

# Project briefing

## WORLD'S LARGEST LITHIUM-VANADIUM HYBRID BESS TRIALLED AT OXFORD

**Project name:** Energy Superhub Oxford  
**Location:** Oxford, UK  
**Capacity:** 55 MWh (50 MW/50MWh Lithium-ion, 2MW/5MWh Vanadium flow battery)  
**Energisation date:** July 2021 (Lithium-ion), December 2021 (Vanadium flow)  
**Developer/asset owner:** Pivot Power, part of EDF Renewables  
**Technology providers:** Wärtsilä, Infinity Energy Systems  
**Optimiser and trader:** Habitat Energy

Known globally for its university, Oxford is now making a name for itself as a testing ground for the largest hybrid battery energy storage system (BESS) of its kind anywhere in the world.

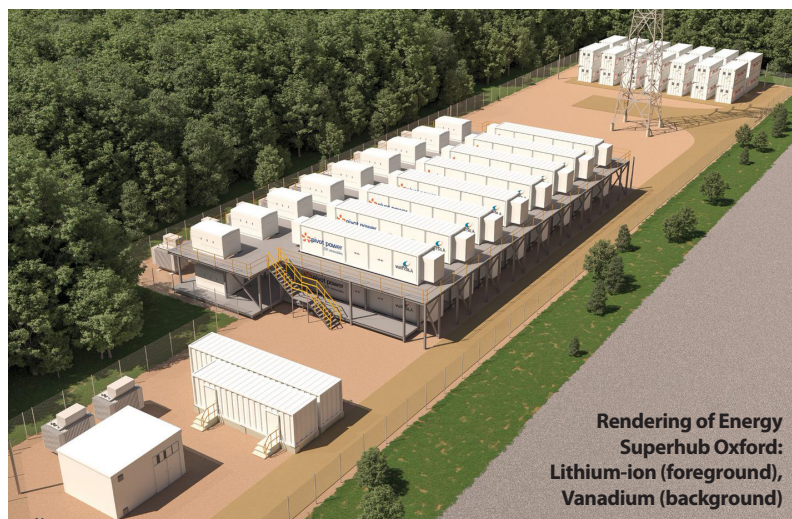
Energy Superhub Oxford (ESO), set to fully launch in the next few months, is the result of three years' work by a consortium of private sector organisations, the local council (local authority) and the University of Oxford, plus government body Innovate UK which funded a quarter of its £41 million (US\$55.8 million) cost.

The engine room of the ESO is the largest lithium-vanadium hybrid BESS in the world, which combines the high-power of lithium-ion battery storage with heavy-cycling, non-degrading vanadium redox flow. Also part of the project are the UK's largest public electric vehicle (EV) charging park and 60 residential ground source heat pump retrofits. Vanadium batteries are at a much earlier stage of commercialisation than lithium, making the ESO fundamentally a demonstrator project with multiple, complementary aims.

Ask the council and it is likely to talk about reducing CO2 emissions by boosting EV take-up, demonstrating the smart heat pumps' potential for energy and cost-saving, and helping the grid's efforts to decarbonise.

Project developer Pivot Power's COO/CTO Mikey Clark — perhaps unsurprisingly given his engineering background — was keener to talk about the underlying unique hybrid battery technology's potential to capitalise on developments in the UK grid services market.

"We really want to test how a flow battery could be co-optimised into lithium-ion-type



Credit: Pivot Power / Energy Superhub Oxford

systems," he tells PV Tech Power about the reasoning behind the project.

The BESS is already live and set to be fully operational and trading in the electricity markets in the coming weeks - the lithium-ion system is already - while the EV park will open to the public in Q2 2022. But even before any of that, the project has already delivered numerous firsts and superlatives.

The 55MWh BESS was the first grid-scale battery system with a tertiary connection to the UK grid's transmission system when it connected in July 2021. Tertiary connections provide a way of connecting directly to National Grid's high voltage transmission network, with each connection providing up to 57MW demand or generation capability.

As well as being the largest lithium-vanadium hybrid installed anywhere in the world, it has the largest vanadium flow battery system in the UK, and largest BESS optimised by an AI-enabled optimisation & trading engine (OTE) in the country to date, provided by optimisation specialist Habitat Energy.

The EV park will outnumber any other public one in the country for charging points when it opens in Q2 this year. It was also Finnish energy giant Wärtsilä's first BESS project in the UK and vanadium battery supplier Invinity Energy Systems' largest ever installed.

"We're really proud of how Energy Superhub Oxford has delivered on its promises and the feedback we have received from government bodies and Innovate UK. It's

been a truly collaborative project and its success is down to the relationships we've cemented with our partners," Mikey Clark added.

The unique hybrid battery launch is noteworthy amidst a total reshaping of the market for providing services to National Grid, the UK's electricity grid operator. Increased volatility due to growing renewable intermittent generation, a saturation of the ancillary services market and new services for power producers and BESSs to bid for, means a myriad of potential ways its effectiveness can be demonstrated.

More locally, Oxford City Council is hoping Energy Superhub Oxford can reduce the city's annual CO2 emissions by 10,000 tonnes in year one and 25,000 tonnes by 2032 — equivalent to 3-4% of the city's total scope 1 emissions in 2019 — primarily through energy trading, providing a model for other cities looking to decarbonise their economies.

### Launching the project and division of BESS responsibilities

ESO's story begins before the COVID-19 pandemic struck. It launched in April 2019 when planning and preparation processes kicked off. Construction on the BESS and heat pumps started a little over a year later while the EV station broke ground in the first quarter of last year.

The lithium and vanadium flow batteries were energised in July and December of 2021, respectively.



## RENEWABLES HUB PILOT

"The lithium-ion battery is trading in the market. The flow battery is live but not yet trading in the market, but we expect it to be there in the next few weeks," Clark says.

The lithium battery is a 49.9MW one-hour system while the vanadium flow packs 2MW/5MWh and the system sits beside and connects to the Cowley National Grid substation on the southeast outskirts of the city. Project manager Tim Rose said in a webinar that the two battery systems will provide grid services separately for the first three to six months of them both being in the market.

A total £41m has been invested into delivering ESO of which £11.3m was a grant provided by Innovate UK to part-fund the activities of all consortium partners. Of the battery costs, 15% was for the vanadium flow with the remainder on the lithium system, site construction and grid connection, though Pivot wouldn't be more specific.

Wärtsilä delivered the lithium system and will also control the entire BESS through its GEMS software and energy management system (EMS) platform. It will process operational data at its expertise centre in Trieste, Italy, and is working on three other similar UK projects with Pivot Power.

The vanadium flow system was supplied by Invinity Energy Systems while Habitat Energy is playing the role of trader and optimiser, providing instructions to the

GEMS about what services the BESS should do based on market demands, while also maximising the lifetime of the asset, all through its AI machine learning-enabled OTE platform.

Habitat Energy's head of UK business development Ralph Johnson says machine learning (ML) has a lot to offer energy storage assets like ESO's which require the constant analysis of hundreds of different data points to get the most accurate forecasting of prices and market value.

"We have developed all our forecasting ML algorithms from the ground up. They take all that data and use it to forecast prices really effectively across different spaces. So day-ahead markets, intraday markets, the Balancing Mechanism, system price markets etc. And we then utilise those forecasts with our algorithmic dispatch platform or to inform our trading team," he tells PV Tech Power.

He adds that its platform has mainly focused on 1/1.5-hour systems, so he sees a real learning opportunity for Habitat with this project too. But recent shocks to the system in the UK market have highlighted the need to combine algorithms and the human element, adds Jon Doughty, Habitat's UK managing director.

Habitat and Invinity are both keen to emphasise their roles well before and well after the project's launch, respectively.

Habitat provided revenue forecasts and

### Timeline

<b>Q2 2019:</b>	Planning and preparation begins on BESS, EV network and heat network
<b>Q1 2020:</b>	EV procurement by council bodies begins
<b>Q3 2020:</b>	Construction begins on heat pump network
<b>Q4 2020:</b>	Construction begins on BESS
<b>Q2 2021:</b>	Construction begins on EV network; operation & evaluation starts on heat network
<b>Q2 2021:</b>	Lithium-ion energised and begins trading in market; operation and evaluation begins on BESS
<b>Q3 2021:</b>	Construction complete on vanadium flow battery
<b>Q4 2021:</b>	Vanadium flow battery energised
<b>Q1 2022:</b>	Vanadium flow starts trading in market
<b>Q2 2022:</b>	All heat pumps built; EV charging park to open to general public
<b>Q2 2023:</b>	ESO fully operational after ramp-up period with evaluation of all three parts complete

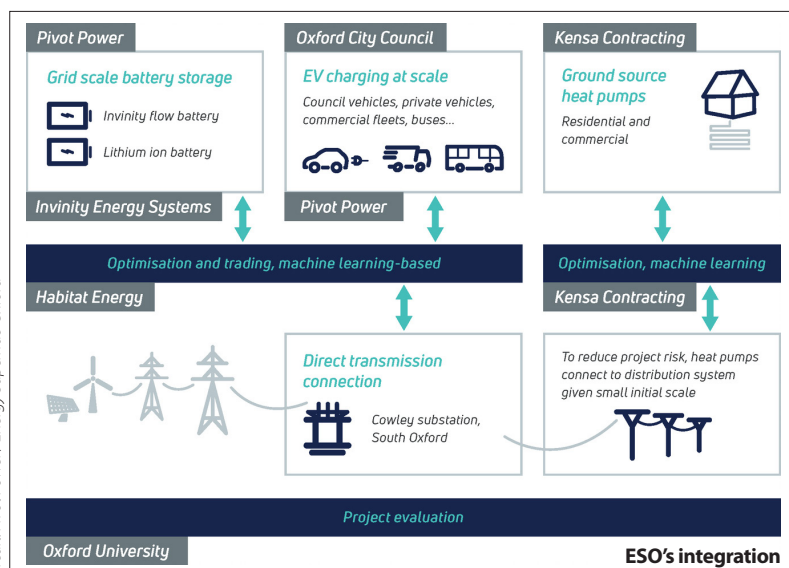
commercial implications of certain designs and worked with Wärtsilä early on to ensure the BESS could enter markets as soon as possible. Invinity will continue to track systems remotely and assess individual subcomponents combined with site visits, says Ed Porter, business development director.

### Adjacent technologies and challenges faced

As part of the project, Pivot also delivered the 8km private wire which connects the new Redbridge Park & Ride electric vehicle (EV) charging park to the National Grid substation. The park will have 38 fast-to-ultra-rapid chargers.

Pivot decided to have the EV network connect directly to the substation, rather than the BESS, so that EV charging was not reliant on the BESS being charged. However, the BESS has an island mode capability which ensures that it can continue to operate independently and power the EV charging network in the event of a grid-level blackout, Pivot tells PV Tech Power.

The private wire is also strategically routed to enable future connections to



other vehicle hubs en-route to support Oxford city's wider push to electrify its vehicles. ESO has helped fund an electric waste collection truck and made available grants to taxi drivers to switch to EVs as part of the project.

The charging park will be the responsibility of the City Council as well as charger supplier-operators Fastned, Tesla & Wenea, each of which has committed to sourcing power via renewable sources (Fastned has a solar roof at the park, for example). The flow of power to the park will go through Habitat's OTE platform.

Kensa Contracting delivered the 60 grid-connected ground source heat pumps providing homes with clean heating. They feature smart controls, dynamic pricing and load shifting to allow users to save money and increase the renewable mix of their heating's power sources. Tim Rose said that residents preferred a direct grid connection rather than the BESS.

Like any project of this scale, ESO faced several challenges and delays, including pushing back the project's completion date by a year to March 2023, which was blamed on the Covid-19 pandemic. Clark and Rose both talk about planning processes initially restricting the project's size but praise the council for its flexibility when helping get the project on its feet.

Wider regulatory changes also hit ESO's ambitions. For example, the removal of the UK government's Renewable Heat Incentive (RHI) in 2020 forced a scaling back of the number of heat pumps planned by 80% from 300 initially to just 60.

That said, some wider rule changes have been positive. Clark says there was no Connection and Use of System Code (CUSC) agreement written for energy storage when ESO launched in 2019, and Pivot has worked with National Grid to rectify this during the project's development.

PV Tech Power roughly estimates that a lithium-ion system of ESO's total size in MWh could generate £4.5-9m in revenue and £2.3-2.8m gross profit a year, based on industry benchmarking data from Habitat and UK energy market data firm Modo Energy. Pivot wouldn't comment on this nor discuss internal rate of return (IRR) forecasting.



**Energy Superhub Oxford Invinity vanadium flow battery. Energised and expected to go into commercial operation very soon.**

Credit: Invinity Energy Systems

### Unique potential in the grid services and electricity trading market

All our interviewees agree that the hybrid battery system will give the ESO's BESS versatility when going out into the merchant and ancillary services markets. 'Merchant' means operating in the electricity trading market without long-term contracted revenues from National Grid for things like frequency response.

"We didn't want to rely on contracted revenues but instead want to go out to the market with a nearly 100% merchant model. That plays into getting the right tech into the stack in order to give us a lot of versatility," Clark says. "The majority of the hub's revenue will be from merchant as well as some ancillary services but, over time, a trend towards more and more merchant."

He gave a specific example of how the hybrid BESS could tackle frequency response services in the ancillary market: "As most of the deviations from 50hz happen within a two-megawatt tolerance, a lot of those cycles can go through the Invinity battery, that doesn't degrade like a lithium-ion one which can pick up anything big. This is one hypothesis that is really interesting to us and me as the CTO, given the number of cycles we could potentially take off," he says.

Clark and the other consortium partners are reluctant to provide more specific examples at this point.

"To say exactly what markets and what benefit we can achieve from the asset is probably difficult at this stage," says Johnson.

"Its ability to dispatch for longer durations, and to hold its state of charge with fewer concerns around asset degradation, gives us opportunities to potentially capture value across long periods of the day in the merchant space. So interestingly, periods where the market price shape is flatter (and less volatility exists) and you're

actually looking to capture more lower margin spreads over longer durations of time. That's really an interesting opportunity where long-duration energy storage can add value," he says.

"Combining that approach with the strategy we would employ to capture the value you can achieve in volatile conditions, where those spreads can be larger, across multiple power markets (day ahead, intra-day, Balancing Mechanism), but over much short time periods (30 mins to 1 hour) with the 50MW one-hour lithium ion battery is a really interesting challenge. Being able to access both sets of value with the same asset is a real positive for this project and something we're really looking to investigate and explore."

New pre-fault, higher-output ancillary services like dynamic regulation (DR) and dynamic moderation (DM) will be accessible for the vanadium flow battery thanks to its longer duration, Johnson and Porter both say.

It should be noted that Pivot's more recent projects of similar power magnitude have two-hour lithium batteries. The business case has shifted towards two-hour systems since ESO was launched, Brent Iversen, Senior Business Development Manager at Wärtsilä Energy Business tells PV Tech Power.

"People in the UK market are still looking at between one and two-hour batteries and the business case debate is quite balanced, though I think the majority of developers are now starting to go for two-hour systems," he adds.

Wärtsilä and Invinity both say integrating the two battery systems into one GEMS went smoothly.

Iversen: "It required a lot of software programming and development to integrate the two batteries but essentially this is one of the features of the GEMS system, that we can integrate multiple



generators or assets into the GEMs to operate those assets in the best possible way.”

### Capitalising on an evolving market and decarbonising the sector

As alluded to before, the National Grid services and trading market is going through numerous changes which ESO can capitalise on.

Habitat’s Ralph Johnson tells PV Tech Power the energy market is becoming increasingly volatile due to the closures of baseload power plants and increased intermittent renewable generation. Providing the flexible capacity to mitigate that is the bread-and-butter opportunity for energy storage.

He also expects a saturation of the market for frequency response ancillary services which will drive down price and push energy storage owners to move towards a merchant strategy, already seen in other ancillary areas. As Clark said earlier, having a flexible BESS like a hybrid makes ESO well-positioned for that.

US readers should be reminded that, as Iversen alluded to, a 2.5 hour battery is at the very long end in the UK market which still focuses on 1-2 hour systems. The big challenge for longer duration systems has always been the higher capex, Johnson says, and combining it with a lithium-ion system could mitigate some of that and improve its IRR from its standalone figure.

“There is still more value available for longer duration systems in contracts such as the capacity market agreement, but for longer duration storage to generate better IRR, we may need another ancillary service or another market opportunity or a change in the existing ones that adds value on that front,” he says, though expects future changes in price shape could favour long-duration.

Pivot Power’s Mikey Clark tells PV Tech Power that without the Innovate UK grant “...we wouldn’t have moved as quickly with Invinity as we did.”

In response to PV Tech Power’s question about when Invinity would be able to sell vanadium batteries like this one without the benefit of a grant, Porter points out that all

low-carbon and long-duration flexibility tech is subsidised right now. He expects emerging energy storage technologies to be partially reliant on grants for a while.

ESO promises to save 10,000 tonnes of CO<sub>2</sub> a year once fully operational, increasing to 25,000 tonnes by 2032. Rose said the bulk of this would initially be related to the trading activity of the BESS as the EV impact would be relatively low at first.

The simplest example of that is buying energy from the grid when there is excess renewable generation and selling it back when it’s needed. He indicates that the University of Oxford will have a role in measuring ESO’s impact here and keep Pivot’s “feet to the fire on that” alongside its assessment of the BESS’ performance against a digital twin.

However, Johnson is rather tentative on this: “There is some argument that you are potentially reducing the need for higher carbon generation during those periods (of higher demand). To measure this you’d need to look at the generation mix at different times and National Grid are looking at doing this, looking at CO<sub>2</sub>-intensity for settlement periods,” he says.

Clark touches on this point more broadly: “Storage is an enabler for renewable energy and reducing carbon emissions as part of the UK’s energy transition. We have 60-70% of Europe’s winds, we’ve got 16GW of solar and 15GW of wind and massive potential for interconnection. There is a lot going on in the market which requires flexible assets which can dispatch quickly.”

### Future

This project has come at an exciting time for the UK energy storage market. Data from

Solar Media’s UK Battery Storage Project Database Report shows that the UK has a BESS pipeline totalling 25GW, of which 99% is lithium-ion systems and just under half already has planning permission approved. Today, 1.6GW is operational.

ESO is the first of up to 40 similar projects that Pivot Power is targeting across the UK which could total 2GW of energy storage, or 50MW each, all grid-connected. Clark says that all will have a similar power magnitude to ESO’s but it is the only one using a vanadium flow battery, for now, as “we are still waiting to see how the technology performs.”

The company is looking at a range of technologies and industries that can combine with its BESS projects. This could be renewable generation or even industries that could be directly powered by its batteries. The most obvious one is EV charging but BESS has the potential to help power light railways, for example.

Doing this would also have the effect of demonstrating more tangible positive results of BESS installations, with grid balancing and renewable load shifting far from the average person’s thought process.

The company’s target of 2GW is certainly ambitious and commendable, and if achieved it would account for 5-10% of the 20-40GW of energy storage the UK needs by 2050, according to National Grid’s modelling.

All involved will be hoping ESO delivers on all its promises, many of which it already has, and provides a model for other cities wanting to contribute to the decarbonisation of the UK’s energy sector. ■

**Rendering of the project’s Redbridge Park & Ride EV charging park**

