ENERGY STORAGE FOR PORT ELECTRIFICATION

A white paper

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1 Why Energy Management in Ports is Important

Ports are under growing pressure to access ever-increasing amounts of electrical energy in order to meet their own and their customers' requirements, including:

- Supplying shore power to vessels at berth (to help meet their carbon indexing obligations);
- Decarbonising port infrastructure (cranes, buildings etc);
- Recharging of electrically propelled vessels when at berth, as such vessels become ubiquitous;

Ensuring availability of these electrical resources to meet loads which are intermittent and uncertain is becoming a critical port function. It requires investment in multi-vector energy supply chains, energy storage in ports and their associated energy management systems. MSE International has implemented the ESSOP project (Energy Storage Solutions for Ports) in order to highlight solutions that seem most attractive now and in the future.

2 What are the Challenges?

Storing energy, particularly in the form of electrical energy which is the form required for shore power and vessel recharging, is expensive. Although lithium-ion batteries are considered to be the 'go-to' technology, there are other types of battery chemistry which could become attractive. The ESSOP project has analysed the relative performance of these various options to assess them under typical port use cases.

To minimize the dependence on grid-supplied electricity, ports are also investing in renewable generation notably PV solar on warehouse roofing and parking areas. Energy storage is also needed to optimize utilization of in-port generation and avoid curtailment when generation exceeds the available demand. However, it is unclear how much PV solar generation and associated energy storage would achieve a minimum levelized cost of energy.

Finally, it is widely acknowledged that for vessel operators, grid electricity provided through shore power is currently uncompetitive with on-board generators running on low-carbon fuels such as biofuel. How can ports achieve an energy system which minimizes or reverses this competitive disadvantage? ESSOP has been designed to shed some light on these questions.

3 Battery Options

For ports interested in electricity storage (for example, to reduce the peak load on their local distribution network) it is important to assess the different storage technologies available against their through-life cost. ESSOP has considered six different options:

- Lithium-ion batteries

- Vanadium flow batteries (VRFB)
- Hybrid lead-acid batteries (of the type used in the PESO project)
- StorTera's SLIQ (Single Liquid) battery
- Compressed Air Energy Storage (CAES)
- Liquid Air Energy Storage (LAES)

A review of Commercial Readiness Levels of these technologies indicated that CAES and LAES were too immature for commercial deployment in the near future. StorTera's technology is more mature at small scale but was judged to have some way to go to be a viable option for large-scale storage applications. As a result, three battery options were considered in more detail:

- Lithium-ion, for which a significant amount of published data on performance and price is available;
- VRFB, for which some performance and price data is available from one of the leading manufacturers (Invinity);
- Hybrid led-acid and lithium-ion for which some performance and price data is available from the supplier to the PESO project (Yuasa).

Based on literature surveys and private correspondence with manufacturers, the following capital cost estimates have been applied:

	Capital Cost of Storage [£/kWh]	
	2023	2030
Lithium-ion	296	239
VRFB	669	373
Hybrid lead-acid/Li-ion (PESO)	481	336

3.1 Levelised Cost of Storage (LCOS)

In assessing the relative merits of different storage technologies it is essential to look beyond the up-front cost of storage, to take into account the different lifetimes and round-trip efficiencies which can vary significantly. This is achieved by the calculation of so-called 'levelised cost of storage' which is a measure of the total discounted cost of each kWh of energy delivered by the storage system over its lifetime.

For ESSOP, the main cost centres in this analysis are:

- The up-front capital cost of the battery
- The discounted cost of the energy input to the storage over its lifetime (ie the net present cost of input energy needed to deliver the energy outputs demanded by a specific use-case).

This cost is divided by the discounted energy supplied by the battery over its lifetime. The result is effectively the 'levelised cost of stored energy' (ie the net present cost of energy delivered by the storage system). For simplicity, the annual maintenance costs and end-of-life costs have been ignored since these costs are relatively small after discounting.

For all ESSOP analysis, a discount rate of 5% per annum has been assumed which is reasonably typical for renewable energy projects.

3.2 Integration of PV Solar Generation

If some of the energy supplied to the storage is on-site renewable energy, the cost of this energy must form part of the total discounted cost of energy input to the storage. For PV solar generation, apart from the small annual maintenance cost, the cost of energy is effectively the cost of finance for the capital investment. This can be accommodated by including the up-front capital cost of the PV solar facility in the LCOS calculation.

For the ESSOP analysis, the capital cost of PV solar is estimated at £1k per kWp including inverters which is representative of small commercial systems around 50-100 kWp capacity.

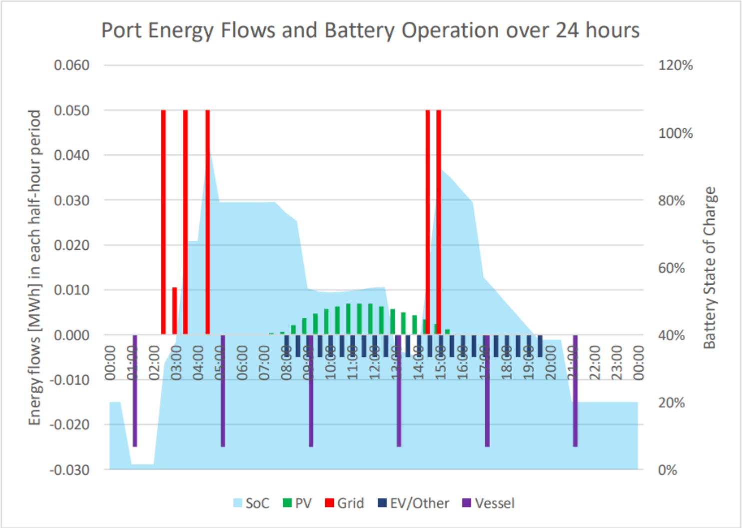
4 Optimising Energy Costs

The ability to use energy storage as a means of minimizing the port's cost of procured energy is a key advantage of in-port batteries. ESSOP has explored two ways in which ports can minimize their energy costs by using energy storage:

- Optimising when they buy electricity to exploit low price periods;
- Optimising how to use PV solar generation to offset grid electricity.

4.1 Optimising Electricity Prices

The wholesale price of energy varies every half-hour, and on a time-of-day tariff this variation is passed onto users. An intelligent battery controller can avoid buying electricity during peak periods and instead focus on periods when low price is expected (including occasional periods when prices can become negative). ESSOP has developed a model that simulates this intelligent battery control to determine the cost savings achievable under real-life electricity price histories.

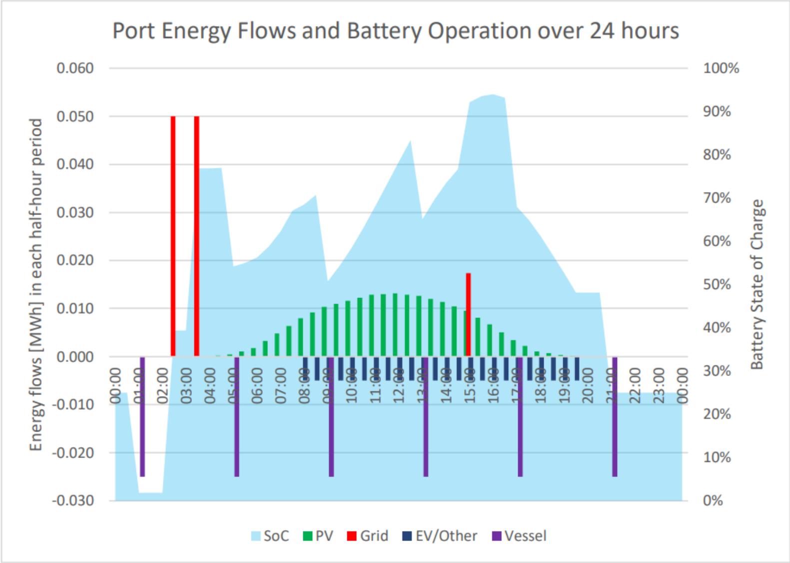


Operation of the ESSOP tool is illustrated in the figure to the right. The purple bars show the energy demanded by the vessel (a ferry berthing 6 times per day). The red bars show energy drawn from the grid, while the blue shaded area shows the battery's state of charge (between 0% and 100%). The red bars show how the tool prioritises grid power at times of least price (early hours of the morning and early afternoon, which is typical).

The algorithm driving this optimization forecasts the amount of grid energy needed by the port in the next 24 hour period and identifies the times when power can be purchased at the lowest prices, based on historic wholesale price profiles over time[1]. This means that the average price paid by the port can be lower than the average over 24 hours.

4.2 Optimising PV Solar

A relatively small amount of PV solar generating capacity can bring significant reductions in the expenditure on grid electricity. The figure on the right shows the battery status for the same use-case as above, but this time in summer when PV solar generation (green bars) is greater.



In this case, less grid energy is required and this can be provided by drawing on the grid during only three half-hour periods.

4.3 Optimising Battery Storage

The ESSOP tool can be used to experiment with different battery types and capacities in order to identify the most favourable solution for a specific port use-case. For the lithium-ion and PESO-type batteries, the minimum state-of-charge of the battery should be kept above 20% and 40% respectively. However, for the vanadium flow battery (VRFB) the battery state-of-charge can drop to almost zero, allowing a smaller battery capacity than for the other two battery types.

5 Trial Use Case

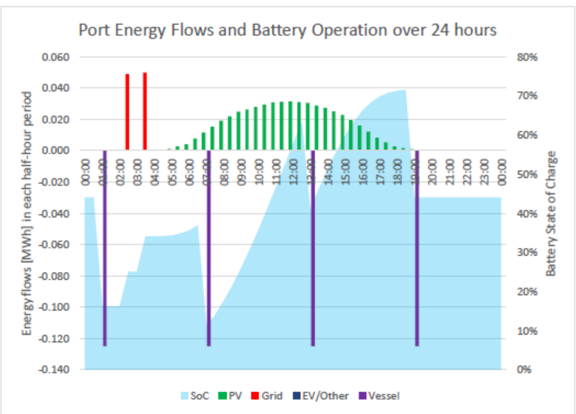
During the ESSOP project MSE has been working with a harbour authority seeking to decarbonize their vessel operations. This requirement is a useful trial use-case for the ESSOP tool.

[1] For this version of the ESSOP tool, time histories during May 2023 have been used, with weekly average profiles generated from 7 days of price data. This avoids the risk of project results being biased through using time histories with unusually high price volatility.

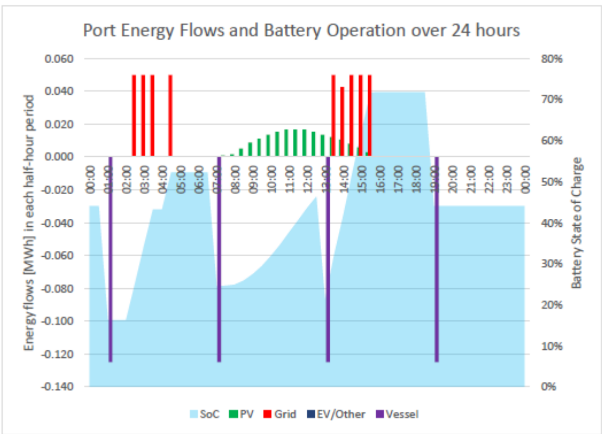
The requirement involves recharging of harbour vessels potentially twice per day for two vessels (or four vessel recharges per day). The system parameters are:

- Recharging load = 125kWh per recharge. (Recharging power can range between 65kW over 2 hours to 250kW over half an hour);
- Recharging frequency = once every 6 hours, all year round;
- Battery type/capacity = 500kWh VRFB battery with round trip efficiency 80% and a life of 25 years;
- Grid connection capacity = 100kVA.

The figures below show the battery behaviour in summer and winter, to observe the impact of seasonal PV solar variation.



Performance of a system with 120kWp of PV solar capacity in Summer, showing the small amount of grid energy needed to supplement the solar power. This is able to use cheap electricity in the early hours of the morning.



Performance of the same system in Winter, showing the need to buy more grid power to supplement the lower PV solar generation. Use of grid power is timed to exploit the 9 lowest price periods during each day.

The PV solar capacity has been varied between zero and 140kWp (above which the PV solar generation would be curtailed in the summer), with the following results:

PV Solar Capacity [kWp]	0	40	80	120	140
% of energy from PV (summer)	0	28	56	84	98
LCOS (annual) [£/MWh]	279	252	226	200	188
Carbon Intensity[2] [kg/MWh]	184	148	113	77	60

In comparison, the LCOS for a direct connection from grid to vessel, with no battery and no PV solar, is £203/MWh and the carbon intensity is 149kg/MWh. However, the limitation on

[2] Using Ofgem's estimated carbon intensity of the UK grid for 2024, of 149 kg-CO_2/MWh

grid connection capacity means that the recharging duration would have to be at least 1.25 hours. This constraint could be operationally inconvenient for the operator.

The battery state-of-charge results above indicate that the battery capacity of 500kWh is over-sized for this use-case. The ESSOP tool has then been used to explore performance of a smaller battery and finds that a capacity of 320kWh gives operation over the full range of possible state-of-charge (in this case, from 4% to 98%). With this smaller battery, the LCOS of the system reduces to 175 £/MWh (with 120kWp of installed PV solar capacity).

These results show that an optimally sized PV solar + battery system can achieve (for some use-cases) both a lower cost of energy and a lower carbon content compared with a simple direct connection to the grid, as well as improved operational flexibility permitted by higher recharging power rating.

6 Conclusions

As demand for shore power expands, ports will increasingly function as major energy hubs. This will require new electrical infrastructure and new capabilities to manage it.

The optimal solution for a port depends on multiple factors including: capacity of grid connection and cost of potential expansion of connection capacity; access to in-port renewable energy resources; types of vessel requiring shore power and their duty cycle. Shore power facilities will generally form part of a wider port energy network including electric power for port assets and back-up power generators.

Ports that have a high-power grid connection (or could upgrade their connection at reasonable cost) do have the option of supplying shore power directly from the grid. In many cases, however, battery storage will be beneficial: allowing the port to optimize its procurement of electricity under a time-of-day tariff, to reduce its peak load on the grid connection and to optimise use of on-site renewable generation, notably PV solar.

The ESSOP decision support model allows ports to investigate the optimal mix of battery power rating, energy capacity and PV solar to achieve a minimum levelized cost of energy delivered to shore power systems. Although batteries of all type are presently quite costly, and introduce round-trip losses, the use of battery storage can be attractive for some use-cases. This is especially true for more frequent loads (eg ferries and workboats that berth several times each day) where the flow battery option is shown to offer cost advantages over direct grid connection and other battery technologies. Conversely, high infrequent loads (eg shore power provision to cruise ships) are much more challenging, with levelized costs dominated by high capital cost of battery storage.

The ESSOP model also allows PV solar deployment to be optimised, to ensure that 100% of solar energy can be utilised whilst offering also the greatest overall reduction in cost of energy.