

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

## 4<sup>th</sup> Annual Progress Meeting – Overview

21<sup>st</sup> November 2016 – 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. MacKay R: "Sustainable energy storage - with hot air, or cold air or liquid air ", submitted to *Contemp Phys*
9. Wojcik J, Wang J: Feasibility study of Thermal Energy Storage (TES) integration into conventional power plant cycle, submitted to *Applied Energy*
10. 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.
11. 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
12. 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., Deveze, A.(in prep): *Determining constraints imposed by salt fabrics on the morphology of brined cavities in relation*
13. Planning a paper on ArcGIS related operations for varied and numerous databases.

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## 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 12<sup>th</sup> 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. Thomson M, Barton J: ‘The Role of Storage in the GB Grid’, presented at SolaStor, London, 12th April 2016.
14. 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
15. Garvey S D: “Generation-Integrated Energy Storage” UKES conference 2015.
16. Garvey S D: “Generation-Integrated Energy Storage” Meeting of the EERA technical sub-group on Mechanical Energy Storage in Padua, April, 2016.
17. 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.
18. 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.

# 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).

## 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 15<sup>th</sup> March 2016 – no postdoc working on the project.
5. **Xing Luo** has been promoted to Senior Research Fellow, new post for RF is advertised.

## Other:

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



## 2) Workshops: OSES&UKES



Valletta, Malta 13-15 July 2016



Birmingham 30<sup>th</sup> Nov - 2<sup>nd</sup> Dec 2016

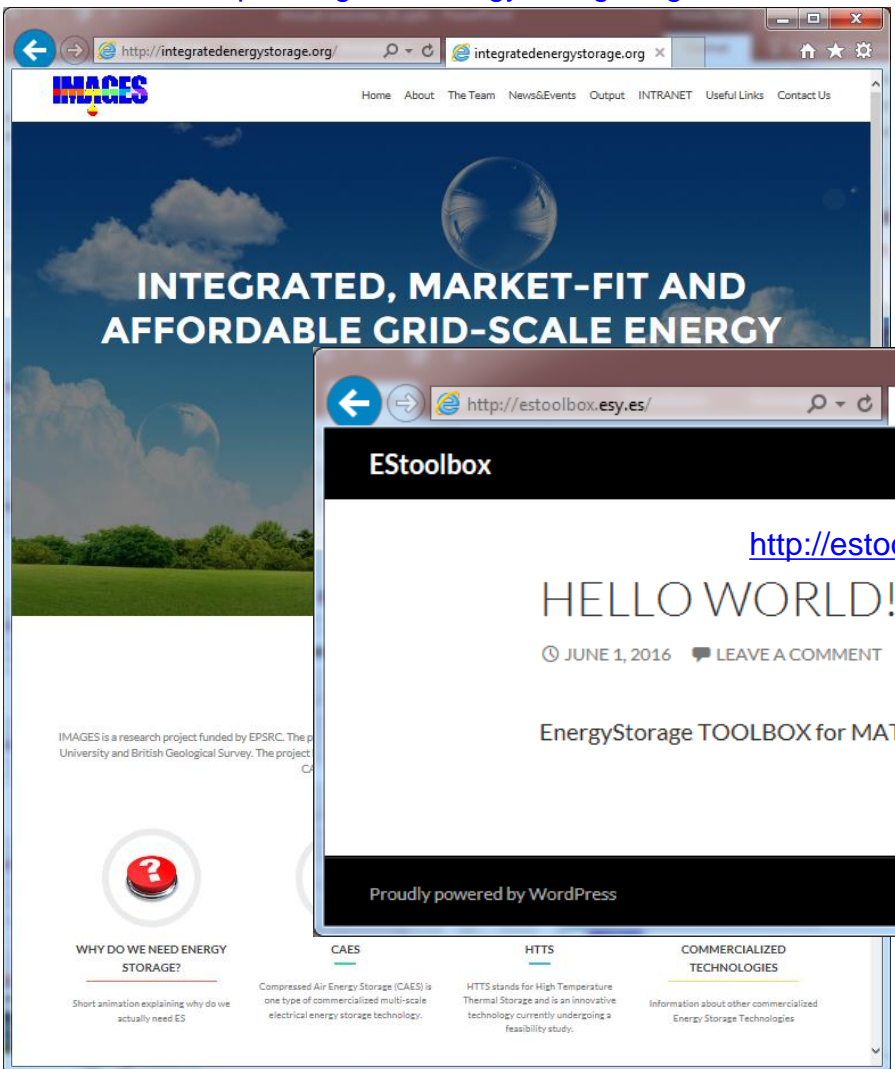
*Bringing together the energy storage research community, inspiring future collaborations.*

**Elgar Concert Hall and Great Hall,  
University of Birmingham (Edgbaston)**

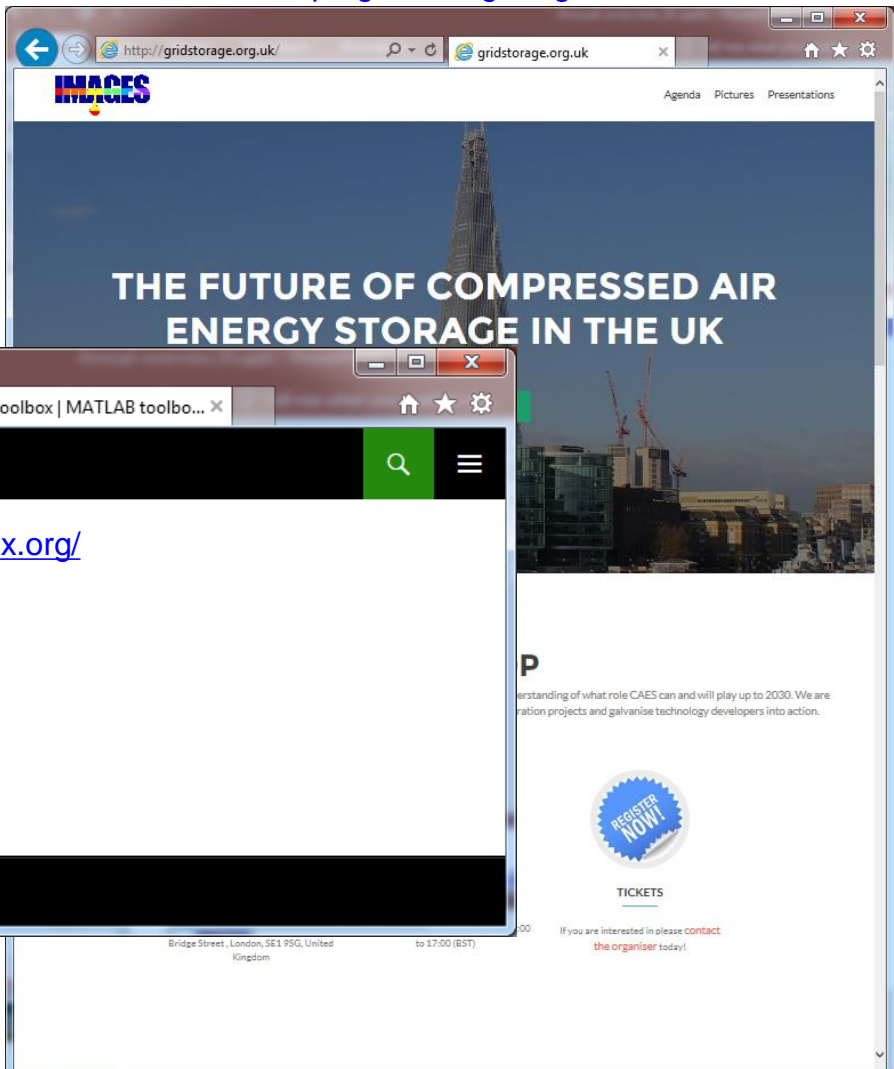
### 3) Website development

<http://integratedenergystorage.org/>

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



The screenshot shows the homepage of the IMAGES website. The header includes the IMAGES logo and navigation links: Home, About, The Team, News&Events, Output, INTRANET, Useful Links, and Contact Us. The main banner features a globe and the text "INTEGRATED, MARKET-FIT AND AFFORDABLE GRID-SCALE ENERGY". Below the banner, there is a section titled "WHY DO WE NEED ENERGY STORAGE?" with a red question mark icon. Further down, there are sections for "CAES" (Compressed Air Energy Storage), "HTTS" (High Temperature Thermal Storage), and "COMMERCIALIZED TECHNOLOGIES". The footer contains contact information for Bridge Street, London, SE1 9SG, United Kingdom, and a phone number.



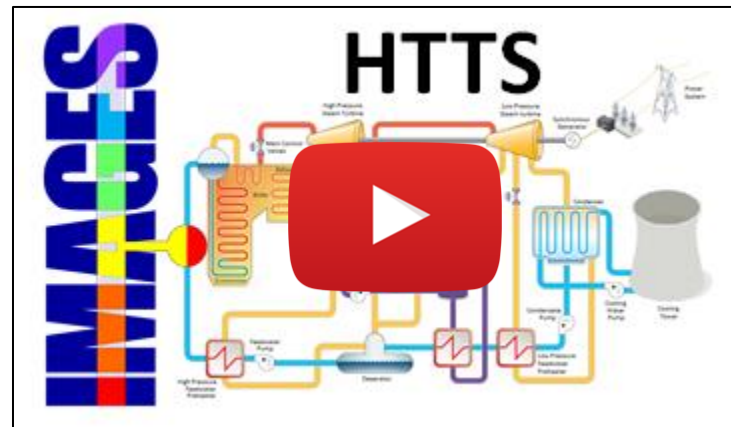
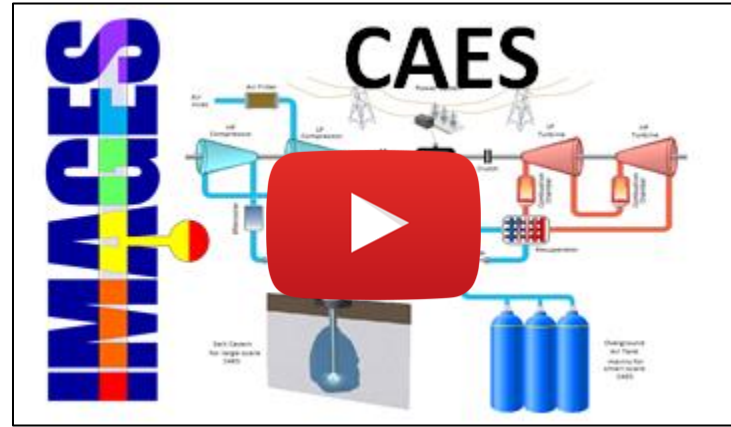
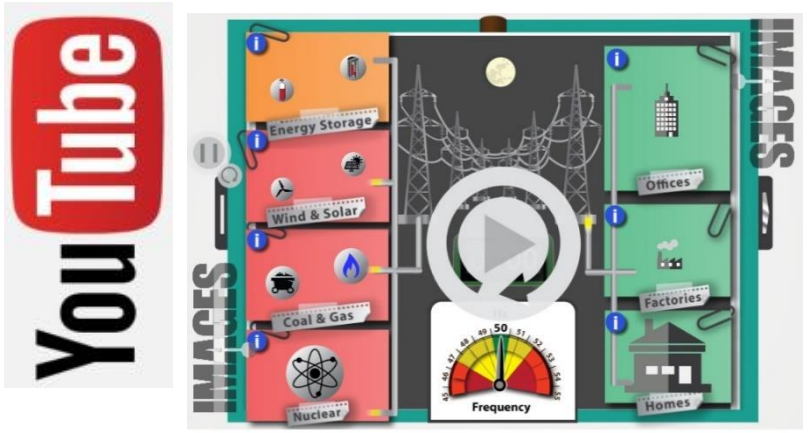
The screenshot shows the homepage of the gridstorage.org.uk website. The header includes the IMAGES logo and navigation links: Agenda, Pictures, and Presentations. The main banner features a cityscape with a tall building and the text "THE FUTURE OF COMPRESSED AIR ENERGY STORAGE IN THE UK". Below the banner, there is a section titled "P" (likely part of a paragraph) and a "REGISTER NOW!" button. The footer contains contact information for Bridge Street, London, SE1 9SG, United Kingdom, and a phone number.





The screenshot shows the homepage of the EStoolbox website. The header includes the EStoolbox logo and navigation links: Home, Search, and Menu. The main banner features the text "HELLO WORLD!" and "EnergyStorage TOOLBOX for MATLAB". Below the banner, there is a section titled "Proudly powered by WordPress".

# 4) Website development – Animations & YouTube

<https://www.youtube.com/channel/UCPnIFd0ltsce-BN3onm4LaA>



no	video	Visits
1	CAES new	2116
2	CAES old 	992
3	HTTS new	334
4	HTTS old 	62
5	Why do we need energy storage	51
<b>TOTAL</b>		<b>3555</b>



## 4<sup>th</sup> Annual Progress Meeting – Agenda

### **09:00**      **Arriving, Tea & Coffee**

09:25      Welcome, Professor Jihong Wang

09:30      EPSRC, Andrew Macdonell - Invited talk

10:00      Overview of the IMAGES project progress (Jihong Wang and Jacek Wojcik)

10:20      Presentation from BGS

### **10:50**      **Tea & Coffee Break**

11:00      TBC - Invited talk

11:25      Presentation from UoL

12:15      Presentation from UoN

### **12:45**      **Lunch – Lakeview Restaurant at Scarman House**

14:00      Presentation from UoW - Engineering

14:30      Presentation from UoW - Economics

15:00      Gaelectric, Chuan Zhang: 'Current Trends within the Energy Sector Including Energy Storage'

### **15:30**      **Tea & Coffee Break**

15:45      EAG board meeting (for EAG members only)

### **18:00**      **Dinner – Lakeview Restaurant at Scarman House**