

Integrated **M**arket-fit **A**ffordable **G**rid-scale **E**nergy **S**torage

4-month Progress Meeting – Overview

10th March 2017 – University of Warwick

1) Summary of activities

Journal Papers:

1. Luo X, Wang J, Krupke C, Xu H: "Feasibility study on recovering low pressure exhaust energy from a vehicle engine system via the modified scroll expander technology", *Energies*, 9, no. 4: 231.
2. Luo X, Wang J, Krupke C, et al.: "Modelling Study, Optimization and Efficiency Analysis of Large-scale Adiabatic Compressed Air Energy Storage Systems with Low-temperature Temperature Thermal Storage", *Applied Energy*, vol. 162, pp. 589-600. (2016).
3. Garvey S D, et. al.: "On Generation-Integrated Energy Storage" *Energy Policy*, 86, pp544-551. (Nov 2015).
4. Flatley L, MacKay R, Waterson M: "Optimal strategies for operating energy storage in an arbitrage or smoothing market", *Journal of Dynamics and Games* 3(3) July 2016, *J D Games* 3 (2016) 371-398
5. Flatley L, Giulietti M, Grossi L, Trujillo E, Waterson M: "Analysing the potential value of energy storage", *Documents de Treball de l'IEB* 2016/2
6. Krupke C, Wang J, Clarke J, Luo X: Modelling and experimental study of a wind turbine system in hybrid connection with Compressed Air Energy Storage, accepted by *IEEE Trans on Energy Conversion*.
7. McKenna E, Barton J, Thomson M: 'Short-run impact of electricity storage on CO2 emissions in power systems with high penetrations of wind power: a case-study of Ireland, accepted for publication in the Institute of Mechanical Engineers, Part A: Journal of Power and Energy.
8. Waterson M: "The characteristics of electricity storage, renewables and markets. *Energy Policy*, 10.1016/j.enpol.2017.01.025
9. Wojcik J D, Wang J: "Technical feasibility study of thermal energy storage integration into conventional power plant cycle", *Energies* 2017, 10(2), 205, doi:10.3390/en10020205.
10. MacKay R: "Sustainable energy storage - with hot air, or cold air or liquid air ", submitted to *Contemp Phys*
11. Barton J, McKenna E, Thomson M: 'Time-Step Analysis of the DECC 2050 Calculator Pathways', submitted to the Institute of Mechanical Engineers, Part A: Journal of Power and Energy.
12. Davenne T R, Garvey S D, Cardenas B, Simpson M C: "The Cold Store for A Thermal Pumping Energy Storage System" Offshore Energy and Storage (OSES) symposium in Malta, July 2016. This manuscript was selected for submission to the Offshore Energy Storage Special Issue of Elsevier's Journal of Energy Storage, paper submitted for peer review on 15th October
13. Evans, D J, & Busby, J: Going Underground. *Hydrocarbon Engineering - Tanks & Terminals* (In press - short paper selected to discuss underground gas storage and its relevance to the UK's security of energy supply, together with risks of varying nature).
14. Draft of first paper on the Arm Hill and Victoria experiments is underway - Field, L.P., Milodowski, A.E., Palumbo-Rae, B., Hall, M.R., Evans, D., Marriott, A.L., Barlow, T., Devez, A.(in prep): *Determining constraints imposed by salt fabrics on the morphology of brined cavities in relation*
15. Planning a paper on ArcGIS related operations for varied and numerous databases.

1) Summary of activities

Presentations:

1. He W, Wang J: Dynamic modelling of discharge behaviour of a low temperature adiabatic compressed air energy storage system, Offshore Energy and Storage Symposium and Industry Connector Event (OSES), Malta.
2. Wang J, Garvey S, Eames P, Evans D, Waterson M, Thomson M, Busby J, Giulietti M, MacKay R, Milodowski A, Wojcik J, Barton J, Luo X, Flatley L, Pimm A, Field L, Romanos P, Parkes D, Kantharaj B, Krupke C, Webborn E, Hutchinson AD, Liu F, Dooner M, Chen B: A REPORT ON THE PROJECT OF “INTEGRATED MARKET-FIT AND AFFORDABLE GRID-SCALE ENERGY STORAGE (IMAGES)”, Offshore Energy and Storage Symposium and Industry Connector Event (OSES), Malta 2016.
3. He W, Wang J: Dynamic modelling of adiabatic compressed air energy storage using packed bed thermal energy storage, UK Thermal Energy Storage (UKTES), London 2016.
4. Li Y, Miao S, Luo X, Wang J: “Optimization Model for the Power System Scheduling with Wind Generation and Compressed Air Energy Storage Combination”, The 22nd IEEE International Conference on Automation and Computing (ICAC’16) Conference, 7-8 September 2016, University of Essex, Colchester, UK.
5. Li Y, Miao S, Luo X, Wang J: “Optimization Scheduling Model Based on Source-Load-Energy Storage Coordination in Power Systems”, The 22nd IEEE International Conference on Automation and Computing (ICAC’16) Conference, 7-8 September 2016, University of Essex, Colchester, UK.
6. Wojcik J, Wang J, Romanos P, Eames P: Initial Study on Power Plant Operational Flexibility Improvement through High Temperature Thermal Storage (HTTS) Integration. UKES2015 Conference in Birmingham, 26th November 2015.
7. Luo X, Wang J “Mathematical modelling and efficiency improvement study of adiabatic compressed air energy storage systems”, UK Energy Storage conference UKES2015, Birmingham, 26th November 2015.
8. Evans D, Parkes D, Garvey S, He W, Luo X: “Geological storage of energy – comments on UK CAES potential” presented on The Future of Compressed Air Energy Storage in the UK Workshop, held at the Shard on 12th Sep 2016.
9. Waterson M: “The impact of the German response to the Fukushima earthquake”, Madrid October 2015; “Analysis of the potential value of energy storage in Britain”, Barcelona, November 2015;
10. Waterson M: “Energy storage technology and the characteristics of renewables”, International Academic Symposium on energy sustainability, Barcelona, February 2016;
11. Waterson M: “Characteristics of electricity storage, renewables and markets”, Mannheim energy conference, May 2016; “Intertemporal arbitrage”, EARIE Lisbon, August 2016.
12. Giulietti M: “Assessing the economic value of energy storage”, Energy and Environment Conference, University Jaume I, Spain, July 2016.
13. Giulietti M: “Assessing the economic value of energy storage”, Presentation at Ofgem seminar series, January 2017.
14. Thomson M, Barton J: ‘The Role of Storage in the GB Grid’, presented at SolaStor, London, 12th April 2016.
15. Barton J: “High-Temporal-Resolution Analysis of UK Power System Used to Determine the Optimal Amount and Mix of Energy Storage Technologies”, presented to the Department of Mathematics and Statistics of the Open University, 26th May 2016
16. Garvey S D: “Generation-Integrated Energy Storage” UKES conference 2015.
17. Garvey S D: “Generation-Integrated Energy Storage” Meeting of the EERA technical sub-group on Mechanical Energy Storage in Padua, April, 2016.
18. Kantharaj B, Garvey S D, Pimm A: “Flexible Versus Rigid Containments for Underwater Compressed Air Energy Storage” Offshore Energy and Storage (OSES) symposium in Malta, July 2016.
19. Garvey S D, Chee M, Pimm A: “Deployment Methods for Flexible Air Containments in Deep Water Far Offshore” Offshore Energy and Storage (OSES) symposium in Malta, July 2016.
20. Evans, D J, Parkes, D, Busby, J, Garvey, S D, He, W, Luo X & Wang, J. Initial Studies to Derive Estimates of Potential UK Salt Cavern Volumes and Exergy Storage (CAES). UKES conference, Birmingham, 2016.

1) Summary of activities

Book chapters:

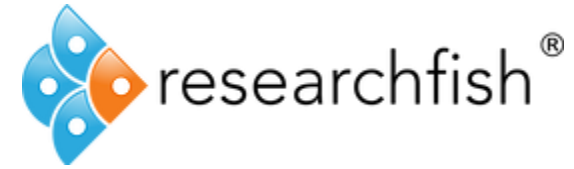
1. Wang J, Luo X, Dooner M, Krupke C “Compressed Air Energy Storage” a book chapter, accepted by the World Scientific Series on Current Energy Issues, Volume 4, 2016.
2. Garvey S D: “Storing Energy – with special reference to renewable energy sources”. co-authored three chapters of the book (mid 2016).
3. Evans, D J: Chapter 4 - Availability of suitable salt formations with a focus on the UK. Special issue of the UK Journal of Power and Energy on use of the geological underground: CAES and H2 storage. (in prep – submission Feb 2017)

Patents:

1. GB1521372.1. “Compressed Air Energy Storage System Exploits Low Grade Heat Capture to Increase Exergy Output” – Garvey, Pimm, Cardenas, Simpson and Kantharaj. Filed Dec. 2, 2015.
2. GB1612878.7. “Energy Storage System Blends Two Different Air Compression Resources and Exploits External Low Grade Heat Input” Increase Exergy Output”)
3. The patent “direct air electricity conversion” is assigned to a company.

Staff changes:

1. **Tristan Davenne** is recruited on part-time basis.
2. **Mark Dooner** is involved in SuperGen HUB project.
3. **Tony Milodowski** left BGS at the end of June 2016. His role is covered by **Lorraine Field**
4. **Lisa Flatley**: on maternity leave since 15th March 2016 – no postdoc working on the project.
5. **Xing Luo** has been promoted to Senior Research Fellow.
6. **Jianguo Wang** has been recruited as Research Fellow.

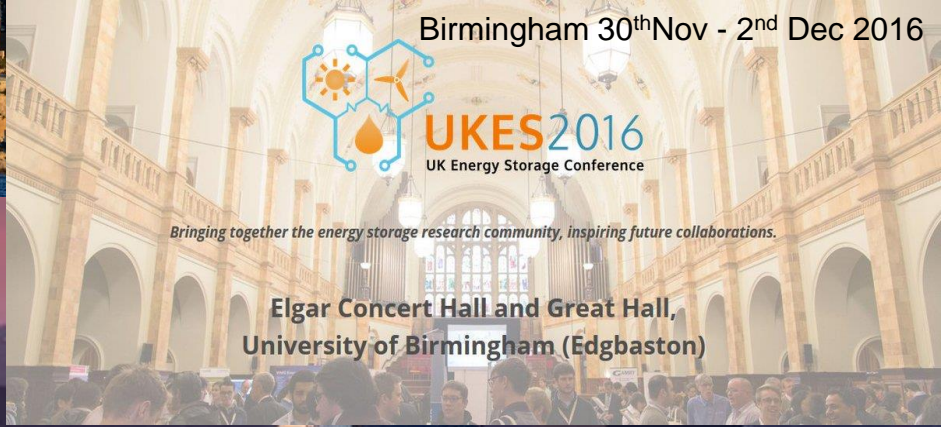


Other:

1. International event organisation: Future of Compressed Air Energy storage in the UK. London Sept 2016 (<http://gridstorage.org.uk/>)
2. CAES Dynamic System Simulation Software (2016)
3. Energy Storage toolbox is on development stage, HTTS feasibility study is ongoing.
4. Two laboratories of HTTS systems are being developed in Loughborough: use of **aluminium** for sensible heat storage media and **nitrate molten salts** for sensible and latent storage media.
5. Mike Waterson has initiated a project with James Mitchell (Economic forecaster, WBS) concerning **forecasting wind generation and the implications for storage**
6. Mike Waterson have been applying Lisa’s software on optimal use of a store to some realistic scenarios
7. Response submitted on behalf of IMAGES consortium to the DECC Consultation URN 15D/554 “Consultation on ensuring regulation encourages innovation, 12th February 2016

2) Workshops/Conferences

- 100 delegates from Industry
- 10 presentations
- Discussion Panel
- Networking Session



3) Website development

<http://integratedenergystorage.org/>

INTEGRATED, MARKET-FIT AND AFFORDABLE GRID-SCALE ENERGY STORAGE

ABOUT NEWS & EVENTS

Hits Statistics Chart

Hits in the last 77 days

Date	Visit	Visitor
Dec 20	100	20
Dec 24	260	30
Dec 28	100	30
Jan 1	180	40
Jan 5	120	40
Jan 9	100	50
Jan 13	120	40
Jan 17	140	40
Jan 21	120	40
Jan 25	210	50
Jan 29	100	40
Feb 2	40	30
Feb 6	20	20
Feb 10	30	20
Feb 14	50	20
Feb 18	100	30
Feb 22	140	40
Feb 26	180	30
Mar 2	120	30
Mar 6	60	20
Mar 10	70	20

Hits Statistics Summary

	Visit	Visitor
Chart Total:	6,694	2,105

<http://gridstorage.org.uk/>



THE FUTURE OF COMPRESSED AIR ENERGY STORAGE IN THE UK

INFO AGENDA

WORKSHOP

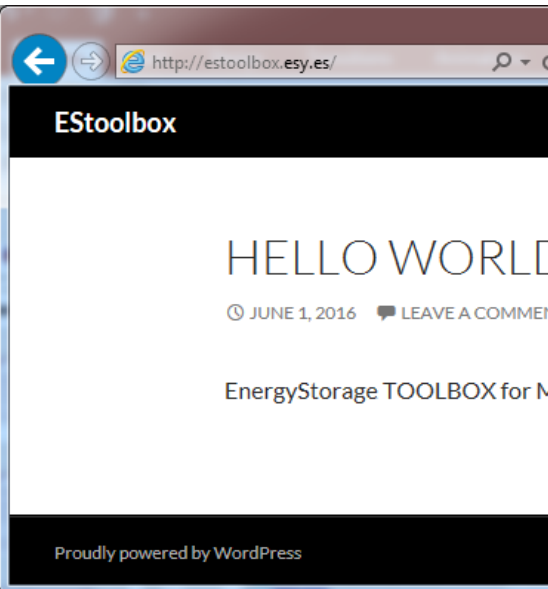
The purpose of event is to bring together various potential stakeholders to form a consistent understanding of what role CAES can and will play up to 2030. We are hoping for serious discussions aiming to affect UK government policy, kick start some demonstration projects and galvanise technology developers into action.

- LOCATION**
The Shard, 17th floor (WBS), 32 London Bridge Street, London, SE1 9SG, United Kingdom
- WHEN**
Monday, 12 September 2016 from 09:00 to 17:00 (BST)
- TICKETS**
If you are interested in please contact the organiser today!

3) Website development

<http://estoolbox.org/>

<http://estoolbox.hqjt.co.uk/>



The screenshot shows the 'esToolBox' website. At the top, there's a navigation bar with 'Home', 'About', 'Software', 'Download', and 'Forum'. Below this is a large image of a turbine with the text 'Turbine Fluid Compression and Expansion Modelling'. To the right is a login section with fields for 'Username' and 'Password', a 'Remember Me' checkbox, and a 'Log in' button. Below the login is a 'Create an account' link and a 'Site Search' section with a search input and a 'Go' button. The main content area has four columns: 'Background' with a photo of power lines, 'Compressed Air Energy Storage' with a CAES diagram, 'Thermal energy storage' with a TES diagram, and 'Software toolbox' with a grid of software icons.

Background

In recent years the research in the field of energy storage and its applications has rapidly increased, including research in Compressed Air Energy Storage (CAES) and Thermal Energy Storage (TES). ...

Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) works in the process: the ambient air is compressed via compressors into one or more storage reservoir(s) during the periods of low electricity demand (o...

Thermal energy storage

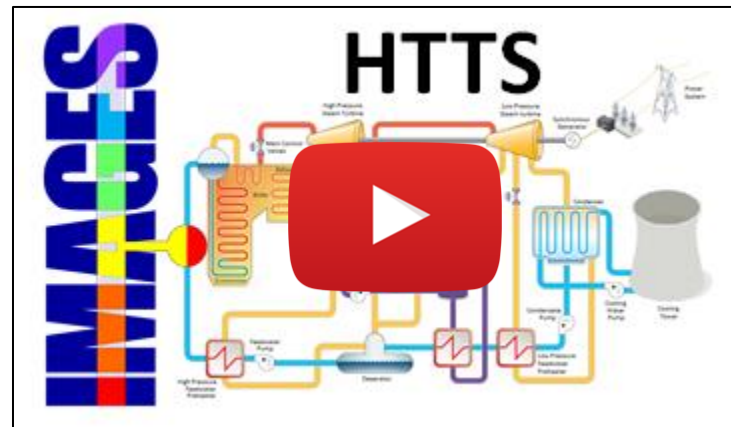
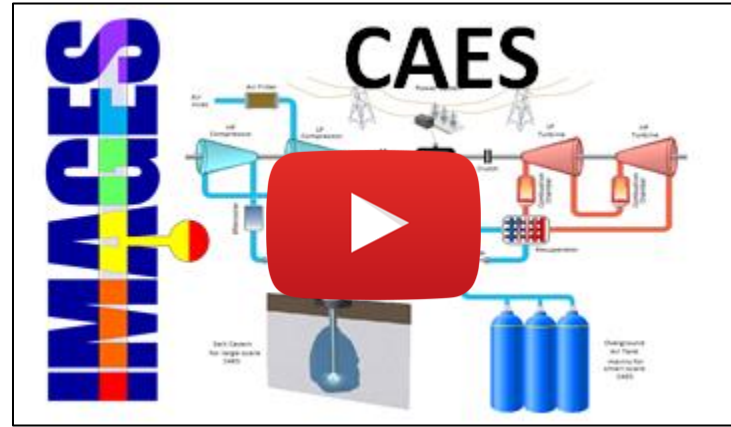
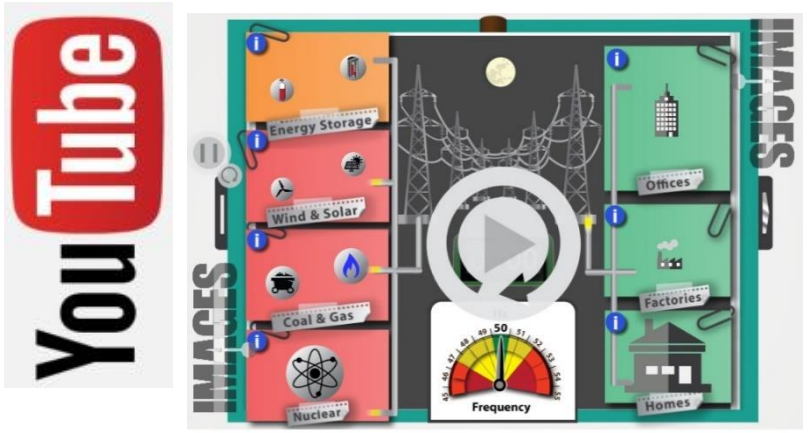
Thermal (TES) is a technology that stocks thermal energy by heating or cooling a storage medium so that the stored energy can be used at a later time for heating and cooling applications and power...



Software toolbox

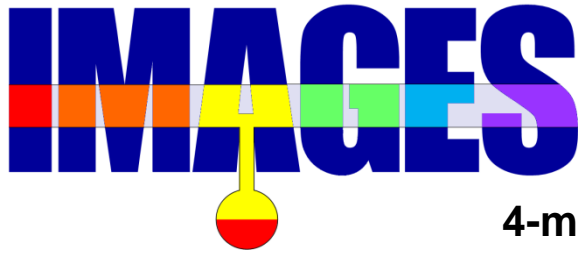
CAES-TES software toolbox introduction The structure of the library of the developed CAES-TES software toolbox is shown in the below chart. The multi-level classification method has been used. To...

4) Website development – Animations & YouTube

<https://www.youtube.com/channel/UCPnIFd0Itsce-BN3onm4LaA>



no	video	Visits
1	CAES new	3412
2	CAES old 	1060
3	HTTS new	594
4	HTTS old 	70
5	Why do we need energy storage	79
TOTAL		5216



4-month Progress Meeting – Agenda

10:00	Arrival/Registration + tea/coffee	(30 min)
10:30	Welcome , Prof J Wang	(05 min)
10:35	Project overview , Prof J Wang & Dr J Wojcik	(15 min)
10:50	Presentations by Warwick Economics	(25 min)
11:15	Presentations by Loughborough – Network and storage	(15 min)
11:30	Presentations by BGS	(15 min)
11:45	Presentations by Warwick Engineering	(30 min)
12:15	Presentations by Nottingham	(15 min)
12:30	Lunch and Networking	(45 min)
13:15	PMT meeting (for PMT board members only)	(~1.5 h)