCES

[1] Jiaheng Li, Yingbo Zhang, Xinyu Cao, et al. Accelerated discovery of high-strength aluminum alloys by machine learning. Commun Mater2020; 1:73.

[2] Lei jiang, Changsheng Wang, Huadong Fu, et al. Discovery of aluminum alloys with ultra-strength and high-toughness via a property-oriented design strategy. J mater sci techno2022; 98:33-43.

5. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage; AI and energy storage

APPENDIX A

A Machine Learning and Empirical Wavelet Transform- based Framework for Online Capacity Estimation of Lithium-ion Batteries under Generalized Operating Conditions

Ma'd El-Dalahmeh, Maher Al-Greer, Mo'ath El-Dalahmeh, Imran Bashir

School of computing, Engineering, and Digital Technologies, Teesside University, UK.
Ma'd.el-dalahmeh@tees.ac.uk, M.al-greer@tees.ac.uk, Mo'ath.el-dalahmeh@tees.ac.uk, I.bashir@tees.ac.uk

Abstract- Capacity degradation monitoring of lithium-ion batteries is necessary to ensure the reliability and safety of electric vehicles. However, the capacity of lithium-ion batteries cannot be evaluated directly due to their complicated internal physicochemical interactions and temperature effects. This work presents a novel generalized approach for analyzing the electrochemical properties and estimating the capacity of lithium-ion batteries based on the adaptive empirical wavelet transform (EWT). In this method, the adaptive EWT is a potent tool for analyzing the discharging/charging voltage signal with non-stationary and transient phenomena in lithium-ion batteries. EWT-based multi-resolution analysis (MRA) is used to simultaneously extract information on the electrochemical properties in the time-frequency domain. Using the adaptive EWT in conjunction with wavelet decomposition, the electrochemical features of lithium-ion batteries can be retrieved from the charging/discharging voltage signal over a frequency band range. The advantage of employing the EWT method over other approaches such as continuous wavelet transform, and discrete wavelet transform is that there is no need for a mother wavelet selection procedure since EWT is an adaptive approach and the mother wavelet signal is designed based on the measured signal. Specifically, the measured voltage signals of the LIBs are decomposed into eight multi-resolution modes to display their high and low-frequency components. Moreover, 13 statistical features are extracted to investigate the correlation between the capacity degradation and the extracted features. Afterwards, machine learning algorithms are (CNN and LSTM) developed to estimate the LIB's capacity by using the extracted features as an input to the machine learning models. The proposed approach has been validated using NASA randomized lithium-ion battery usage dataset with 23 LIBs cycled under generally varying operational conditions. The capacity estimation results show that the proposed method can accurately estimate the capacity of the LIBs with an average RMSE of 0.978% and max error of 2.061%

Keywords: Lithium-ion batteries, machine learning, wavelet transform, online capacity estimation.

1. METHODOLIGY

The proposed framework for the online capacity estimation of lirhium-ion batteries is shown in Fig. 1. The proposed framework involves 4 main steps. The first step is the cycling process of the lithium-ion batteries; in this work the batteries were cycled at randomized current profiles to refelect the real-world operating conditions of the batteries. The seconds step is to apply the wavelet transform to the measrued voltage signal. The wavelet transform decomposed the measrued votlage signal into multi-resolution sub-signals to show more information about the measured signal in time-frequency domain. In the third step, the obtained signals from the wavelet transform are then used to train a machine learning al gorithm for capacity estimation process of the batteries. Lastely, the trained machine learning algorithm is tested to validate the estimation accuarcy of the proposed framework. Fig. 2. and Fig. 3. Present the strucutre of the convloutional neural network and the long short-term neural network algorithm, respectively [1,2].

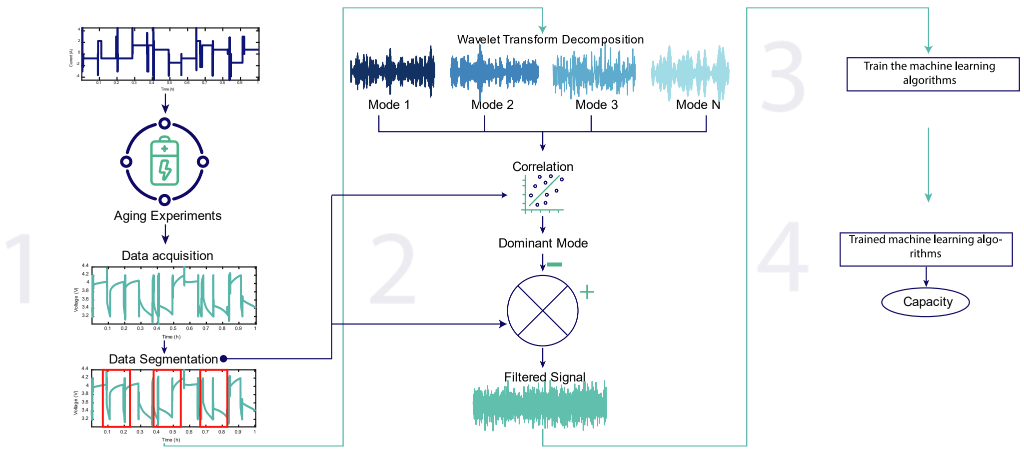


Fig. 1. The proposed framework for online capacity estimation.

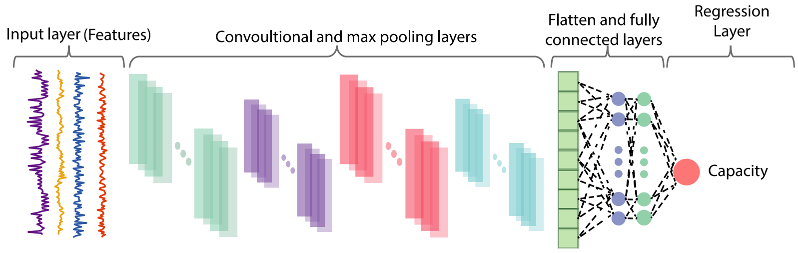


Fig. 2. CNN structure.

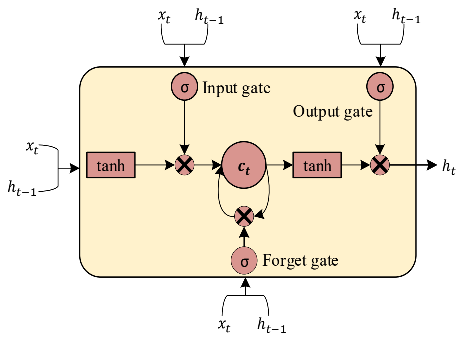
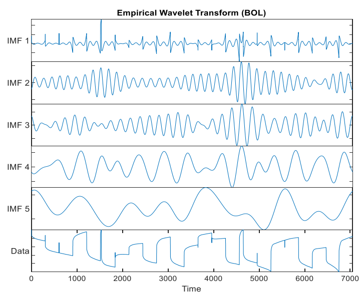


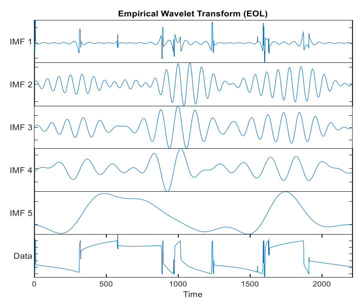
Fig. 3. LSTM structure.

2. RESULTS

Part of the results are presneted in this section; the detail discussion and clarification of the obtained results will be presented in the full version of the paper. Fig. 4. Illustrates the obtained results from the wavelet transform decompostion method. Fig. 5. shows the estimated capacity of the lithium-ion batteries using the trained machine learning algorithms.

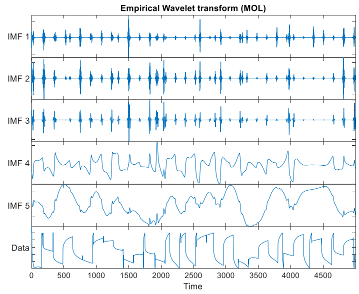


(a)

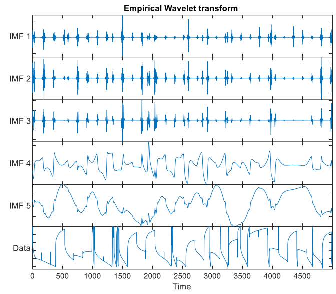


(b)

APPENDIX A

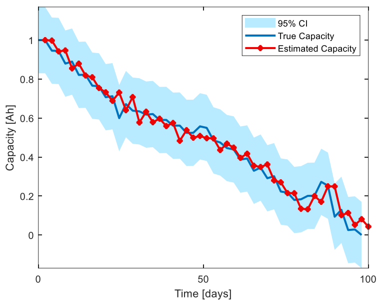


(c)

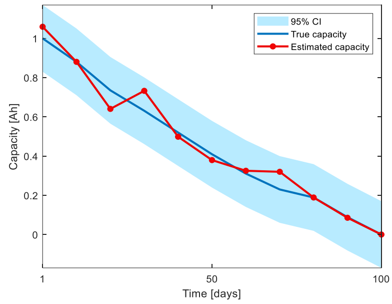


(d)

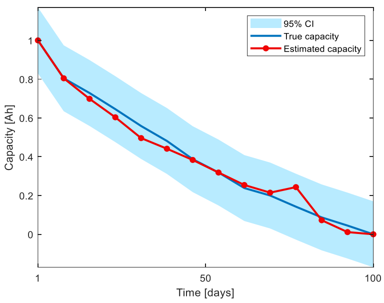
Fig. 4. The multi-resloution results using wavelet transform for the lithium-ion battery at different capacity values.



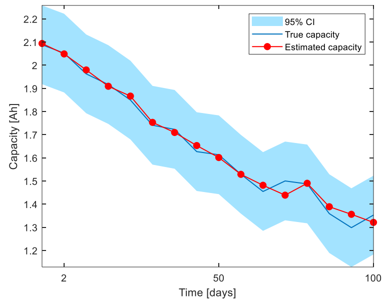
(a)



(b)



(c)



(d)

Fig. 5. The estimated capacity using the traine machine learning algortihms.

3. REFERENCES

[1] M. El-Dalahmeh, M. Al-Greer, M. a. El-Dalahmeh, and M. Short, "Time-Frequency Image Analysis and Transfer Learning for Capacity Prediction of Lithium-Ion Batteries," Energies, vol. 13, no. 20, p. 5447, 2020.

[2] B. Bole, C. S. Kulkarni, and M. Daigle, "Adaptation of an electrochemistry-based li-ion battery model to account for deterioration observed under randomized use," in Annual Conference of the PHM Society, 2014, vol. 6, no. 1.

4. CONFERENCE TOPIC

AI and energy storage.

Life cycle analysis and sustainability of energy storage technologies.

APPENDIX A

Study on the dynamic modelling framework for the solid-gas sorption energy storage system

Dacheng Li[1], Nan Hua[1], Tiejun Lu[1], Yulong Ding[1], Yongliang Li[1]

1 University of Birmingham
(d.li.6@bham.ac.uk ; n.hua@bham.ac.uk ; t.lu.20@bham.ac.uk ; y.ding@bham.ac.uk ; y.li.1@bham.ac.uk)

Keywords: solid-gas sorption, dynamic modelling, intelligent framework, coefficient identification

1. INTRODUCTION

The effective utilisation of low-grade waste heat is essential in the energy industry to achieve the decarbonisation target. Thermal storage using solid-gas sorption is one of the promising methods to achieve this. However, the dynamic characteristics in the mass kinetics and heat transfer lead to the fact that the performance of the reaction is unpredictable and hard to be identified. Fully clarifying the dynamic characteristics can facilitate the optimisation of the design and operation of this kind of energy system to improve energy efficiency and reduce system cost [1]. Despite various types of dynamic modelling have been established, lack of investigation has been conducted to consider the dynamic characteristics of the adsorbate in the adsorption and desorption process. Furthermore, an intelligent identification framework that can recognise the operation mode of the reaction and effectively identify the modelling coefficient ought to be developed. This study aims to fill the research gap and provide an optimisation route for utilising the solid-gas sorption storage system in a high-efficiency and economically viable way.

2. EXPERIMENTAL ANALYSIS

An experimental system of solid-gas sorption is built to investigate the main factors that influence the adsorption and desorption reactions. The variation of the temperature and pressure and the degree of the reaction are measured and evaluated to provide the basis for the identification of the coefficient in the dynamic modelling.

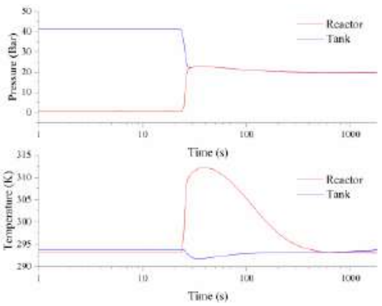


Figure.1 Pressure and temperature

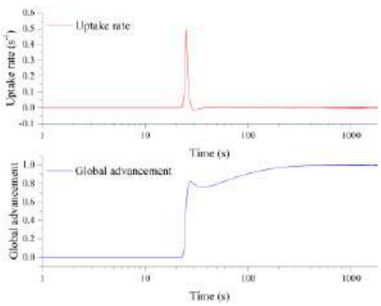


Figure.2 Global advancement and rate

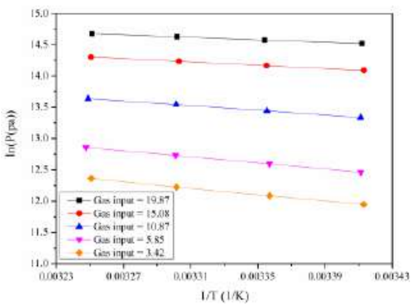


Figure.3 Equilibrium reaction line

3. DYNAMIC MODELLING ANALYSIS OF THE SOLID-GAS SORPTION

Development of the dynamic modelling of the solid-gas sorption process is conducted from the aspects of both mass and heat transfer inside the reactor [2]. The unevenness of the adsorbent surface is embedded in the evaluation of the thermodynamic parameters and the dynamic characteristic of the buffer tank is considered in the system modelling.

(1) Advancement: $$\frac{dX}{dt} = f(X)\cdot K(P,T);\ f(X) = [1 - X(t)]^{M(N)},\ K(P,T) = \begin{cases} Ar_{\mathrm{ad}} \cdot \exp\left(-\frac{E_{\mathrm{ad}}}{RT}\right)\cdot\left(\frac{P - P_{\mathrm{eq}}(T)}{P}\right) \\ Ar_{\mathrm{de}} \cdot \exp\left(-\frac{E_{\mathrm{de}}}{RT}\right)\cdot\left(\frac{P_{\mathrm{eq}}(T) - P}{P_{\mathrm{eq}}(T)}\right) \end{cases} \quad \text{(eq. 1)}$$

(2) Temperature: $$\begin{cases} (c_{\mathrm{s}} m_{\mathrm{s}} + c_{\mathrm{g}} m_{\mathrm{g}}(t))\frac{dT}{dt} = n\Delta H(t)\cdot\frac{dX(t)}{dt} - h_{\mathrm{ad}} A\big(T(t) - T_{\mathrm{HTF}}(t)\big) \\ (c_{\mathrm{s}} m_{\mathrm{s}} + c_{\mathrm{g}} m_{\mathrm{g}}(t))\frac{dT}{dt} = -n\Delta H(t)\cdot\frac{dX(t)}{dt} + h_{\mathrm{de}} A(T_{\mathrm{HTF}}(t) - T(t)) \end{cases} \quad \text{(eq. 2)}$$

4. OPTIMISATION FRAMEWORK AND IDENTIFICATION RESULT

An intelligent framework based on the multipop Genetic Algorithm is designed by integrating the artificial criterion to track the process of the reaction and identify the value of the modelling coefficient.

APPENDIX A

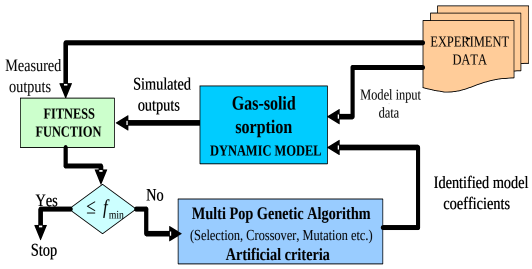


Figure.4 Optimal identification procedure

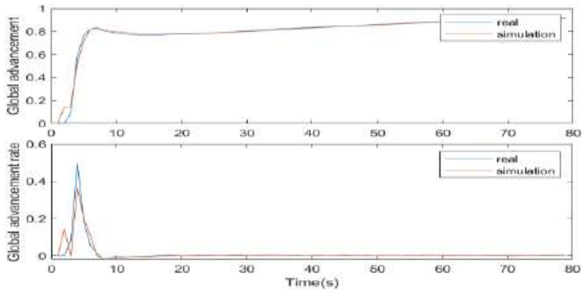


Figure.4 Optimal validation result

5. CONCLUSION

(1) The proposed dynamic modelling can reflect the real performance of the gas-solid sorption process.

(2) The developed intelligent framework can identify the modelling effectively by considering the operation criteria.

6. REFERENCES

[1] G.L. An, L.W. Wang, J. Gao, R.Z. Wang. A review on the solid sorption mechanism and kinetic models of metal halide-ammonia working pairs. Renew Sustain Energy Rev 2018; 91:783–92.

[2] Hua-Jiang Huang, Guo-Bin Wu, Jiao Yang, Ying-Chun Dai, Wei-Kang Yuan, Hui-Bo Lu. Modeling of gas–solid chemisorption in chemical heat pumps. Sep Purif Technol; 34(1-3):191-200.

7. CONFERENCE TOPIC

AI and energy storage

Solid state hydrogen storage: Decoding the path through machine learning

Ashwini Verma[1,2], Kavita Joshi [1,2]

1 Physical and Materials Chemistry Division , CSIR-National Chemical Laboratory, Pune 411008
2 Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh- 201002, India.

ad.verma@ncl.res.in; k.joshi@ncl.res.in

Keywords: Metal hydrides, High Entropy Alloys, H2wt%, Machine Learning, Random Forest Regressor

1. ABSTRACT

The globe has reached a point where switching to renewable or green energy sources is one of the few viable options for a sustainable environment. Today 80% of the world's energy requirements are met by depleting fossil fuels, accompanied by the release of hazardous greenhouse gases. Therefore, exploring new avenues for environment-friendly energy generation is at the forefront of the research focused on renewable fuel sources. In this milieu of sustainability, hydrogen as an energy carrier is linchpin in achieving energy security due to its high energy density (142 MJ Kg-1). One of the major impediments in realizing the hydrogen economy is its economic storage. While compressed and liquefied hydrogen is utilized widely in industries, operational conditions such as elevated pressure and cryogenic temperature often restrict its use at a wider scale. Storing hydrogen in solid-state compounds via chemical absorption will result in higher volumetric energy densities than compressed gas or liquid hydrogen. Metal hydrides, complex hydrides, and high entropy alloys are some options proposed for solid-state hydrogen storage. Most of the solid-state compounds investigated so far do not satisfy the norms set by DoE for economic viability. Trial-and-error-based synthesis of solid-state compounds has a hard limit on efficiently exploring an infinite chemical composition domain. Moreover, the integration of traditional approaches for the exploration of the chemical space should be combined with faster and more sophisticated statistical tools like ML.

This talk focuses on the ML models developed for predicting hydrogen storage capacity, enthalpy of hydride formation, and equilibrium H2 pressure of metal alloys at room temperature. The model is probably, the first of its kind to predict hydrogen weight capacity at a given temperature using elemental properties as features. The transferability of the model is demonstrated by extending it to predict the hydrogen weight capacity of unseen compositions of HEAs. Models are also trained to predict the enthalpy of hydride formation and the equilibrium plateau pressure at room temperature. Even though the feature set consists only of weighted average properties of constituent elements of alloy, the model's accuracy is comparable to that described in the literature, where 145+ features have been used. We have also examined each model's correlation matrix and feature importance to select the right features to enhance learning and uplift the model's predictive performance. Finally, predictions of binary, ternary, and quaternary alloys suitable for hydrogen storage will be presented. Trends emerging out of these predictions demonstrate the power of machine learning-based models to screen the infinite chemical space.

2. REFERENCES

[1] K. Joshi and A. Verma, A system and method for identification of materials for hydrogen storage. Provisional Indian patent no 202211028454. [2022]

3. CONFERENCE TOPIC

AI for energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

A machine learning optimization of MOFs for thermal energy storage applications

Trezza Giovanni[1], Bergamasco Luca[2], Fasano Matteo[3], Chiavazzo Eliodoro[4]

1 Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy, giovanni.trezza@polito.it
2 Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy, luca.bergamasco@polito.it
3 Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy, matteo.fasano@polito.it
4 Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy, eliodoro.chiavazzo@polito.it

Keywords: Metal Organic Frameworks, Sequential Learning, Thermal Energy Storage

1. INTRODUCTION

Metal Organic Frameworks - MOFs are relatively new compounds consisting of metal ions/clusters and organic linkers, and are characterized by unique properties, such as tunable porosity and incredibly high surface area [1]. Those materials are therefore employable in the thermal energy storage (TES) field by exploiting physisorption phenomena, which can be accompanied by significant amount of energy exchange. In this work, we consider adsorption/desorption-based heat pumps as possible application [2], with the aim of shedding light on how crystallographic properties of MOFs influence the performances of a heat pump with water being the sorbate. We also aim at providing a comprehensive comparison of algorithms for sequential optimization of MOFs physisorption properties (e.g., H_2O solubility, specific surface area), thus significantly reducing the number of evaluations to be performed [3].

2. METHODS

First, we proceed with a featurization of the Crystallographic Information Files (CIFs) of roughly 8000 potential MOFs [4], leading to 1557 CFID (Classical Force-field Inspired Descriptors). Such descriptors include chemical features (e.g., averages of chemical properties of elements in the cell), and structural features (e.g., radial distribution function, nearest neighbor distribution). Furthermore, for each compound, we extracted by the database from Boyd *et al.* [4] four properties: Henry coefficient for CO_2, working capacity for CO_2, Henry coefficient for H_2O, internal surface area, here utilized to train/validate four regression models.

3. RESULTS

We ranked the importance of the 1557 features over the models' outputs, getting the few dozens of effectively relevant descriptors for each of the four target properties. We predicted performance of potential MOFs in closed water sorption TES, thus identifying compounds expected to maximize the cycled heat. Those optimal compounds are Vanadium-based and outperform many of the known microporous materials in terms of specific stored energy [2]. Finally, we have compared several Sequential Learning (SL) methodologies for efficiently choosing the next material to be tested, aiming at the maximization of the DFT-based properties in [4].

4. CONCLUSION

We describe a fast procedure to optimize specific energy in a closed sorption energy storage system with only access to a single water Henry coefficient value and to the specific surface area. We are thus able to identify hypothetical candidate MOFs that are predicted to outperform state-of-the-art water-sorbent pairs for thermal energy storage applications. Furthermore, a comprehensive comparison of several SL algorithms for MOFs properties optimization is performed and the role of those descriptors is clarified.

5. REFERENCES

[1] Kitagawa S. Metal–organic frameworks (MOFs). Chem Soc Rev 2014; 43.16:5415-5418.

[2] Trezza G, *et al.* Minimal crystallographic descriptors of sorption properties in hypothetical MOFs and role in sequential learning optimization. npj Comput Mater 2022; 8.1:1-14.

[3] Brochu E, *et al*. A tutorial on bayesian optimization of expensive cost functions, with application to active user modeling and hierarchical reinforcement learning. arXiv preprint 2010; arXiv:1012.2599.

[4] Boyd, Peter G., *et al.* Data-driven design of metal–organic frameworks for wet flue gas CO2 capture. Nature 2019; 576.7786:253-256.

6. CONFERENCE TOPIC

Applications of AI to energy storage.

Study on thermophysical properties and application in cold storage of the C_9-C_{11} alkane phase change material

Donghao Fan[1], Zunrui Zhong[2], Hao Peng[3*]

1 Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing Tech University; dhfanmail@163.com

2 Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing Tech University; 202061107017@njtech.edu.cn

3 Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing Tech University; phsight1@hotmail.com

* Corresponding author

Abstract: In this work, the phase equilibrium behavior and thermophysical properties of C_9-C_{11} binary alkane system were investigated to develop potential phase change materials for cryogenic applications. Using its eutectic system as the phase change cold storage material, a low-temperature refrigerator was designed and the effects of ambient temperature and cold storage medium on the cold storage characteristics of the refrigerator were investigated. The results show that the C_9-C_{11} system exhibits eutectic behavior with 10wt%C_{11} eutectic component and eutectic temperature of -58 °C. The phase change material with 10wt%C_{11} combination of C_9-C_{11} binary system has a unit volume exotherm of 150.91 MJ/m^3 in the temperature range of -60 °C to -20 °C. Compared with the ambient temperature of 23 °C, the cold-keeping time of the refrigerator at the ambient temperature of 5 °C is extended by 3000 s. Compared with calcium chloride brine, mixed alkanes have relatively less cooling time, but have a lower cooling temperature zone and are stable and non-corrosive. Taking anhydrous ethanol as an example, the refrigerated box with the addition of cold storage material prolonged the rise from -55 °C to -20 °C by 2400 s, showing a better cold storage and insulation performance.

Keywords: phase change material; alkane; phase diagram; thermodynamics; refrigerator

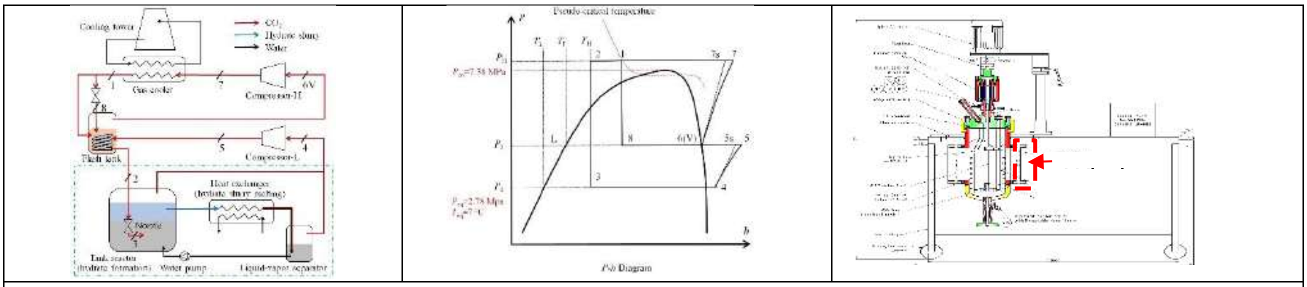
Experimentally study on carbon dioxide hydrate formation for a new partial cold storage two-stage carbon dioxide (CO_2) hydrate-based vapor-compression refrigeration system

Dacheng Li, Nan Hua, Tiejun Lu, Yi Wang, Yongliang Li*
School of Chemical Engineering, University of Birmingham, Birmingham, United Kingdom
e-mail: y.li.1@bham.ac.uk1

Keywords: hydrate, carbon dioxide, refrigeration, energy storage, PCMs

1. INTRODUCTION

This is the second topic of the project of Generation of REfrigerated ENergy Integrated with Cold Energy Storage (GREEN-ICEs). It composed of three topics: Whole System Modelling and Assessment; Rapid Carbon dioxide (CO_2) hydrate formation and Transport and Dissociation Behaviors of CO_2 Hydrate Slurry. Aimed to develop a novel integrated system for cold energy generation and storage using CO_2 hydrate as both refrigerant and storage material (Figure 1). Vapor-compression refrigeration has been pervasively used. As pointed out [1], the refrigeration is responsible for nearly 7.8% of total global greenhouse gas emissions. It is also reported [2] that the refrigeration sector accounts for more than 17% of total electricity consumption. Therefore, interests in development of new refrigerants and system configurations to minimize the environmental impact and maximize the energy efficiency have been considerably resurged.



Firure 1. Schematic (left), P-h Diagram (middle) and test rig (right) of GREEN-ICEs system

A hydrate-based vapor compression refrigeration system [3] using refrigerant gas hydrates as the primary refrigerant can provide superior performance. Gas hydrates are crystalline solid consisting of water molecular cavities and refrigerant gas guested molecules. Different from a conventional VCRS, evaporation and condensation are replaced by hydrates dissociation and formation, respectively. One of the notable hydrate properties is that the heat of formation/dissociation is generally several times as large as the latent heat of the conventional refrigerants.

Due to high Global warming potential (GWP) of the fluorocarbons (HFCs) refrigerants, natural refrigerants are becoming popular guest gases. Carbon dioxide (CO_2) as one of ideal refrigerant gas forming the hydrate has attractive properties of no ODP, very low GWP (GWP = 1), non-flammable, non-toxic and low-cost. Normally, pure CO_2 hydrate is formed under high pressure and low temperature.

Cold thermal energy storage (CTES) is one of manners dealing with peak-load shift. CTES technologies can effectively decrease mismatches between timing of supply and demand. Refrigeration system incorporating CTES is one of the most promising options for peak-load shift. All hydrate-based refrigeration systems are actually CTES systems. The formation vessel also plays a role of a cold energy storage. The gases discharged from compressor are injected into a crystallizer to form hydrate and used as PCM stored during the off-peak period. Later the hydrate slurries are expanded via a slurry pump and directly delivered to the users during the on-peak period.

A novel two-stage CO_2 hydrate-based vapor-compression refrigeration system (CHB-VCRS) using pure CO_2 hydrate as primary refrigerant was proposed in GREEN-ICEs project [4]. Compared to literature, it is retrofitted from conventional two-stage CO_2 VCRS. Through a 24-hours operation modelling in a typical day, the simulation results revealed that it saved more operation cost and had wider economic feasibility than non-storage CO_2 VCRS.

2. EXPERIMENT AND RESULTS

APPENDIX A

In this work, focus o the second theme of GREEN-ICEs, the effect of operating parameters on hydrate formation is experimentally investigated. The experiment uses water and carbon dioxide as feed materials produced hydrates within the scope of work conditions set by the project.

Phase equilibrium data of CO_2 hydrate was calculated using Sabil [5] reported equation (1), based on the project conditions, (figure 1) 28 bar and 7.064 °C were chosen as our test standard point. It is found the experimental results are agreed well with calculations.

$$T_{eq} = -6.80048 + 0.7037p - 0.00745p^2 \qquad \text{(eq. 1)}$$

The tests were carried out in the ranges listed in Table 1

Pressure (bar)	Temperature (°C)	Stirring (rpm)	Water (Liter)	Water (Re-using)	Coolant (°C)	Heating (from min.)	Gas inlet on shaft
30-40	22-27	250-700	5-5.5	1-5	-5	210	close

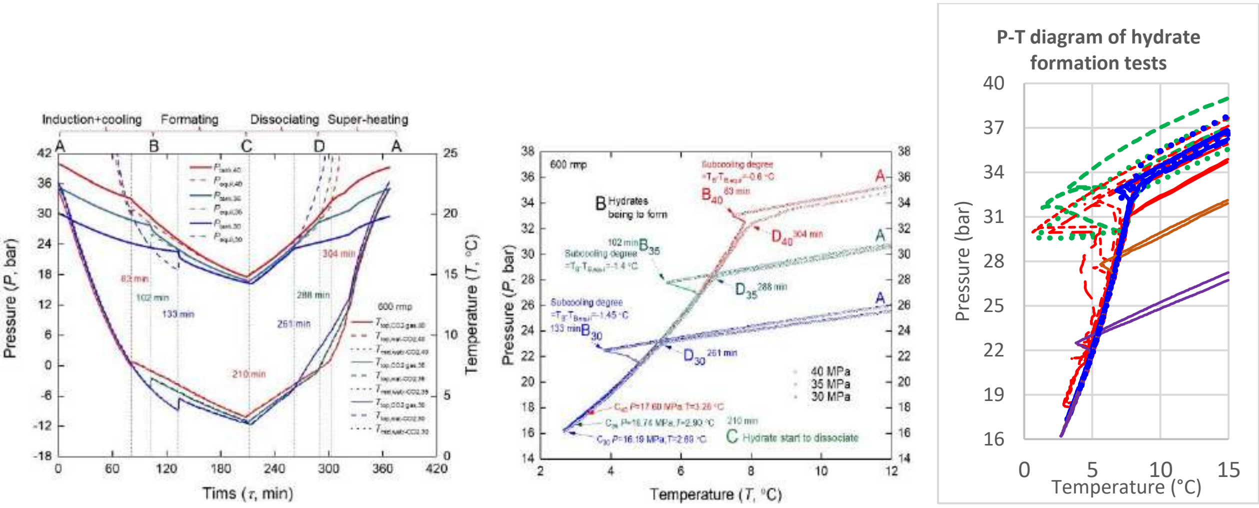


Figure 2. Tests results. Stir at 600 rpm, start pressure at 40, 35 and 30 bar (left and middle), all tests (right)

The experimental results show that the stirring speed has the most significant effect on the hydrate formation. When the rotation speed is 250 rpm, the supercooling causes sudden solidification, which leads to the formation of a large monolithic solids in the system, which deteriorates heat and mass transfer. When the stirring speed is higher than 400 rpm, the formatting and dissociating points are perfectly located on the equilibrium curve no mater the start pressure and the time of water re-use (Figure 2. left and middle); free flow hydrate slurry was produced. In all conditions, the measured dissociating points are agreed with equilibrium curve and the amount of hydrate formed directly associated with start pressure (Figure 2. right)

3. REFERENCES

1. McLinden, M. O., Seeton, C. J., and Pearson, A.,. New refrigerants and system configurations for vapor-compression refrigeration, *Science*, Vol. 370, No. 6518, pp 791-796, 2020.
2. Coulomb, D., Dupont, J. L., Pichard, A., The Role of Refrigeration in the Global Economy-29, Informatory Note on *Refrigeration Technologies*, 2015.
3. Ogawa, T., Ito, T., Watanabe, K., Tahara, K. I., Hiraoka, R., Ochiai, J. I., .and Mori, Y. H., Development of a novel hydrate-based refrigeration system: A preliminary overview, *Appl. Therm. Eng.*, Vol. 26, No. 17-18, pp 2157-2167, 2006.
4. Hua, N., Lu, T., Yang, L., Mckeown, A., Yu, Z., Xu, B., Sciacovelli, A., Ding, Y., and Li, Y., Thermodynamic analysis and economic assessment of a carbon dioxide hydrate-based vapor compression refrigeration system using load shifting controls in summer, *Energy Convers. Manag*., Vol. 251, pp 114901, 2022.
5. Sabil K., Phase Behaviour, Thermodynamics and Kinetics of Clathrate hydrate System of Carbon Dioxide in Presence of Tetrahydrofuran and Electrolytes, PhD thesis, Delft University of Technology, 2009

4. CONFERENCE TOPIC

3.4 Cold storage and sustainable cooling

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Performance of ice source heat pump based on supercooled water method

Mingbiao Chen[1,], Qun Du[2], Wenji Song[3*], Ziping Feng[4]

1 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China chenmb@ms.giec.ac.cn
2 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China duqun@mail.ustc.edu.cn
3 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China songwj@ms.giec.ac.cn
4 Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, Guangzhou 510640, China fengzp@ms.giec.ac.cn

Keywords: ice slurry; supercooled water; system performance; direct evaporating

1. INTRODUCTION

Ice source heat pump is a kind of special heat pump which can abstract latent heat from ice water for heating with the combination of original heat pump and dynamic ice-making technology.[1] Compared with the original water source heat pump which can only abstract sensible heat from water, ice source heat pump can extend the limited temperature of input water of heat pump from about 6°C to 0°C. As a result, the use of ice source heat pump could be widened.[2] In order to study the system performance, an ice source heat pump based on supercooled water method is built up. The ice source heat pump adopts the direct evaporating method in the supercooled heat exchanger, which can reduce the heat transfer resistance compared with that of indirect evaporating method.[3]

2. PERFORMANCE OF ICE SOURCE HEAT PUMP

Fig. 1 Ice slurry system with supercooled water method.

It can be seen that the ice source heat pump system using supercooled water method can run steady without ice block, which is the main problem by using supercooled water method. The shortcoming of ice block is overcome by controlling the heat transfer and water flowing in the heat exchanger. The outcome temperature of air is as high as 40°C, which is high enough for residential heating. According to the experimental data, the ice source heat pump COP can reach about 3.0. That means it is energy-saving in cold winter with the help of ice source heat pump as the COP of air source heat pump system is only about 2.0 when the ambient temperature is about -10°C.

3. REFERENCES

[1] Wang, Y.; Song, W.; Chen, M. Study on Energy Efficiency and Economical Performance of Ice Source Heat Pump Based on Ice Slurry. Adv. New Renew. Energy 2021, 9, 48–54.
[2] Fang L, Wang Y. Exploring Application of Ice Source Heat Pump Technology in Solar Heating System for Space Heating[J]. Energies, 2022, 15(11): 3957.
[3]Chen M, Fu D, Song W, et al. Performance of Ice Generation System Using Supercooled Water with a Directed Evaporating Method[J]. Energies, 2021, 14(21): 7021.

4. CONFERENCE TOPIC

Cold storage and sustainable cooling.

APPENDIX A

An Adsorption-Compression Cold Thermal Energy Storage System

Sambhaji Kadam[1], Ebraheem Alanazy[1], Zhibin Yu[1]

1 James Watt School of Engineering, University of Glasgow, UK

Keywords: Vapor compression, Vapor adsorption, thermal storage, adsorbent, ammonia

1. INTRODUCTION

The impact of the climate change has been realized in terms of increasing production and usage of the cold energy in almost every sector. All together this demand put forward concerns about high grade energy consumption (currently 14% of UK's total electricity [1]) and its environmental consequences as a global warming (GWP) among others. The cooling demand increases with increase in air temperature, at the cost of performance degradation of refrigeration system. This poses challenging mismatch between peak cooling demand over a day and system performance. Hence, there is an urgent need of the technology that effectively deals with peak power demand and offering more efficient and flexible operation of refrigeration system. An 'cold thermal energy storage' (CTES) render benefits mentioned above. Another challenge is the use of conventional refrigerants (F-gas) having high GWP. This paper presents novel conceptual integrated compression-adsorption refrigeration system with using ammonia (Fig. 1). It has three operational modes, (1) refrigerator (2) liquid refrigerant storage and (3) adsorption refrigeration storage which can be operated by low grade energy. The conventional refrigeration will operate when cooling demand is equal to its design capacity. When demand is lower than design capacity, the excess liquid ammonia is stored in tank 1 after condenser of refrigerator and utilize when cooling demand in day time is higher than capacity of refrigerator. Adsorption storage tank 2 is in action when liquid ammonia from tank 1 is discharged. The ammonia from tank 2 is desorb during night time when cooing demand is lower than capacity. Ammonia is stored in Tank 2 as a mixture of condensed liquid which is held by capillary force in composite pores and in the form of salts such as $CaCl_2{\cdot}8NH_3$. The solid phase absorption process, $CaCl2\cdot4NH3+4NH3 \rightarrow CaCl2\cdot8NH4+\Delta H_{ad}$, is exothermic ($\Delta H_{ad}$=1965 kJ/kg), while the desorption process $CaCl2\cdot8NH3+ \Delta H_{des} \rightarrow CaCl2\cdot4NH3+4NH3$, is endothermic ($\Delta H_{des}$=4294 kJ/kg).

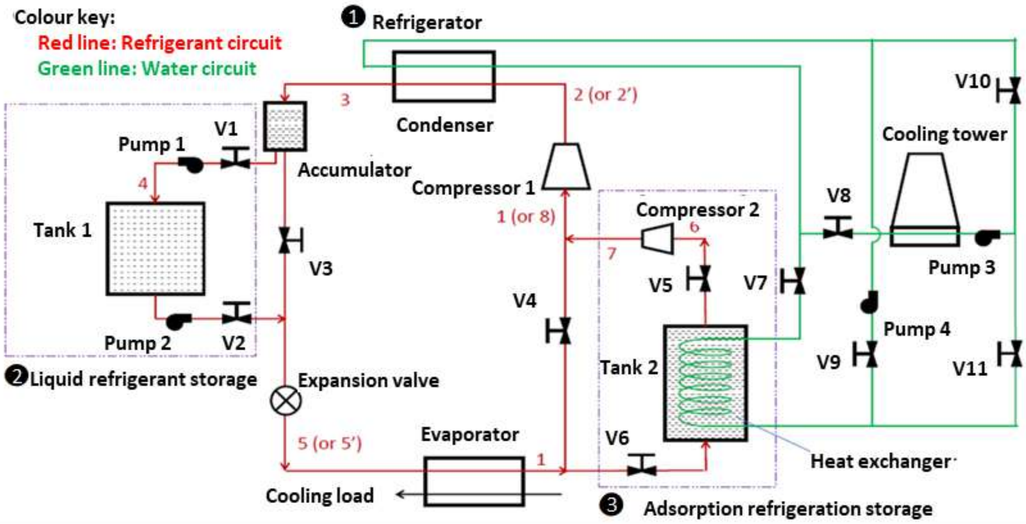


Figure.1 Schematics of proposed integrated vapor compression-adsorption refrigeration system.

The proposed adsorption-compression technology can be cost effective (~0.5£/kg of NH3, ~ 100$/ton of CaCl2), better heat transfer across different heat exchangers, operational flexibility, and lower heat loss. However, there are several issues are associated with adsorption refrigeration that needs further investigations such as heat and mass transfer enhancement, heat source temperature, salt swelling and agglomeration.

2. REFERENCES

[1] The Carbon Trust, The emerging cold economy, 2015

3. CONFERENCE TOPIC

Session: Application to Through Integration – Cold storage and sustainable cooling.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Sorption composites for sustainable cooling: a comparison among different salts and host matrices

Vincenza Brancato[1], Yannan Zhang[1], Andrea Frazzica[1]

1 Consiglio Nazionale delle Ricerche – Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano" (CNR ITAE) – Via S. Lucia Sopra Contesse, 5 – 98126 Messina (Italy) vincenza.brancato@itae-cnr.it

Keywords: Cooling, SWS materials, sorption salts, silica gel, vermiculite

1. INTRODUCTION

Nowadays, energy saving is the fulcrum of scientific development worldwide [1]. The sorption cooling is a novel energy-saving and environmentally friendly technology which has arisen considerable interest during the last decades. The aim of this study is the characterization of three composite sorbents, based on porous matrices and salts, developed for cooling application to overcome several issues related both to the pure hygroscopic salts and to the porous matrices, that are: the swelling of salt and its low thermal conductivity [2]; significant volume changes during hydration and de-hydration [3]; poor adsorption capacities of some porous matrices. In the present work, two different salts, lithium chloride and calcium chloride, and two different matrices, mesoporous silica gel and vermiculite, have been investigated with the scope to find an efficient composite sorbent for sustainable cooling applications from renewable and waste sources.

2. MATERIALS AND METHODS

Mesoporous silica gel with a pore volume of 0.95 cm^3/g and macro-porous expanded vermiculite with a pore volume of 1.6 cm^3/g were chosen as the matrices, while $CaCl_2$ and LiCl were selected as the hygroscopic salts. The composites were developed by adopting the dry impregnation method: the matrices were firstly fully dried at 150°C, and a certain mass of matrices was mixed with the pre-prepared aqueous salt solution whose volume equals the total pore volume of the matrices and containing the desired salt amount. Three types of composites were obtained, namely, silica gel-30% $CaCl_2$, silica gel-30% LiCl and Verm-45% LiCl. Afterward, the sorption isobars at two evaporation temperatures- 15°C and 20°C were measured with Dynamic gravimetric vapor sorption analyzer (DVS) equipment.

3. RESULTS AND DISCUSSION

The typical evolution of the obtained isobars is reported in Figure 1.

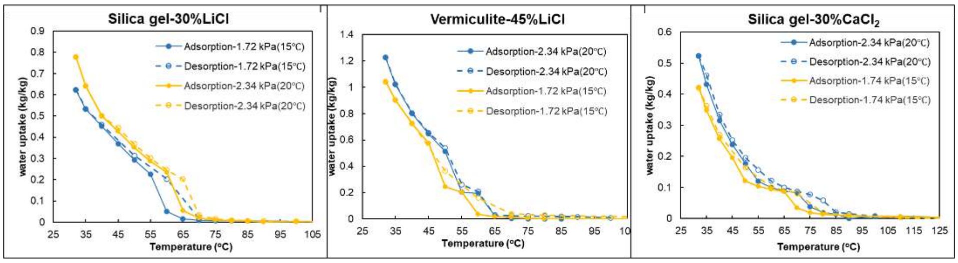


Figure 1: DSV isobars for the developed composite materials

Verm-45% LiCl shows the highest water uptake in both tested conditions with a plateau at high ad/desorption temperatures. This behavior is common also with the other composites, that show lower water uptakes under the same operating condition. The water uptake of silica gel-30% CaCl2 and silica gel-30% LiCl is about 0.76 g/g and 0.52 g/g at 20°C, respectively.

4. CONCLUSIONS

The developed composite sorbents possess a high water uptake capability, particularly when the used salt is lithium chloride. All the sorbents present a similar behaviour with a higher adsorption capacity at low temperatures. Therefore, the obtained results demonstrate a good potential of these composites for sorption cooling application.

5. REFERENCES

[1] T. Kousksou, P. Bruel, A. Jamil, T. El Rhafiki, and Y. Zeraouli. Energy storage: Applications and challenges. Solar Energy Materials and Solar Cells, 120:59–80.

[2] Aydin D, Casey SP, Riffat S. The latest advancements on thermochemical heat storage systems. Renew Sustain Energy Rev 2015;41:356–67

[3] Donkers PAJ, Pel L, Adan OCG. Experimental studies for the cyclability of salt hydrates for thermochemical heat storage. J Energy Storage 2016;5:25–32

6. CONFERENCE TOPIC

Cold storage and sustainable cooling

Numerical simulation and optimization of a compact thermal energy storage device for electric vehicles

Peng Xie[1], Cailin Gu[2], Lin Cheng[1]

1 National Engineering Research Center of Electric Vehicles, Beijing Institute of Technology, Beijing, 100081, China
2 Institute of General Mechanics, RWTH Aachen University, Aachen 52062, Germany

Keywords: Thermal energy storage; Miscibility gap alloy; Composite phase change material; Electric vehicle; CFD simulation

1. INTRODUCTION

The heating of the cabin of an electric vehicle (EV) in a low temperature environment consumes considerable battery power, resulting in a significant reduction in the cruising range. On-board thermal energy storage (TES) is considered to be an effective way to improve the cruising range of EVs in winter [1]. Miscibility gap alloys (MGAs) are a new type of shape-stabilized composite phase change material, which have the advantages of high energy storage density, high thermal conductivity, low cost and good safety. Therefore, using it to replace battery to heat EVs can reduce the price of the whole vehicle, increase the cruising range and prolong the battery life. Against this background, the heat transfer of a TES system based on MGAs is numerically studied. Firstly, the structure, specific size and MGA materials are chosen to meet the requirements of a 5-kWh heat capacity and a small heat loss. A numerical model of the designed system is built, and the charging, storage and discharging processes are studied under various conditions, and certain methods are applied to optimize the heat transfer performance.

In summary, a compact TES device is designed with an electric heating rod as the heat source, Fe-Mg as the thermal storage material, silica aerogel as the insulation material, and air as heat transfer fluid. The TES device is in the shape of a cylinder, with the heating source in the middle and MGA all around it. Between the MGA and the insulation layer is the fluid flow path. Copper foam is filled in the fluid flow path to further enhance the discharge performance. The volume of the TES device is 8.8 L, the effective heat storage capacity is 4.87 kWh, and the discharging power can reach 1.44 kW. This investigation provides guidance for the engineering development of MGA-based heat batteries for EVs.

2. STRUCTURE AND SIMULATION RESULTS OF THE THERMAL ENERGY STORAGE DEVICE

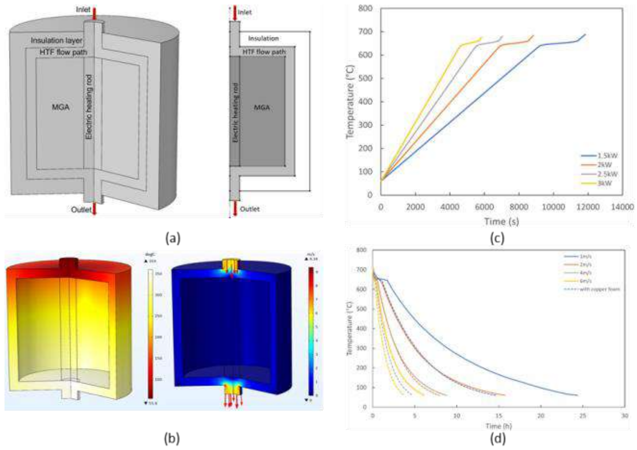


Figure 1: (a) geometry of the MGA-based thermal energy storage device; (b) temperature and velocity contours of the flow path; (c) temperature variation during charging process; (d) temperature variation during discharging process.

3. REFERENCES

[1] Xie P, Jin L, Qiao G, Lin C, Barreneche C, Ding Y. Thermal energy storage for electric vehicles at low temperatures: Concepts, systems, devices and materials. Renewable and Sustainable Energy Reviews. 2022; 160: 112263.

4. CONFERENCE TOPIC

Energy storage for decarbonisation of transport

Planning and Optimal Operation of Battery Replacement Hub Integrating with a Local Energy System

Jinqi Liu, Jihong Wang[1]

School of Engineering, University of Warwick, Coventry CV4 7AL, UK
[1]The author for correspondence: jihong.wang@warwick.ac.uk
Keywords: Local energy system, Battery hub, Capacity planning, optimal operation.

1. INTRODUCTION

The paper presents our recent attempt to analyse the potential of adopting Battery Replacement Hub (BRH) to meet the EV energy need and support optimal local energy system (LES) operation. BRH refers to a station which accommodates a sufficiently large number of EV batteries which can be charged at the station and the EV users can replace their batteries with the charged batteries while their batteries have no sufficient energy. With the multiple batteries at the station, the station can possess a relatively large capacity of batteries and can manage the battery charging and discharging process to meet grid or energy system balance needs. The main advantages of this scheme are: 1) encourage EV usage by reducing EV capital cost as the EV owners only need to purchase the EV with the leased battery; 2) establish a relatively large-scale energy storage capacity to provide service to energy systems. Building an electrical moped BRH on campus is in discussion between industry and the university, which will help understand the optimal operation of BRH.

2. INSTALLATION CAPACITY PLANNING AND OPTIMAL OPERATION

The installation capacity of BRHs has been analysed and determined to meet LES load and generation balance requirements. The study chooses the University of Warwick campus energy system as an example of LESs. The optimisation process considers the characteristics of BRHs, including battery replacement frequency and degradation, investment cost, and round-trip efficiency; the optimisation incorporates the campus energy demand, the generation of Combined heat and power plant (CHP) and Photovoltaic (PV) of the University of Warwick (UoW) into the analysis. Five intelligent algorithms are used to search for the optimal solutions, as shown in Figure 1(a). Five algorithms deliver relevantly consistent results for BHS capacity/power, which was 52.2 MWh/30MW under the current electricity price. The grid battery station was introduced in combination with the BHR to balance the power system on the University of Warwick campus, as there is no need for such a considerable installation capacity/power for BRHs within the University of Warwick campus. Based on our analysis and capacity limitation of BHR, the best combination for BRH and battery station is 6MWh/6MW and 29.2MWh/16.6MW. The optimal operation strategy for single BRHs is further investigated to balance load and generation at minimal cost within the constraints of network and battery replacement requirements. Twin Delayed DDPG (TD3), an improved reinforcement learning strategy, was adopted to control daily battery energy dispatch in hour resolution. The energy exchange between 3MWh BRH and grid, and hourly electricity trading prices show in the upper figure in Figure 1(b). The net LES electricity demand, LES electricity demand integrating with BRH, and the BRH energy exchange are shown in the middle figure in Figure 1(b), while the number of energy status (fully charged units, empty units, and intermediate states) for BRH units is displayed in the bottom figure of Figure 1(b).

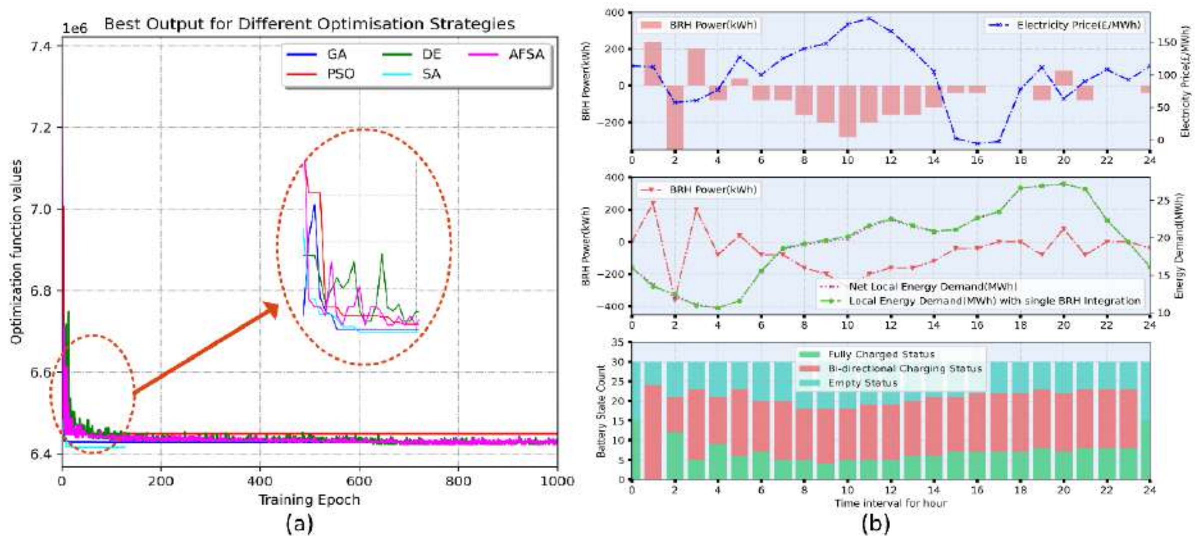


Figure 1. (a)Convergence processes for five selected methods, (b) TD3-based optimal control results.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Experimental Investigations of DC-Linked Hybrid Lead-Acid and Li-Ion Battery Energy Storage Systems

Andrei Dascalu[1], Suleiman Sharkh[2], Andrew Cruden[3], Peter Stevenson[4]

1,2,3 CDT – Energy Storage and its Applications, University of Southampton
4 GS Yuasa Europe

Keywords: Battery Energy Storage, Hybrid Energy Storage, Dual Chemistry, Lead-acid, Li-ion

1. ABSTRACT

Energy storage systems are already playing an increasing role in advancing the renewable energy transition and investigating new technologies is a top priority for governments and industry alike. This paper discusses the idea of hybrid energy storage and details the specific option of lead-acid and li-ion DC-linked hybrid battery systems. After a brief introduction to the hybrid lead-acid and li-ion behaviour, five domestic-size battery storage systems are being examined to understand how this behaviour changes with the number of strings and system voltage. This is done by cycling four 24V (1 li-ion & 1 lead-acid strings, 1 li-ion & 2 lead-acid strings, 1 li-ion & 3 lead-acid strings and 2 li-ion & 1 lead-acid strings) and one 48V (1 li-ion & 1 lead-acid) hybrid systems at 0.2-1C rates and 10-50% depth of discharge. The results include observations about the overall round-trip efficiency, transient currents, energy transfers between the strings, and the amount of energy discharged by each string across all systems. The general observation is that the roundtrip efficiency drops from a maximum of around 95%, in the first stages of the charge/discharge process, when only li-ion strings are active, to around 82-90% for DOD up to 50%. The most important parameters in the roundtrip efficiency function are the ratio between the li-ion & lead-acid energy available and the charge/discharge current. The energy transfer between the strings, caused by the transient currents, is negligible in the first stages of the discharge and grows with the DOD peaking at around 60% DOD (around 5% of the total discharged energy). Finally, in the first stage of discharge, only the li-ion strings are active, and the amount of energy discharged decreases to almost half between 0.2-1C. This is generally the case across all systems.

2. CONFERENCE TOPIC

Energy storage for decarbonization of transport. The analysis is part of a larger project which aims to use hybrid battery systems to avoid power network upgrades for EV charging points clusters.

Energy storage for port decarbonization

Ilias Sarantakos[1], Charalampos Patsios[2]

1 School of Engineering, Newcastle University, ilias.sarantakos@newcastle.ac.uk
2 School of Engineering, Newcastle University, haris.patsios@newcastle.ac.uk

Keywords: Energy storage, port decarbonization, digitalization, carbon emissions.

1. INTRODUCTION

Maritime transportation accounts for more than 80% of global trade and produces 3-5% of the global GHG emissions, which could rise up to 18% by 2050, if no appropriate actions are taken, according to the IMO. Ports can play a key role in zero emission shipping by 2050, which is a strategic ambition of the UK Government (Clean Maritime Plan). According to this plan, ports will require significant investment to reach that target. Port decarbonization will be realized via: 1) electrification, e.g., a) shore power, which means transitioning from "dirty" fuel oil to clean electricity, b) electrifying cargo handling equipment (CHE), i.e., switching from diesel-powered CHE to mains-connected or battery-powered CHE, and c) battery charging for (partly or fully) battery-powered vessels; 2) digitalization, e.g., a digital platform, which automatically collects data of various types, with the capability to control assets, if combined with a decision-making tool (typically based on optimization); and 3) bunkering and production of alternative fuels (e.g., hydrogen, ammonia, methanol) from onsite renewables/storage.

This work demonstrates the impact of energy storage (aided by digitalization) on port decarbonization. We use a number of scenarios ranging from now to 2050 to show the benefits (in terms of cost saving and reduction of carbon emissions) that energy storage can bring about in the context of a port. This work also studies the impact of sizing energy storage, when digitalization is present, and shows that significant savings can be realized.

2. METHODOLOGY

This work employs convex optimization for the optimal operation of the port, and probabilistic analysis based on Monte Carlo simulation to quantify the CapEx saving (related to storage) that can be achieved when digitalization is in place.

3. RESULTS AND DISCUSSION

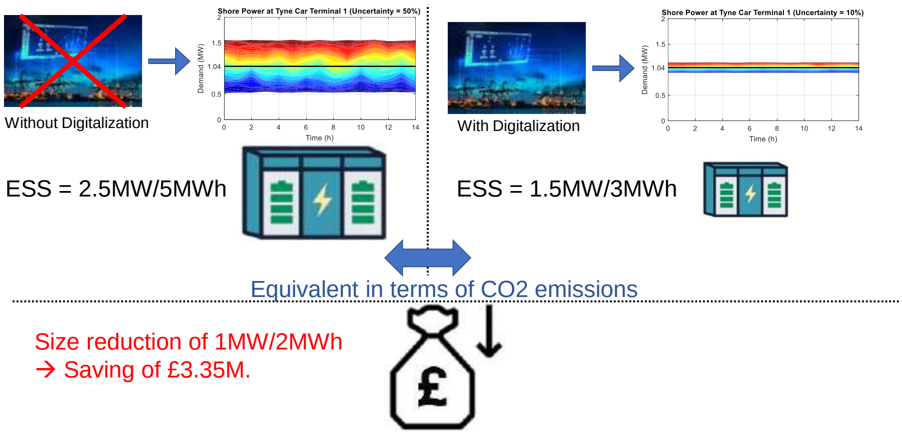


Figure 1: Impact of energy storage sizing (aided by digitalization) on capital expenditure [1].

4. ACKNOWLEDGMENTS

This work was supported by Clean Tyne Project and the EPSRC Supergen Energy Networks Hub Sub-Project "Turning accelerated decarbonization challenge into an investment opportunity: Port of Tyne case study".

5. REFERENCES

[1] Sarantakos I, Patsios C *et al*. Digitalization for Port Decarbonization. IEEE Electrific Mag 2023 (Under Review).

6. CONFERENCE TOPIC

Energy storage for decarbonization of transport.

Thermal Management Simulation of Automotive Supercapacitors

Ze SUN[1], PanChun TANG [2]

1 National Engineering Research Center for Integrated Utilization of Salt Lake Resource, East China University of Science and Technology,Shanghai 200237, China; zsun@ecust.edu.cn
2 National Engineering Research Center for Integrated Utilization of Salt Lake Resource, East China University of Science and Technology,Shanghai 200237, China; y30210104@mail.ecust.edu.cn

Keywords: supercapacitor, thermal management, thermal modeling progress, COMSOL

1. INTRODUCTION

Super capacitor is a kind of energy storage device with high power density, high energy density and high charge and discharge efficiency[1]. It has a wide range of temperature and long service life. It is widely used in electric power, transportation, industry and other fields, and also provides a guarantee for the energy storage system of new energy vehicles[2]. Supercapacitors are an integral part of energy storage technology[3].

2. METHODS

Using the means of simulation to predict the heat distribution law and the degree of temperature change during the use of supercapacitors, the mainstream software is ANSYS and COMSOL. ANSYS is a relatively classic software, while COMSOL is an increasingly popular multiphysics finite element software. In COMSOL, geometry, materials, and physics interfaces are added, and research calculations can be performed after meshing. Simulation of thermal management of supercapacitors requires the use of electric and thermal fields and coupled electro-thermal multiphysics.

3. RESULTS AND DISCUSSION

The temperature distribution of the stacked supercapacitor is the highest in the middle, because the electrical and thermal conductivity of the diaphragm is very poor, and it is difficult to dissipate heat; the temperature near the case is lower, because the aluminum-plastic film can dissipate heat well. The temperature at the positive tab is higher than that at the negative tab, which is related to material properties and current density.

4. CONCLUSIONS

Generally speaking, the working temperature range of supercapacitors is large. Within the normal working range, the temperature rise of one charge-discharge cycle is very small, and it can still work normally after repeated charge and discharge reaches a steady state. When the ambient temperature is too high, the problem of heat dissipation needs to be considered. At this time, the geometry can be changed, such as adding fins, or the heat exchange medium can be changed, such as air or flowing water or cooling oil.

5. REFERENCES

[1]GUALOUS H, GALLAY R, LOUAHLIA-GUALOUS H, et al. Supercapacitor thermal characterization in transient state [Z]. 2007 IEEE Industry Applications Conference, Forty-Second IAS Annual Meeting (IAS 2007), vol2. New Orleans, Louisiana, USA: 722-9

[2]SAKKA M A, GUALOUS H, MIERLO J V, et al.Thermal modeling and heat management of supercapacitor modules for vehicle applications[J].Journal of Power Sources.2009,194(2):588-600.

6. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Assessing the innovation process for energy storage

Xinfang Wang[1*], Jonathan Radcliffe[1], Peter Taylor [2,3]

1 School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham, UK. B15 2TT

2 School of Chemical and Process Engineering, University of Leeds, Leeds, UK. LS2 9JT

3 School of Earth and Environment, University of Leeds, Leeds, UK. LS2 9JT

*Corresponding author: x.wang.10@bham.ac.uk

Keywords: innovation, investment, levelling up, energy storage

1. ABSTRACT

Energy storage (ES) can play an important role in meeting net zero targets by providing multiple energy system services. In the IEA Net Zero scenario, the globally installed capacity of ES increases 35-fold to 2030 reaching 585 GW (IEA, 2021). This anticipated demand is driving governments and companies to invest in research, development, demonstration and deployment for a wide range of ES technologies. This support is needed because many technologies are at an early stage of technical maturity, and currently have high capital costs but with significant potential for cost reductions (Schmidt, 2017). Furthermore, their value to the system to balance supply and demand will only emerge as generation from variable renewables increases.

This paper takes a Technological Innovation System (TIS) approach to assess in detail the innovation of ES in the UK, considering quantitative and qualitative indicators for each of the seven TIS functions (Bergek, 2008). We highlight the gaps in the innovation system that may prevent commercialisation and scale-up required to meet the levels suggested by net zero scenarios. This provides insights for Governments and innovation agencies seeking to deploy technologies for decarbonised energy systems.

We find that several large-scale ES technologies that are anticipated to provide the greatest benefit through the 2020s are at the pre-commercial stage, but lacking a market that values their future potential in the system. To capture the future benefit from ES and avoid market failures in the future, investment needs to take place now in market formation with support from policy and regulations as well as R&D and deployment. It is essential that policymakers connect closely to national funders of innovation, the innovation community and industry to reap economic rewards in the future through early and aligned investments.

2. REFERENCES

[1] Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., and Rickne, A. 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Research Policy* 37: 407–429.

[2] IEA. 2021. Tracking Clean Energy Progress, https://www.iea.org/reports/energy-storage.

[3] Schmidt, O., Hawkes, A., Gambhir, A. et al. 2017. The future cost of electrical energy storage based on experience rates. *Nature Energy* 2, 17110. https://doi.org/10.1038/nenergy.2017.110 .

3. CONFERENCE TOPIC

Role, value and policy of energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Renewables + storage vs. nuclear power: An analysis of the UK's electricity grid

Bruno Cárdenas[1]*, Roderaid Ibanez[1], James Rouse[1], Lawrie Swinfen-Styles[1], Seamus Garvey[1]

1: Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, NG7 2RD, United Kingdom

Keywords: Nuclear baseload; small modular reactors; energy storage capacity; grid flexibility; levelized cost of electricity

1. ABSTRACT

Although nuclear power in the UK has been submerged in controversy due to the high costs and numerous problems in the construction of Hinkley Pont C, the British government has put nuclear power at the centre of its new energy security strategy, partially motivated by an urgency to eliminate the dependence on Russian gas. The plan is for nuclear power to deliver ~25% of the country's projected electricity demand by 2050. Nuclear power provides a constant energy output, so many consider it ideal to supply a baseload; however, like renewables, this output is inflexible. Therefore, replacing fossil-fuelled generation with nuclear power stations will also bring grid balancing challenges and depending on its level of penetration, energy storage may be required.

In this paper we explore whether there is an economic case for nuclear power to supply a fraction of the country's electricity demand in a future decarbonised grid, or if a combination of 'renewables + storage' will lead to the lowest possible overall cost. Using historical demand and generation data for the UK, we evaluate numerous system configurations or 'scenarios' based on different generation mixes (nuclear, wind and solar PV), different over-generation levels, and several combinations of energy storage technologies to determine the configuration that achieves the lowest total cost of electricity (*TCoE*). Hydrogen in underground salt caverns is considered for long-duration storage while compressed air energy storage is considered for the medium-duration storage duty.

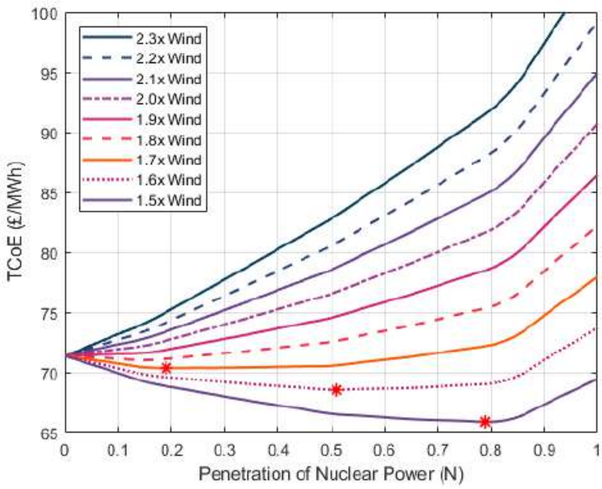


Fig.1. Effect of a reduction in the cost of nuclear power on the total cost of electricity

Figure 1 shows that, considering the current cost of nuclear generation (~92.5 £/MWh = 2.3x the current cost of wind), the *TCoE* is minimized when demand is supplied entirely by 'renewables + storage' with no contribution from nuclear.

Rolls Royce is developing a solution based on small modular nuclear reactors. They envisage that costs as low as ~£60/MWh (1.5x the current cost of wind) could be achieved in the future. Although highly unlikely, if such low costs were archived, supplying ~80% of the country's electricity demand with nuclear power would be the lowest cost alternative (see Fig. 1). In this scenario, wind provides the remaining 20% plus a small percentage of over-generation (~2.5%). Hydrogen storage in underground caverns provides ~30.5 TWh (81 days) of long-duration energy storage capacity while CAES systems provide 2.8 TWh (~8 days) of medium-duration storage capacity. Li-ion batteries provide the capacity required for short-duration imbalances; however, it is small compared to H_2 and CAES. Before including Li-ion costs, this configuration achieves costs of ~65.8 £/MWh.

Through this paper we aim to: 1) demonstrate that, considering current costs in the UK, nuclear generation is too expensive to compete with 'renewables + storage', *ii*) determine the cost threshold below which there could be a future economic case for nuclear power in the country and *iii*) provide some guidance to policy makers in the country regarding what is the best route—from an economic standpoint—towards a 100% carbon-free electricity supply.

2. CONFERENCE TOPIC

Role, value, and policy of energy storage / Energy storage for decarbonisation of power sector / Energy storage modelling

Role and value of energy storage in future market-driven distribution systems

Sayfutdinov T[1,2], Patsios C[1], Greenwood D[1]

1 Newcastle University, Newcastle-upon-Tyne, UK, haris.patsios@newcastle.ac.uk
2 Xi'an Jiaotong-Liverpool University, Suzhou, China, tsaifutdinov@gmail.com

Keywords: Distribution system, energy storage, local energy market, network utilization,

1. INTRODUCTION

The application of Energy Storage (ES) in distribution systems is manifold [1]. First, it can be used by the electricity system operator for whole-system needs, such as balancing and operating reserve. Second, it can be used by Distribution System Operator (DSO) to facilitate economic and reliable power supply, e.g., by providing investment deferral service in overloaded networks. Finally, it can provide energy arbitrage at the Local Energy Markets (LEM), delivering value not only to its owner, but also to other stakeholders, including renewable generators, network customers, and DSO. While the former two applications have been extensively studied in the literature and practice, our work focuses on the latter to investigate the impacts of ES on a distribution system and its stakeholders under market conditions.

2. MATERIALS AND METHODS

We apply a newly developed modelling framework for market-driven distribution system operation [2] to investigate the role of ES within it. The framework comprehensively accounts for the whole-system and distribution system ancillary services procured at the distribution level, local energy trading, main stakeholders, their objectives and demand for distributed flexibility. The research methodology is based on sensitivity analysis of the case study to various factors, such as price signals, the penetration level of DERs (including storage), and their locations. While the considered case study is based on a real distribution network in the North East of England, input data for peak demand, the uptake values of low carbon technologies and DERs are taken from Distribution Future Energy Scenarios (DFES) for a particular network [3].

3. RESULTS AND DISCUSSION

Our results show that ES plays important role in market-driven distribution system management. First, it was found that in a distribution system with multiple markets and services, ES finds the best value from participating at the LEM. By shifting energy over time, ES owners benefit from price differences during the day, renewable generators benefit from increased utilization at the time of low demand, and network customers get carbon-free electricity at a competitive price. For the DSO, integration of ES to distribution networks does not cause only positive effects. For instance, it was illustrated that when participating at the LEM, storage may reduce the net load of a single primary substation, while utilization of an upstream network can be increased. This is because big demand and ES centres that trade electricity may sit at different network locations, causing higher power flows in a network that connects them.

4. CONCLUSIONS

The present study investigates the role of ES within a market-driven distribution system environment. We apply a newly developed modelling framework that comprehensively models a variety of flexibility markets and services, as well as the key stakeholders. The results showed that the highest value for ES originates from the LEM, where it provides energy arbitrage. However, ill-considered integration of ES can cause increased network loading and even create congestions. The proposed methodology can be used to identify the most appropriate locations for ES integration, which can be then considered within various incentive mechanisms, e.g., access rights and connection charges.

5. REFERENCES

[1] – ENA. Open networks project: opening markets for network flexibility. Energy Networks Association; 2017.

[2] – Customer-led distribution system. 2021, https://www.northernpowergrid.com/innovation/projects/customer-led-distribution-system-nia-npg-19.

[3] – Distribution future energy scenarios. 2021, https://odileeds.github.io/northernpowergrid/2020-DFES/.

6. CONFERENCE TOPIC

Role, value and policy of energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Estimate of the cost of overnight storage in natural gas linepack in the Great Britain

Wilson, I.A.G.[1]

1 University of Birmingham, Energy Informatics Group, Birmingham Centre for Energy Storage

Keywords: Linepack, Line pack, gas system storage

1. INTRODUCTION

Great Britain (GB) has an extensive natural gas system that transports gas supplies from a number of key input points through to tens of millions of customers. Over recent decades space-heating and hot-water provision in GB has been supplied predominantly from natural gas with over 80% of domestic properties having access to the natural gas system. Due to a combination of convenience, cost and knowledge, if households were connected to the natural gas grid and had a natural gas boiler and wet heating system then they would overwhelmingly use natural gas for their space heating and potentially hot water.

In order to balance the supply and demand over a daily basis, the natural gas system uses linepack swing to help. Linepack is the amount of natural gas contained within the higher-pressure tiers of the gas network, and linepack swing is the change in value of that linepack. When the pressure in natural gas pipes is increased, more molecules of natural gas are contained within the pipeline volume, i.e., the amount of natural gas has increased. Conversely, when the pressure in natural gas pipes is decreased, there are less molecules of natural gas contained within the pipeline volume, i.e., the amount of natural gas has decreased. This increase and decrease in pressure therefore acts as a store of natural gas, and indeed, this is how the natural gas system is managed on a day-to-day basis. Typically, the pressure in the higher-pressure tiers is increased overnight, so that the system is prepared by having a greater amount of energy in the system, and also closer to the end user ready for the large ramp up in gas demand every morning (much larger in the winter than in the summer).

Using empirical data from the four gas distribution network companies and the natural gas transmission system, the volumes of linepack for every hour for the seven years 2014 – 2020 are analysed. The cumulative sum of the linepack swing is shown in Figure 1, which is the sum of the delta or the change in hourly values over a year. The analysis considers the national transmission system (NTS), and the gas distribution networks (GDNs) separately and in total.

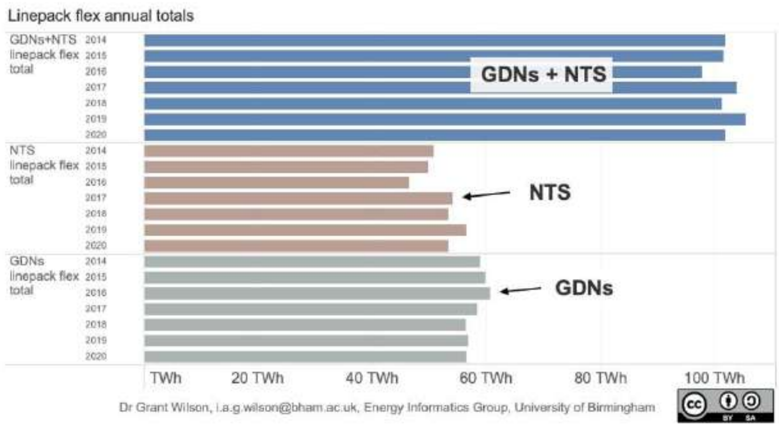


Figure 1 – Cumulative linepack swing per year for 2014 – 2020 by national transmission system and gas distribution system

There are a number of interesting features of linepack swing that will be further detailed in the full paper (including references), but an interesting observation of the annual aggregate values shown in Figure 1 is the consistency of the amount of linepack swing at around 100 TWh per year. In other words, the natural gas system consistently provides 100 TWh of storage service to the wider energy system each year. The costs of providing this are not as well understood, but the paper will consider a range of evidenced values, e.g., if the cost to provide linepack swing was £200 million per year, the cost per kWh for linepack swing would be 0.2 pence per kWh.

Assessing impacts of energy storage policy on deployment in the UK

C. M. Harrison[1], J. W. Radcliffe[1]

[1`]Energy Systems and Policy Analysis Group, Chemical Engineering, University of Birmingham

Keywords: UK Energy Storage Policy

1. INTRODUCTION

HM Government, with both the system operator and the independent regulator, have introduced a number of policies and markets to address historically slow growth of energy storage (ES) in the UK,. This includes (a) a relaxation of planning restrictions, (b) a removal of so-called 'double charging', (c) an increase in R&D funding and (d) a re-structuring of certain electricity markets. In this work, we critically review the current policy framework so as to assess current strengths and weaknesses for driving ES scale-up.

2. MATERIALS AND METHODS

Systematic search engine methods have been employed to analyse the policy framework of the UK in developing the ES market. The progress in deploying ES is assesed via a number of government and organisational databases.

3. RESULTS AND DISCUSSION

In the last 5-6 years, energy storage capacity in the UK has seen year-on-year growth (Figure 1). However, this progress is failing to keep pace with Renewable Energy Systems (RES) scale-up; as a percentage of installed RES capacity, the last decade has seen a relative fall in ES (see Figure 1a). This is concerning, given the need to grow ES alongside the increasing generation from variable renewables and simultaneous loss of dispatchable fossil-fuel generation. There remains significant uncertainty as to 'how much' ES capacity will be required in the future [1]. Regardless of any 'optimal' ES capacity, the underlying message is that a rapid scaling of ES needs to occur in the coming decades from the current ~4GW,of which ~2.7GW is Pumped Hydroelectric Storage (PHS). These PHS facilities were commissioned prior to the market privatisation of the 1980s and there is evidence to suggest this may be difficult to add to in the current, liberalised market [2]. Since 2015 there has been a growing number of grid-scale Battery Energy Storage Systems (BESS) deployed in the UK (Figure 1b). The alleviation of network costs (i.e., 'double charging' [3]) and, perhaps most significantly, the loosening of planning restrictions [4], appears to be supporting this. The effect of the latter effort can be appreciated via the subsequent leap in the number of corresponding applications (Figure 2). Whilst growing deployments can be viewed as one measure of ES policy framework success, analysis of market data also shows some encouragement for ES. In particular, BESS is playing a growing role in both the capacity market (year-on-year increases since 2018) and the recently re-structured [5] frequency regulation market (Figure 3). Critically, it appears that current policy measures and market frameworks have provided the necessary investment case for grid-scale BESS. However, these technologies are focused on short time-scale responses, with duration of an hour or less.

4. CONCLUSIONS

There has been some progress in the deployment of ES in the UK. BESS technology, in particular, has been able to take advantage of changes to regulation and markets. Other, longer duration, ES technologies that can offer alternative and complementary benefits, remain insufficiently incentivised. Policy focus should now switch towards ensuring the broader suite of ES technologies has an opportunity to partake in the energy market and meet future system needs.

5. FIGURES

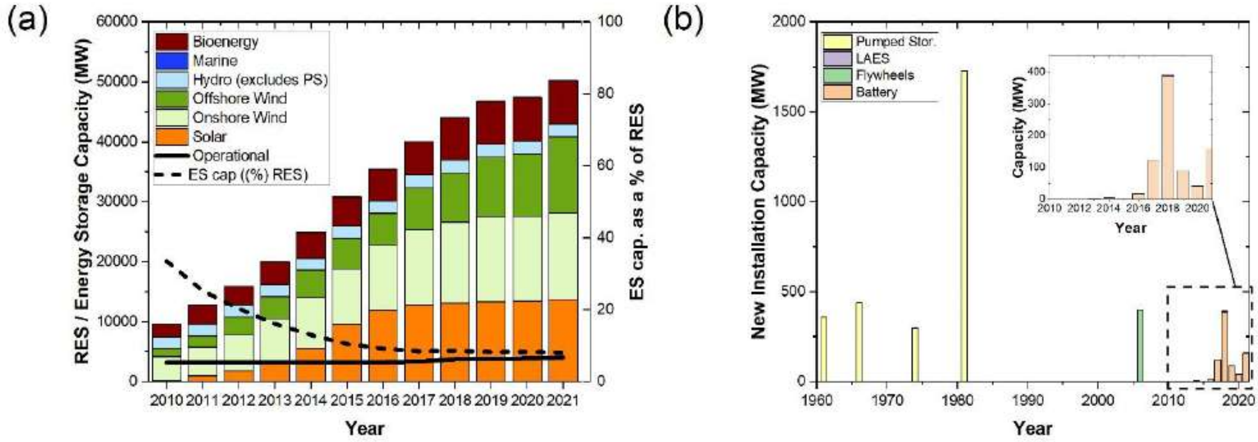


Figure 1 (a) RES deployments vs ES deployments in terms of capacity (dotted line shows ES capacity as a % of RES capacity) and (b) installations of ES technology in the UK since 1960 *[Data from* [6] *and* [7]*]*

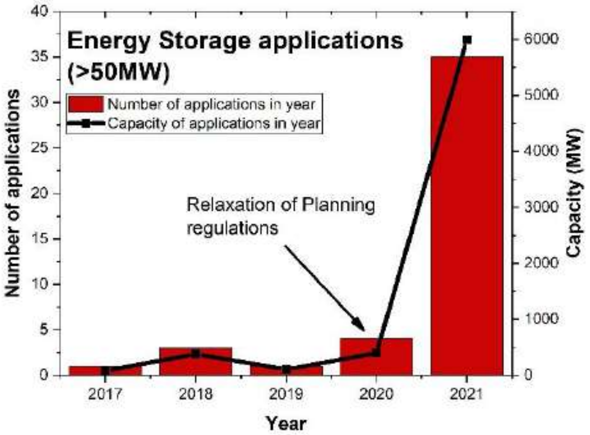


Figure 2 – Energy storage applications (>50MW) by year *[Data from* [7]*]*

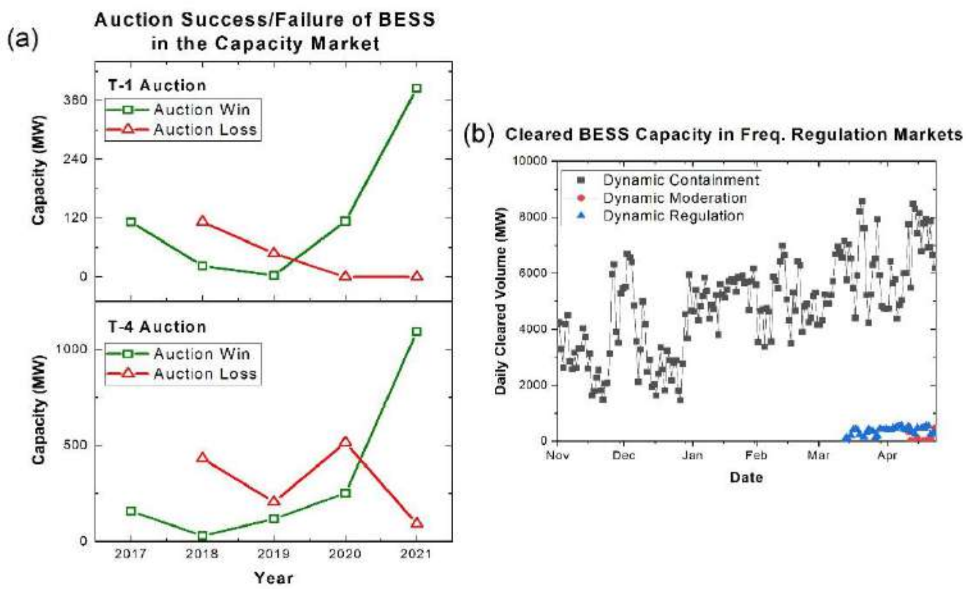


Figure 3 – (a) success and failed BESS bids in the Capacity Market by capacity, (b) successful BESS capacity in frequency regulation markets (Nov 2021-May 2022) *[Data from* [8] *and* [9]*]*

6. REFERENCES

[1] National Grid, Future Energy Scenarios, 2021. https://www.nationalgrid.com/NR/rdonlyres/C7B6B544-3E76-4773-AE79-9124DDBE5CBB/56766/UKFutureEnergyScenarios2012.pdf.

[2] E. Barbour, I.A.G. Wilson, J. Radcliffe, Y. Ding, Y. Li, A review of pumped hydro energy storage development in significant international electricity markets, Renew. Sustain. Energy Rev. 61 (2016) 421–432. https://doi.org/10.1016/j.rser.2016.04.019.

[3] Ofgem, Decision on clarifying the regulatory framework for electricity storage: changes to the electricity generation licence, Ofgem.Gov.Uk. (2020). https://www.ofgem.gov.uk/publications/decision-clarifying-regulatory-framework-electricity-storage-changes-electricity-generation-licence (accessed July 12, 2022).

[4] UK Parliament, The Infrastructure Planning (Electricity Storage Facilities) Order 2020, 2020. https://www.legislation.gov.uk/uksi/2020/1218/contents/made.

[5] National Grid ESO, Markets Roadmap, 2022. https://www.nationalgrideso.com/document/247136/download.

[6] IRENA, IRENASTAT Online Data Query Tool, Pxweb.Irena.Org. (2022). https://pxweb.irena.org/pxweb/en/IRENASTAT.

[7] BEIS, Barbour, Renewable Energy Planning Database, Data.Barbour-Abi.Com. (2022). https://data.barbour-abi.com/smart-map/repd/beis/?type=repd.

[8] National Grid ESO, DC, DR & DM Block Orders Master Data 2021-2022, Data.Nationalgrideso.Com. (2022). https://data.nationalgrideso.com/ancillary-services/dynamic-containment-data/r/dc,_dr_&_dm_block_orders_master_data_2021-2022.

[9] EMR delivery body, Capacity Auction Information, Emrdeliverybody.Com. (2022). https://www.emrdeliverybody.com/CM/Capacity Auction Information.aspx.

7. CONFERENCE TOPIC

Role, value and policy of energy storage

Assessing the economic viability of iron based flow batteries as long duration energy storage

Diarmid Roberts[1], Kathryn Toghill[2], Solomon Brown[1]

1 The University of Sheffield
2 Lancaster University

Keywords: Redox flow batteries, long duration energy storage, techno-economic analysis

1. ABSRACT

That flow batteries are considered long duration energy storage technologies was highlighted recently when BEIS awarded funding in this area to a 4 h vanadium system (VFB) [1]. However, the predicted duration of storage required in a net-zero future UK electrical grid ranges is on the order of multiple days to multiple weeks[2], [3], and VFB are highly unlikely to be economical at this duration due to the high cost of vanadium.

There are however multiple flow battery chemistries, and in this work we employ a bottom up cost model for redox flow battery system costs in order to compare the predicted capital costs of notable systems at a range of durations [4]. Particular focus is given to iron systems which are based on a low cost metal, and are in the process of being commercialized [5]. This chemistry may be deployed in a hybrid (Fe^0 deposited on anode) or all liquid configuration, and we analyse the relative merits of both.

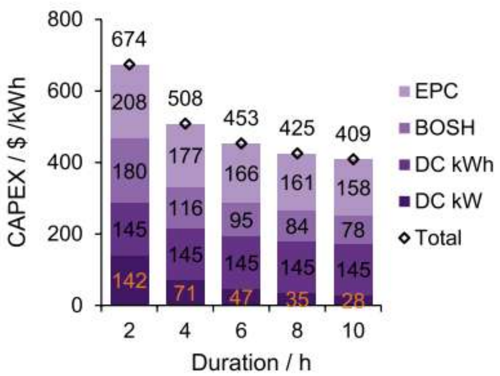


Figure 1: progression of turnkey cost of a VFB as duration is increased [4].

2. REFERENCES

[1] Invinity, "Invinity wins funding for first phase of 40 MWh UK solar +storage project / Invinity." https://invinity.com/invinity-wins-funding-for-first-phase-of-40mwh-uk-solar-storage-project/ (accessed Aug. 04, 2022).

[2] Aurora Energy Research, "Long duration electricity storage in GB," no. February, 2022.

[3] B. Cárdenas, L. Swinfen-Styles, J. Rouse, A. Hoskin, W. Xu, and S. D. Garvey, "Energy storage capacity vs. renewable penetration: A study for the UK," *Renew. Energy*, vol. 171, pp. 849–867, 2021, doi: 10.1016/j.renene.2021.02.149.

[4] D. Roberts and S. Brown, "The economics of firm solar power from Li-ion and vanadium flow batteries in California," *MRS Energy Sustain.*, pp. 1–13, Jun. 2022, doi: 10.1557/s43581-022-00028-w.

[5] A. Dinesh *et al.*, "Iron-based flow batteries to store renewable energies," *Environ. Chem. Lett.*, vol. 16, no. 3, pp. 683–694, Sep. 2018, doi: 10.1007/S10311-018-0709-8/TABLES/5.

3. CONFERENCE TOPIC

Role, value and policy of energy storage.

Exploring energy storage supply chains for energy security and sustainability

Amruta P Joshi[1], Taofeeq Ibn-Mohammed [2]

1 Warwick Manufacturing Group, University of Warwick, amruta.joshi@warwick.ac.uk
2 Warwick Manufacturing Group, University of Warwick, T.Ibn-Mohammed@warwick.ac.uk

Keywords: Energy storage, supply chain, energy security, sustainability, policy

HIGHLIGHTS

- Assessment of energy storage related international strategy, policy documents to investigate emphasis on supply chains
- Limited attention to supply chain issues in energy storage technologies other than batteries
- Proposed a methodology to enable identification of gaps in energy storage supply chain development

INTRODUCTION

Energy storage is a key constituent of the renewable energy systems transforming energy supply to range of applications in domestic, industrial, transport sectors for achieving the net zero targets. Various types of energy storage technologies such as batteries, supercapacitors, thermal energy storage (TES), compressed air energy storage (CAES) [1] are being considered to satisfy energy density, power density needs at different time scales. Energy security, energy equity and environmental sustainability of the energy systems, including energy storage systems, are three pillars of energy sustainability as defined by World Energy Council [2]. The uncertainties posed by pandemic, geopolitical developments as well as the extreme events in the wake of climate change are leading to disruptions of global supply chains impacting the delivery and deployment of various renewable energy projects adversely [3]. This may decelerate worldwide efforts of decarbonisation; so, it is indispensable to ensure that the supply chains are robust in handling these risks.

METHODOLOGY

In this work, the governmental strategies, policies, and regulations [4-7] in different parts of world are assessed in context of supply chain concerns for different energy storage technologies. We observed that the supply chain issues related to batteries have received more attention in comparison with any other energy storage technology; this seems to be driven by role of batteries in electric vehicles [8]. However, other storage technologies such as TES, power-to-x as well as electric are critically important with regards to longer duration storage. Thus, along with technological advancements, supply chains for range of energy storage technologies at higher technology readiness level must be developed.

Like supply chain for batteries from materials, cells, battery packs to power electronics; other energy storage systems also consist of different materials and sub-components. So, we propose a methodology of identifying critical materials and system components and mapping their sources of supply for the variety of energy storage technologies that would be beneficial for planning and execution of the renewable energy system projects. It would also aid in focusing on the areas which need investment support to establish the parts of supply chain which are found to be missing in the existing landscape. This would also entail recycling of critical materials and refurbishing/ remanufacturing sub-components of energy storage systems. Comparative analysis of manufacturing capabilities of different regions for different subcomponents of energy storage systems would support competition and encourage innovation.

CONCLUSION

Visibility of the supply chains achieved through adaptation of the methodological framework not only exhibits potential of lowering the risks of supply chain disruptions but also elucidates the capabilities of reinforcing circular economy principles in energy storage system supply chains. Thus, the methodology aims to promote energy security and sustainability by providing avenues to adapt to low carbon pathways for energy storage systems supply chains.

REFERENCES

[1] Radcliffe, J, Murrant, D, & Joshi, A (2020) UK Roadmap for Energy Storage Research and Innovation, University of Birmingham, UK. https://ukesr.supergenstorage.org/

[2] World Energy Trilemma Index Report, World Energy Council in partnership with Oliver Wyman, 2021. https://www.worldenergy.org/publications/entry/world-energy-trilemma-index-2021

[3] Here's how supply chain issues are affecting renewable energy projects, World Economic Forum, Nov. 2021. https://www.weforum.org/agenda/2021/11/supply-chain-problems-solar-power-renewable-energy

[4] British Energy Security Strategy- Secure, clean and affordable British energy for the long term, HM Government, April 2022. https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy

[5] Grid Energy Storage-Supply Chain Deep Dive Assessment, U.S. Department of Energy Response to Executive Order 14017, "America's Supply Chains", February 2022. https://www.osti.gov/biblio/1871557-grid-energy-storage-supply-chain-deep-dive-assessment

[6] America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition, U.S. Department of Energy Response to Executive Order 14017, "America's Supply Chains", February 2022. https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

[7] European Commission, Directorate-General for Energy, Andrey, C., Barberi, P., Nuffel, L., et al., *Study on energy storage: contribution to the security of the electricity supply in Europe*, Publications Office, 2020. https://data.europa.eu/doi/10.2833/077257

[8] Global Supply Chains of EV Batteries, International Energy Agency, Technology Report, July 2022. https://www.iea.org/reports/global-supply-chains-of-ev-batteries

CONFERENCE TOPIC

Role, value and policy of energy storage

APPENDIX A

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Impact of controlled ortho- to para-hydrogen conversion on liquid hydrogen production for energy storage

Paula Mendoza Moreno[1], Ewa J. Marek[1]
1 Department of Chemical Engineering and Biotechnology, University of Cambridge, Philippa Fawcett Drive, CB3 0AS, Cambridge, UK, corresponding author: pvm21@cam.ac.uk

Keywords: Liquid hydrogen, hydrogen liquefaction, ortho- to para-hydrogen conversion, exergy analysis, life cycle assessment

Liquid hydrogen (LH_2) is a form of chemical energy storage with prospective applications in the global low-carbon energy systems. LH_2 has approximately twice the volumetric density of hydrogen gas (H_2) compressed at 700 bar, making LH_2 easier to store and transport over long distances and time scales. Additionally, the production and usage of LH_2 can be seen as a way to export resources from regions with high renewable energy potential to locations where the resources are brought into effective technological action, still reducing the greenhouse gas emissions in the energy sector. To capitalise on the advantages of LH_2, the energy-intensive liquefaction step in the LH_2 supply chain must consume only up to half the energy used in the current industrial liquefaction practices, which means that optimisation or new liquefaction approaches are needed. One challenge to reduce the energy consumption when producing LH_2 includes limitations in the accuracy of thermodynamic properties of molecular hydrogen used in liquefaction models. Hydrogen exists as a mixture of two isomers, which are defined as ortho- and para-hydrogen, whose fractions change with temperature and the transition between the two releases or consumes heat. Therefore, the applicability of LH_2 as an energy vector in long-term storage depends on the final ortho-hydrogen content because when the ortho-hydrogen transitions to the para-form, the amount of the released heat is sufficient to match the heat of evaporation of LH_2. This work investigates the performance of a hydrogen liquefier with a detailed study on the transition between isomers *via* continuous catalytic conversion from the first and second law of thermodynamics, and environmental sustainability perspectives. The hydrogen liquefaction simulation was done in Aspen Plus and thermodynamic properties of ortho- and para-hydrogen isomers were modelled by REFPROP. The hydrogen feed was simulated as a mixture of ortho- and para-forms with user-manipulable ratios that change at four discrete temperature points upon cooling, mimicking a controlled catalytic ortho-para reaction. The production of liquid 99.8% para-hydrogen in discrete conversion points away from equilibrium was compared to the equilibrium-hydrogen case. The later approach is commonly used in literature and refers to the assumption that the conversion of the ortho-isomer occurs instantaneously and progressively with cooling, with the resulting isomer composition being equal to that at thermodynamic equilibrium at all temperature points. The performance of the modelled liquefication plants was then assessed and compared using specific energy consumption and exergy efficiency. Exergy losses from the ortho- to para-conversion and each modelled unit of operation were quantified. Finally, energy savings from varying degrees of ortho- to para-hydrogen conversion were related to the potential self-evaporation of LH_2 when stored over time and to the effective energy required to compensate for product losses depending on LH_2's application as a chemical feedstock and in aviation. The environmental sustainability of the liquefier was assessed by quantifying the climate change impact using life cycle assessment methods. The environmental impact was compared across scenarios ranging from no isomeric conversion to 99.8% para-hydrogen production, with or without transportation to distribution centres. Greater contributors and emissions savings were identified and compared to conventional jet fuel.

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Offshore wind integration – storage and flexibility modelling

D, Murrant[1], C Jankowiak [2]

1 Energy Systems Catapult, Daniel.Murrant@ES.Catapult.org.uk
2 Energy Systems Catapult, Corentin.Jankowiak@ES.Catapult.org.uk

Keywords: Energy storage modelling, offshore wind integration

1. INTRODUCTION

The UK Government has set a target of 50 GW of Offshore Wind (OSW) by 2050, with a significantly higher deployment likely by 2050. The integration of very high levels of renewables into the wider energy system whilst minimising increases in the cost of operating the system presents a considerable and multi-faceted challenge. The Energy Systems Catapult (ESC) worked with the Offshore Wind Industry Council to explore this challenge, including the need for storage and flexibility services to integrate OSW in a multi-vector, whole-system context such as the GB energy system.

2. METHODOLOGY

ESC used its "ESME Flex" model, a least-cost optimisation national and regional modelling tool which provides a techno-economic evaluation of energy storage and other sources of flexibility in GB, to explore two future scenarios out to 2050:

1) "Further Ambition Unforced" - the level of OSW deployment out to 2050 is unspecified ('unforced'), and is selected by the model based on least system cost.
2) "Further Ambition 125" - 125GW of OSW is specified ('forced') as being deployed into the system by 2050.

3. RESULTS/CONCLUSION

This presentation will provide an overview of this work including methodology, and a summary of the findings including:

- OSW plays a significant role out to 2050 under both scenarios. The relatively low cost of OSW, combined with its low carbon credentials, results in 70GW being deployed in the unforced scenario.
- With OSW becoming the largest generation source, flexible options are needed for daily balancing and to cover rare but extended low wind periods. These options include energy storage, demand side-management and low-carbon thermal generation.
- Energy storage is significant by 2050 (see Table 1), mainly to balance supply and demand daily, with over 70 GW of electrical storage alone in both scenarios by 2050.
- Even with high levels of flexibility, curtailment has potential to be high (up to 30% of wind generation).

Table1: Storage Capacity by Scenario 2050

Scenario	Further Ambition Unforced	Further Ambition 125
Electrical		
— Batteries	70GW / 211GWh	66GW / 188GWh
— Thermo-mechanical	8GW / 123GWh	6GW / 87GWh
Building thermal	276GW / 552GWh	273GW / 546GWh
Gaseous		
— Hydrogen linepack	14GW / 68GWh	13GW / 75GWh
— Gas linepack	27GW / 128GWh	37GW / 158GWh
— Gas long range store	400GWh	900GWh

Additionally, the presentation shall consider how the ESME Flex model has been adapted to allow it to explore how energy storage can be used to integrate renewable generation into other energy networks across the world.

4. CONFERENCE TOPIC

Application of energy storage through integration with renewable generation and energy networks.

Study on the simulation of storage tank for long-term storage of liquid air

Wenwen Du[1], Zhanping You [2], Xiaohui She*

1 Shijiazhuang Tiedao University , China, violadu2021@hotmail.com
2 Shijiazhuang Tiedao University , China, youzhanping@163.com
*Shijiazhuang Tiedao University , China, shexh19@hotmail.com

Keywords: Liquid air, Tank, Self-evaporation, CFD

1. INTRODUCTION

Liquid air energy storage (LEAS) is one of the most promising options for large-scale energy storage.In the form of liquid air tanks, LEAS has the advantages of high energy density and scalability[1].During long-term storage heat leakage from the outside world occurs, resulting in energy consumption.In this paper, the reduction of the daily evaporation rate of the storage tank is discussed from the design of insulation materials and insulation structures.

2. CFD MODEL

The Volume of Fluid (VOF) model with Level Set scheme is chosen .Lee model was chosen to calculate the mass transfer between the gas-liquid phases.The safety valve on the top of the tank is chosen as the velocity inlet compiled by User Defined Functions (UDF).

3. RESULTS AND DISCUSSION

Fig.1 shows the temperature contours of the tank body at 200s.Structure 1 is 0.05 m thick insulation material (0.01 MLIs/0.04 mHGMs) , and the temperature change is very small compared with the initial state.Structures 2 and 3 are composed of 0.01m thick MLIs, 0.02m thick interlayer and 0.02m thick HGMs.In structure 2, the temperature in the interlayer drops rapidly after the safety valve is vented, and a certain amount of cold energy is transferred into the insulation materials on both sides.The interlayer of structure 3 is filled with porous materials encapsulated with phase change materials. The temperature transfer is very slow during the venting process, but most of the cooling capacity is stored, reducing the heat transfer to the inner tank.

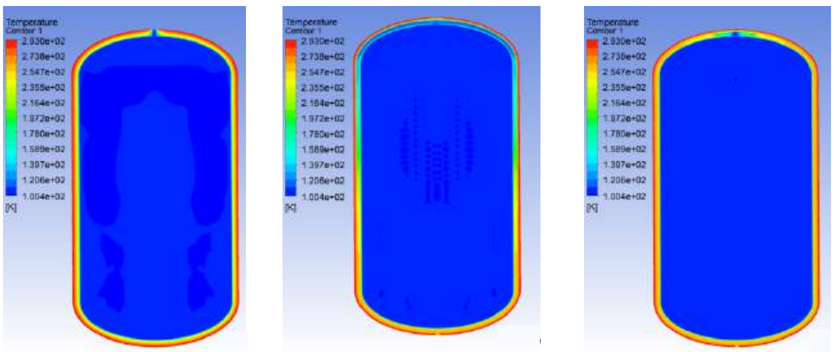


Fig.1 Temperature contours of the tank at t = 200s of structure 1, 2 and 3 from left to right

4. CONCLUSIONS

In this paper, the design and optimization results of the insulation structure for a storage tank with a volume of 1.4 m^3 with a charge rate of 88.2% are presented. The daily evaporation rate of structure 1 is less than 0.8%. The daily evaporation rate of structure 2 and structure 3 is less than 0.5%.Future works of this study may contribute to the study of the evaporation characteristics of different components within liquid air, thereby improving the design of the tank and improving its storage characteristics.

5. REFERENCES

[1] Zhou R, Zhu WL, Hu Z, Wang S, Xie H, Zhang X. Simulations on effects of rated ullage pressure on the evaporation rate of liquid hydrogen tank. Int J Heat Mass Transf. 2019;134:842-851.

6. CONFERENCE TOPIC

Recent advances and breakthroughs in energy storage

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

A mini review on building phase-change thermal storage wall

Yaxuan Xiong[1], Aitonglu Zhang [2]

[1]School of Environmental and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing, China , xiongyaxuan@bucea.edu.cn

[2]School of Environmental and Energy Engineering, Beijing University of Civil Engineering and Architecture, Beijing, China , 1652113229@qq.com

ABSTRACT

Building energy consumption is an important factor in generating carbon emissions. To achieve the goal of carbon peak and carbon neutralization, we must overcome difficulties in the construction field first. As an energy material, phase change material is often used in the field of energy storage because of its high energy storage density, large latent heat of phase transformation, stable performance and excellent cost performance. Using phase change materials in building walls can absorb and store the solar radiant heat entering the room during the day to avoid excessive room temperature. Releasing the absorbed and stored solar radiant heat at night can reduce the indoor temperature fluctuation, improve the thermal comfort of the room, reduce the energy consumption of building heating and cooling, and realize building energy conservation. Phase change thermal storage wall is one of the important measures to realize low-energy buildings, zero-energy buildings and low-carbon buildings. This review analyzes the characteristics of phase change materials, the theoretical research on heat transfer of phase change walls and the application status of phase change walls, points out the development direction of phase change wall materials, and summarizes the characteristics and solution methods of phase change heat transfer. It is indicated that the application of phase change walls with different structures in different climatic regions should be systematically and deeply studied by establishing a theoretical model of heat transfer. This paper discusses several aspects, including the thermophysical properties of phase change materials, the types of phase change materials, the incorporation methods of phase change materials that are suitable for phase change thermal storage walls, and the specific application methods of phase change material walls. Although it is known in theory that PCM walls have relatively good energy-saving potential, more research should focus on real full-scale buildings and actual operating conditions to prove the authenticity and reliability of current research. This paper also studies the thermal energy storage applications of different types of phase change walls, including Trombe wall, double-layer (multi-layer) phase change wall, solar photovoltaic phase change wall. The current research provides a state-of-the-art overview, covering the latest literature on the use of PCM in building thermal energy storage walls.

Keywords: Phase change material(PCM); thermal energy storage(TES); building energy efficiency; building walls

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

The value of heat in thermomechanical energy storage

Audrius Bagdanavicius[1]

1 School of Engineering, University of Leicester, LE1 7RH Leicester, UK

Keywords: Thermomechanical energy storage, exergy analysis, exergoeconomic analysis

ABSTRACT

One of the unique features of thermomechanical energy storage, such as compressed air energy storage (CAES), compared to other energy storage technologies, is the generation and consumption of heat during the charging and/or discharging stages. The generated heat can be stored in thermal storage (TS) and later used in the discharge stage to increase the efficiency of the CAES. The amount of heat produced or consumed depends on the efficiency of the individual components of the energy storage system. For example, the use of low efficiency compressors in CAES is not desirable, because the overall efficiency of the energy storage system will decrease, if the sole purpose of the storage system is to store electrical energy. However, the heat produced and stored by TS could be used not only internally during the discharge phase, but also externally as a product for other applications, such as heating of buildings. In this case, CAES will become a generator.

The aim of this study is to evaluate the possibilities of using the heat produced by CAES as a source of thermal energy for other applications. Steady state exergy and exergoeconomic analyses of a hypothetical single stage compression-expansion CAES using the concept of heat utilisation have been performed to evaluate the energy conversion and storage processes. The exergoeconomic analysis method allows obtaining information about the real costs of thermodynamic inefficiencies of system components and facilitates the understanding of cost formation processes. Using the exergoeconomic analysis the cost associated with exergy destruction, which depends on the efficiency of the CAES components have been calculated. The exergy costs of the final products - electricity and heat at different rates of heat utilisation and using different isentropic efficiencies of compression and expansion devices have been also calculated.

A preliminary study of the idealised CAES combined with the TS model shows that the amount of thermal energy generated in the charging stage increases with decreasing isentropic efficiency. Due to the use of heat for other purposes, the electricity production during the expansion phase is reduced. The exergy costs of electricity and heat generated in CAES also vary depending on the isentropic efficiency of the compression and expansion devices and heat utilisation. The study shows that a more detailed dynamic analysis is needed to investigate the operation of TS and its effect on the overall efficiency of CAES. Also, more accurate exergoeconomic analysis methods have to be developed to understand the real potential of using CAES as heat generators.

Conference topic: Energy storage for decarbonisation of heating and cooling

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Hydrogen production *via* thermochemical water splitting, utilising industrial waste streams

A.F.B. Abu Kasim[1,2], P.V. Mendoza-Moreno[1], S.A. Scott[2], R. Grant[3], E.J. Marek[1]

1 Department of Chemical Engineering and Biotechnology, University of Cambridge, Philippa Fawcett Drive, CB3 0AS, UK, afa37@cam.ac.uk
2 Department of Engineering, University of Cambridge, Trumpington Street, CB2 1PZ, UK
3 Gas Recovery and Recycle Ltd, Aztec House, Perrywood Business Park, Honeycrock Lane, Redhill, RH1 5DZ, UK

Keywords:

- Hydrogen production and storage,
- Thermochemical splitting of water,
- Waste streams reuse and recycle,
- Chemical looping

ABSTRACT
This work focused on a new process that couples H_2 production and energy storage, while utilising low-value waste streams and renewable electricity. The technology is based on the thermochemical splitting of water with chemical looping materials, namely, iron-containing perovskite and mixed oxides, with no requirement for noble metals. In the first step, a packed bed made of the oxide is reduced by a waste stream, gaining the ability to split water thermochemically, which occurs in the second step of the process, yielding high-purity H_2. To close the energy balance, heat is delivered utilising surplus renewable electricity. The 2-step cyclic process is relatively well-known, taking from the chemical looping approach, but has not been properly exploited because of the competition from large-scale steam-reforming of CH_4, and small-scale electrolysis of water. However here, the chemical looping approach is for the first time paired with renewable electricity and zero-cost waste streams, such as dilute industrial gases, waste solvents and no-value side-products, which makes the technology attractive and competitive. The work presented here looks at the new chemical looping process holistically. First, oxides suitable for the two-step process were assessed by analysing the thermodynamics of their reduction and oxidation with waste streams and water, respectively. Then, the experimental work was carried out, employing experiments at a milligram scale in a thermogravimetric analyser and at a gram scale in a packed bed reactor. A thermogravimetric analyser paired with Owlstone's vapour generator was used to assess the reducibility of selected oxides by waste streams and their capability to split water and produce H_2. Liquid reactants (water for oxidation, acetone and ethanol for reduction) were delivered to perform temperature-programmed reduction and oxidation on the oxides: 1) heating to 900°C at 10°C/min in a reducing environment, 2) cooling to 50°C at 10°C/min in an oxidising environment. Best-performing materials from these experiments, $Sr_{0.95}Ce_{0.05}FeO_3$ and Fe_2O_3 on $LaFeO_3$ were further experimented with in a packed bed rig to provide information for process modelling and optimisation, focusing on a low-temperature range of redox reactions with waste streams of different properties. A packed bed was made of 10 g of an oxide, loaded into a stainless-steel reactor, then, heated to a temperature in the range of 400 – 600°C to perform isothermal cycling of the redox reactions with CO and CO_2 as preliminary proxies, then, the waste streams and water. The results from the packed bed experiments were then used to guide the design of an overall system rated to produce 10 Nm^3/h of H_2. The results provided input to life-cycle assessment, performed to assess the environmental impact of the chemical looping with waste streams.

1. CONFERENCE TOPIC
Please indicate here to which of the Conference Topics this abstract refers.

Application of energy storage through integration with renewable generation and energy networks

2nd World Energy Storage Conference and 7th UK Energy Storage Conference

Thermo-mechanical energy storage options for long-duration storage: present and future techno-economic competitiveness

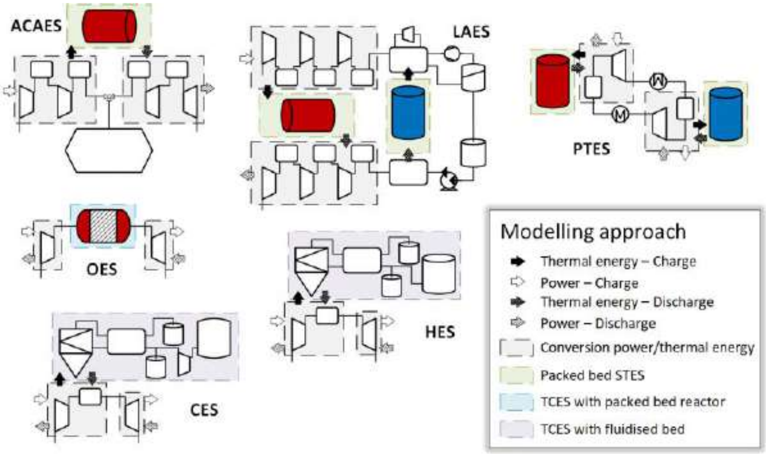
Andrea Vecchi [1], Adriano Sciacovelli[1]

1 Birmingham Centre for Energy Storage, School of Chemical Engineering, University of Birmingham, Birmingham, United Kingdom .
Keywords: thermochemical energy storage; thermal energy storage; optimization

1. INTRODUCTION

Large deployment of renewable energy sources (RES) is a major way forward to decarbonise the energy system, contain anthropogenic climate change and maintain global warming well below 2 °C above pre-industrial levels. RES capacity worldwide is expected to more than triple by 2030 and increase ninefold by 2050 (entailing 600 GW yearly addition of solar photovoltaics and 340 GW of wind). Analyses for the UK under 100% RES penetration show that overproduction could be stored 82% of the time. Although storage is expected to shift energy across periods of 8h or less 80-95% of the time, under an 80% RES penetration, one third of the annual stored energy comes from charging events lasting over 24h and up to more than 60-80h, or 5 consecutive days. Under these circumstances, deployment of long-duration energy storage (LDES) technologies, i.e. capable of addressing energy supply variability across several days and seasons, will be crucial to achieve large RES penetrations cost-effectively. Thermo-mechanical solutions [1] are an attractive technological option but their role and attractiveness still remain not fully appreciated and valued.

2. THERMO-MECHANICAL AND OPTIONS FOR MEDIUM TO LONG DURATION ENERGY STORAGE



Given this background, this work explores and addresses a key unanswered question: *to what extent thermo-mechanical energy storage (TMES) technologies are or will be capable in the future to meet the target techno-economic performance requirements for LDES to sustain decarbonisation?* The present study therefore addresses: i) the currently missing techno-economic assessment of TMES for LDES, in light of the individuated design space and in relation to incumbent storage technologies; and ii) the limited understanding of the potential for LDES applications of novel TMES concepts recently emerged. In so doing, the work also provides cross-comparison between established (ACAES, LAES, Pump thermal [2]) and novel TMES concepts. The latter exploits thermochemical energy storage reactions. The reactions are, respectively, the reversible oxidation/reduction of MnO2/Mn2O3 in the oxides energy storage (OES): the largely investigated CaCO3/CaO reaction in the carbonates energy storage (CES), and the hydroxides energy storage (HES).

3. NOVELTIES AND CONTRIBUTIONS

The research reported here thoroughly characterised all the main relevant existing and emerging TMES solutions for future applications as LDES. Novel TMES technologies featuring chemical storage, limited losses and the cheap materials are also investigate and they represent a promising proposition for LDES, with lower efficiencies offset by a favourable investment cost structure with small capacity contributions. Further, the contribution provides an overview on the topic, the state of knowledge and outlines the latest progress in this field of research.

4. REFERENCES

[1] Liang T, Vecchi A, Knobloch K, Sciacovelli A, Engelbrecht K, Li Y, Ding Y. Key components for Carnot Battery: Technology review, technical barriers and selection criteria. Renewable and Sustainable Energy Reviews. 2022 Jul 1;163:112478.

[2] Vecchi A, Li Y, Ding Y, Mancarella P, Sciacovelli A. Liquid air energy storage (LAES): A review on technology state-of-the-art, integration pathways and future perspectives. Advances in Applied Energy. 2021 Aug 25;3:100047.

An analysis of the optimal long duration storage deployment in a net-zero UK electrical grid

Diarmid Roberts[¥,1], Jude Ejeh[¥,1], Yoga Wienda Pratama[¥,2], Mark Workman[¥,2], Niall Mac Dowell[¥,2], Solomon Brown[¥,1]

¥ Foresight Transitions, 1 University of Sheffield, 2 Imperial College London

Keywords: Long duration storage, Medium duration storage, UK net-zero, techno-economic analysis, energy storage

1. ABSTRACT

The present policy direction of the UK indicates that the dominant future source of electricity will be wind power. As the output from this power source is intermittent, either abated dispatchable fossil fuel plant or energy storage will be required to maintain a robust grid. The challenge for the latter is that the predicted duration of storage required is on the order of multiple days [1], which necessitates a very low cost of incremental energy capacity that cannot be provided by batteries[2].

We perform a quantitative review of the literature on cost and round-trip efficiency of energy storage technologies, and show that they may be broadly classified into three categories:

- 1: High £/kWh - high efficiency (e.g. Li-ion, vanadium flow)
- 2: Medium £/kWh - high efficiency (pumped hydro)
- 3: Low £/kWh – low efficiency (hydrogen in salt cavern, compressed air (CAES))

Based on representative cost estimates for these classes multi-objective optimisation is performed for various scenarios in order to estimate which combination of low carbon power generation and long-duration storage technologies gives the lowest CAPEX across a range of renewable penetration levels. This work builds on a recent study [3] by addressing the following questions:

- Can combining storage from the different classes above give a lower system cost than a single technology?
- Does nuclear power provide value to a predominantly wind powered system?

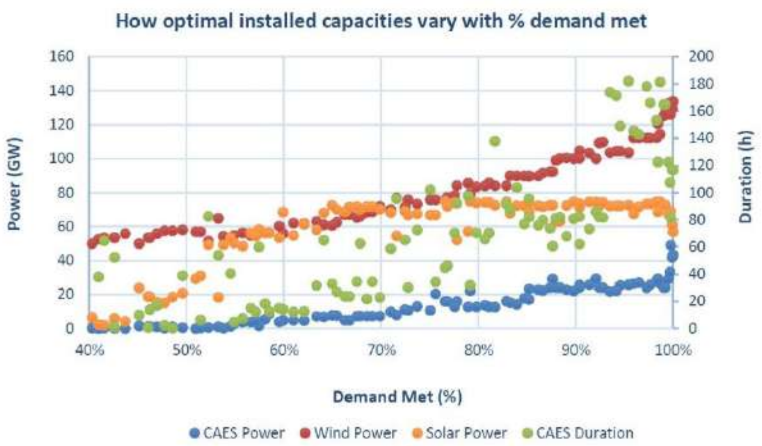


Figure 1: Pareto set of minimum cost wind/PV/CAES deployments versus % demand met (renewable penetration). Under the assumed cost parameters, there is a reduction in PV and increase to wind and storage power at >95%.

2. REFERENCES

[1] Aurora Energy Research, “Long duration electricity storage in GB,” no. February, 2022.

[2] C. Smerdon and P. Adams, “Strategy for Long-Term Energy Storage in the UK Future role to meet Net Zero Emissions Targets Strategy for Long-Term Energy Storage in the UK,” *Jacobs*, 2020, [Online]. Available: www.jacobs.com.

[3] B. Cárdenas, L. Swinfen-Styles, J. Rouse, A. Hoskin, W. Xu, and S. D. Garvey, “Energy storage capacity vs. renewable penetration: A study for the UK,” *Renew. Energy*, vol. 171, pp. 849–867, 2021, doi: 10.1016/j.renene.2021.02.149.

3. CONFERENCE TOPIC

Role, value and policy of energy storage. Application of energy storage through integration with renewable generation and energy networks