Update from University of Nottingham

IMAGES Meeting
Warwick University
10th March 2017

S.D.Garvey T.R.Davenne
Faculty of Engineering
University of Nottingham

GREEN • AFFORDABLE • DISPATCHABLE

http://www.wind-tp.com/

Contents

Progress on Wind-TP – compressor and cold store

Response to BEIS consultation on smart flexible energy systems

Hybrid energy storage proposal

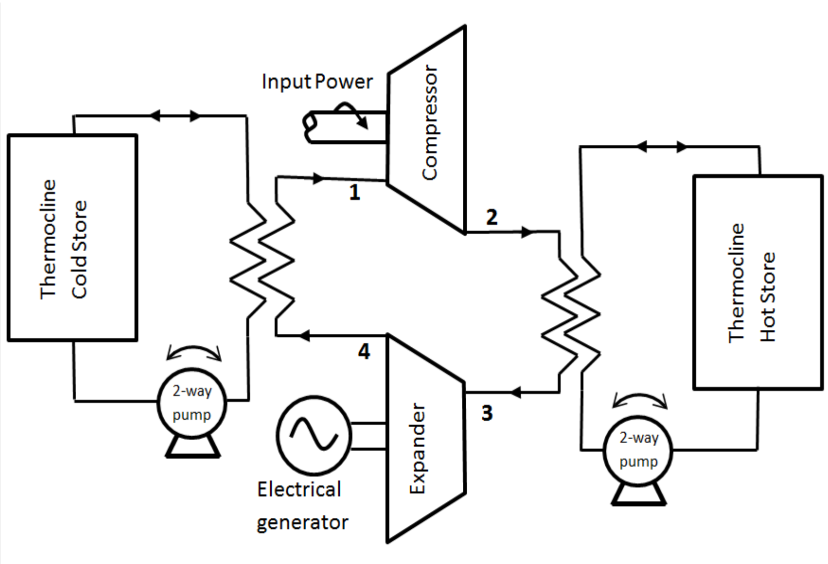
GIES proposal

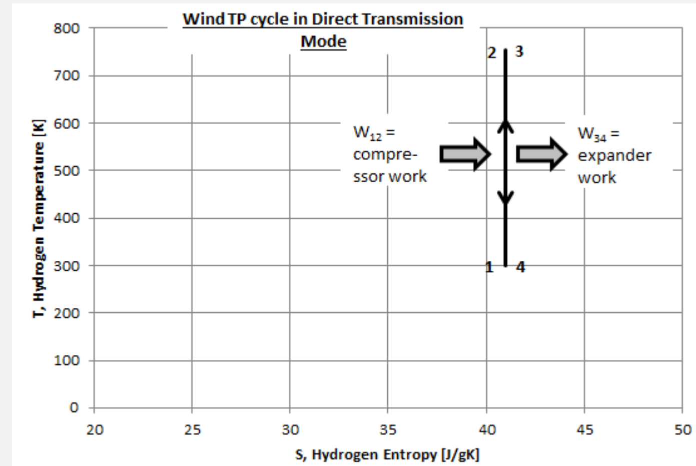
Representation at Westminster

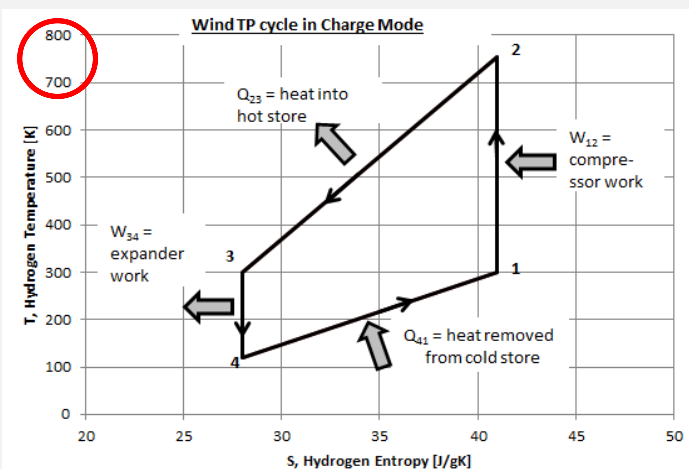
Pumped Thermal Energy Storage

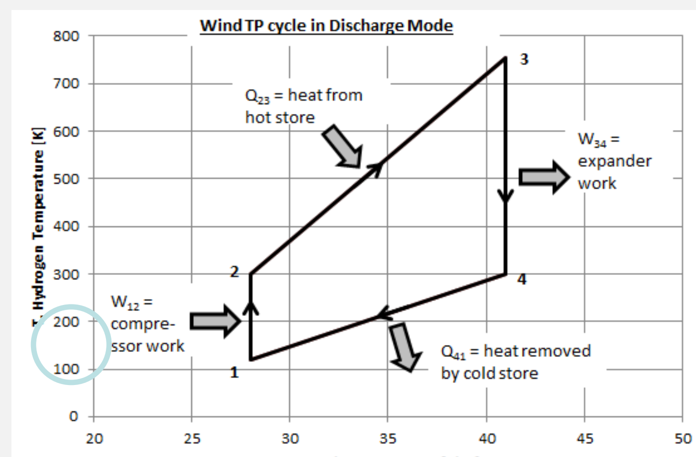
principal components and example T-S diagrams

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA





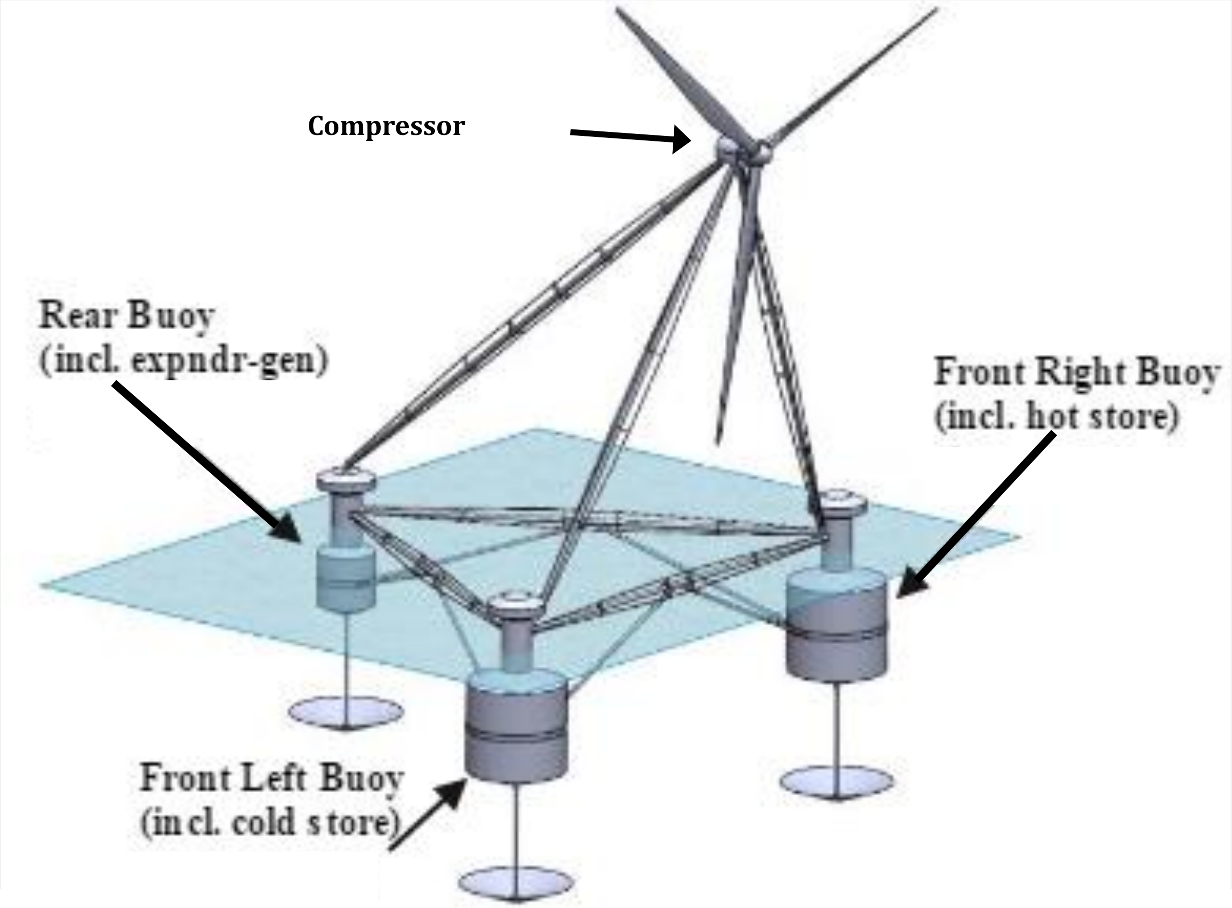




Need high isentropic efficiency compressors and expanders and **effective thermal stores**

Wind Driven - Thermal Pumping

Off shore platform



Progress on Wind-TP compressor

Since last meeting there has been a large effort to progress the Wind-TP compressor design

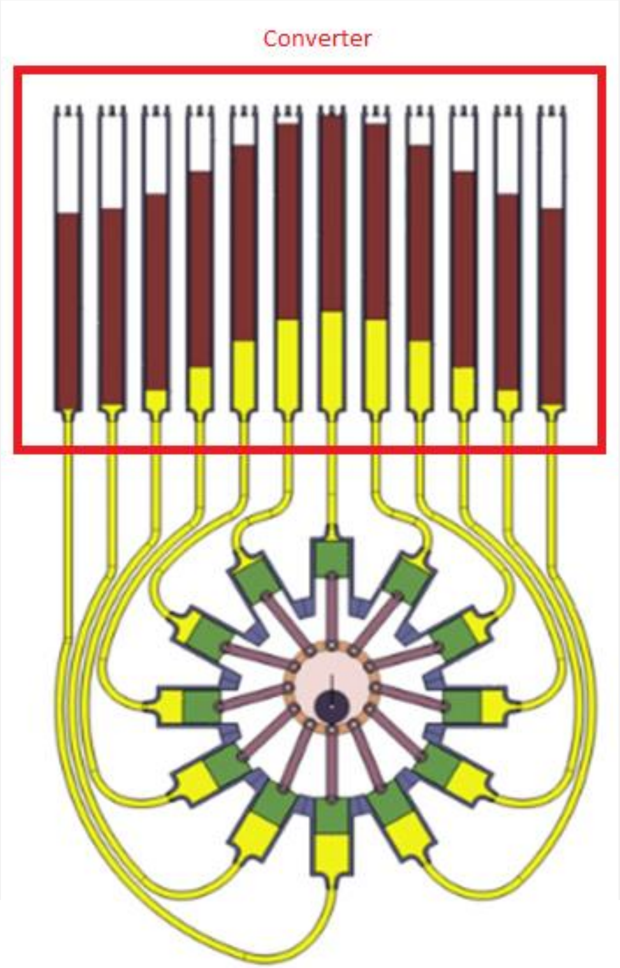
Seamus Garvey

Tristan Davenne

James Rouse

Nat Newman

Chris Reckless (CNR Design)



Main Features

Oil displacer

Converter (liquid piston gas compressor)

Main Aims

High isentropic efficiency

Near adiabatic compression

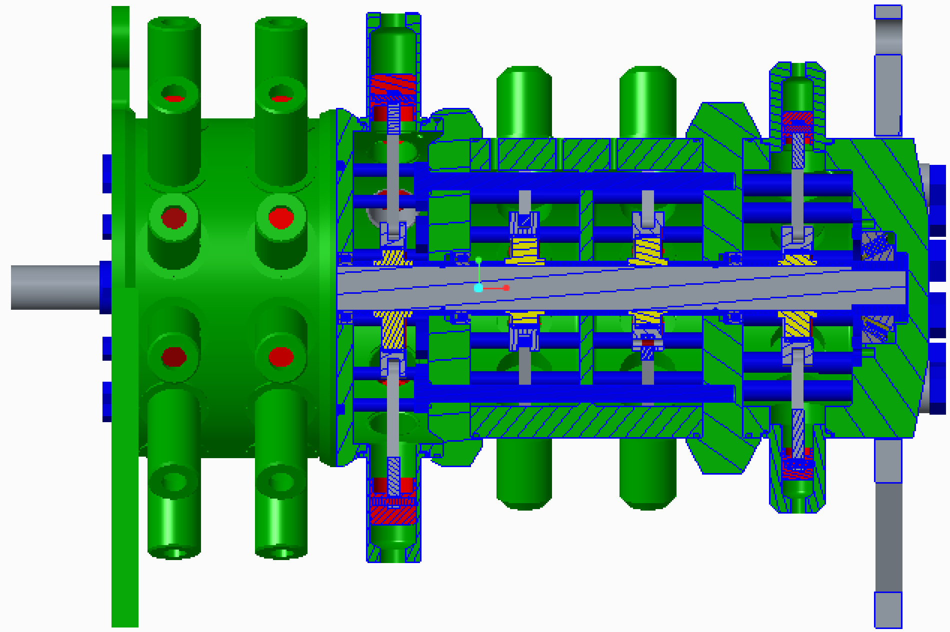
Minimal exergy loss

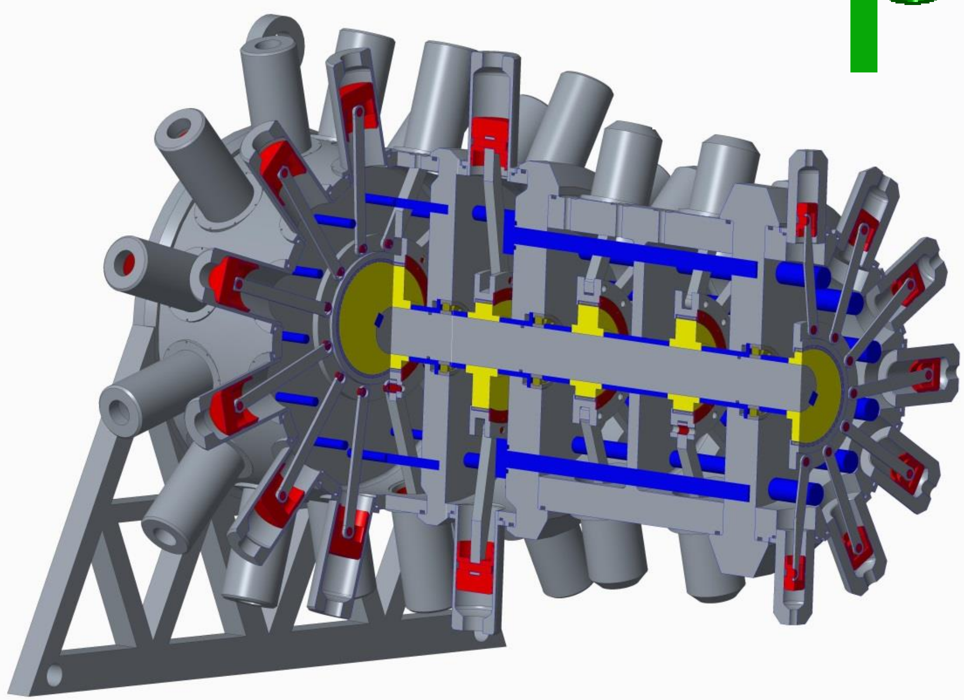
Direct couple to wind turbine

Capable of efficient part load operation

Displacer status

Design complete
Parts delivered





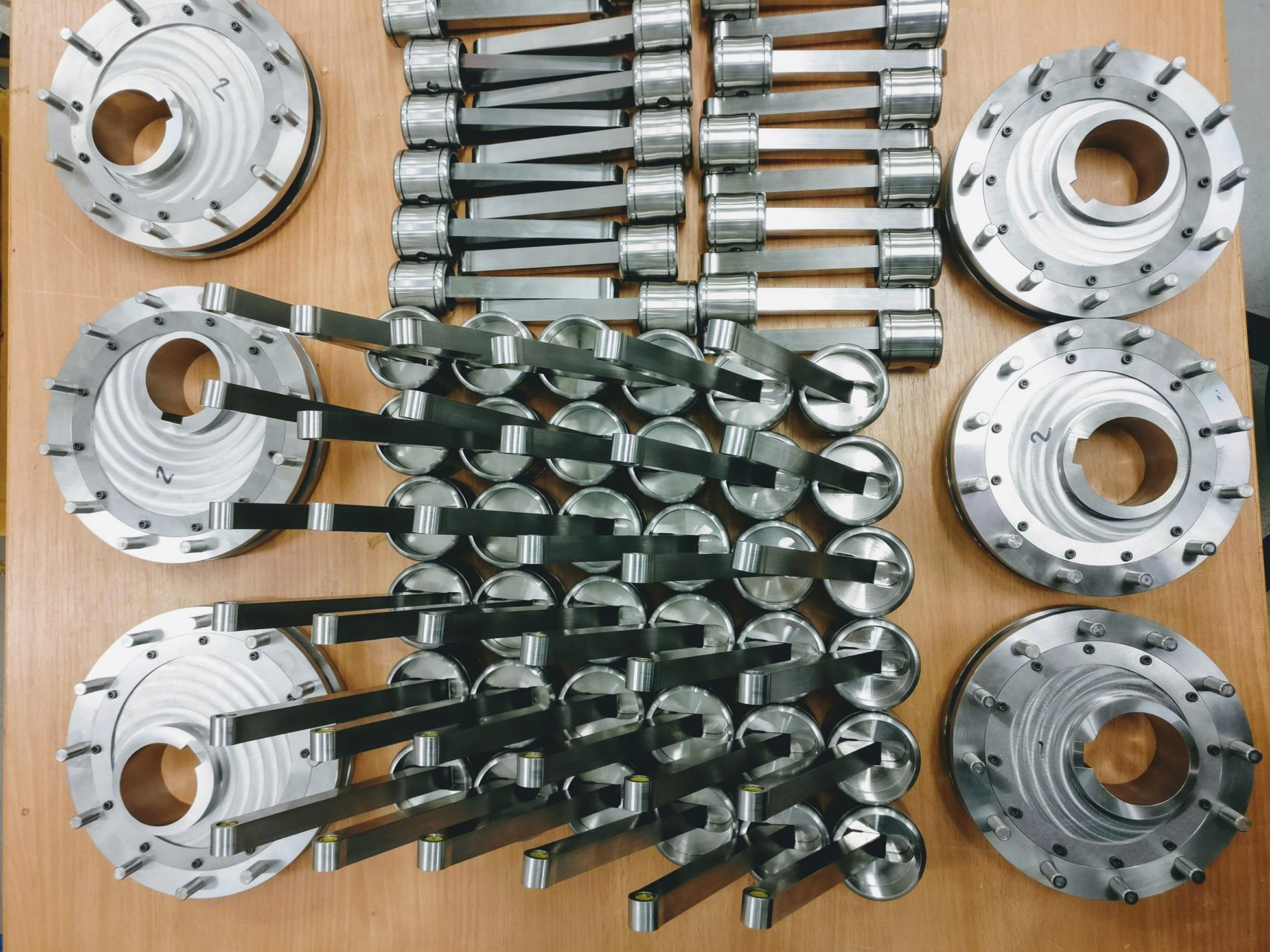
Clipping State:XSEC0003

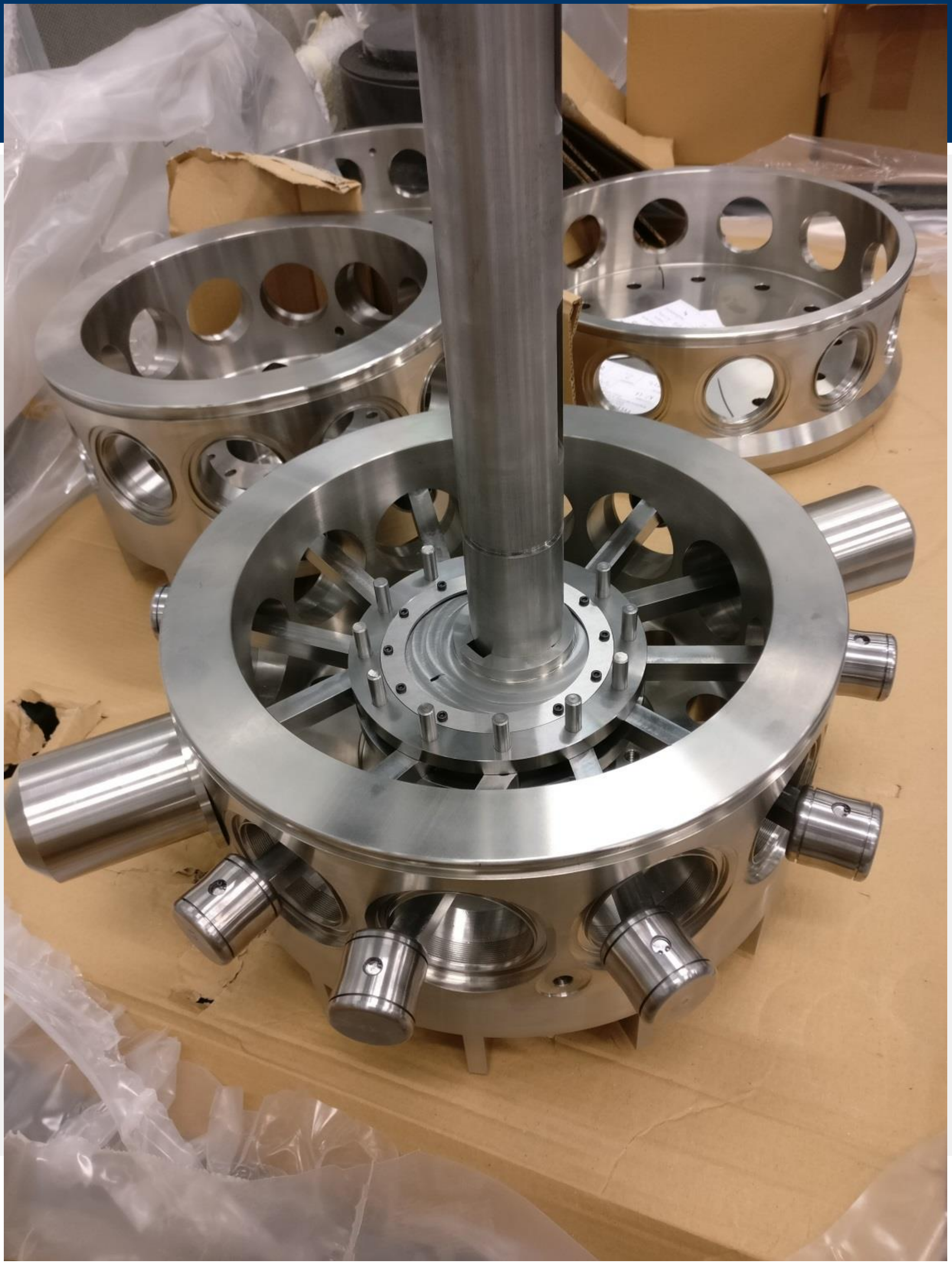
4 stage oil displacer

Assembly of displacer under way

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

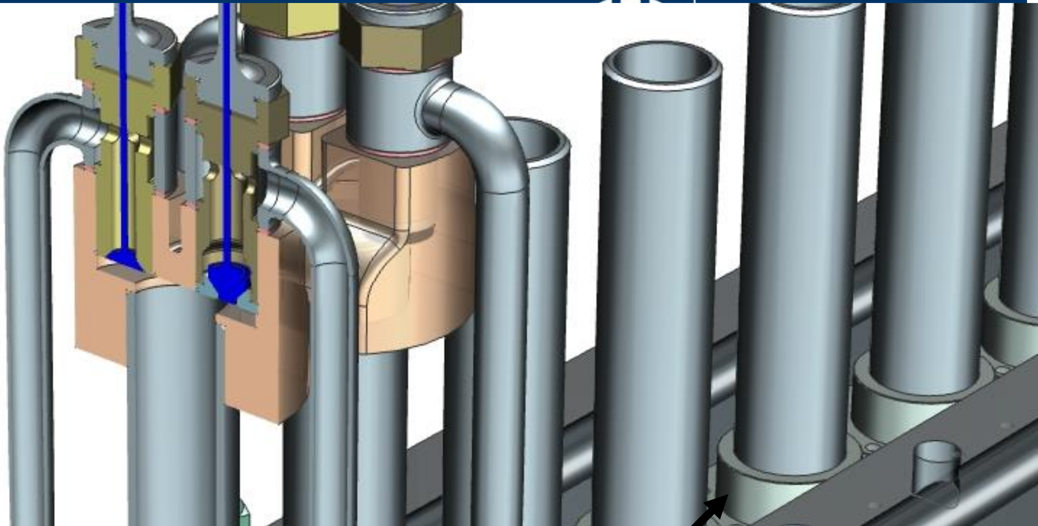
12 pistons per stage
2 LP stages
2HP stages
Cam ring ensures phased piston displacement



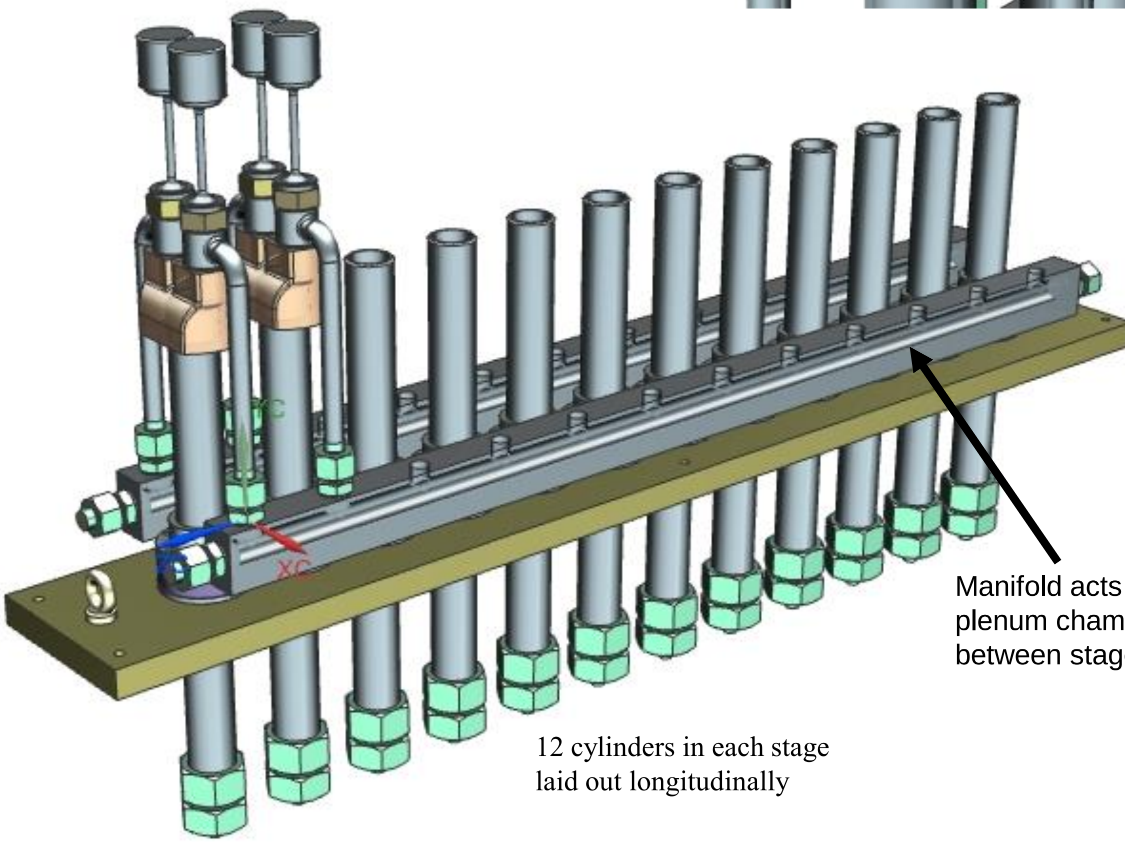


Convertor status

Design concept finalised
Detailing underway
Convertor has 4 stages each with 12 cylinders

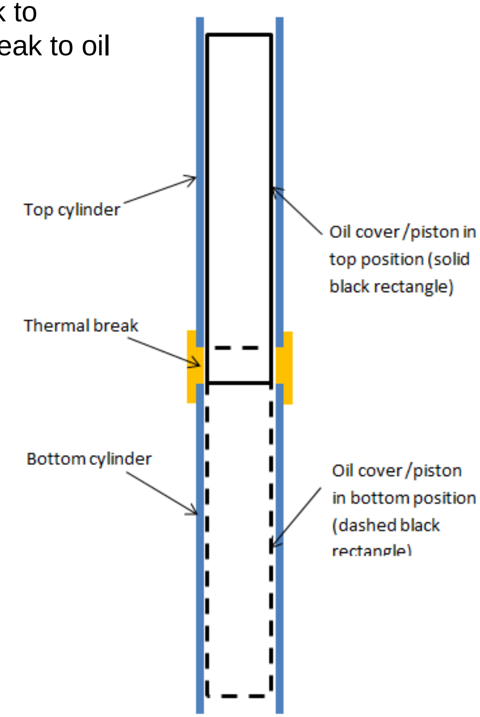


Convertor tubes segmented with thermal break to reduce heat leak to oil



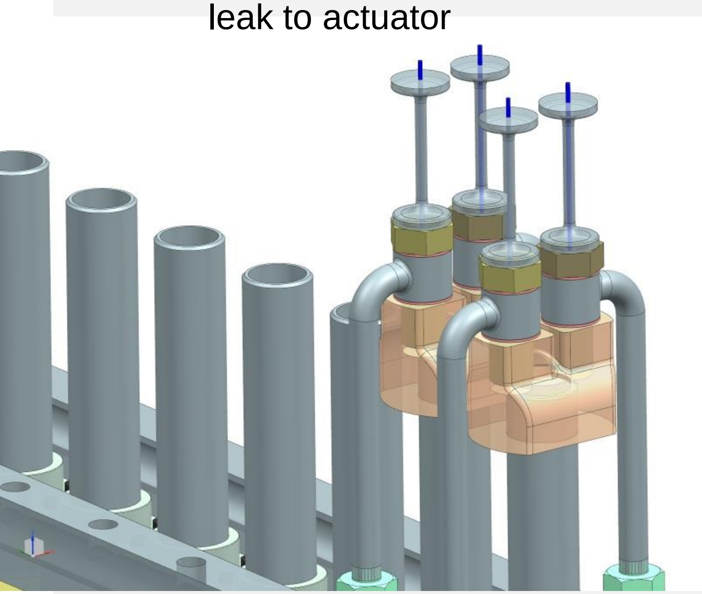
Manifold acts as plenum chamber between stages

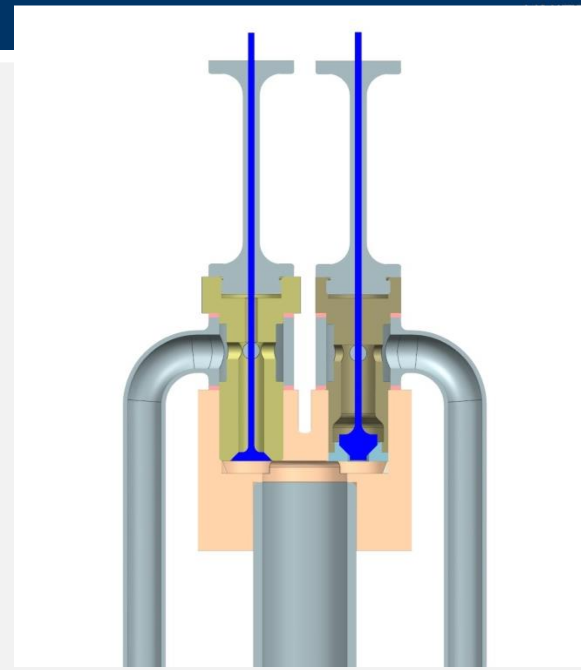
12 cylinders in each stage laid out longitudinally



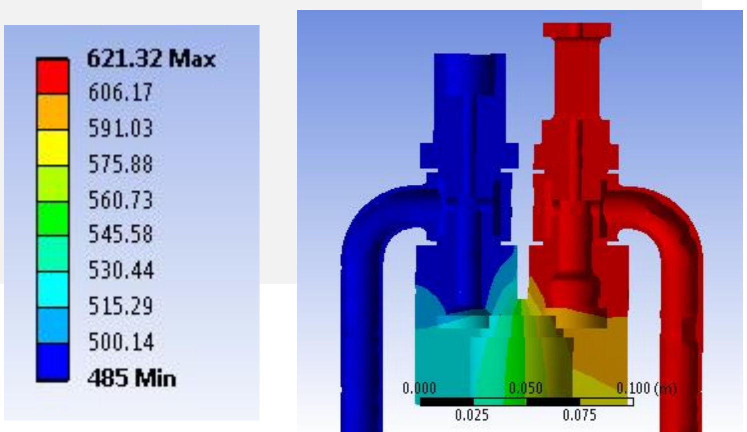
Cylinder head design

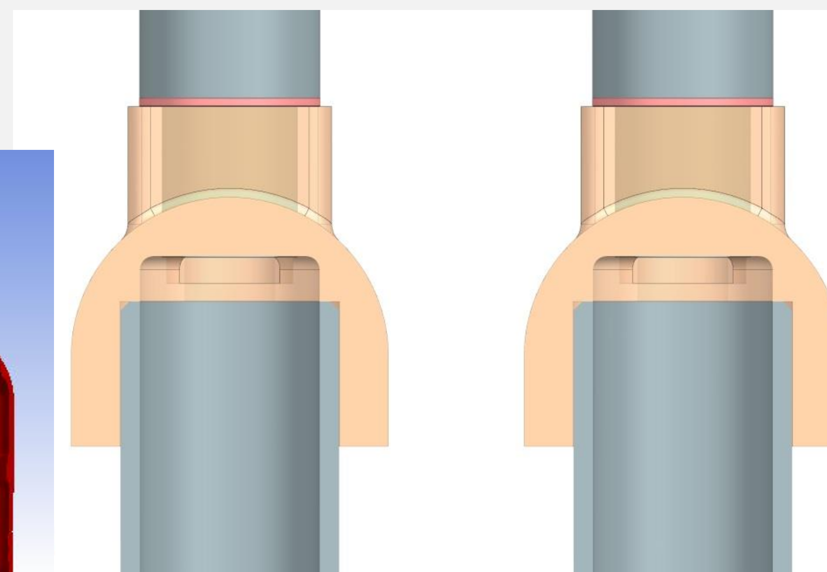
Long valve stems to reduce heat leak to actuator





Valve design for minimum pressure drop, and actuator power





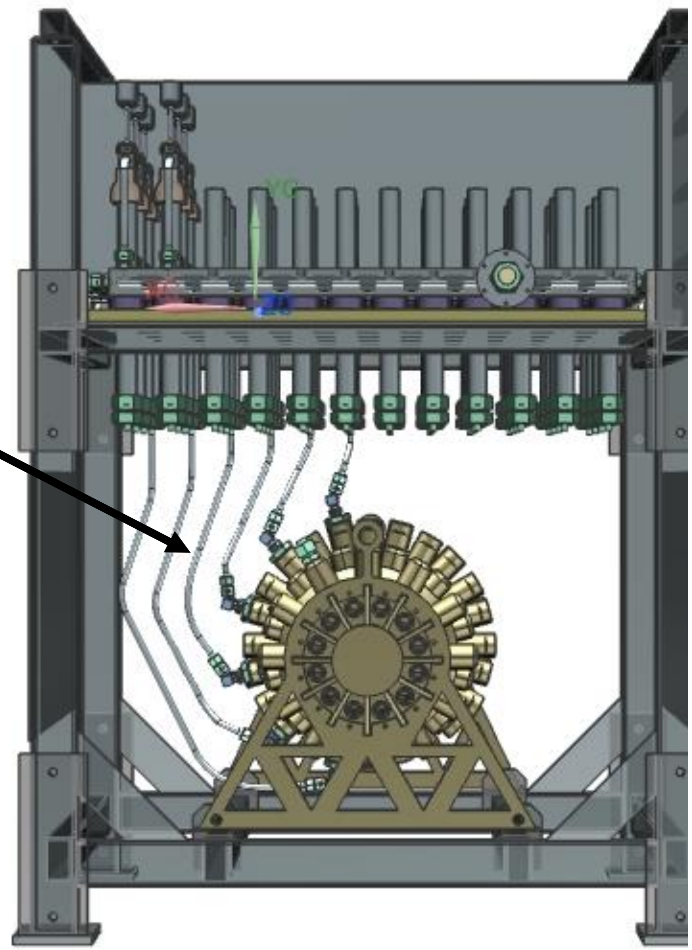
Minimal conduction area to reduce heat leak from hot side to cold side

Complete compressor design

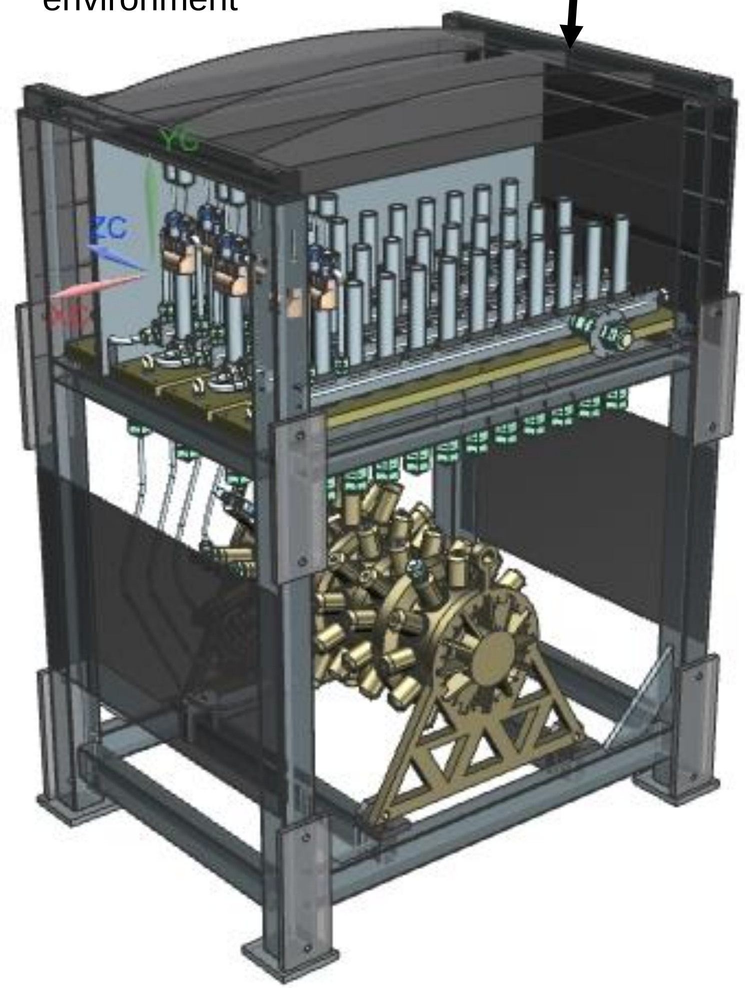
The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

Displacer connected to convertor via standard pipe and fittings



Convertor housed in a vacuum chamber with internal dividers to minimise heat transfer from stage to stage and to outside environment



Compressor operating parameters

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

INPUTS		
ratio of specific heats	1.41	
intake pressure	2.00E+06	Pa
total pressure ratio	25	
total compression power	60000	W
number of tubes per stage	12	

Calculated values		
required intake volume for convertor	5.63E-03	m3/s
required intake volume per tube	4.69E-04	m3/s
required rotational speed	1.80	revs per second
compression power per stage	15000.0	W
compression work per stage per cycle	8.32E+03	J
compression work per tube per cycle	6.94E+02	J

DISPLACER DIMENSIONS, derived SWEPT VOLUMES and PRESSURE RATIOS

stage	displacer stroke length [m]	intake volume [m3]	displacer piston diameter [m]	number of displacer cylinders	swept volume in each convertor tube derived from displacer swept volume [m3]	total volume in tube at bdc (clearance vol = 5% of swept vol) [m3]	exhausted volume per tube per cycle [m3]	Pressure ratio	inlet pressure [Pa]	outlet pressure [Pa]	inlet temp in charge mode [K]	outlet temp in charge mode [K]	inlet temp in discharge mode [K]	outlet temp in discharge mode [K]
1	0.0580345	0.000248	0.05215	2	2.5E-04	2.6E-04	1.2E-04	3.08	2.00E+06	6.17E+06	350	486	120	166
2	0.0521519	0.000111	0.05215	1	1.1E-04	1.2E-04	6.4E-05	2.33	6.17E+06	1.44E+07	486	621	166	213
3	0.0294841	6.08E-05	0.03624	2	6.1E-05	6.4E-05	3.9E-05	1.98	1.44E+07	2.85E+07	621	758	213	260
4	0.0362409	3.74E-05	0.03624	1	3.7E-05	3.9E-05	2.6E-05	1.77	2.85E+07	5.04E+07	758	894	260	307

CONVERTOR DIMENSIONS

stage	tube inner radius [m]	stroke length [m]	swept volume per tube [m3]	cover height [m]	min oil column in tube [m]	tube length [m]
1	0.0199	0.198	2.5E-04	0.22	0.0721	0.5
2	0.0134	0.198	1.1E-04	0.22	0.0721	0.5
3	0.01	0.198	6.2E-05	0.22	0.0721	0.5
4	0.0077	0.198	3.7E-05	0.22	0.0721	0.5

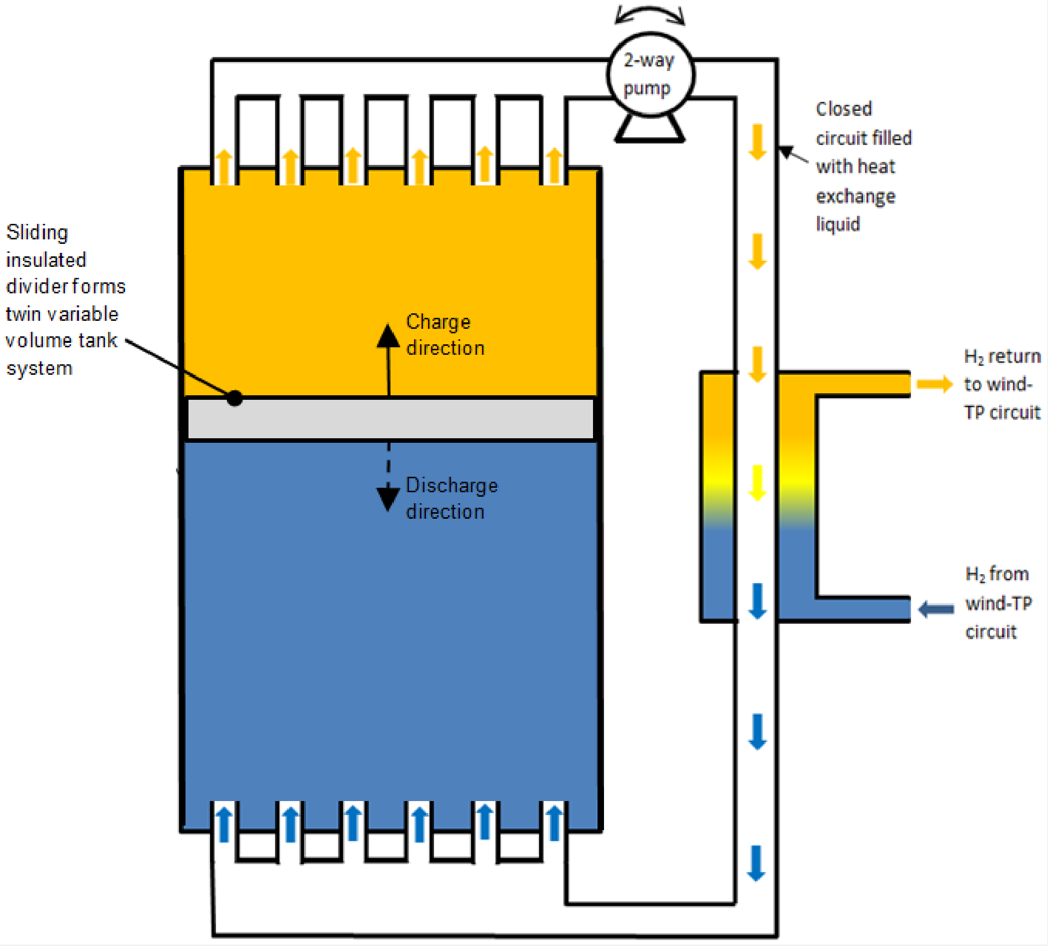
Design of an isopentane cold store

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

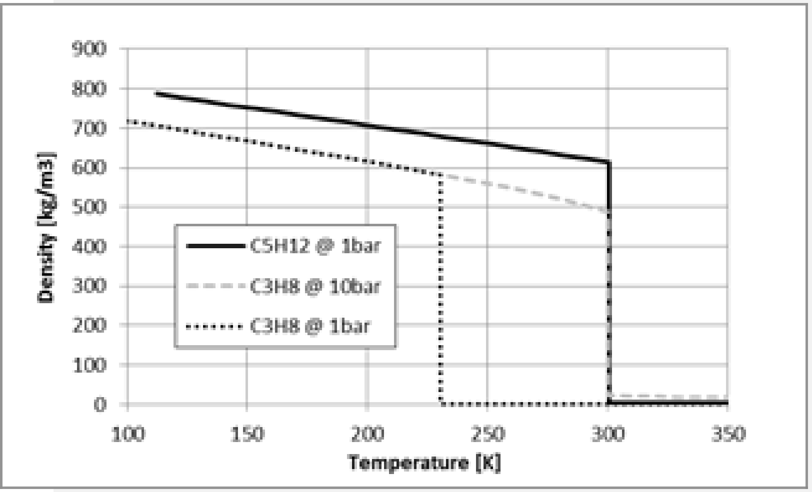
Avoids mixing between hot and cold storage media using a sliding divider

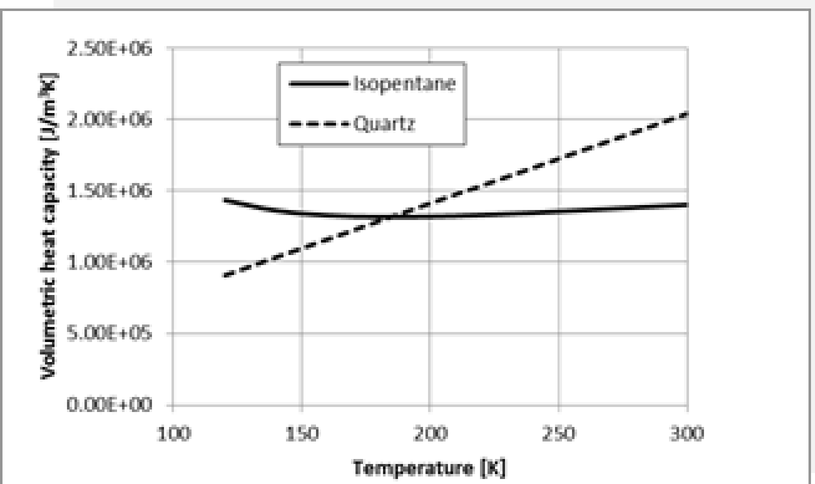
No exergy loss due to thermocline smearing

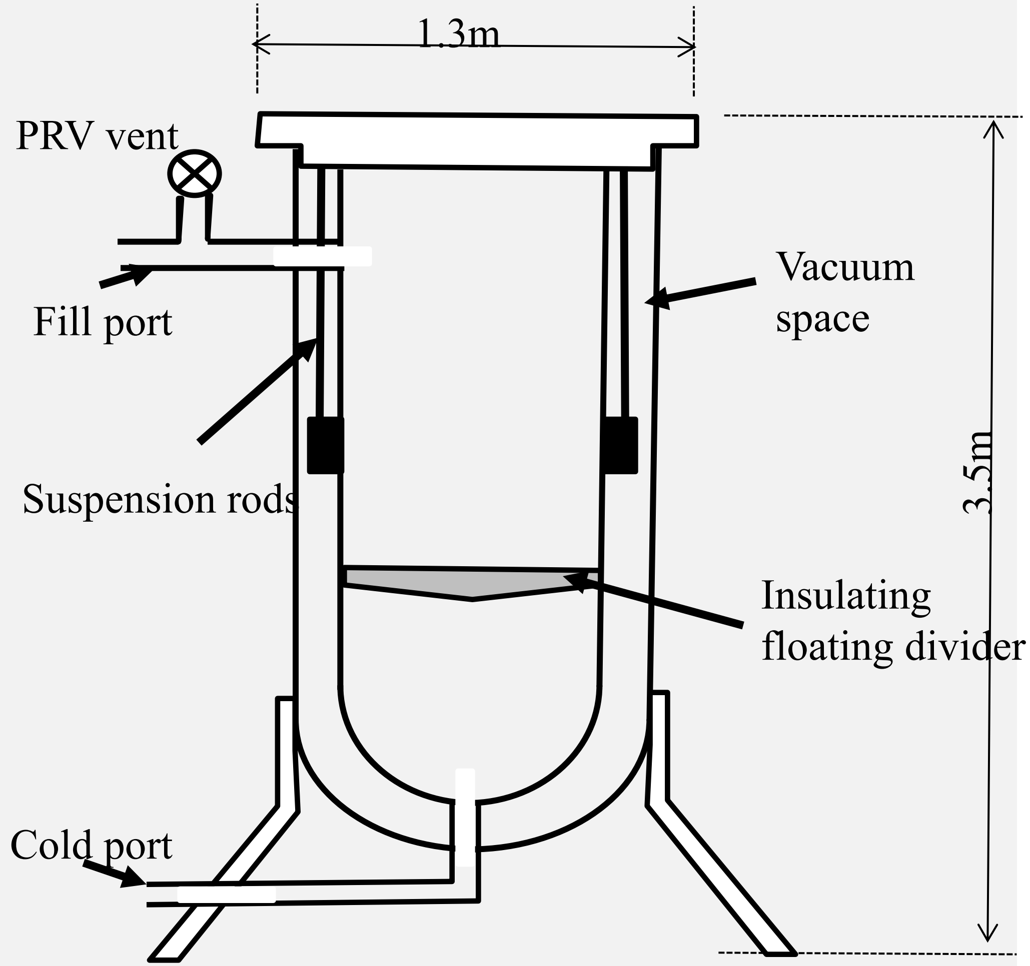
Half the volume required of a traditional two tank system



Vacuum insulated isopentane store







Response to BEIS/OFGEM Consultation:

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

BEIS/OFGEM issued a consultation around *Smart Flexible Energy Systems* requiring response on Jan 12th. A response was drafted making several key points:

(1) Yes there are regulatory barriers in addition to those identified in the consultation. G.I.E.S. systems are not recognized and several elements of the present electricity militate directly against them (eg. EMR).

(2) Recommendation for a time-dependent charging model for energy storage assets based on the current, i. Positive i would represent power flowing out of the asset.

$$c = A(t) \times |i| + B(t) \times i$$

Importantly, $A(t)$ would always be positive but $B(t)$ would negative at some times and positive at other times.

Response to BEIS/OFGEM Consultation:

(4) Network operators should not be allowed to own storage assets outright – it could contaminate the market

(5) Regulatory approaches certainly do affect investment in storage and much greater clarity is required.

(6) The consultation's definition of *Energy Storage* is too restrictive. It does not: (a) allow for G.I.E.S. systems or (b) recognise that true inertia is in fact an energy storage function.

(Synchronous condensers in particular are making a comeback!).

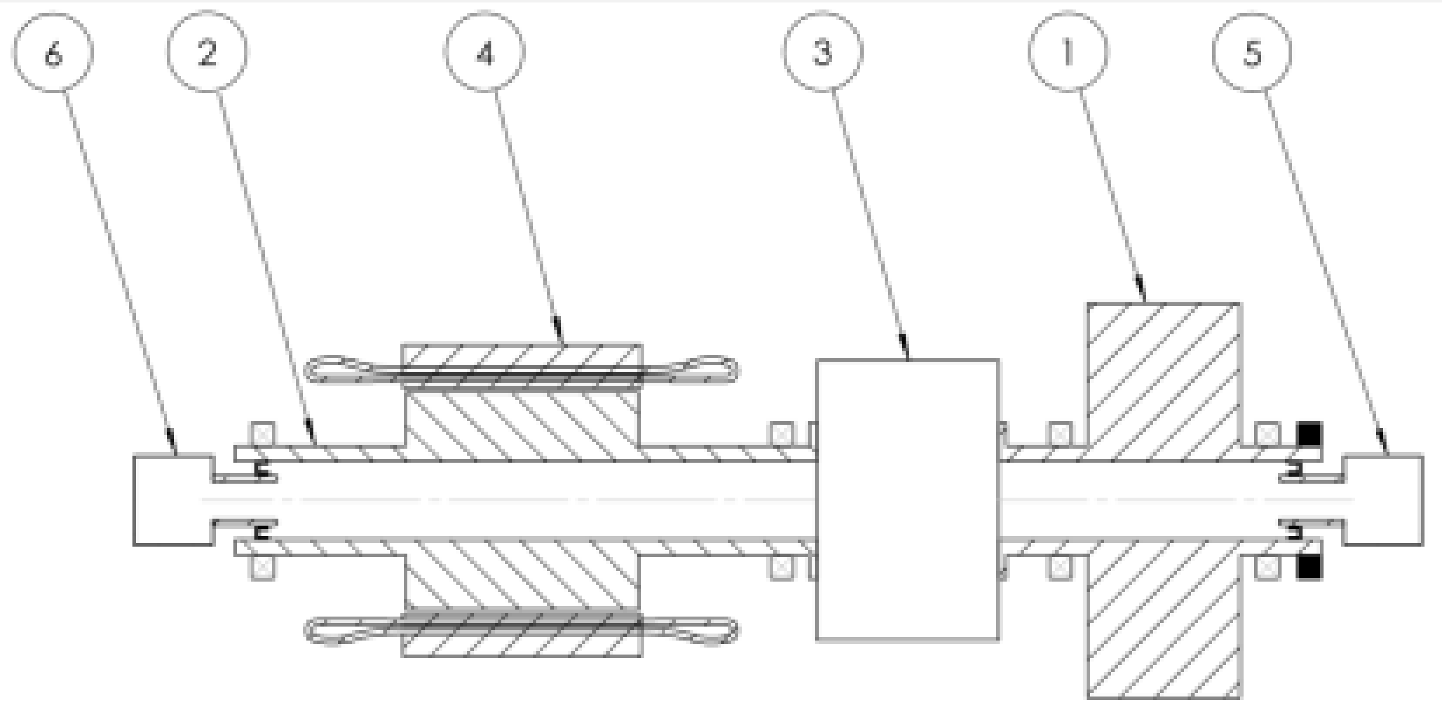
A new hybrid energy storage system.

Hybrid energy storage systems evidently have a strong place. Past work by Nottingham has looked at these in a general economic sense and in connection with the specific potential for combining LAES+CAES and papers are published on each of these.

A completely different hybrid energy storage system has been conceived where ultra-fast response energy storage in the form of a flywheel is combined with CAES. The main service provided by the KE store is *true inertia*. Note that National Grid's S.O.F. document of Nov. 2016 highlights that the UK system needs a minimum of 130 GVAs of "real inertia" and at one time in August of 2016, the inertia fell as low as 135GVAs. An inertia crisis is looming!

A new hybrid energy storage system.

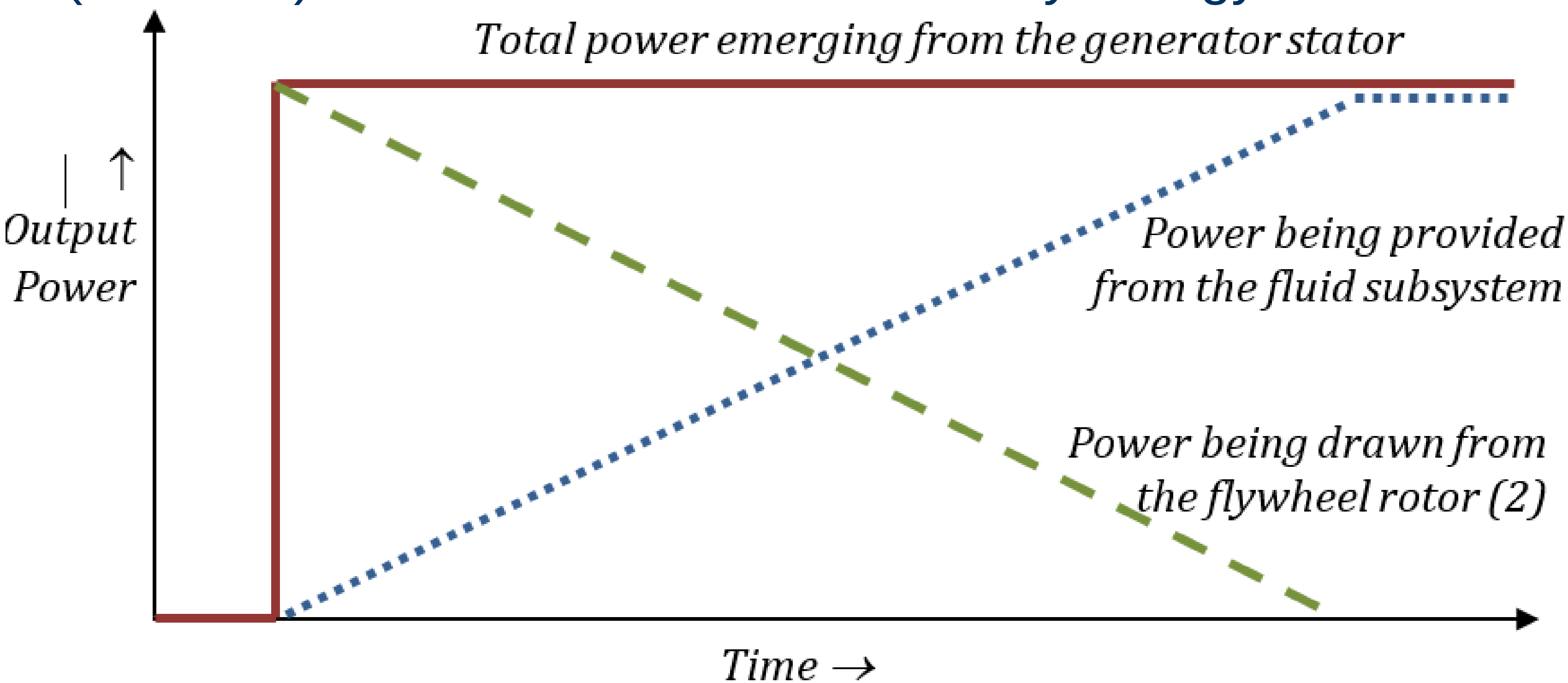
Directly coupling a synchronous generator (2,4) to a very large flywheel (1) via a *differential drive unit* (3) means that the generator can always turn at synchronous speed whilst the flywheel is decelerated.



A new hybrid energy storage system.

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

For very small fluctuations in frequency, the DDU (3) remains locked. To liberate larger amounts of the flywheel KE, a secondary energy store (normally CAES) provides some additional input. If, say, only 20% of the flywheel energy was removed and this was 2MWh, then only 20% of this energy (0.4MWh) has come from the secondary energy store.



A new hybrid energy storage system.

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Submission to EPSRC “Feasibility Studies in Energy” has been successful for

Serial Hybrid Kinetic Energy Storage Systems.
Starting Date: 01/06/2017. End date: 31/08/2019

GIES – A Paradigm Shift

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

The Supergen call for challenge proposals in late 2015 (deadline in Feb 2016) was instigation for University of Leeds to contact SDG in respect of a possible submission.

A proposal developed involving Universities of Cambridge, Leeds, Birmingham and Nottingham in which the central theme was a broad look at GIES systems. In the event, the SuperGen competition was very heavily oversubscribed and this consortium decided collectively to submit instead to *responsive mode*.

An international collaboration group was gathered around GIES concepts including Universities in Canada, Australia, Malta, Ireland, California, Indianapolis, Boston (MIT) and Italy.

GIES – A Paradigm Shift

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

WP1: Fundamental thermodynamic reasoning concerning the number of transformations undergone by energy in the ideal cycle. This should enables us to identify what systems

WP2: Cataloging existing GIES systems and exposing opportunities for where more GIES systems can exist

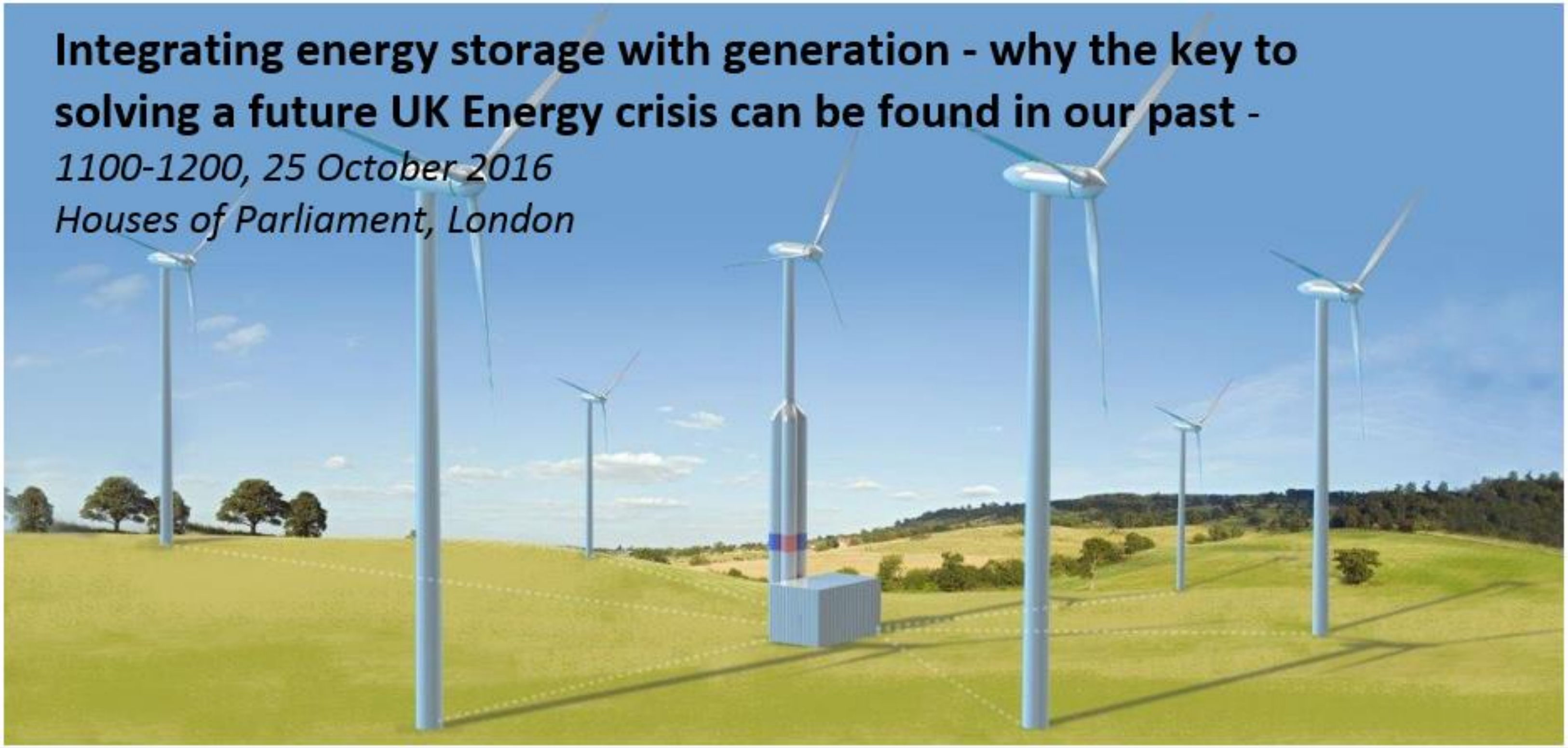
WP3: *Real Options* approaches to the economics of GIES (and other) energy storage systems.

WP4: Systems integration.

Proposal (to EPSRC) was approved in Feb. 2017.

Engagement with Policy Makers.

Following the IMAGES event run on Oct. 25th of 2017 in Palace of Westminster, SDG wrote up a set of notes from the occasion. These are available for upload to IMAGES website.



Engagement with Policy Makers.

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

A subsequent meeting was held with James Heappey (formerly) on the Energy and Climate Change Committee in Portcullis House on Feb. 28th, 2017.

The ECCC (as was) and ministers connected directly with the new incarnation of DECC are set in a different mode of thinking about flexibility in the electricity system (mainly around DSR and the utility that may be provided by electric cars). An opportunity to address these ministers directly is being sought.

Other outputs.

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Davenne T, Garvey S "The cold store for a pumpred thermal energy storage system" being reviewed by J. Energy Storage

Garvey SD. *The case for CAES*. A keynote address at UKES conference, Nov. 30 - Dec. 2, 2016. Birmingham

Garvey SD. *Integrated Grid-Scale Energy Storage*. Presentation at Marcus-Evans Commercial Applications of Grid-Level Energy Storage Solutions. NH Collection Hotel, Berlin, Feb. 16-17.

Papers required for OSES2017 please!

OSES 2014

OSES 2015

OSES 2016
Offshore Energy & Storage Symposium

OSES 2017