Hybridizing energy storage systems to improve cost-effectiveness and expand service range

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Hybrid & Integrated Energy Storage - mainstays of a carbon-free energy system
18th December 2017, The Shard, London

Newcastle University

EPSRC
Pioneering research and skills

CESI
National Centre for Energy Systems Integration

Overview

- Newcastle Research on Hybrid Energy Storage Systems
  - Hybrid Systems Sizing and Technology Selection
  - Complementing Renewables
  - Multiple Applications considering uncertainty
  - Industrial Applications
  - Laboratory facilities and integration

Why?

- Increased Flexibility
- Expanded service provision
- Increased competitiveness
- Future-proofing
- Expand lifetime
- Inform technology development

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Skoltech Skolkovo Institute of Science and Technology

redT energy storage

EPSRC Pioneering research and skills

Innovate UK Knowledge Transfer Partnerships

The team:

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Hybrid Energy Storage Systems for complementing renewables

What is the issue?

- Large-scale Renewable Generators are required to provide Mandatory Frequency Response (MFR)

Hybrid Energy Storage Systems for complementing renewables

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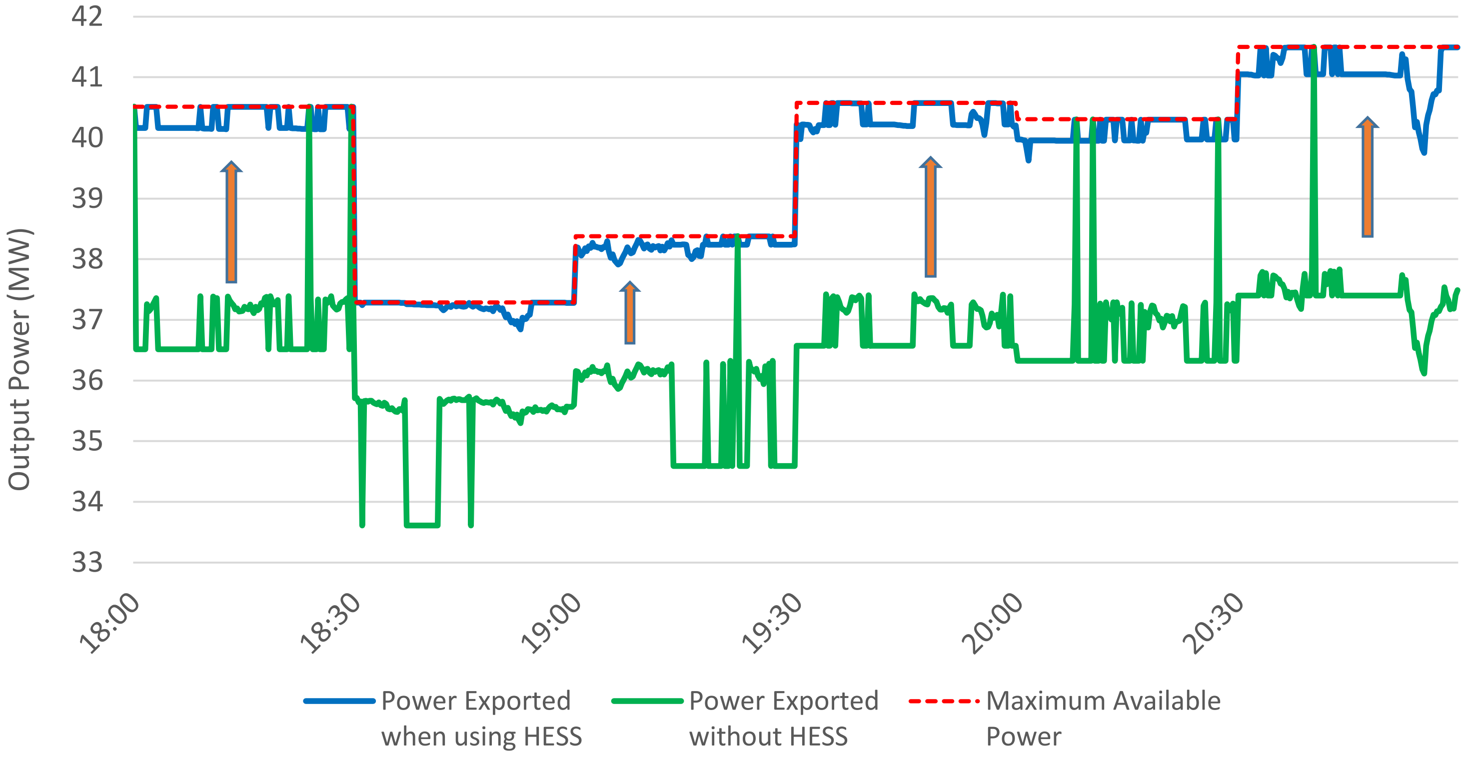


Hybrid Energy Storage Systems for complementing renewables

Methodology

Maximizing Revenue by optimally sizing ES technologies for complementing renewables in MFR

- Generator, ES1 and ES2 are considered active elements for participating in MFR
- The ES can also be used for Arbitrage when possible
- The revenue streams for Total System Profit (TSP) are the Wholesale Market and Freq. Market
- Objective function considers annualized **cost of purchasing** the ESS and **cost of degradation**. The TSP is scaled to the **project lifetime**

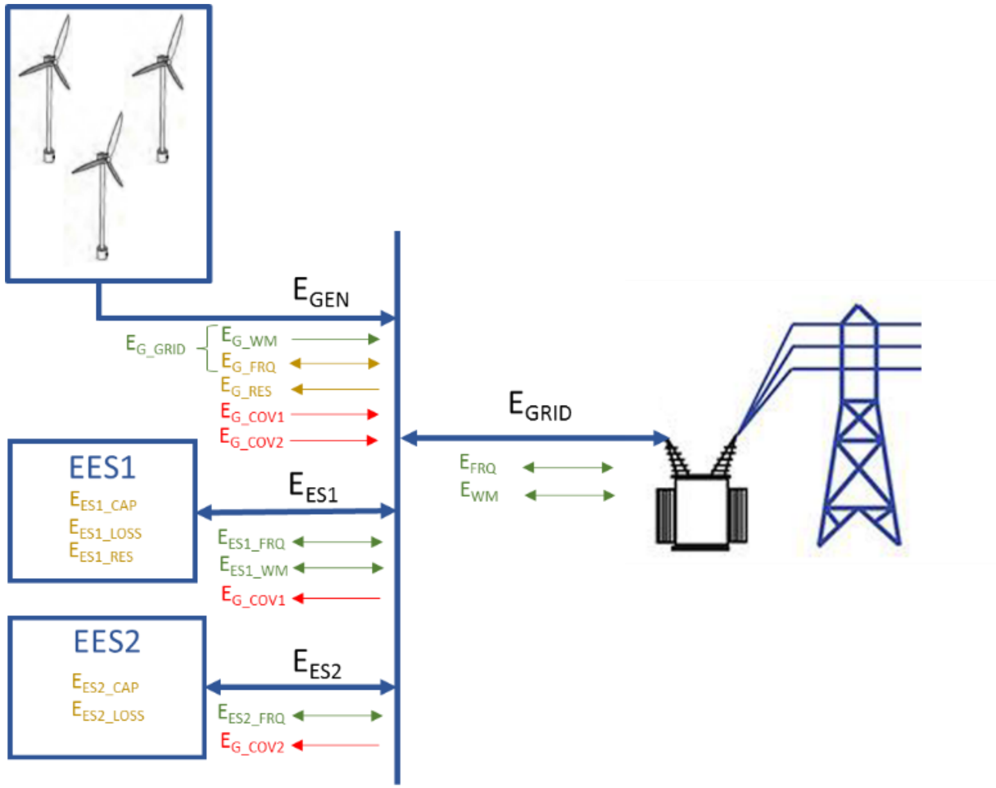
$$\mathrm{TSP} = \mathrm{PT} \cdot \left(-\mathrm{C_{HESS}} \cdot C\mathit{RF} + \sum_{\mathrm{t=t_0}}^{\mathrm{N}} \mathrm{I_{WM(t)}} + \mathrm{I_{FREQ(t)}} - \mathrm{C_{DEG(t)}} \right)$$

- Optimal solution achieved through linear programming
- Constraints of sub-component operation (generator and ESS), self-discharge losses, service and market regulations, and revenues calculation.

Hybrid Energy Storage Systems for complementing renewables

Case Study

- A 50MW wind farm with hybrid ESS composed of NaS and Supercapacitors

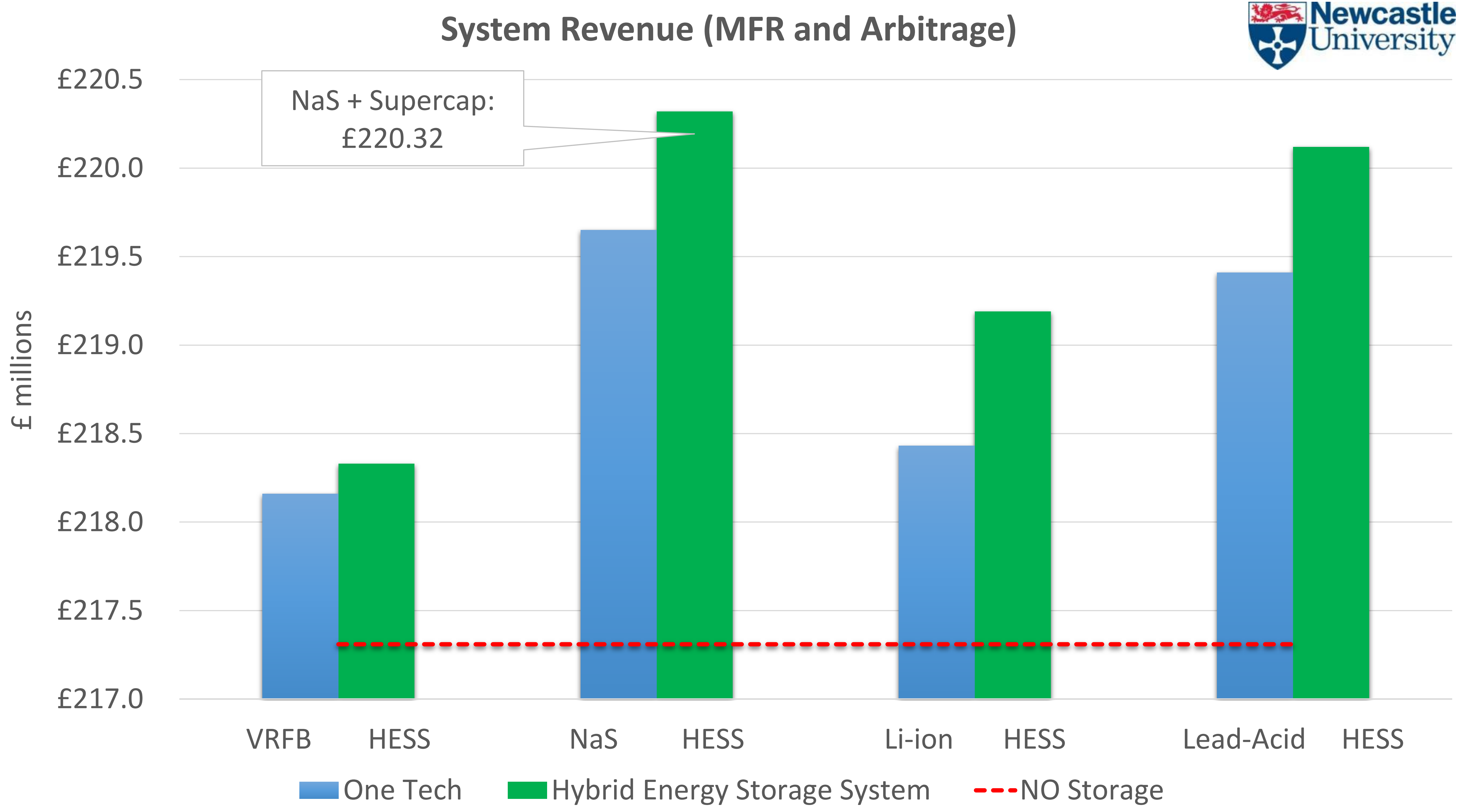


ES Parameters	NaS	SUPERCAPACITOR
Max SOC (%)	95	95
Min SOC (%)	10	10
Round Trip Efficiency (%)	75	80
Cost of Energy (£/kWh)	450	8820
Cost of Power (£/kW)	200	132
Cost of Degradation (£/kWh)	0.1	0.0079
Daily Self-Discharge (%)	10	10

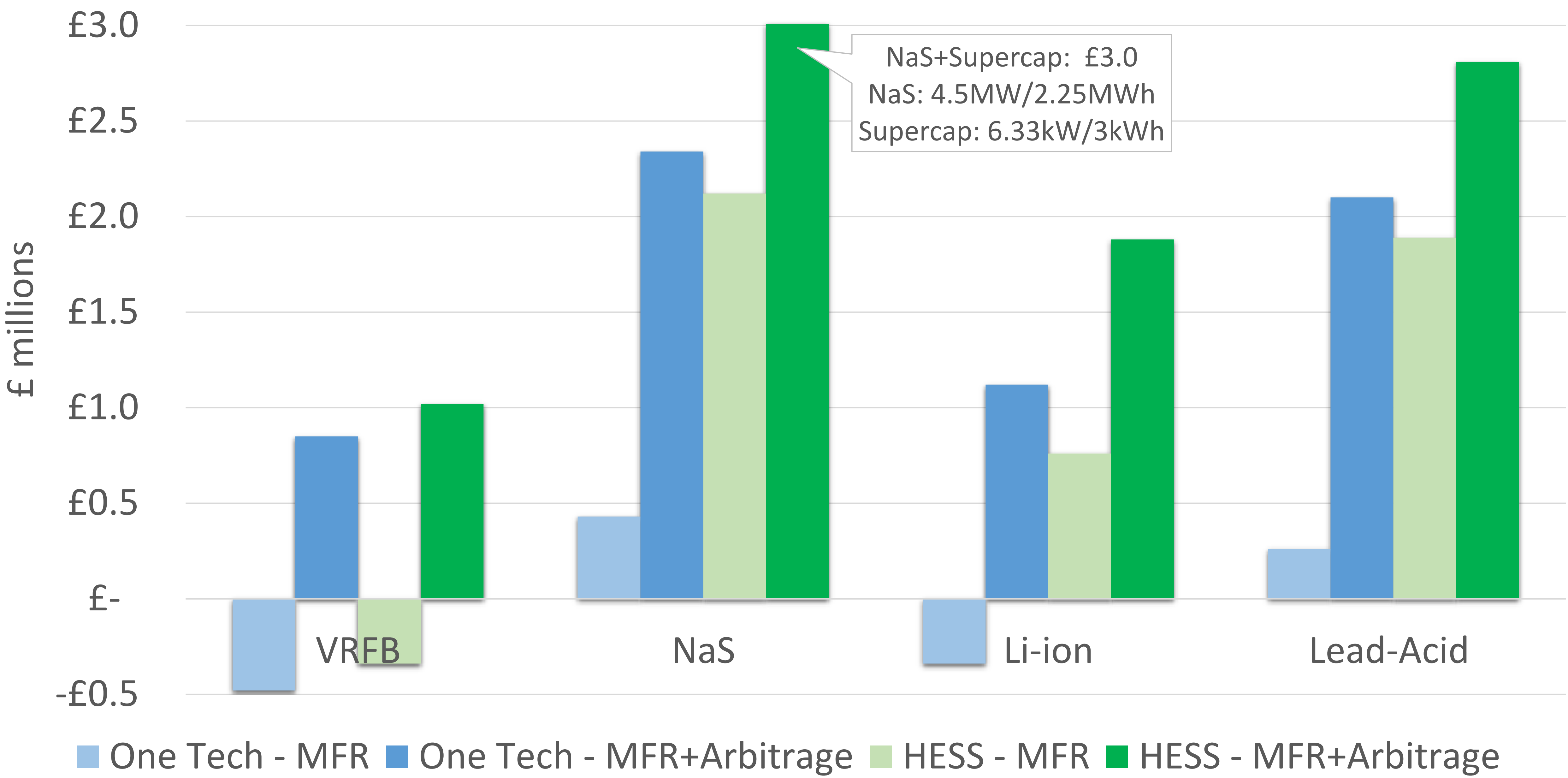
Hybrid Energy Storage Systems for complementing renewables

Results

	Revenue (Millions)	ESS Description
Single ESS	£219.65	NaS: 4.7MW/2.4MWh
HESS	**£220.32**	NaS: 4.5MW/2.25MWh Supercap: 643kW/3kWh
NO – ESS	£217.1	No Storage

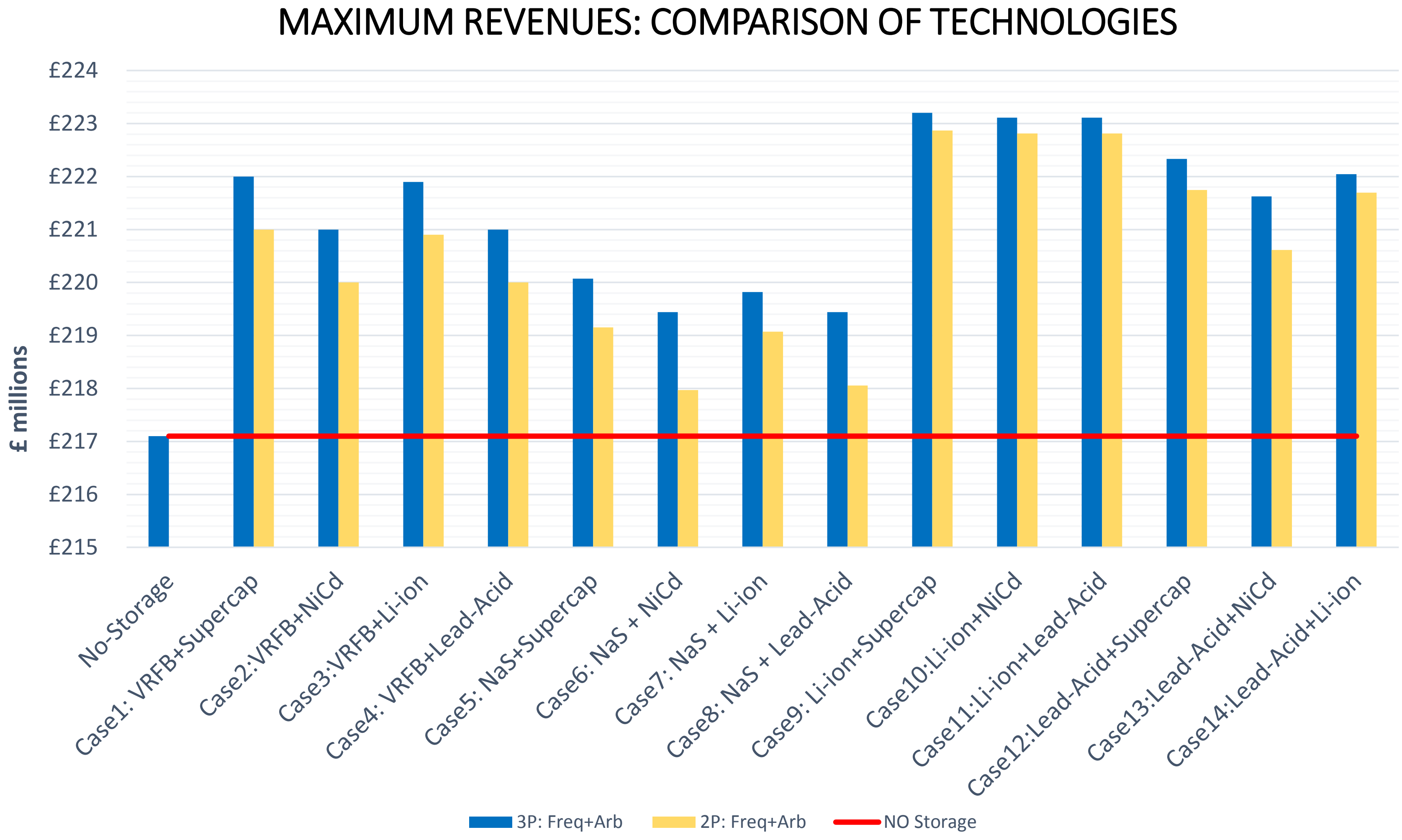

System Revenue (MFR and Arbitrage)
NaS + Supercap: £220.32
£ millions
£220.5
£220.0
£219.5
£219.0
£218.5
£218.0
£217.5
£217.0
VRFB
HESS
NaS
HESS
Li-ion
HESS
Lead-Acid
HESS
One Tech
Hybrid Energy Storage System
NO Storage

Incremental System Revenue (MFR and Arbitrage)



Hybrid Energy Storage Systems for complementing renewables

Results



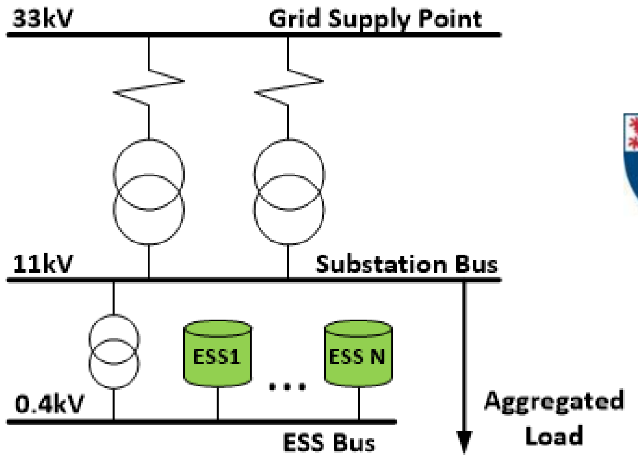
Energy Storage Systems Technology Selection and Sizing

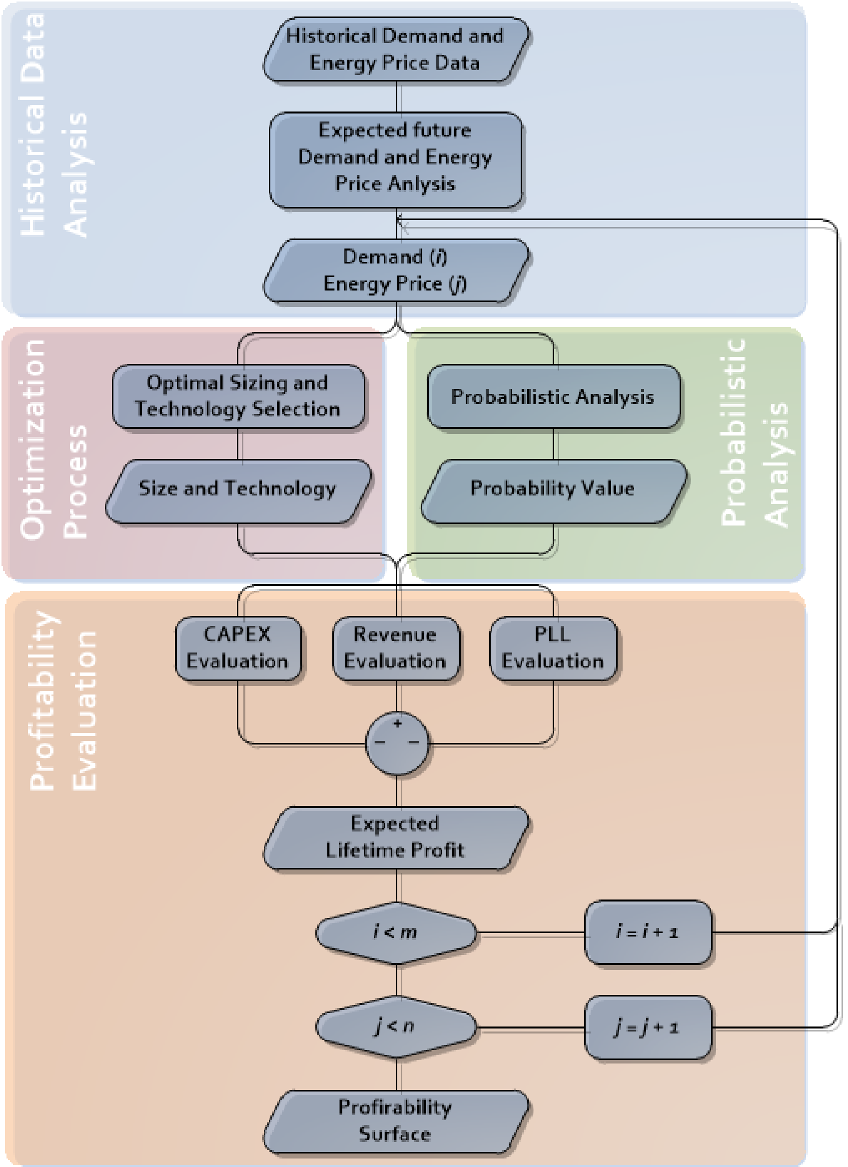
- Optimal sizing and technology selection of ESSs for multiple power system applications.
- Methodology tested for Energy Arbitrage and Peak Shaving services.

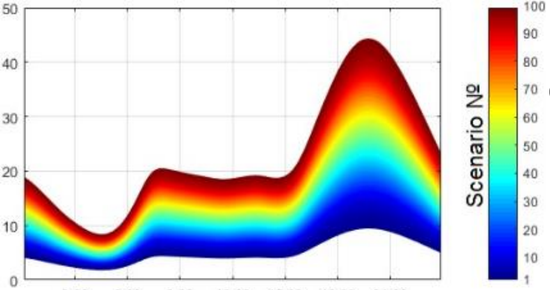
Methodology

- Algorithm for evaluating lifetime profitability
- Includes historical data analysis, optimization process, probabilistic analysis, and profitability evaluation for every expected demand and energy price scenario.

Case Study





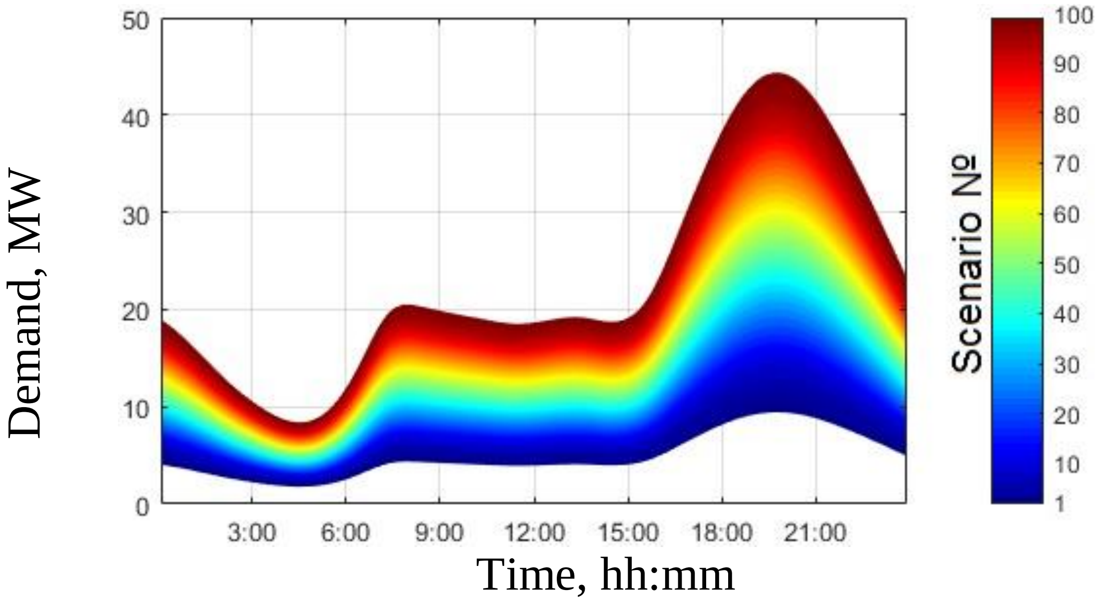


age Systems Technology Selection and

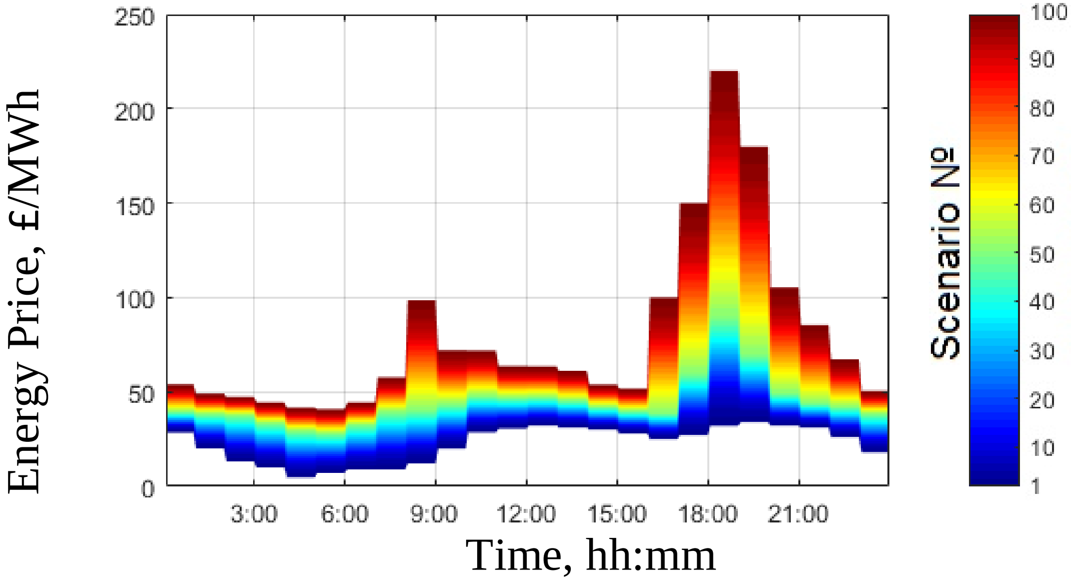
Case study

- Scenarios are found based on assumptions of expected changes in demand and energy price

- 365 days of historical demand data from actual trials (CLNR), Energy price data taken from Nord Pool Spot



Expected demand profiles for 15 future years



Expected energy price profiles for 15 future years

- Considering demand and price growth for a 15-year horizon

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Energy Storage Systems Technology Selection and Sizing

Problem definition

ES system characteristics and constraints

No	Technology	Roundtrip efficiency, (%)	Cycle Lifetime, (cycles)	Calendar Lifetime, (years)	Self-Discharge rate, (%/day)	Energy Capacity Cost, (£/kWh)	Power Capacity Cost, (£/kW)	Energy to Power ratio
ES1	Li-ion	95	5 000	15	0.2	490	325	0.1 - 6
ES2	ZnBr	70	3 000	15	0	320	320	2 - 8
ES3	VRFB	70	10 000	15	0	490	325	4 - 15
ES4	NaS	75	4 500	15	0	285	285	6 - 7.2
ES5	Lead-acid	85	1 500	15	0.2	260	320	0.25 - 6
ES6	SC	90	1 000 000	15	10	8 100	175	0.005 - 0.025

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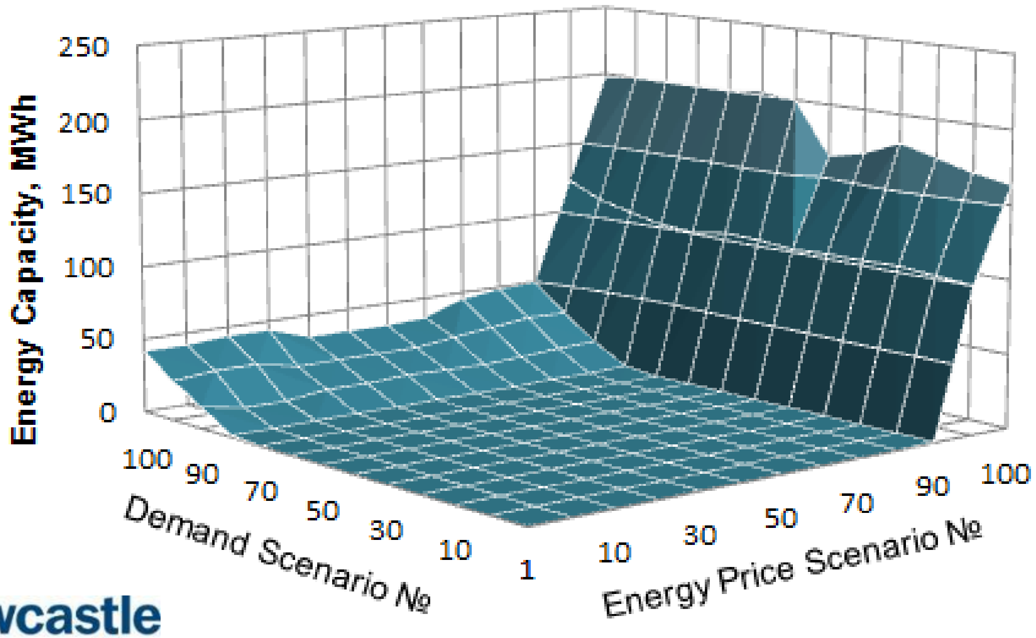
Energy Storage Systems Technology Selection and Sizing

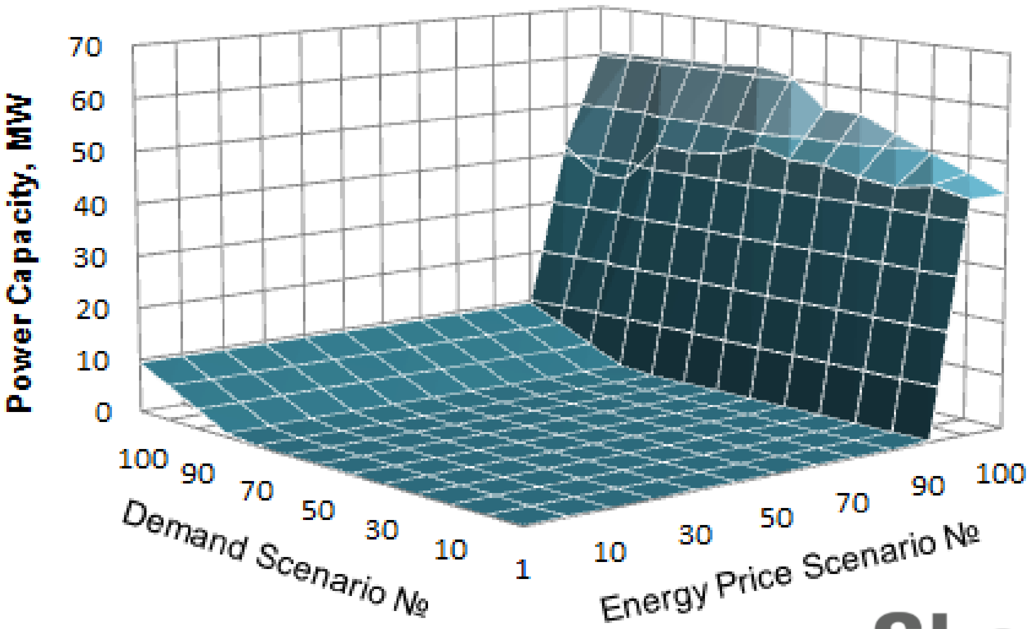
Results

Optimization problem solved for every expected scenarios of demand and energy price

Optimal Energy Capacity



Optimal Power Capacity



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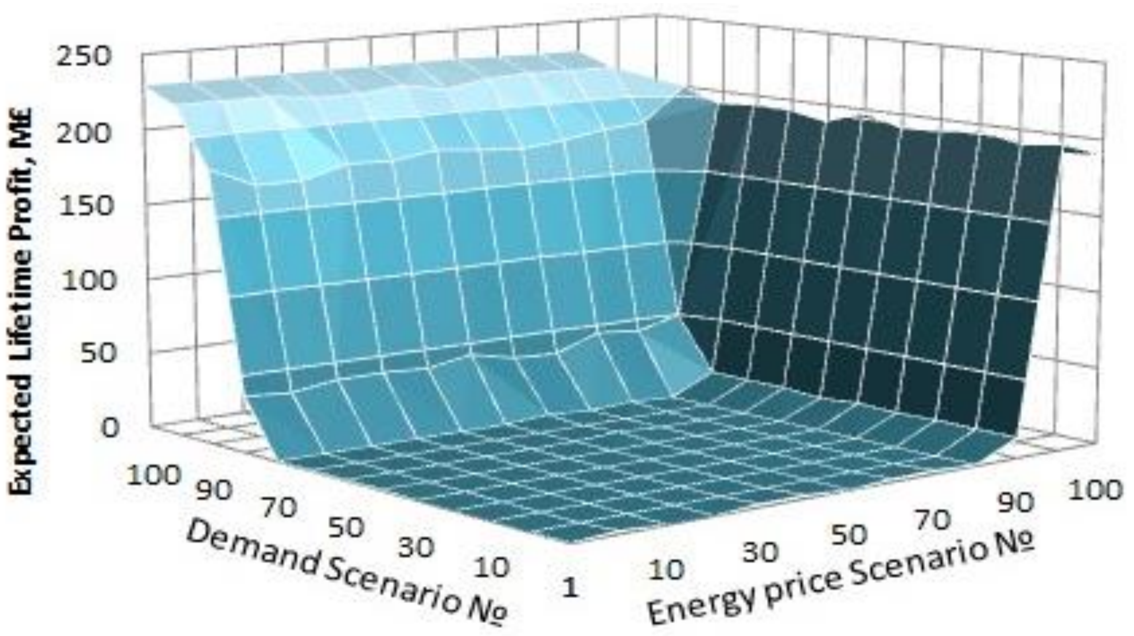
Energy Storage Systems Technology Selection and Sizing

Results

- Probability Mass Function is found for every expected scenario of demand and energy price with respect to historical data
- Expected profitability is found for every optimal solution with respect to PF



Optimal Solution

Technology	E, MWh	P, MW	CAPEX, M£	Expected Profit, M£
Li-ion	17.7	6.6	10.8	229.8
NaS	16.4	2.8	5.5	
Total	34.1	9.4	16.3	

Industrial Application

“redT’s vanadium redox flow machines address the disadvantages of conventional batteries such as lithium-ion, lead-acid or supercapacitors. A hybrid system combines both types of technology to serve complex energy needs.

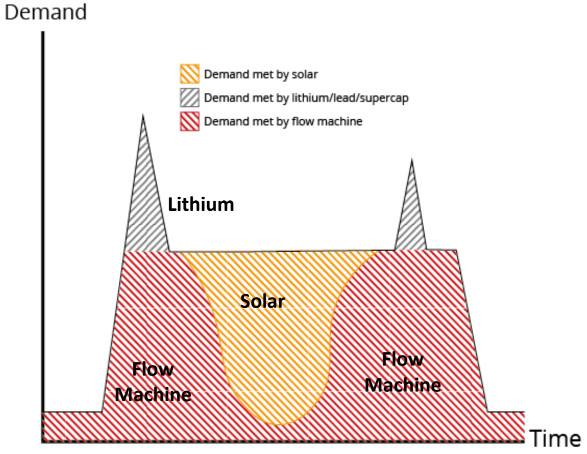
- Vanadium flow machines are an energy centric technology, ideally suited to energy intensive applications (standard duration 5 hrs and range up to 7.5hrs or 15hrs depending on size and application).”
- “Battery technology, on the other hand, is power-centric, making it ideally suited to occasional, high power, short duration discharge (less than 3 hours) cycles”

Battery | **Redox Flow Machine**

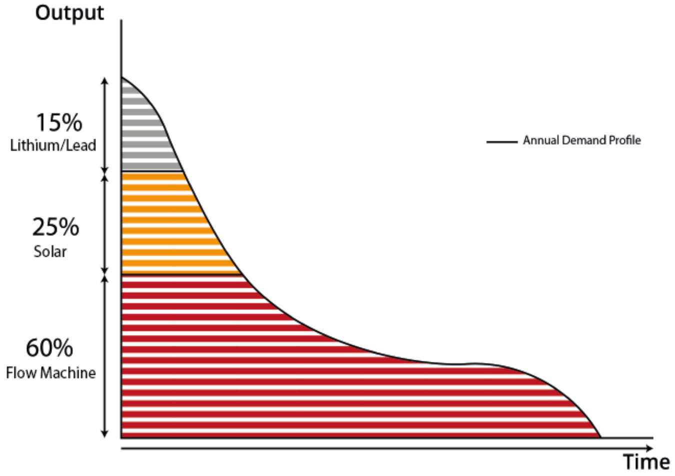
Hybrid Energy Management

Optimised Performance | **Increased revenue streams** | **Multiple functionality**

Independent and simultaneous operation of flow machine and lithium battery to maximise revenue



Lithium/Lead acid battery provides about 15% of annual demand profile



redT energy storage | Newcastle University | Innovate UK Knowledge Transfer Partnerships

KTP Partnership Co-funded by Innovate UK

Commissioned redT 1.08MWh Redox Flow Machine at Olde House (Cornwall UK)

Flow/Lithium Hybrid Energy Storage Systems

- **First Commerical Vanadium flow and lithium hybrid energy storage** in Australia
- 300kW 1MWh Hybrid flow and lithium energy storage system
- 180kW/900kWh of redT flow machine coupled with a 120kW at approx 100kWh C1 rated lithium battery
- System used for arbitrage charging during off-peak and discharging during high peak times. Peak shaving through solar PV at later stages

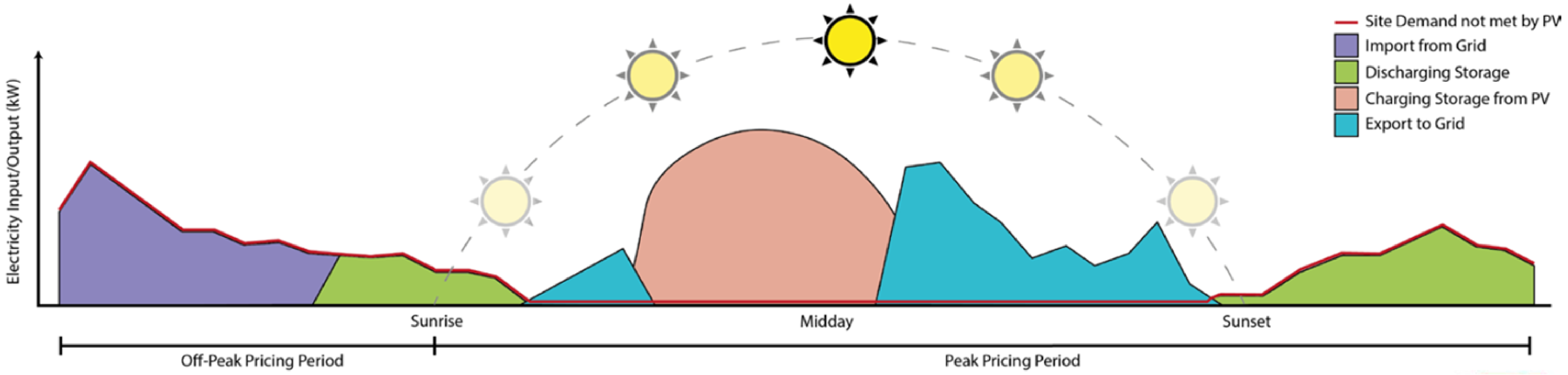
- R&D Facility for Hybrid Energy Storage commmisioned Q1 2018 at Wokingham
- Assembly and manufacturing through our manufacturing partners JABIL and Heights Manufacturing
- Open and flexible testing and demonstration plaftorm to refine soultions and next generation product line.
- **A Collaboration with Newcastle University** to improve energy managmenemt systems of the hybrid.

redT to supply first vanadium flow/lithium hybrid energy storage solution to Australia

redT Facility at Heights Manufacturing

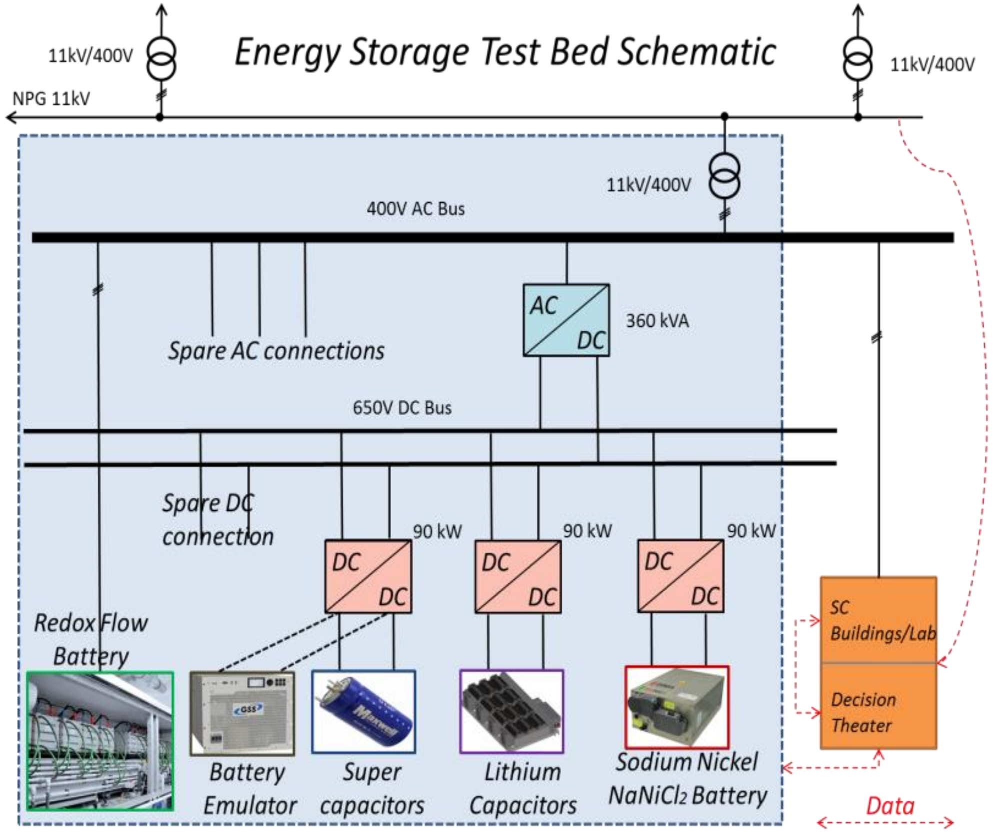
Industrial Application - Energy Management of Hybrid Energy Storage Systems

Collaboration with Newcastle University to improve energy management, refine business cases and maximise revenue and benefits to investors and customers



- Maximise revenue through Arbitrage during off peak and on peak periods with Solar PV generation.
- Energy Management of Lithium/Lead battery for short duration events (10 - 15% of uncaptured annual demand) with VRFB for longer duration events
- Explore **new revenue streams possible** (e.g. ability to simultaneously stack two services to customers)
- **Optimise daily schedules** to maximise revenues
- Improve energy dispatch **scheduling and sizing** for of both assets

Laboratory facilities dedicated to hybrid energy storage system integration



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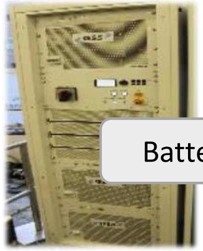
Sodium Nickel Chloride Batteries

Redox flow Battery

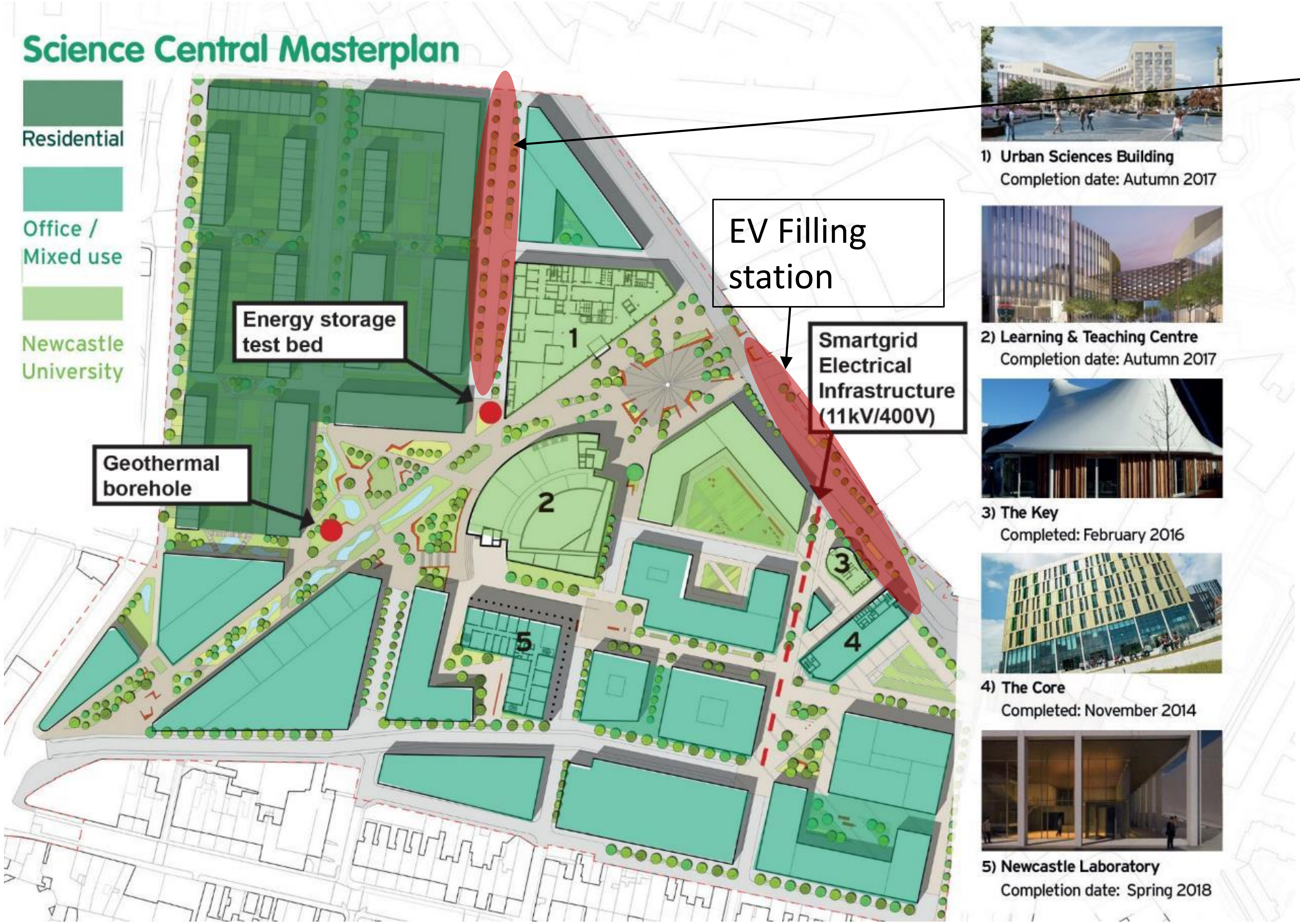
Lithium Ion Batteries

Super-capacitors



Battery Emulator

Science Central - The Site as a Living Laboratory



Sustainable Urban Drainage Lab and demonstrator

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Multi-Scale Analysis of Facilities for Energy Storage (MANIFEST)

£5m/4 years EPSRC-funded project (EP/N032888/1) started Sept. 2016

Wide collaboration of universities that shared £30m capital investment from the 2013 'Eight Great Technologies' call.

Vision:

- To be the catalyst which leads to
  - improved understanding of physical processes,
  - accelerated technology development, and
  - shared learning from the operation of energy storage technologies.
- To drive further collaboration between institutions.
- To maximise the impact from these capital facilities in the international energy landscapes.

www.birmingham.ac.uk/UKESTO

http://gtr.rcuk.ac.uk/projects?ref=EP/N032888/1

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Conclusions

- **Combinations** of energy storage technologies with complementary characteristics can **unlock a wider set of network services** and increase revenues against using a single technology
- **Co-locating storage** combinations with RE generation units provides major benefits in resolving power network issues and can assist decarbonisation
- Energy storage technology **selection and sizing as investment tools** can be used to **inform the design** of new technologies and services and improve existing ones

UKES 2018 – UK Energy Storage conference

Hosted by CESI in partnership with Imperial College London, the Energy Storage Network, Energy Superstore Hub

- Tuesday 20th March 2018 - Thursday 22nd March 2018
- CALL FOR POSTERS OPEN
- ukenergystorage.co
- Addressing Energy Network research challenges with a Whole Systems View
- Urban Sciences Building, Newcastle University

UKES2018
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