Energy storage: technology and policy innovation

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University of Birmingham

Top 20 university in the UK, top 100 in the world
c. 20,000 undergraduates, 10,000 postgraduates

Outline

- The UK's energy system need for flexibility
- Energy storage technology options
- Eenergy storage: research and applications
  - Cryogenic energy storage at UoB
  - Behind-the-meter
  - Network-connected
  - Clean cold / CryoHub
- Policy barriers

BIRMINGHAM
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The Birmingham Energy Institute is driving technology innovation and developing the thinking required to solve the challenges facing the UK as it seeks to develop sustainable energy solutions in transport, electricity and heat supply. Co-ordinated research, education and global partnerships are at the heart of our vision. By creating technology and guiding policy today we aim to help shape energy solutions of tomorrow.

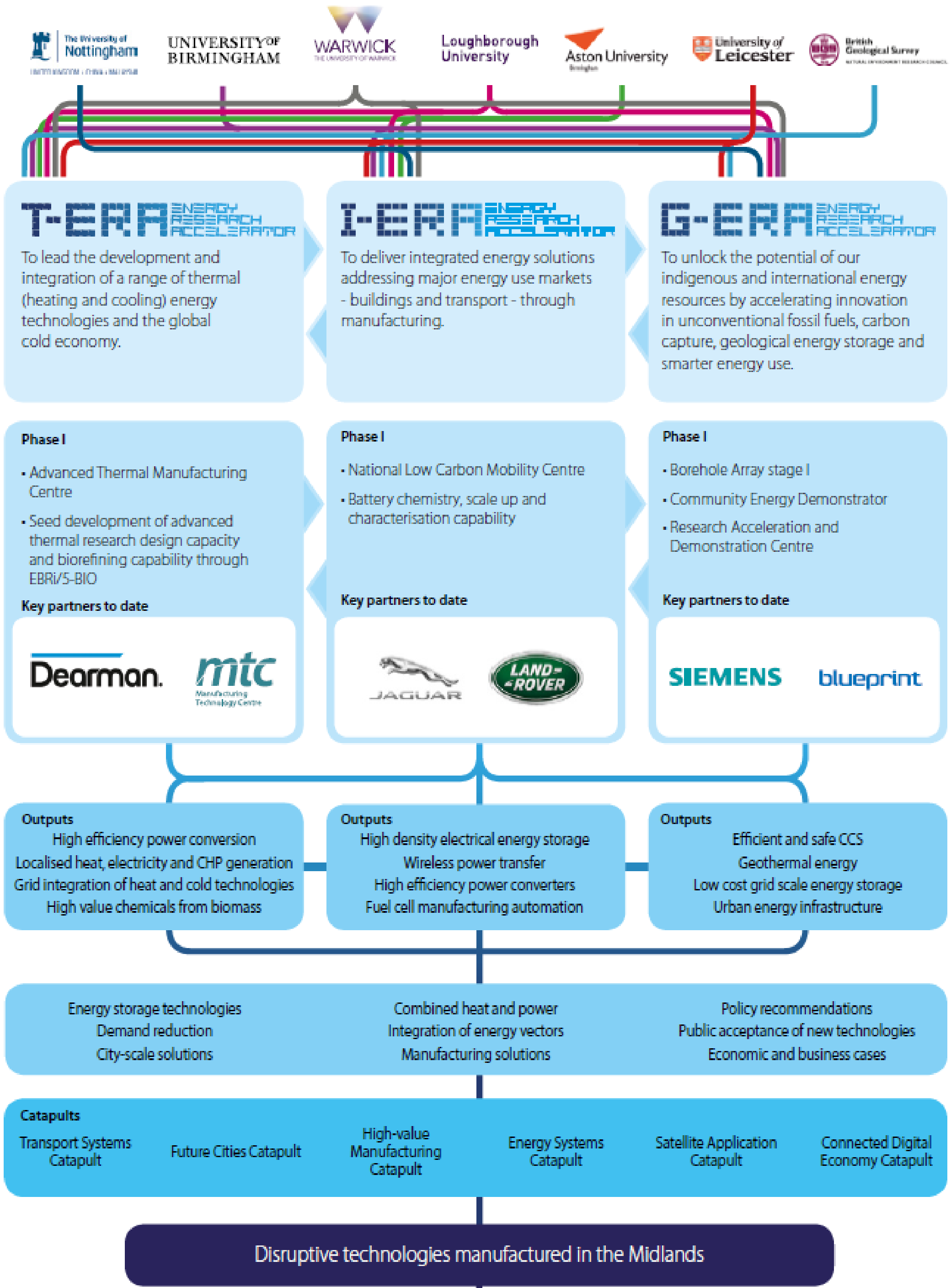
- Energy Storage
- Nuclear Energy
- Hydrogen and Fuel Cells
- Transport
- Smart Grids
- Oil and Gas
- Bioenergy
- Materials

WE HAVE OVER... **140** ACADEMICS FROM **4** COLLEGES

ENGAGED IN ENERGY AND ENERGY RELATED RESEARCH AND DEVELOPMENT

£75 MILLION

AWARDED FROM EXTERNAL PROJECT FUNDING RELATED TO ENERGY

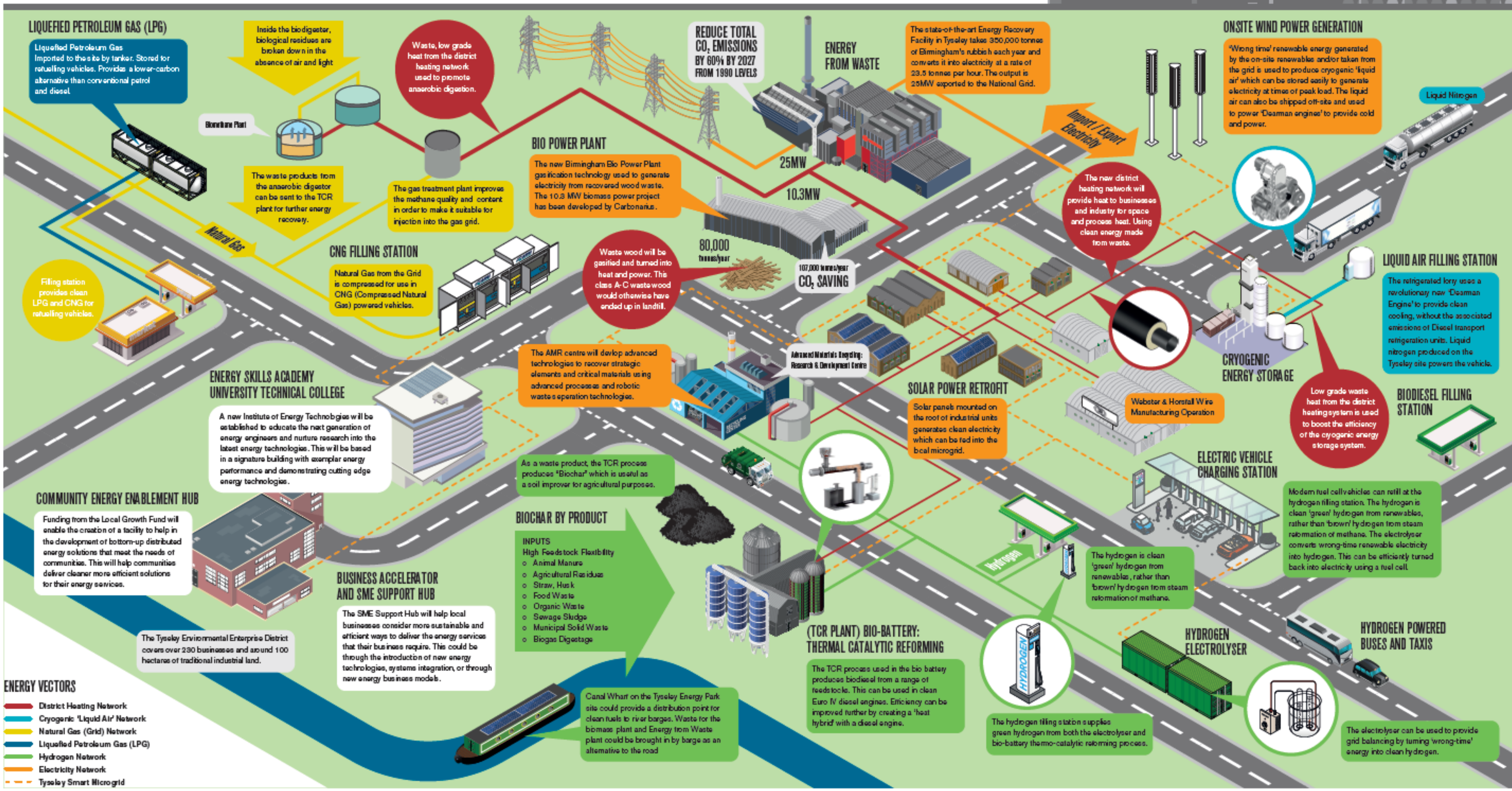


The Energy Research Accelerator brings together the Universities of Aston, Birmingham, Leicester, Loughborough, Nottingham and Warwick and the British Geological Survey to form a £250M research hub which will deliver on UK expertise and leadership to give the UK competitive advantage in energy research and development.

BIRMINGHAM: ENERGY CAPITAL

TYSELEY ENVIRONMENTAL ENTERPRISE DISTRICT

The City of Birmingham has ambitious plans to deliver carbon reductions, create a low carbon infrastructure and to modernise how it deals with waste. These priorities are captured in the Carbon Roadmap produced by the City's Green Commission which articulates the ambition via CO_2 Emissions Target and Carbon Budgets.



Video

BHAMENERGY

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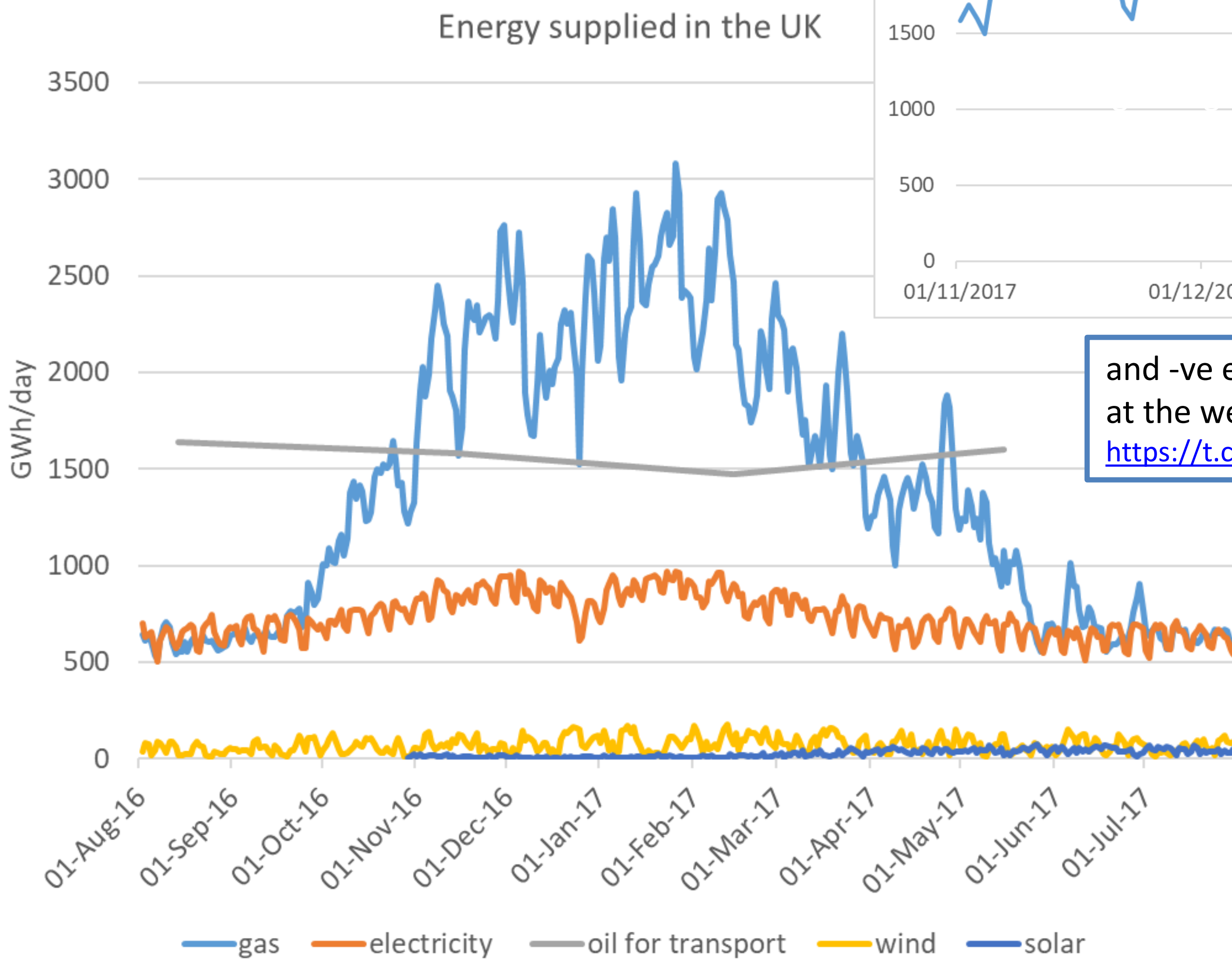
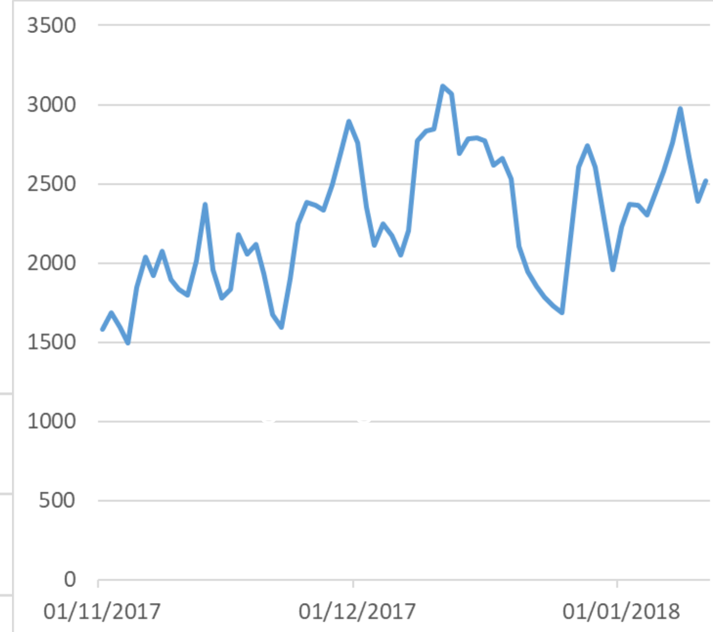
The UK's energy system

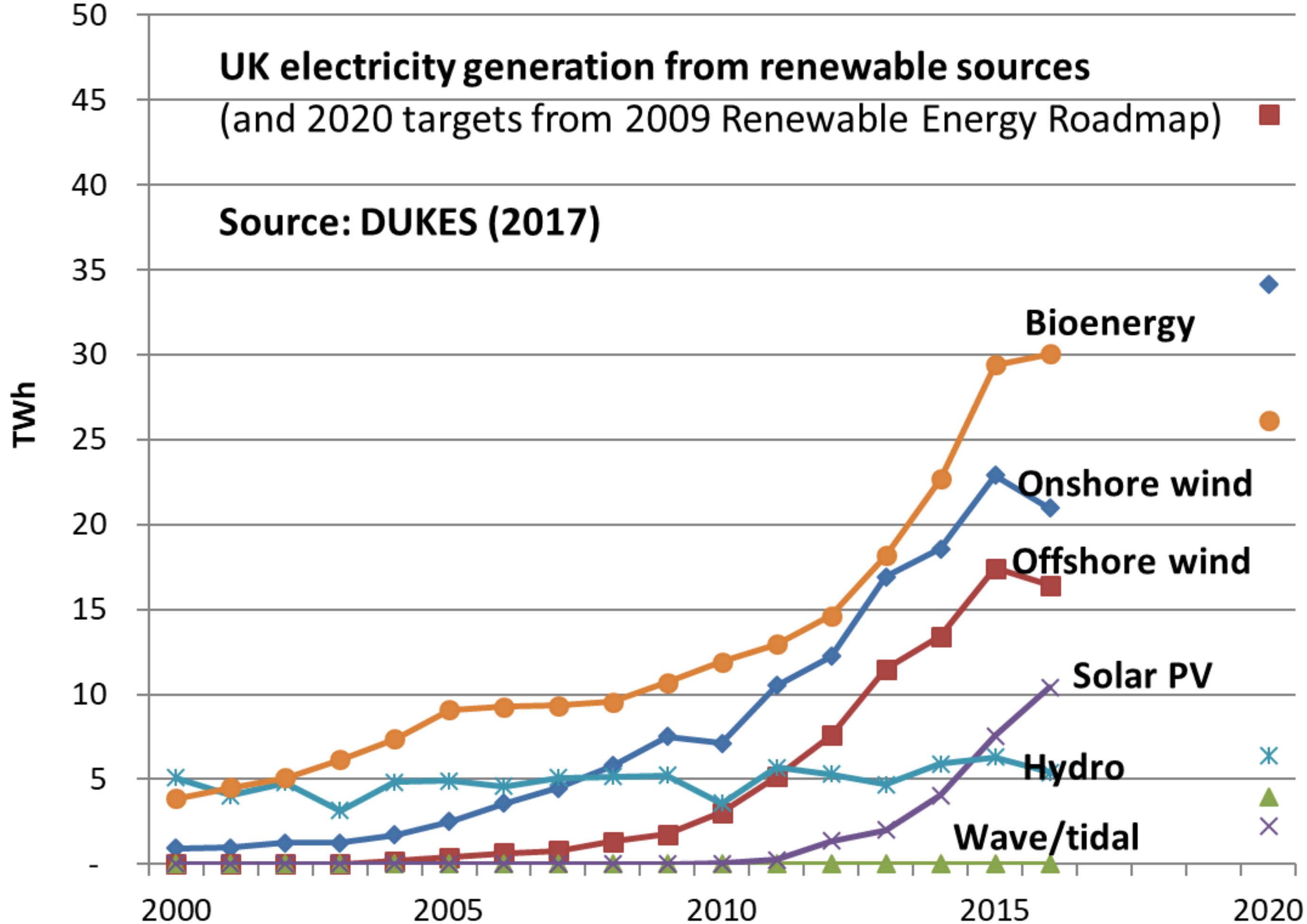




and -ve electricity prices at the weekend!
https://t.co/s1Vez3Ufv1

Sources: National Grid (electricity & gas [LDZ offtake]); DfT (petroleum products for transport, quarterly data); Gridwatch (wind and solar [solar from Nov 2016])

Decarbonising electricity

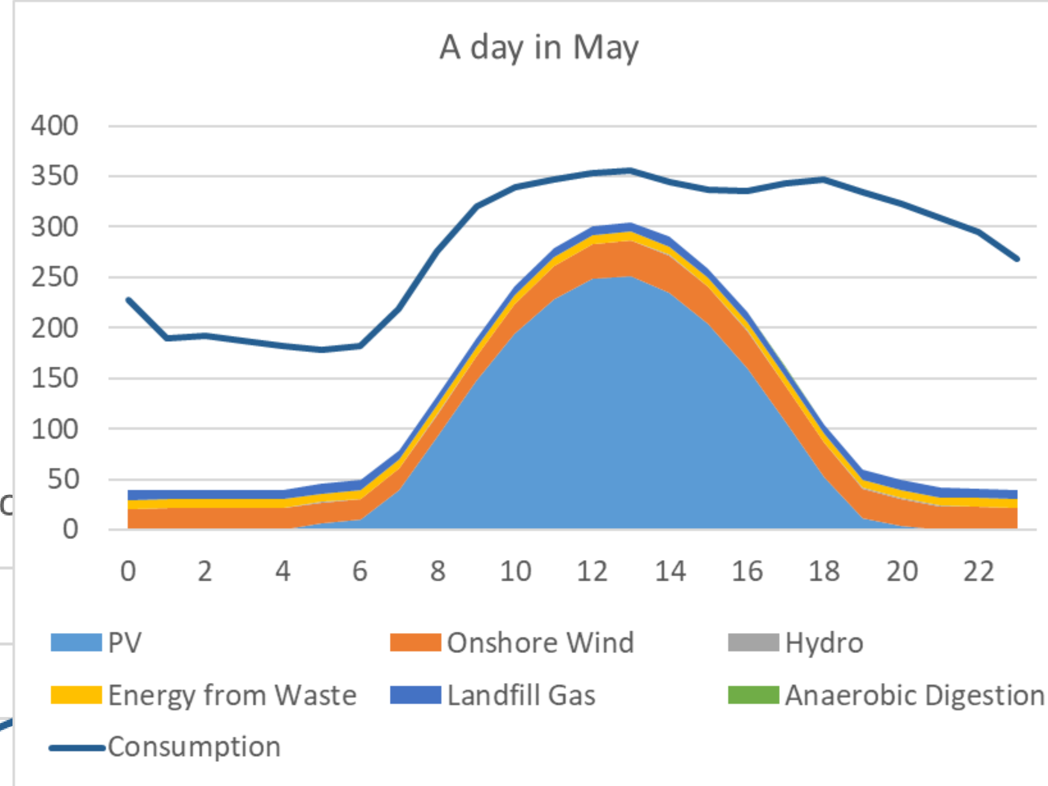


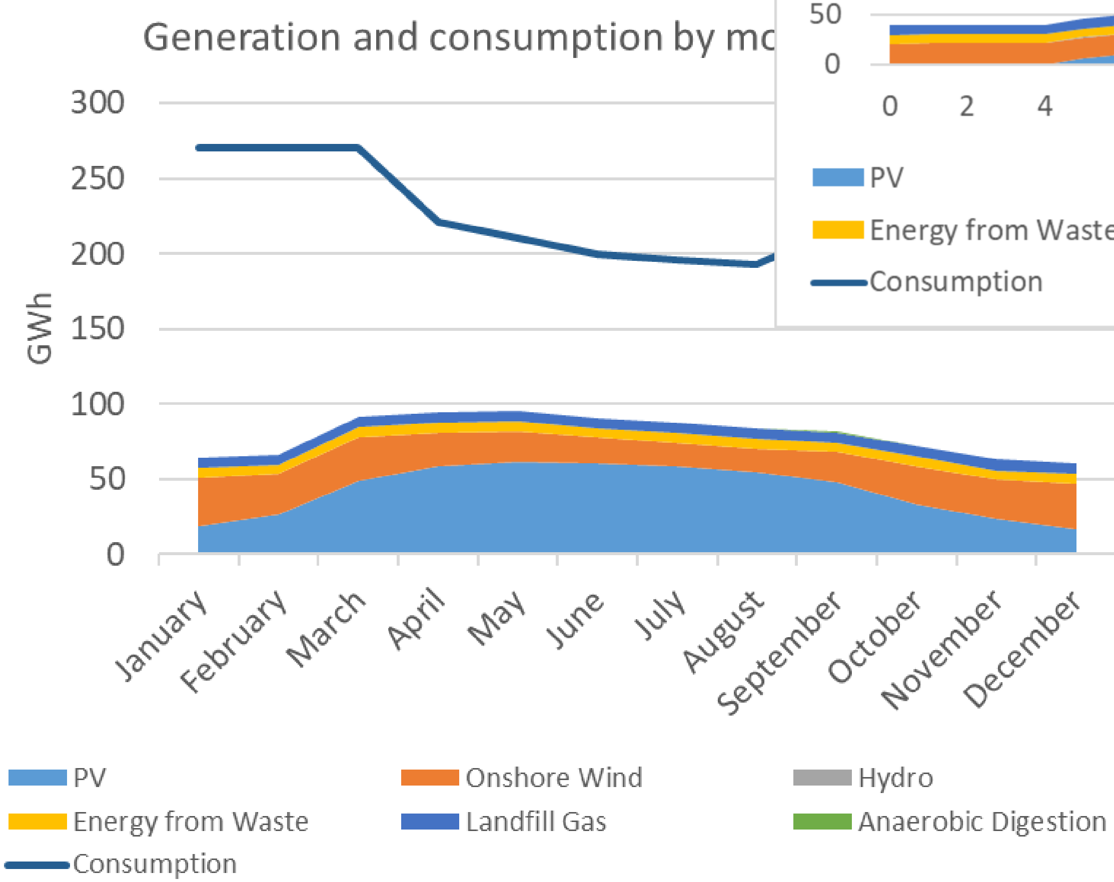
Latest projections for 35% of electricity from renewables by 2020

Sources: Digest of UK Energy Statistics (DECC, 2017)

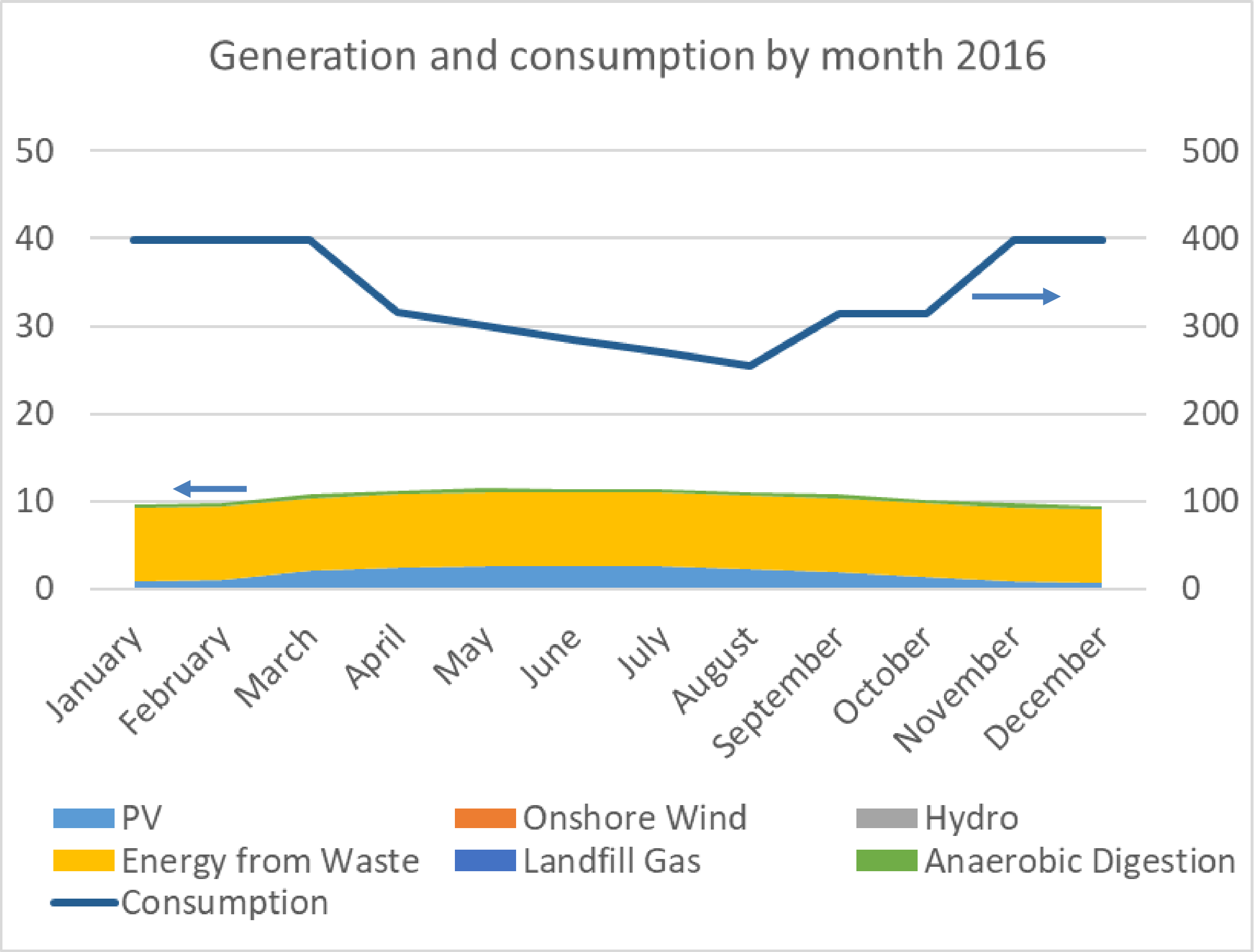
Cornwall

Local supply and demand for electricity in south-west UK:



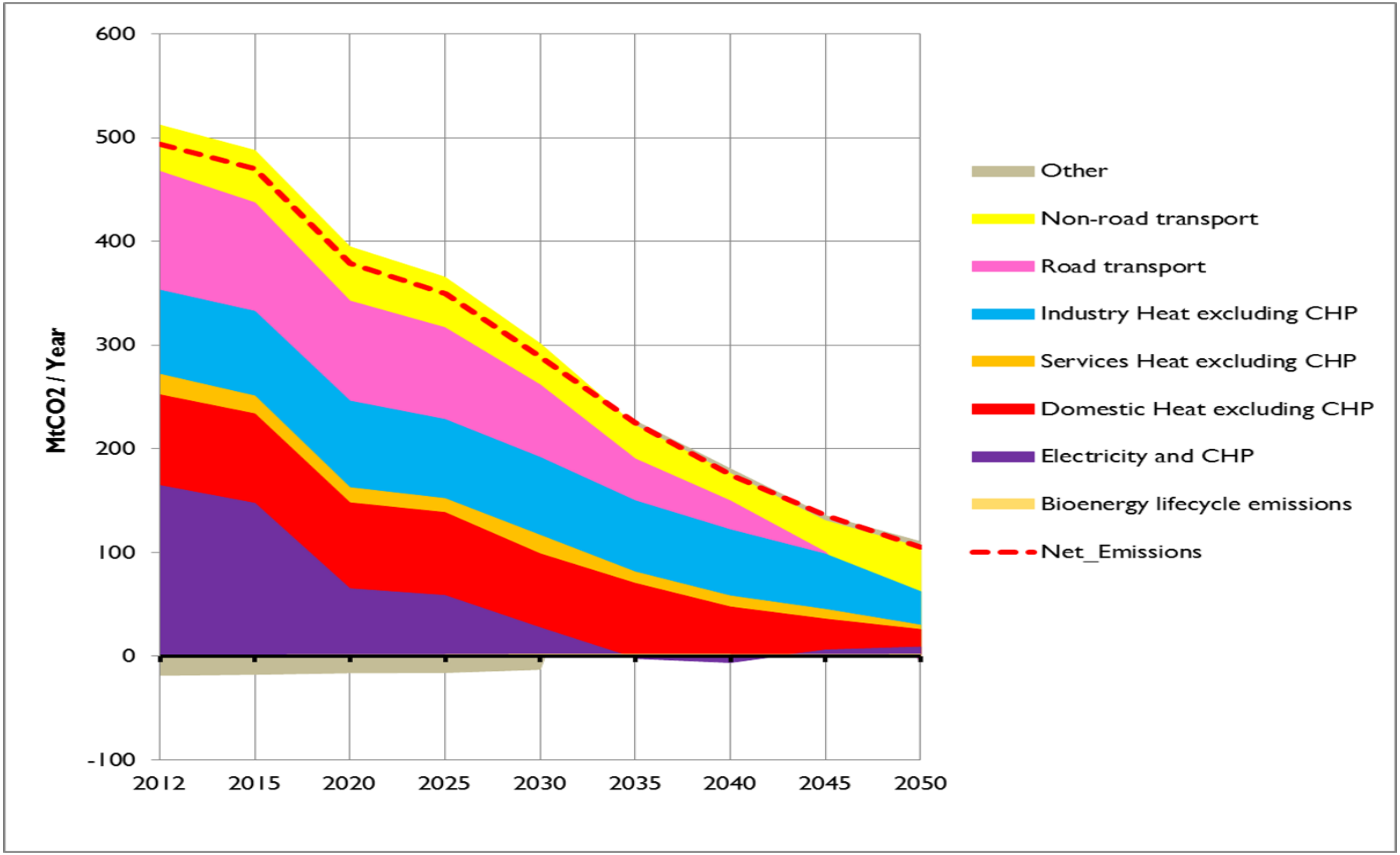


Birmingham

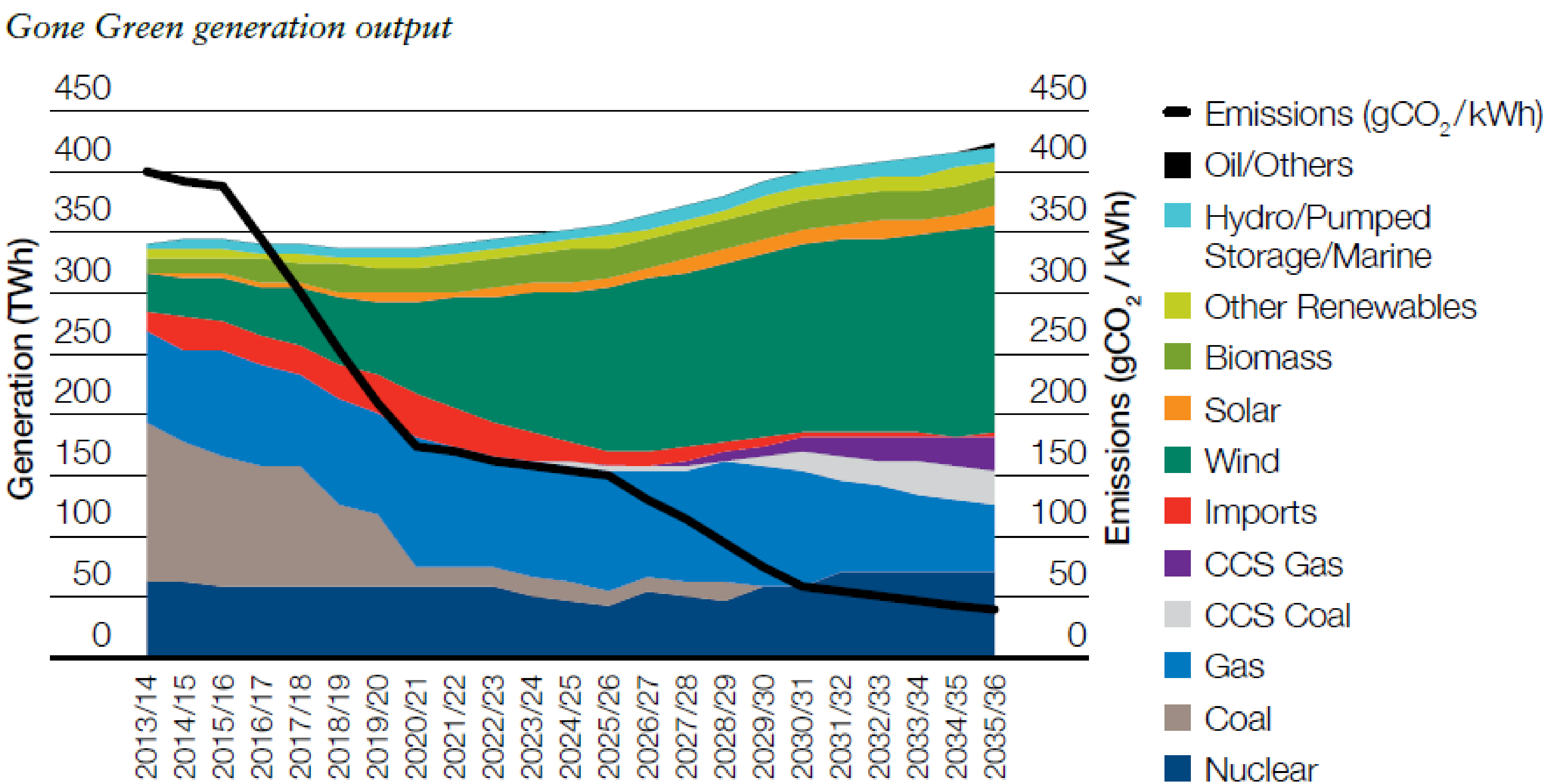


- Carbon Roadmap has a commitment to reduce emissions 60% by 2027.
- Failure of Birmingham Energy Savers Scheme with demise of Green Deal
- BCC establishing a municipal energy company.

Meeting 2050 CO_2 targets

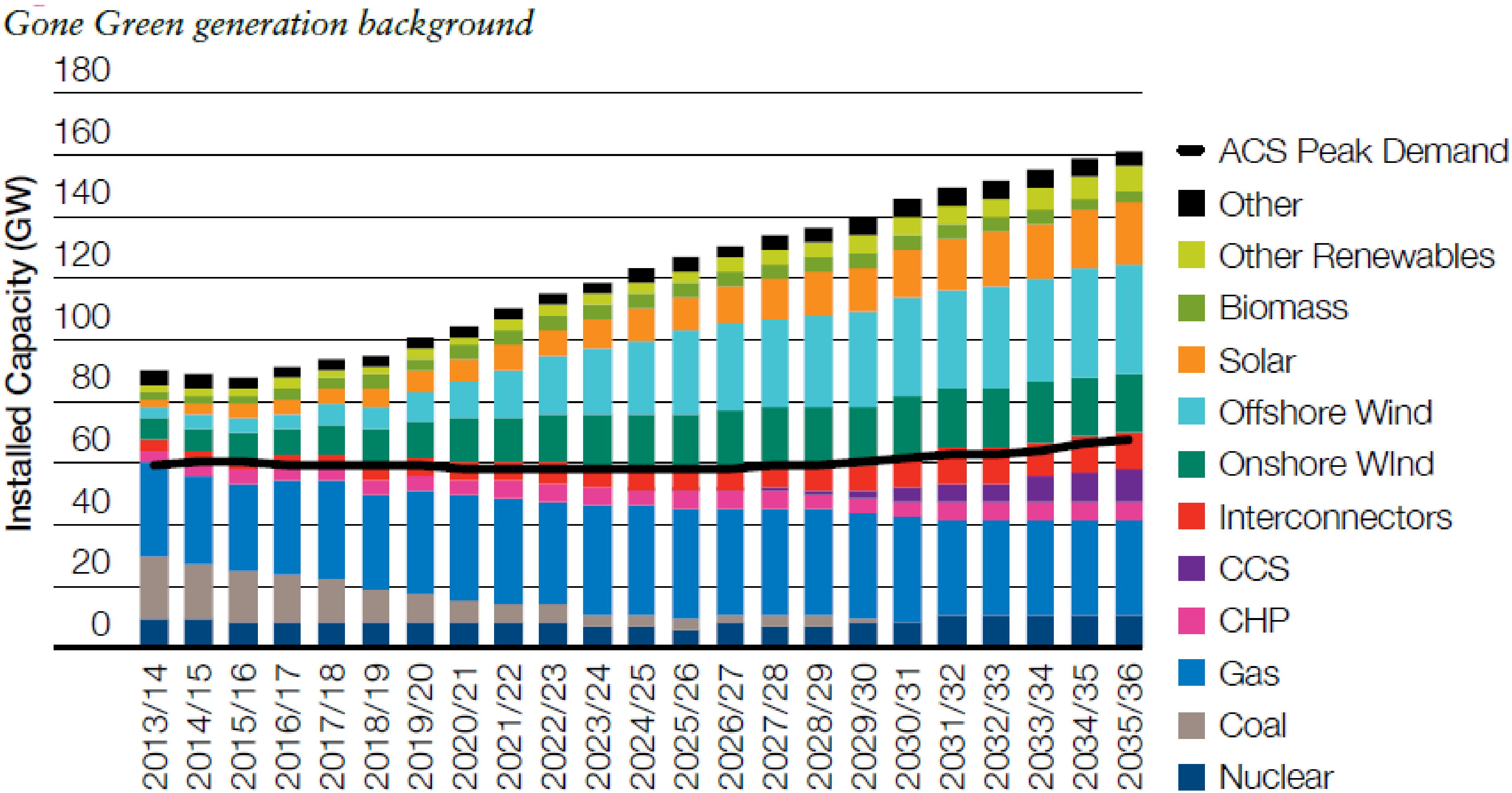


Decarbonising electricity – future?



National Grid, Future Energy Scenarios (2014)

Decarbonising capacity



National Grid, Future Energy Scenarios(2014)

UK Energy system need for flexibility

Timescale	Challenge
Seconds	Renewable generation introduces harmonics and affects power supply quality. Reduced inertia from less rotating machinery.
Minutes	Rapid ramping to respond to changing supply from wind/PV generation.
Hours	Daily peak for electricity is greater to meet demand for heat and EV.
Hours - days	Variability of wind generation.
Months	Increased use of electricity for heat leads to strong seasonal demand profile.

Global challenges

Drivers: increasing renewables, improving reliability, lowering costs, increasing access, greater urbanisation, energy security…

Applications:

- Component of ‘smart grids’
- Meeting cooling demands in summer
- Managing rise in distributed generation from solar PV
- Maximising transmission line use
- Improving power quality with integration of renewables
- ‘Behind the meter’ arbitrage
- Increasing the efficiency of thermal plant
- Off-grid small-scale renewables

….

Flexibility options

With an increase in generation from ‘must run’ and intermittent sources, and rising demand for electricity with less predictable profiles, ***flexibility*** becomes a critical component of the energy system

There are various means of meeting the same general and specific challenges:

- ***Flexible plant*** – Gas CCGT/OCGT is the default option Future options may include nuclear and fossil fuel CCS with greater ability to flex generation cost-effectively.
- ***Demand side response*** – smart meters, heat pumps and EVs deployed over the next decade can give consumers a mechanism to shift loads, but needs appropriate functionality and incentives.
- ***Interconnection*** – provides additional capacity or load for the UK, but operated on merchant basis is not solely for UK benefit, and relies on capacity being available elsewhere.
- ***Energy storage*** – can capture off-peak or excess generation and deliver at peak times, does not compromise national security of supply, does not require behavioural change from consumers.
  (Include consideration of alternative energy vectors – hydrogen, liquid air, heat…).
  But energy storage has its own challenges as an emerging disruptive technology: cost/performance; acceptance by the industry and wider energy community.

Storage can reduce electricity system costs

Significant cost savings achievable if market arrangements allow for use of energy storage – up to £7bn/yr in 2030.

Early action leads to greatest savings.

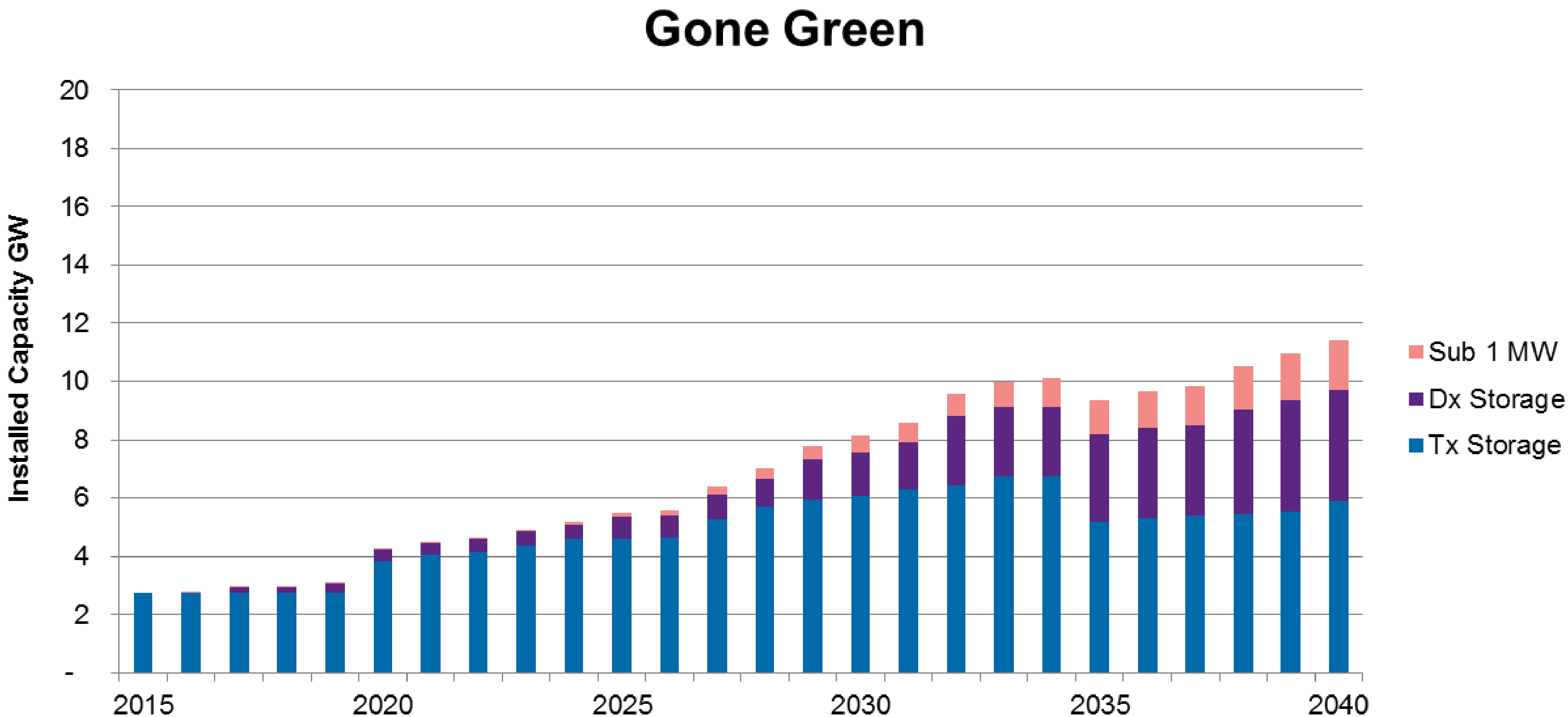
The value is contingent on progress to meeting carbon targets, removal of barriers and technology cost reductions.

Storage can also increase security by reducing dependency on imported fossil fuels and electricity though interconnection.

Carbon Trust and Imperial College 'Can storage help reduce the cost of a future UK electricity system?' (2016)

https://www.carbontrust.com/resources/reports/technology/energy-storage-report/

Analysis showing role for storage



National Grid, Future Energy Scenarios 2016
http://fes.nationalgrid.com/

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Tesla mega-battery in Australia activated

1 December 2017 | Australia

Share

REUTERS

The battery has been installed in Jamestown, South Australia

The world's largest lithium ion battery has begun dispensing power into an electricity grid in South Australia.

The 100-megawatt battery, built by Tesla, was officially activated on Friday. It had in fact provided some power since Thursday due to demand caused by local hot weather.

South Australia has been crippled by electricity problems in recent times.

Tesla boss Elon Musk famously vowed to build the battery within 100 days - a promise that was fulfilled.

"This is history in the making," South Australian Premier Jay Weatherill said on Friday.

yFT

wer UK switch to renewables

deal agreed as National Grid moves to prevent

8 Save

Environment Correspondent

m entered a new era on Friday with the announcement that tems will be used to help the country's power grid cope with the ar power.

rance's EDF are among the energy companies to win the first d contracts to supply split-second power to the electricity system alysts said was the largest of its kind in Europe.

Bloomberg

Tesla Cont Calif

It's the lates

by Tom Randall
tsrandall

September 15, 2016 –

Tesla j electri Power d time—by the end of this year.

Tesla Motors Inc. will supply 20 megawatts (80 megawatt-hours) of energy storage to Southern California Edison as part of a wider effort to prevent blackouts by replacing fossil-fuel electricity generation with lithium-ion batteries. Tesla's contribution is enough to power about 2,500 homes for a full day, the company said in a blog post on

http://www.bloomberg.com/news/articles/2016-09-15/tesla-wins-utility-contract-to-supply-grid-scale-battery-storage-after-porter-ranch-gas-leak

Existing energy storage

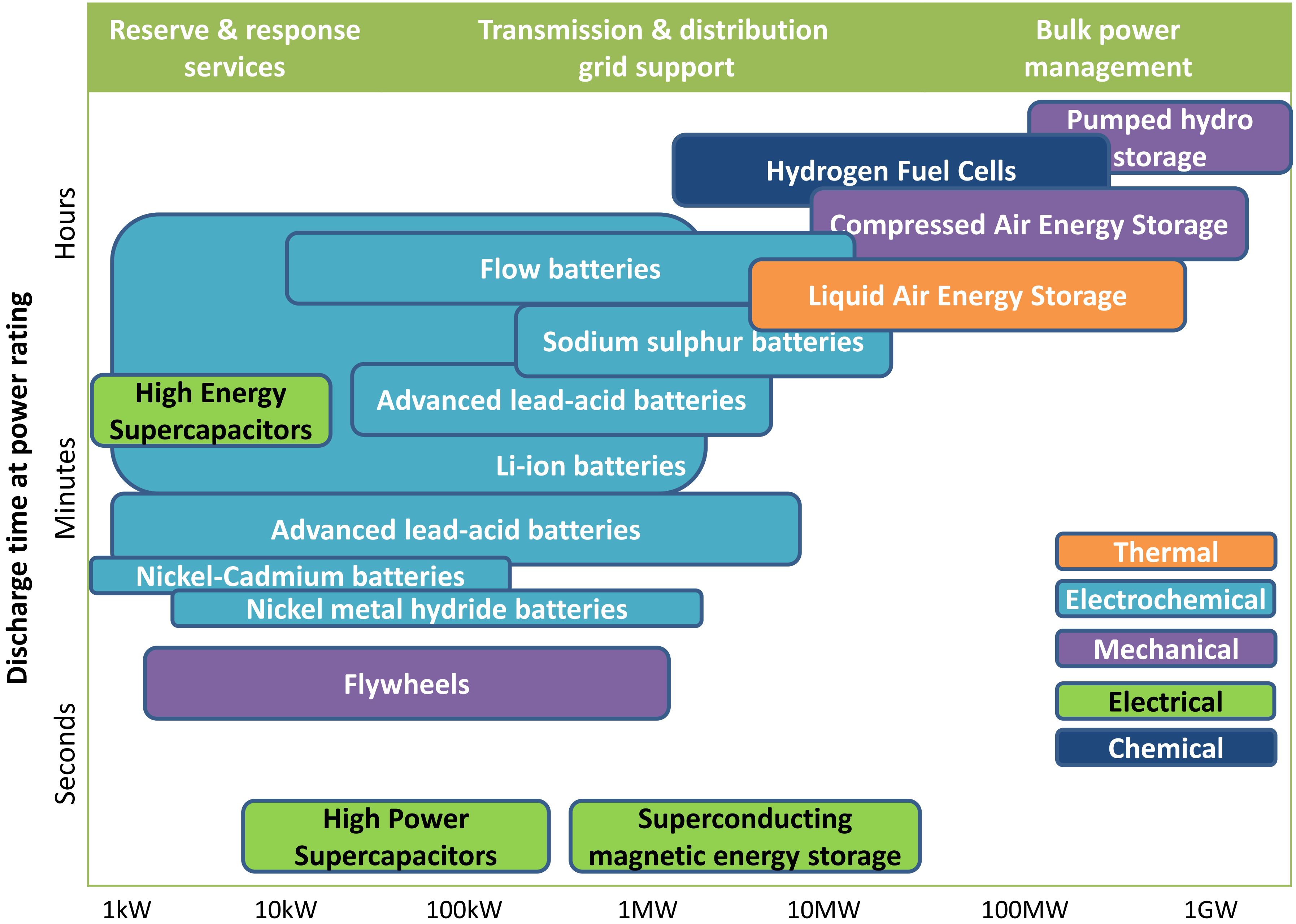
Coal: 1Mt coal = 3,000 GWh_e
(about two months output at 2GW)

Current gas storage~ 50,000 GWh

Pumped hydro storage:
total UK = 28GWh_e

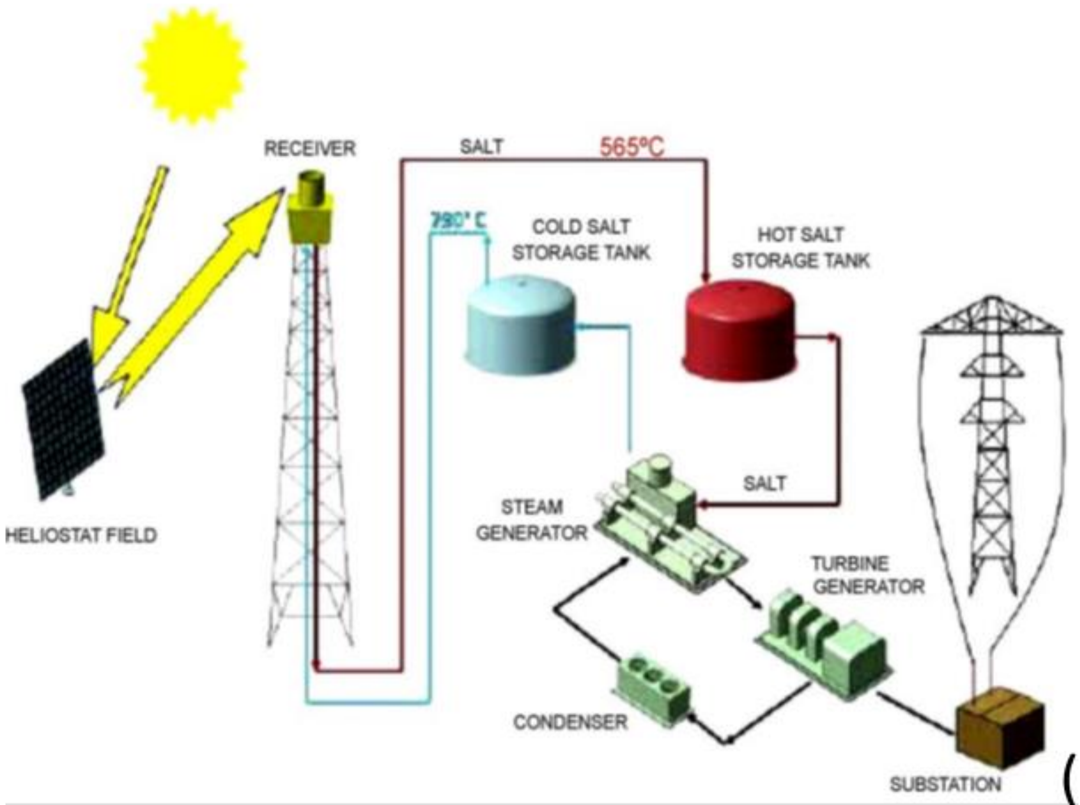
Hot water cylinder:
one tank = 6kWh_{th};
14m tanks = 84GWh_{th}

Electricity Storage Technology options



Thermal energy storage

- Sensible heat: raising/lowering temperature of a material
- Phase change: stores latent heat at a constant temperature corresponding to the phase transition temperature of the material.
- Thermo-chemical: reversible chemical reaction which give up or absorb heat.



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Applications and technologies

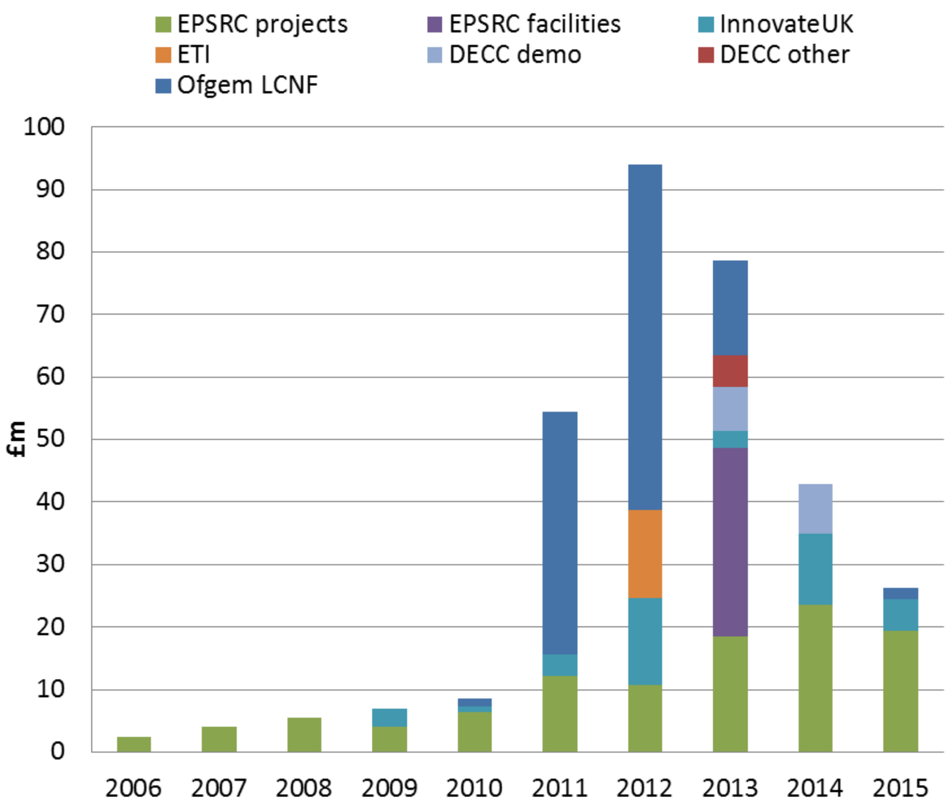
Application description	Scale of storage	Technology options (red indicates future potl)
Domestic scale energy storage for domestic peak shaving	2-5 kW 4-10 kWh 2-8 hours	• Li-ion/lead-acid batteries • TES
District scale energy storage for peak shaving, deferring distribution n/w reinforcement	50-500 kW 200 kWh –2 MWh 2 – 8 hour	• Li-ion/Pb-acid/NaS batteries, H2, flow batteries • TES with heat network • CES, SMES
District scale energy storage for balancing microgrids and renewables integration	200 kW – 1 MW 1-10 MWh 6 – 12 hours	• NaS/Pb-acid batteries, Hydrogen, flow batteries • TES with heat network • CES, SMES
District scale seasonal energy storage	200 kW – 1 MW 100's MWh months	• Thermal energy storage - underground hot water/rock storage • PCMs, hydrogen
Large scale storage for renewables integration	10 – 200 MW 100 MWh–2 GWh 12 – 48 hours	• PHS, CAES, Hydrogen, flow batteries • PTES, CES, A-CAES
Energy storage for spinning reserve	5-500 MW 10 MWh – 1GWh 24 hours – weeks	• PHS, CAES, flow batteries • PTES, CES
Centralised large scale grid storage for wind integration	1-10 GW several GWh days - weeks	• PHS • PTES, CES, H2

Energy storage innovation in the UK

- Near-term storage service demands likely to be over timescales of seconds – minutes, but high penetrations of "inflexible" generation means increasing need for large stores of energy over hours – days.
- There has been a lag in support, and lack of vision across the innovation landscape, which is needed to enable the appropriate technologies to be developed.
- Other than electrochemical batteries, overall level of funding for energy storage, while increasing, is low compared to other technologies, and fragmented. It is not sufficiently supported by policy to provide confidence to private sector investors.

From Taylor and Radcliffe, paper presented at the 2016 BIEE Research Conference "Innovation and Disruption: the energy sector in transition"

UK public sector funding for energy storage technologies has been patchy

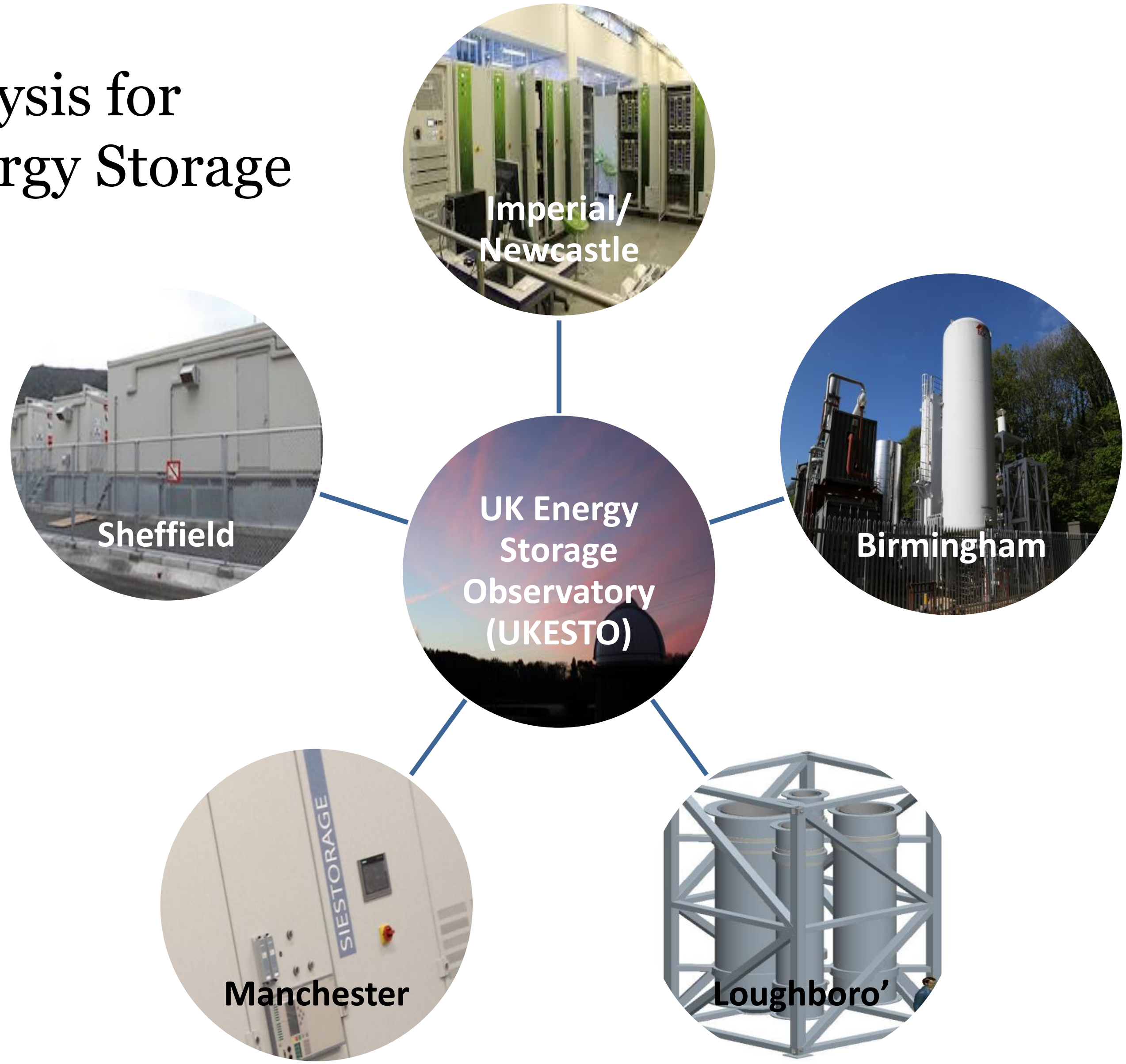


Source: UKERC Research Register

IEA energy category	Funding 2000 – 2009 (£k)
Energy storage	7,551
Wind energy	25,816
Solar energy	37,721
Ocean energy	39,511

Relatively small amounts for thermal and large-scale Generation Integrated energy storage that could be important.

Multi-scale ANalysis for Facilities for Energy Storage (MANIFEST)



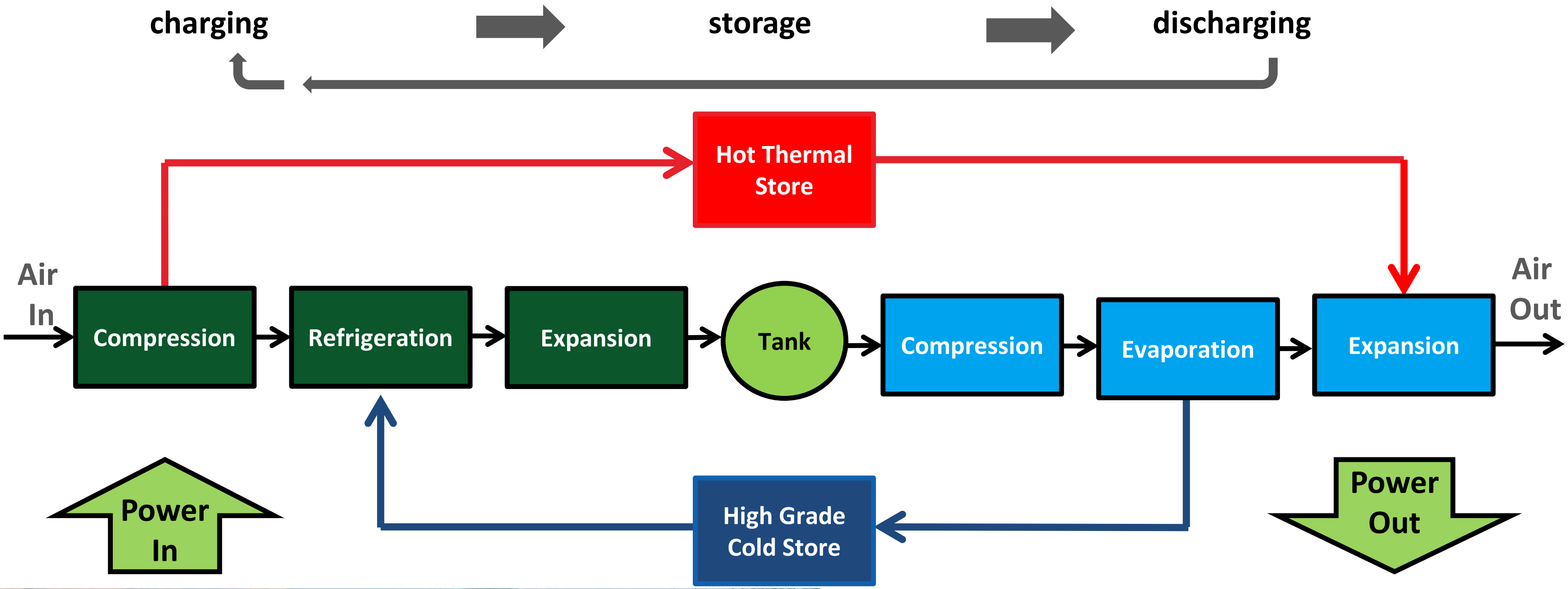
£5m project to address key challenges:

- Materials
- Modelling of processes
- Energy system integration
- Real-world performance

UK Energy Storage Observatory
https://www.birmingham.ac.uk/ukesto

Liquid Air Energy Storage at UoB

Grid-connected Cryogenic Energy Storage



Pilot plan tat UoB connected to heat & power network.

- 300 kW max output
- 8 hours operation – 2.6MWh capacity with 60t LN2
- 1.4t/hr LN2 production

DECC now funding Highview Power Storage to build 5MW/3 hour demo.

Cryogenic energy storage - key development challenges

Research themes at UoB:

1. Novel materials: address key materials challenges, inc. performance of deep cold and low to medium temperature heat storage materials
2. Thermodynamic and generation processes: address process challenges, develop high efficiency hot & cold exchange devices
3. Systems integration, control and optimization: address energy management challenges of an operational CES plant

Pilot scale test-bed for full CES system and generation-only

Now undertaking techno-economic analysis of energy storage on UoB campus:

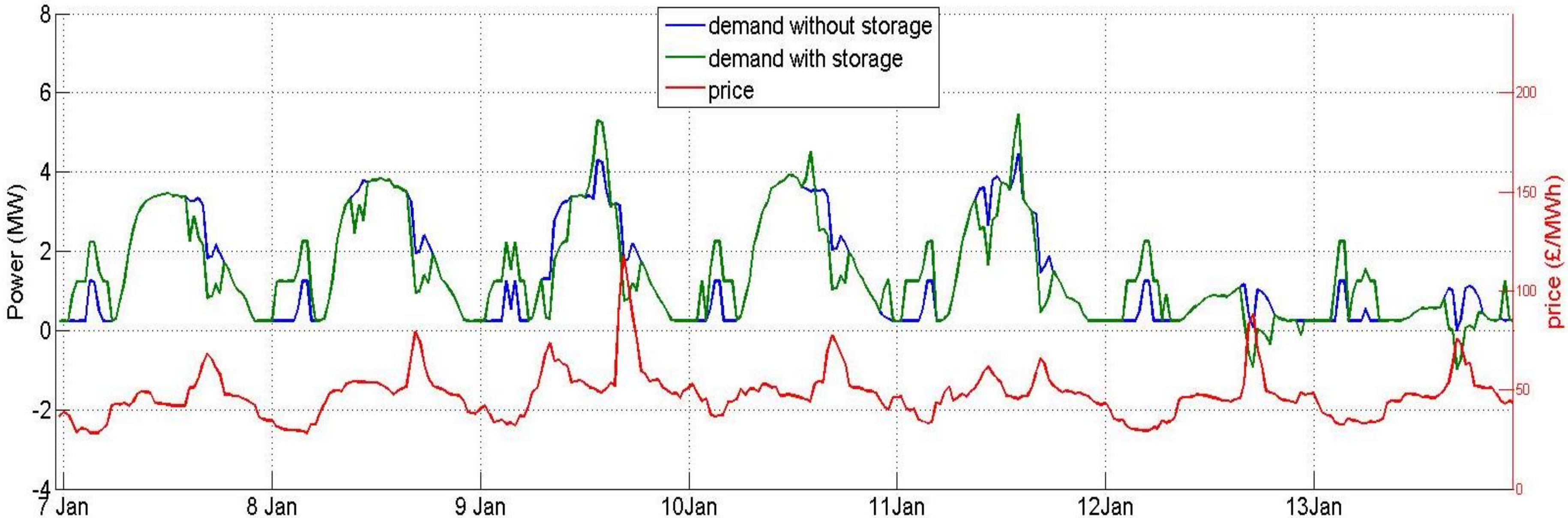
- Reduce demand at peak times
- Buy electricity when cheap, use when expensive

Economic case study for "behind-the-meter" energy storage at UoB

- The university provides an ideal test case of a small network in which energy storage could be situated
- 132kV connection to the transmission network
- Peak demand 10-14 MW
- Heat network – ability to integrate waste heat
- 4.5 MW CHP plant, 5 steam boilers, some diesel gensets

Energy ~5.6×10^7 kWh (@ 6p/kWh)	>£1,500,000
'Green' tariffs (ROCs/FITs)	£300,000
Capacity charge	£180,000
Balancing charges	£70,000
Transmission Losses	£15,000
Transmission charges	£83,000
Total / year	**~£2.2 million**

Modelling energy storage



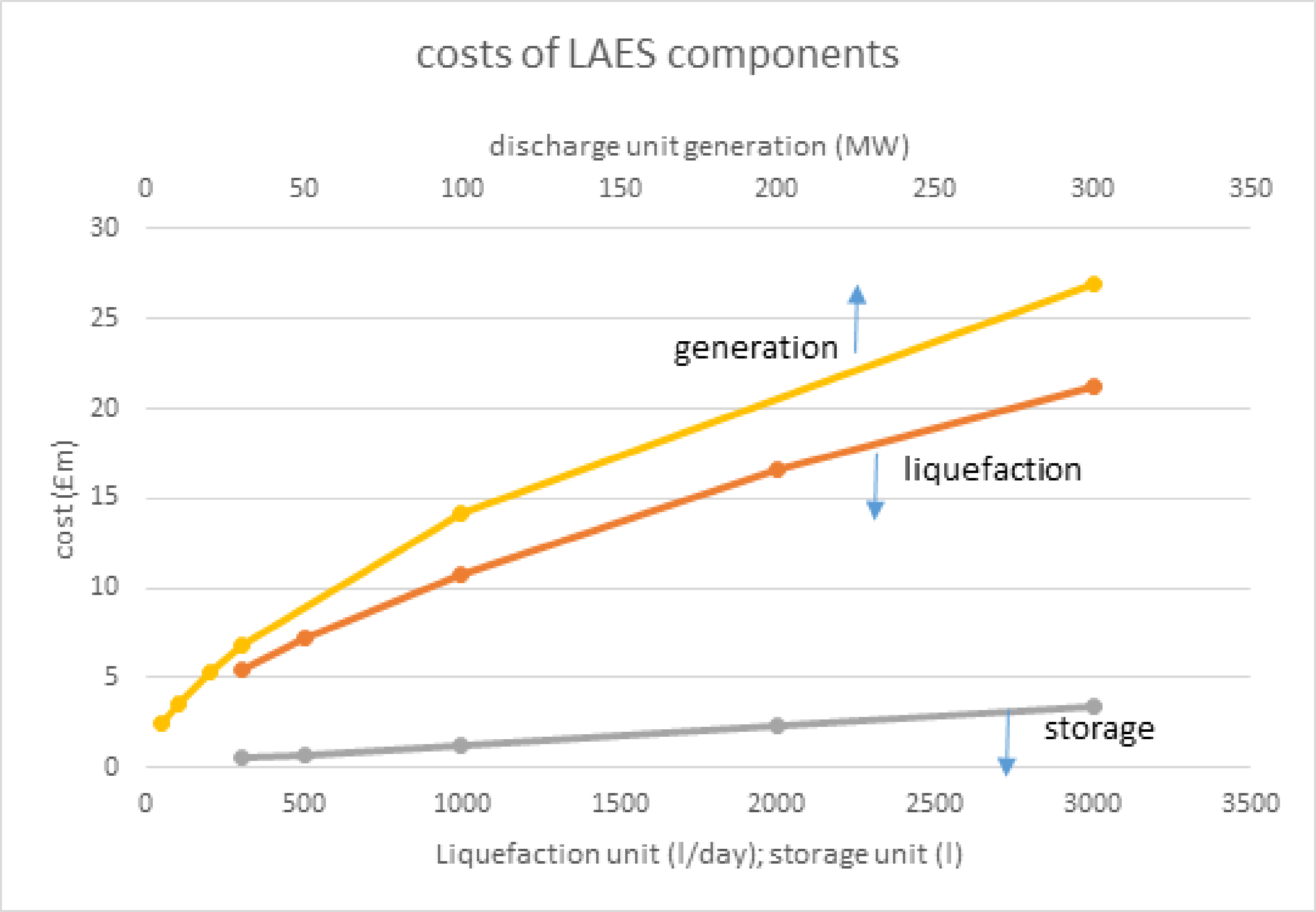
Example of model output to reduce UoB electricity bill, considering price arbitrage and system services (TRIAD avoidance).

Can reduce electricity bill by £0.1m/year

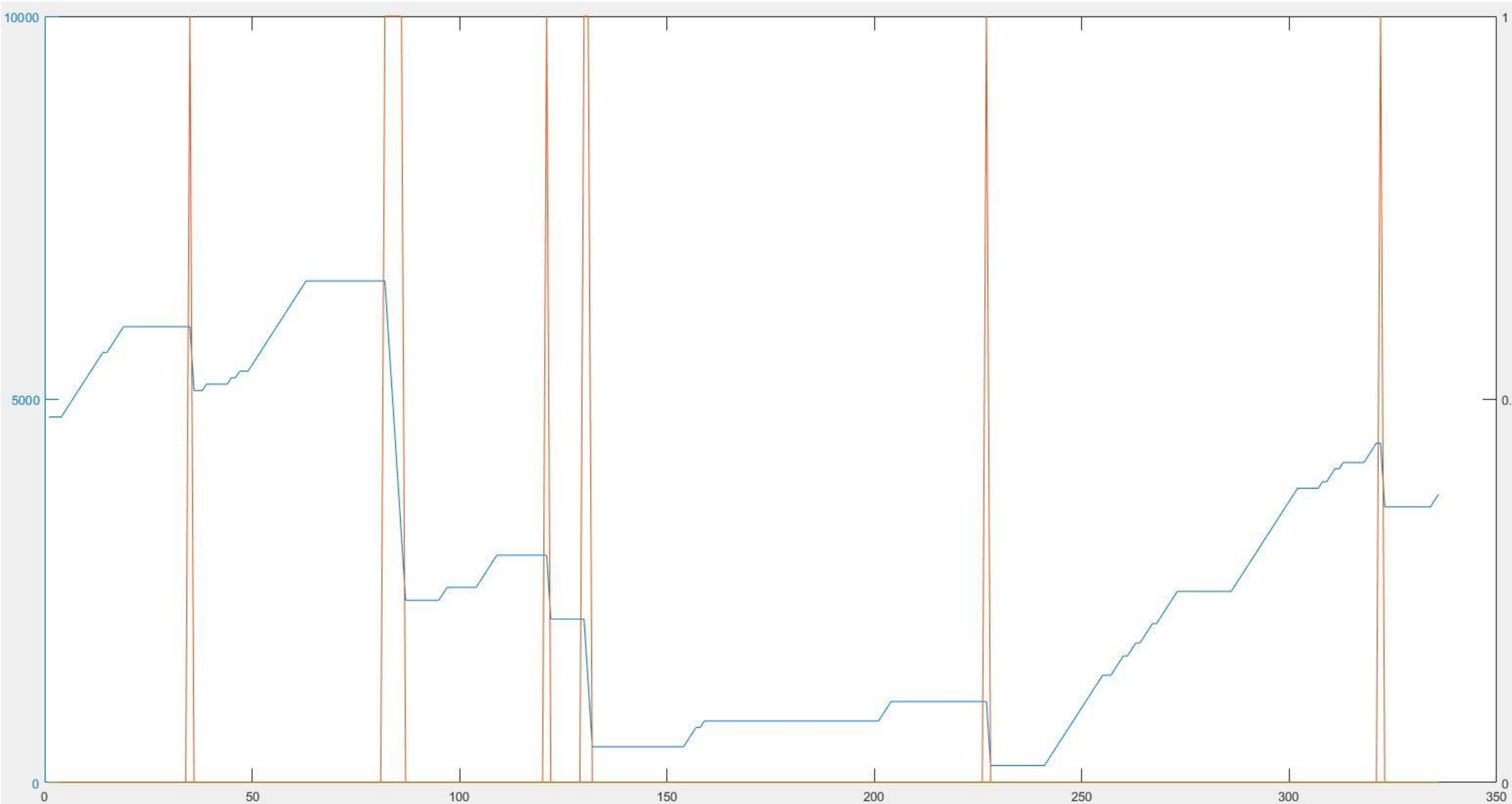
Making a business case for network-connected liquid air energy storage

LAES is a case of a decoupled energy storage system - charge, store and discharge can be sized individually, and have different cost characteristics.

We want to vary their size to optimise profitability of the LAES system.

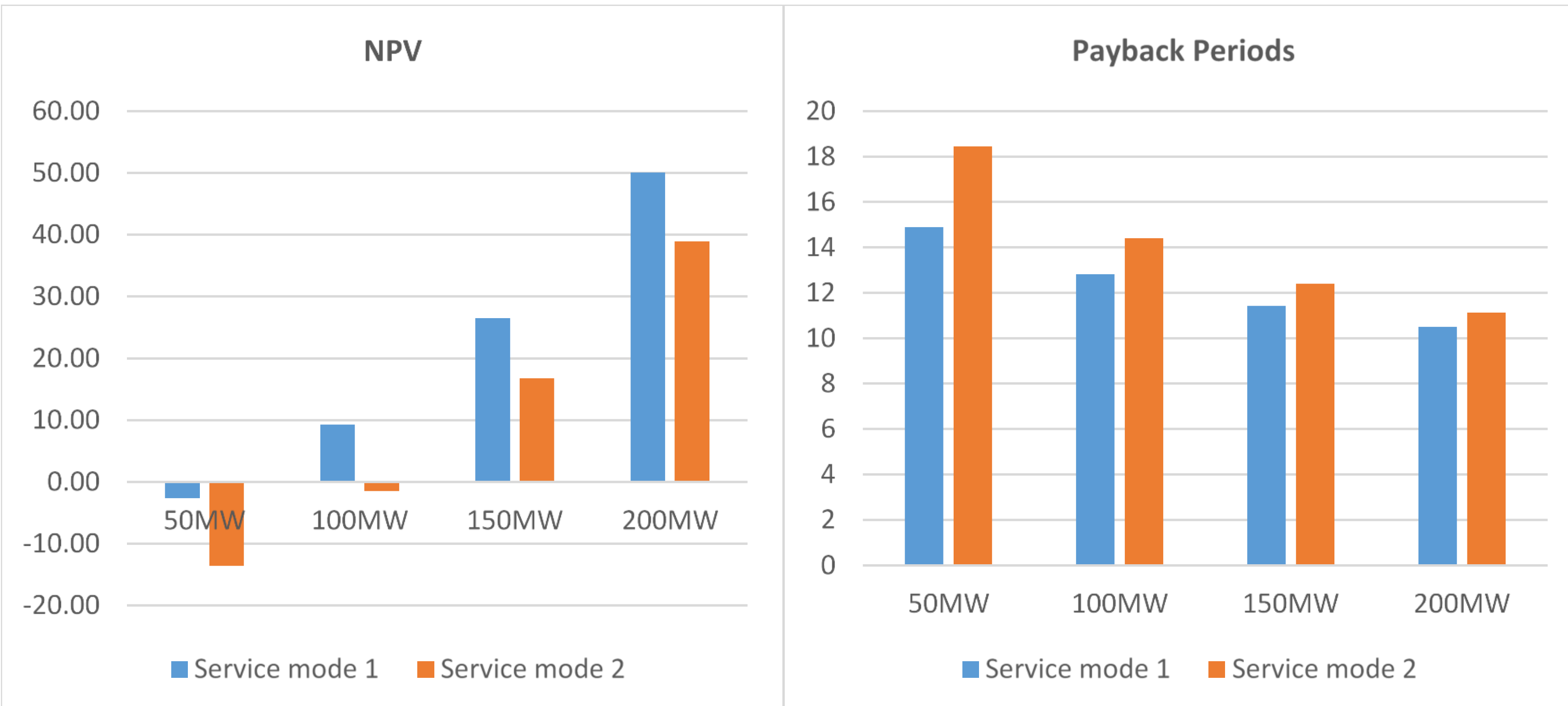


LAES charge/discharge cycles



For the case of a 200MW over one week (336 half-hours delivery periods)

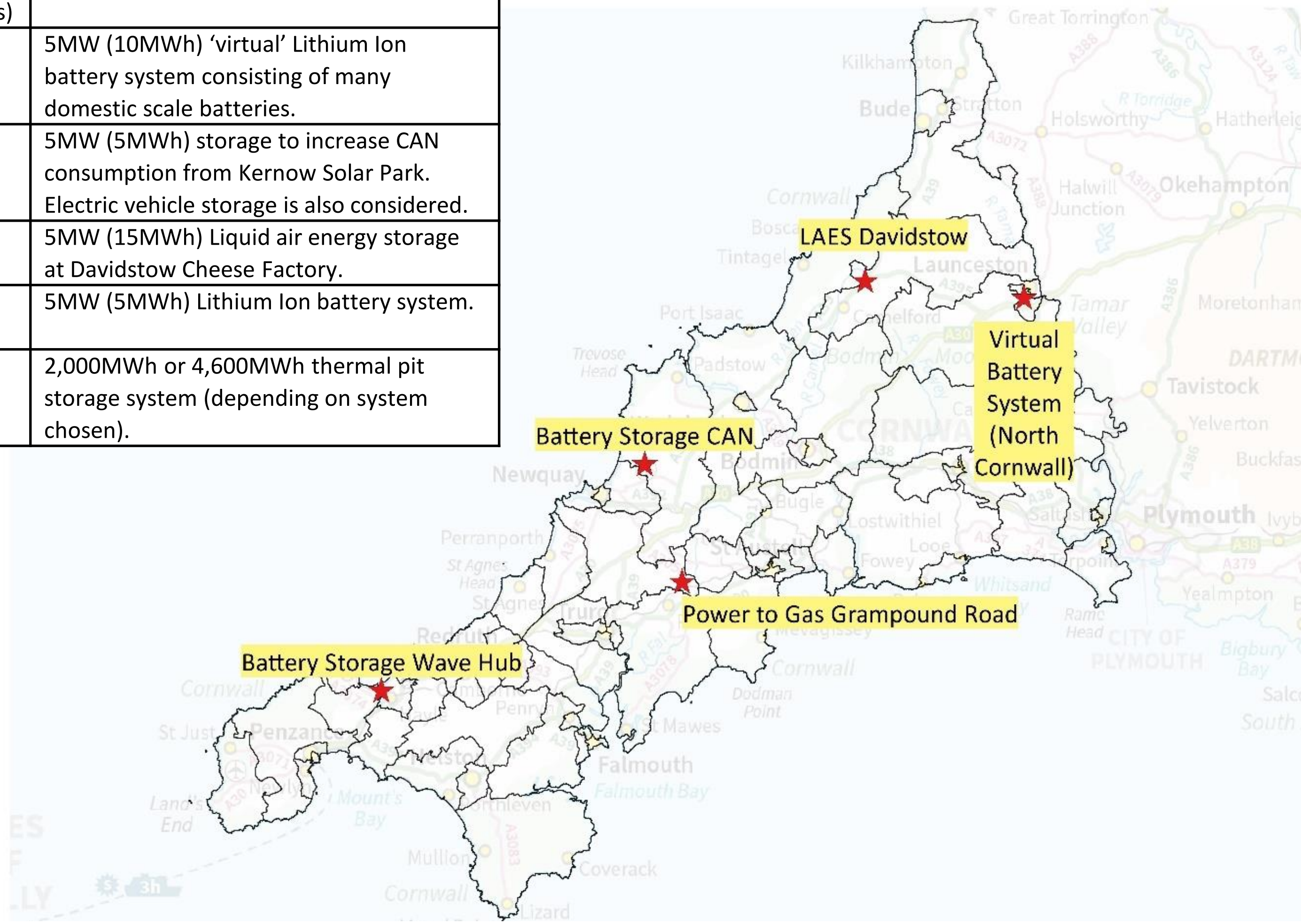
Blue line shows liquid air volume (i.e. stored energy), orange line shows discharge times (i.e. generating electricity).



NPV
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
50MW
100MW
150MW
200MW
Service mode 1
Service mode 2
Payback Periods
20
18
16
14
12
10
8
6
4
2
0
50MW
100MW
150MW
200MW
Service mode 1
Service mode 2

Potential distributed energy storage in Cornwall

Site Name	Type of ES	Description
Power to Gas, Grampound Road	Electrical (Power to Gas)	12MW electrolyser system.
Virtual Battery System North Cornwall	Electrical	5MW (10MWh) 'virtual' Lithium Ion battery system consisting of many domestic scale batteries.
Battery Storage, Cornwall Airport Newquay (CAN)	Electrical	5MW (5MWh) storage to increase CAN consumption from Kernow Solar Park. Electric vehicle storage is also considered.
LAES, Davidstow	Electrical	5MW (15MWh) Liquid air energy storage at Davidstow Cheese Factory.
Battery Storage, Wave Hub	Electrical	5MW (5MWh) Lithium Ion battery system.
Residential new build – no specific site	Thermal	2,000MWh or 4,600MWh thermal pit storage system (depending on system chosen).



‘Clean cold’

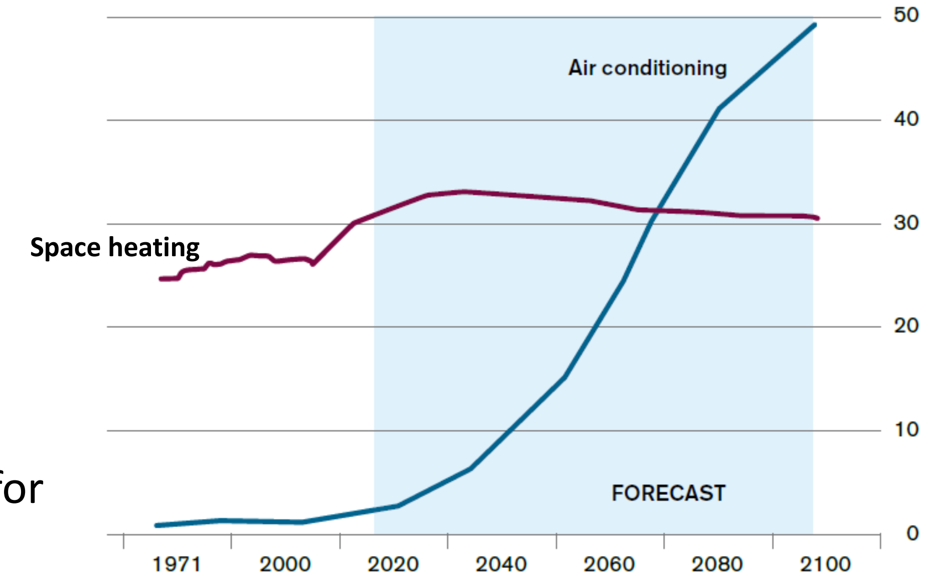
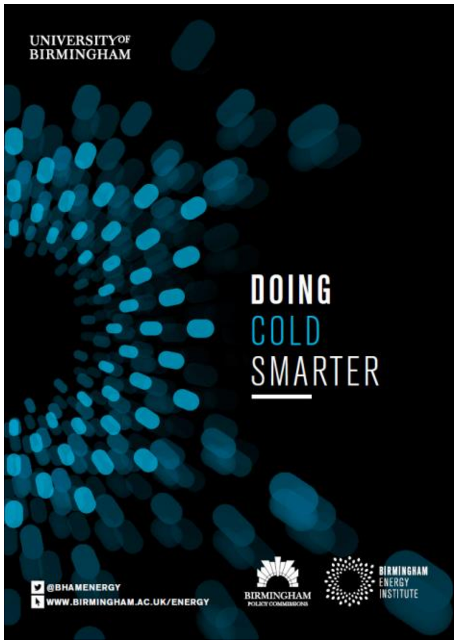


Figure 6: Worldwide forecast energy demand for space heating and space cooling, exajoules. Source: PBL Netherlands Environmental Assessment Agency[79]

- UoB Policy Commission ‘Doing Cold Smarter’ project produced a roadmap for sustainably providing the cold energy
- There is a need to re-shape the way we address cold needs.
- We need to start with the services required, not simply the electrical demand.
- We must think about how to make, harness, transport and access cold to meet these cooling loads.

University of Birmingham to host ‘Cool World’ conference, the first international congress dedicated to clean cold, in 18 – 19 April 2018
https://www.birmingham.ac.uk/research/activity/energy/events/2017/clean-cooling-congress.aspx



http://www.birmingham.ac.uk/doing-cold-smarter.aspx

Overcoming barriers to deployment

- Technology cost and performance: other technologies are currently cheaper
- Uncertainty of value: the future value is dependent on the energy system mix
- Business: capturing multiple revenue streams is difficult to establish, both for a potential business and the market in which it will operate
- Markets: the true value of energy is not reflected in the price; more fundamentally, the future long-term value of storage cannot be recognized in today's market
- Regulatory/policy framework: restrictions on ownership; paying levies twice
- Societal: wider community acceptance has not yet been considered

Technology push + policy pull

- **Innovation support**

Research Councils; Innovate UK; Energy Technologies Institute/Energy Systems Catapult; Ofgem; Dept. Business, Energy & Industrial Strategy

- **Industrial strategy White Paper (2017)**

References energy system challenges, but auto-focused £246m Faraday Battery Challenge, inc. £45m research-focused Faraday Institute

- **Ofgem/HMG 'Upgrading Our Energy System' (2017)**

Clarity on licensing, planning and charging, addresses short term barriers, but focused on electricity and central policy/regulation

- **Markets opening**

Enhanced Frequency Response: 200MW contracted (Nov 2016)

Capacity Market: 500MW to new storage (Dec 2016)

Energy storage: Conclusions

- Analysis can show a future benefit
- Need combination of technological and policy support to drive innovation
  - R&D is cheap
  - Changing regulations is free-ish (to Government)
  - Supporting industry could be good value
  - Deployment support is expensive, subsidies not popular, but what is a subsidy
- Complexities associated when taking whole-systems perspective with multiple objectives
- Risk of jurisdictional arbitrage
  - Develop in one country, deploy in another
- Time horizons for support mechanisms are critical
  - Need coordinated and long-term view: not currently in place
  - Short-term fixes could crowd the market for more efficient long-term solutions

Consider also the case for CCS, SMRs?

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‘Institute for Global Innovation’

- Resilient Cities priority theme

will investigate the drivers of urban distress and the conditions for securing city resilience, with a focus on global cities that are undergoing transitions at different levels of analysis: individual; community; city; national.

Applying interdisciplinary approaches to key city sub-systems:

  - Communities
  - Economy
  - Environment
  - Infrastructure
  - Institutions
  - Health

Energy is critical infrastructure, with wide impacts on people/communities in cities.

Thank You

and to colleagues in Energy Systems and Policy Analysis group:
Dan Murrant, Chunping Xie, Oluyemi Jegede, Xinfang Wang, Timea Nochta

and to EPSRC for funding:

- Energy Storage SUPERGEN Hub
- Multiscale Analysis for Facilities for Energy Storage (MANIFEST)
- Consortium for Modelling and Analysis of Decentralised Energy Storage (C-MADEnS)
- Realising Energy Storage Technologies in Low-carbon Energy Systems (RESTLESS)
- Assessing the innovation process for energy storage
- Across Scales in Energy Decision-making (ASCEND)
- Generation-Integrated Energy Storage: A paradigm shift

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