# Submission by [REDACTED] (for role of Alternate Delegate) and [REDACTED] (as Task leader) for Lot 1

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| ***Criterion*** | ***Description*** |
| 01 | Technical experience in the TCP area.  |
|  | 01a – **Understanding of the sector in the UK and internationally****1. Energy storage in general, for Alternate Delegate**The analysis below draws on a number of reports/papers I have written or co-authored:* for the Energy Storage Supergen - [REDACTED] ([REDACTED]) (currently being updated),
* for the Energy Research Partnership ([REDACTED]),
* submitted as evidence to Select Committee inquiries (Gluyas et al, 2021; Harrisson and Radcliffe, 2022)
* on market and regulatory barriers (Castagneto Gissey et al, 2018), and
* on the economics of energy storage, across both short and longer duration (Uddin et al, 2017; Xie et al, 2018).

**1.1 Opportunities** The key attribute of energy storage is to balance supply and demand, when both are varying. Energy storage provides system flexibility and resilience across multiple scales of time and geography. Different technologies can help at different timescales, though there is overlap, and our current understanding may change as technologies mature:Seconds: Renewable generation introduces harmonics and affects power supply quality, with reduced system inertia due to less rotating machinery from fossil fuel generation. Rapid response can be provided from ES technologies such as batteries, supercapacitors and flywheels.Minutes - hours: Variations in supply from variable renewables (wind, PV) due to weather changes; and expect future electricity demand profiles to be altered as Electric Vehicles and Heat Pumps are deployed at scale. Batteries are covering part of this need. Thermal storage can also help balance when heating/cooling services are being delivered.Days - weeks: large scale weather patterns will affect supply from renewables, and demand, either positively or negatively (e.g. winter high pressure systems with low wind and cold temperatures; or warm, windy periods in spring/autumn). Medium duration ES, in particular, thermo-mechanical systems, are well suited to this scale.Months – seasons: Increased deployment of heat pumps through the 2020s will lead to strong seasonal electricity demand profile. This will be countered by a positive correlation with winter wind generation, but the opposite from solar PV. Hydrogen storage (for electricity generation), or long-term thermal storage (potentially underground), are possible technology options, though neither is currently deployed commercially at scale.Geographically, energy storage could be placed:* on transmission or distribution networks to manage constraints and avoid infrastructure reinforcements,
* integrated with generation to provide ‘firm’ power output,
* behind the meter, to manage consumer demand according to price tariffs, or integrate with onsite renewables.

**1.2 Challenges**I categorise challenges into six key areas:Technology cost and performance: other technologies are currently cheaper than ES for providing flexibility and resilience at longer timescales (more than a few hours), though batteries are being deployed in the current market for shorter timescales.Uncertainty of value: the future value of storage could be dependent on local contexts, where renewables are being deployed, and/or network constraints.Business: capturing multiple revenue streams can be difficult to establish, both for a potential business and the market in which it will operate. Stacking revenue is done by ES at shorter timescales now, but it’s unclear how that would be feasible for longer duration ES or whether single services (hence revenue stream) would be necessary.Markets: the true value of energy is not reflected in the price in the current market; more fundamentally, the future long-term value of storage is not recognized in today’s market.Regulatory/policy framework: many barriers, such as double-charging and planning, have been (or are being) addressed, which has improved conditions for deploying shorter timescale ES. It is not clear how deployment at scale of ES, when coupled to EV and HP roll-out, will be affected by policy and regulation – this is a gap in our knowledge. Societal: wider community acceptance has not yet been considered in detail. There is a risk of a backlash if publics are not engaged. **2. System flexibility from Medium-Duration Energy Storage (MDES)**As noted in section 1, energy storage spans a wide range of scales along the dimensions of energy, power and time. Very different solutions are appropriate for distributed energy storage than are suitable for centralised storage and it is similarly true that very different solutions apply for the different timescales. It tends to be that distributed ES solutions are smaller in scale (a few 10’s of MW maximum) and address shorter timescales (<10hrs) whilst the more centralised ES solutions are large monoliths addressing longer timescales (>10hrs). In a number of different presentations (including the document presenting the case for the new Annex on MDES), I have presented a graphic explaining why there are really four distinguishable time-ranges for energy storage. *Very short duration* *energy storage* (VSDES) is dominated by considerations of extremely high turnaround efficiency, virtually unlimited cycle count and low cost per unit of power-slew-rate (£/(MW/s)). *Short duration energy storage* (SDES) is the category owned by batteries and this demands high round-trip efficiency (>85%), reasonable cycle life and low cost per unit of power (£/MW). *Long duration energy storage* (LDES) is best handled by fuels because the over-riding concern is cost per unit of energy storage (electricity output) (£/kWh) and hydrogen storage in caverns is the key option here for territories such as the UK fortunate to have bedded salt resources underground. The round-trip efficiency may be very low because relatively little energy actually passes through the LDES stores in a cost-optimal framework. The MDES technologies fall between SDES and LDES because they combine reasonable round-trip efficiency with reasonable costs per unit power and per unit energy. The natural tendency for policy-makers is to regard MDESThe MDES technologies are predominantly mechanical in nature. The main MDES candidates comprise: compressed air solutions (with underground, underwater and tank-based pressurised air stores), pumped thermal plant (including liquid air) and pumped hydro installations. All of these tend to be characterised by the same features: (i) strong scale dependency in most cases, (ii) naturally very long service lifetimes and long development cycles, (iii) high degrees of sustainability and (iv) they are naturally endowed with *grid-forming* capabilities in nearly all cases – meaning that they can actually address many of the requirements of VSDES also.The requirements for energy storage stem mainly from the non-constant nature of our renewable resources. Some rough numbers outline the importance of MDES in the context of a cost-optimal zero-carbon UK (drawn from the forthcoming Royal Society report on Energy Storage to which Prof. Garvey has contributed significantly on MDES)* Renewables will generate ~30% more energy in the average year than consumers take out – with around half of that being turned-down and the other half lost in storage operations
* ~25% of all energy consumed will have passed through storage
* Approximately two thirds of all energy emerging from storage will have passed through MDES and most of the remainder through H2.

**3. References for** [REDACTED]**.**Castagneto Gissey, G., Dodds, P., Radcliffe, J. (2018) Market and regulatory barriers to electrical energy storage innovation, Renew Sustain Energy Rev, 82, pp. 781 – 790 <https://doi.org/10.1016/j.rser.2017.09.079> Jon Gluyas, Jonathan Radcliffe, and Clare Grey (2021) to Science and Technology Select Committee, ‘The role of hydrogen in achieving Net Zero’ (HC 2022-23 99) <https://committees.parliament.uk/writtenevidence/36801/html/> Chris Harrison and Jonathan Radcliffe (2022) to Business, Energy and Industrial Strategy Select Committee, ‘Decarbonisation of the power sector’ <https://committees.parliament.uk/writtenevidence/109617/default/> Radcliffe, J, Murrant, D, & Joshi, A (2020a) UK Roadmap for Energy Storage Research and Innovation, University of Birmingham, UK. <https://ukesr.supergenstorage.org/> Jonathan Radcliffe, John Greaves, Richard Heap, Yi-Chung Chen (2020b) ‘Immediate Need for Substantial Investment in Energy Storage’ for the Energy Research Partnership. <https://erpuk.org/project/immediate-need-for-substantial-invesment-in-energy-storage/> Uddin, K., Gough, R., Radcliffe, J., Marco, J. and Jennings, P.A. (2017) Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. Applied Energy, 206, pp.12-21. <https://doi.org/10.1016/j.apenergy.2017.08.170> Xie, C., Hong, Y., Ding, Y., Li, Y., Radcliffe, J. (2018) An economic feasibility assessment of decoupled energy storage in the UK: With liquid air energy storage as a case study, Applied Energy, 225 pp 244 – 257. <https://doi.org/10.1016/j.apenergy.2018.04.074> **4. References for** [REDACTED]**.**Cárdenas, B., Swinfen-Styles, L., Rouse, J. and Garvey, S.D., 2021. Short-, medium-, and long-duration energy storage in a 100% renewable electricity grid: A UK case study. *Energies*, *14*(24), p.8524.Swinfen-Styles, L., Garvey, S.D., Giddings, D., Cárdenas, B. and Rouse, J.P., 2022. Analysis of a Wind-Driven Air Compression System Utilising Underwater Compressed Air Energy Storage. *Energies*, *15*(6), p.2142.Pottie, D., Cardenas, B., Garvey, S., Rouse, J., Hough, E., Bagdanavicius, A. and Barbour, E., 2023. Comparative Analysis of Isochoric and Isobaric Adiabatic Compressed Air Energy Storage. *Energies*, *16*(6), p.2646.Parkes, D., Evans, D., Dooner, M., He, W., Busby, J. and Garvey, S., 2019, January. Estimating Potential for CAES (Compressed Air Energy Storage) in the bedded halites of the UK. In *Geophysical Research Abstracts* (Vol. 21).Garvey, S.D., Eames, P.C., Wang, J.H., Pimm, A.J., Waterson, M., MacKay, R.S., Giulietti, M., Flatley, L.C., Thomson, M., Barton, J. and Evans, D.J., 2015. On generation-integrated energy storage. *Energy Policy*, *86*, pp.544-551.Dodds, P.E. and Garvey, S.D., 2022. Energy storage options to balance renewable electricity systems. In *Storing Energy* (pp. 13-33). Elsevier.Cárdenas, B. and Garvey, S.D., 2019. A load-based approach for optimizing a packed-bed thermal store. *Journal of Energy Storage*, *25*, p.100835.Pimm, A.J. and Garvey, S.D., 2014. The economics of hybrid energy storage plant. *International journal of environmental studies*, *71*(6), pp.787-795.Pimm, A. and Garvey, S.D., 2022. Underwater compressed air energy storage. In *Storing Energy* (pp. 157-177). Elsevier.Pimm, A. and Garvey, S., 2009, August. Analysis of flexible fabric structures for large-scale subsea compressed air energy storage. In *Journal of Physics: Conference Series* (Vol. 181, No. 1, p. 012049). IOP Publishing.Pimm, A.J., Garvey, S.D. and de Jong, M., 2014. Design and testing of energy bags for underwater compressed air energy storage. *Energy*, *66*, pp.496-508.Garvey, S.D., 2015. Integrating energy storage with renewable energy generation. *Wind Engineering*, *39*(2), pp.129-140.Garvey, S.D., Pimm, A.J., Buck, J.A., Woolhead, S., Liew, K.W., Kantharaj, B., Garvey, J.E. and Brewster, B.D., 2015. Analysis of a wind turbine power transmission system with intrinsic energy storage capability. *Wind Engineering*, *39*(2), pp.149-173.Pimm, A.J., Garvey, S.D. and Kantharaj, B., 2015. Economic analysis of a hybrid energy storage system based on liquid air and compressed air. *Journal of energy storage*, *4*, pp.24-35.Garvey, S.D., 2010. Structural capacity and the 20 MW wind turbine. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *224*(8), pp.1083-1115. |