Shore power infrastructure for decarbonisation of shipping (SPIDS)

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Introduction

Seagoing vessels are one of the world's most polluting forms of transport and contribute greatly to poor air quality in port towns. Electrification of such vessels has been limited by the absence of batteries with sufficient endurance for a sea voyage.

Flow battery technology offers the possibility of sufficient endurance. This project assesses the technical and commercial feasibility of shore-based charging systems for vessels using this type of battery.

Concept

Conventional batteries are expensive, their energy storage capacity is constrained and if used on a ship, recharging during berthing requires high power from shore.

A flow battery ship could be replenished by pumping off spent electrolyte and replenishing it with fully charged electrolyte. This enables the onshore recharging to be carried out continuously and not limited by the ship's berth time, reducing the peak grid power.

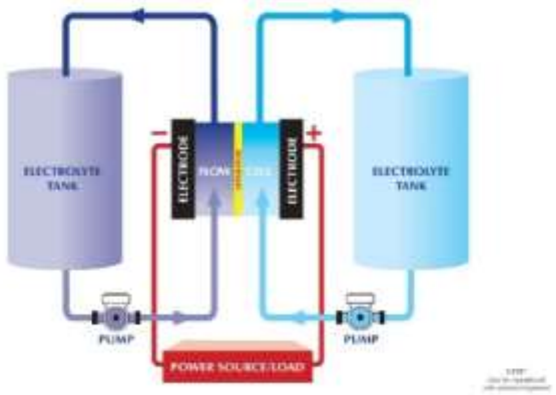

Figure 1. A single flow cell, ©IFBF

Other benefits

The ship's electrolyte tanks can be located anywhere in the hull, including irregular shaped compartments, and used as ballast. The electrolytes are non-volatile and non-flammable. Flow batteries have good capability for frequent deep discharge, good charge retention properties and at the end of life the components and electrolytes can be readily recycled.

Modelling

Portsmouth International Port (PIP) is a mid-sized UK port with a mid-sized fleet of ferries. PIP provided a record of the 5,043 ship visits to the port in 2018, including departure and destination ports and times of arrival and departure. Using standard data for vessel dimensions, cruise speed, engine power we estimated the energy requirement for each trip.

Charge density

The main determinant of size of infrastructure on the port side and in the vessel is the energy density of the electrolyte.

Four figures were used:

- **15 Wh L^{-1}:** achieved in first generation all vanadium electrolytes.
- **30 Wh L^{-1}:** target for deployment of second-generation vanadium electrolytes
- **75 Wh L^{-1}:** target for emerging organic electrolytes
- **240 Wh L^{-1}:** target for future electrolytes

Preliminary investigation of ship borne tanks

The tank size for various ship types and routes was considered and we eliminated cruise ships and freight ships because they visit multiple ports and it would not be practical to replenish them on these routes and fast ferries and catamarans because of weight sensitivity and limited hold size for electrolyte tanks.

Ferries typically travel between a limited number of destinations with established facilities and infrastructure and have spare capacity to accommodate electrolyte tanks.

PIP's ferry routes include long distance crossings of nearly 600 nautical miles (nm) to Bilbao and Santander and short distance crossings below 200 nm to Caen, Channel Islands, Cherbourg, St Malo, Roscoff. The CAP FINISTERE ferry which serves Bilbao would require 9,609 m^3 of electrolyte at 75 Wh L^{-1} for its crossing (in practice, more would be required for contingency). This is approximately 47% of the ship's displacement, which is impracticable.

The ARMORIQUE ferry, which serves Roscoff would require 2,257 m^3 of electrolyte representing 13% of the ship's displacement, which is feasible.

The detail of the ship layout was not considered. A consortium of companies including Marine South East, Houlder Ltd, Lloyds Register and Swanbarton have received funding from MarRI-UK's Clean Maritime Call to assess the feasibility of using innovative flow batteries in vessels to enable zero-emission marine propulsion and auxiliary power.

Port side infrastructure

The shore charging system was modelled to determine the quantity of electrolyte to accommodate the seasonality of demand and the short demand fluctuations due to normal shipping schedules. The spent electrolyte would be offloaded from arriving ships into dedicated holding tanks and fully charged electrolyte loaded from dedicated holding tanks. Between these two stages the electrolyte would be charged in batches, using small holding tanks connected to the cells. See below:

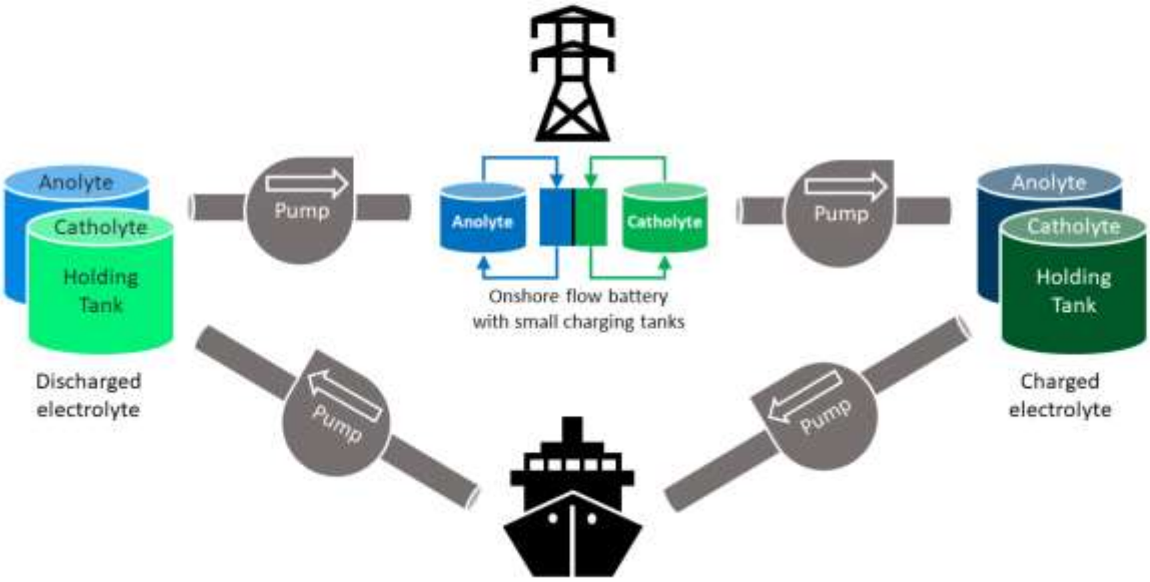

Figure 2: Representation of the shore-side system simulated

The modelling showed how the required grid connection could be affected by storage capacity for two scenarios: Scenario A all ferry routes, and Scenario B routes below 200 nm.

For each scenario, the inventory of electrolyte was modelled for the minimum possible grid connection and the minimum possible grid connection + 10%. For the two scenarios the inventory of electrolyte could be reduced by 88% and 77% respectively. These are shown in figures 3, 4, 5 and 6:

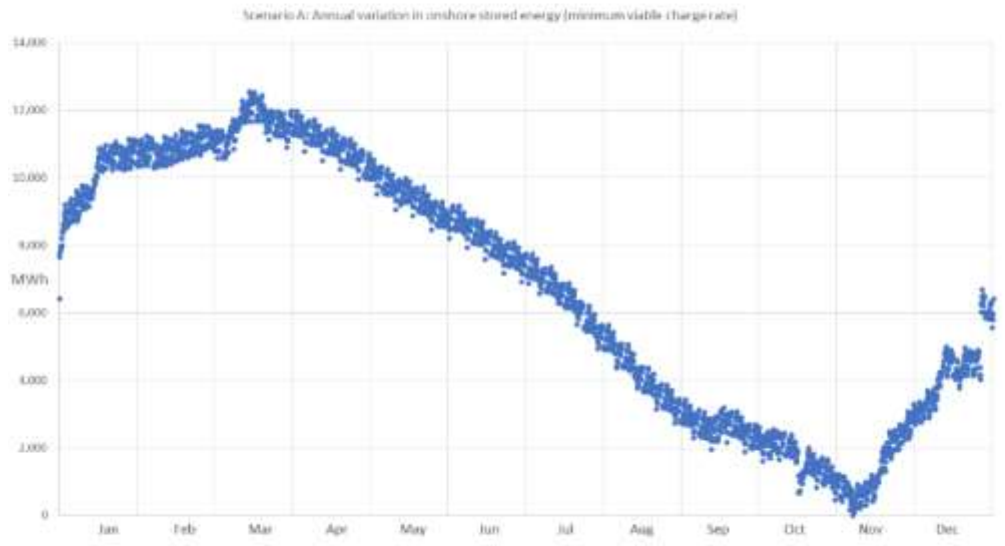

Figure 3: Scenario A annual variation in stored energy with 46.5 MW of onshore cells

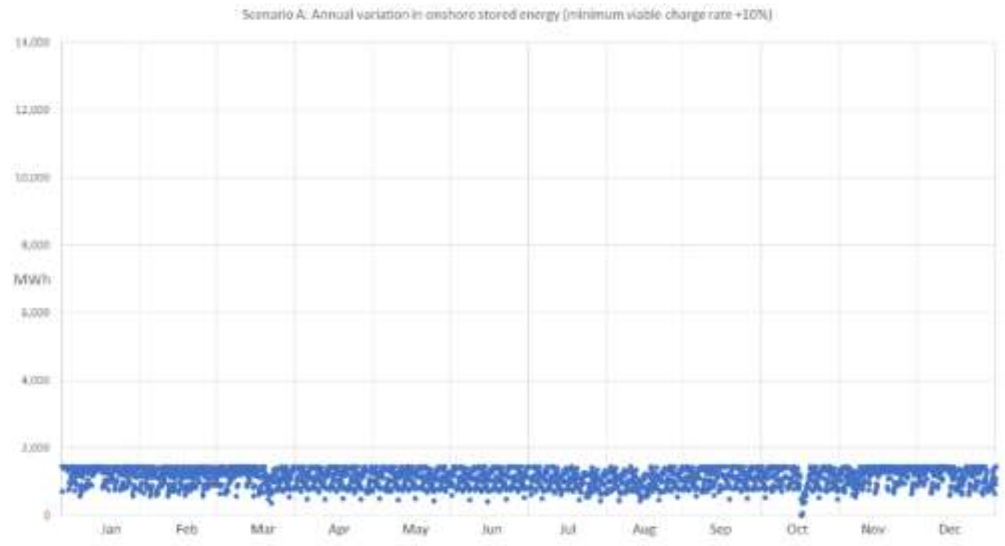

Figure 4: Scenario A annual variation in stored energy with 51.2 MW of onshore cells

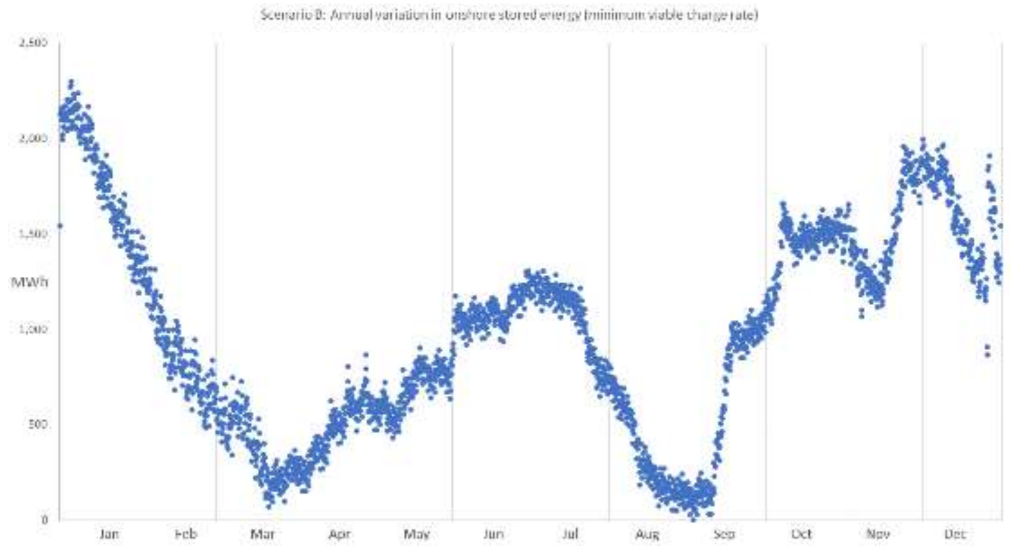

Figure 5: Scenario B annual variation in stored energy with 22.2 MW of onshore cells

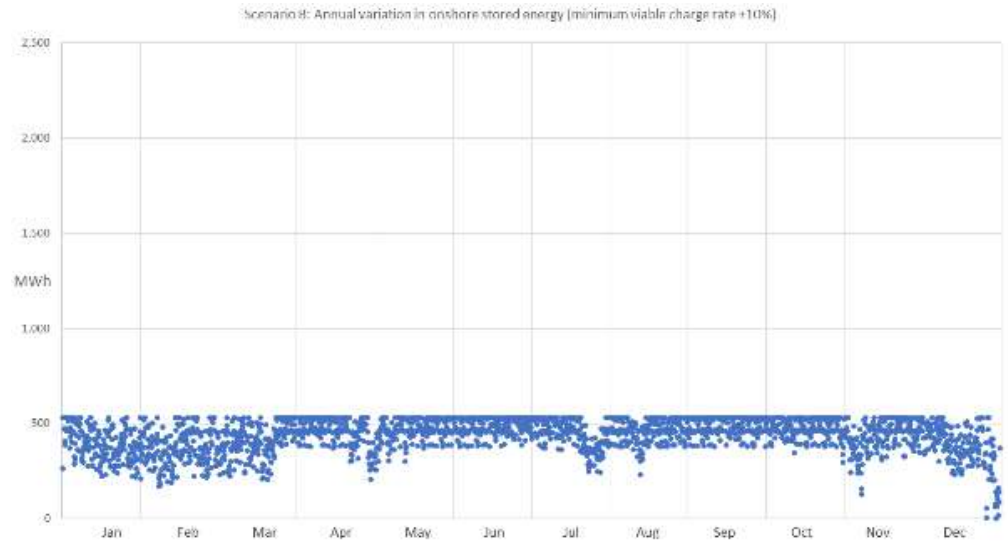

Figure 6: Scenario B annual variation in stored energy with 24.4 MW of onshore cells

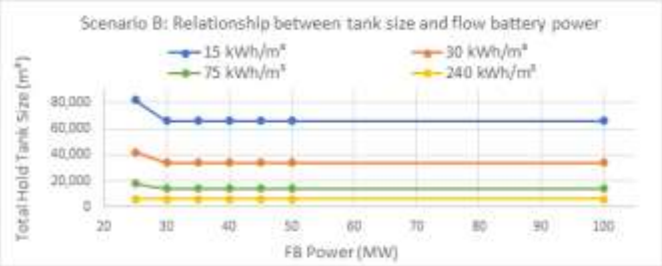

Figure 7: Scenario B – relationship between electrolyte density, power of cells and storage

The relationship between storage capacity and shore tank capacity for the four electrolyte densities is shown in figure 7: Assuming a cell power of 24.4MW and an electrolyte energy density of 75 Wh L^{-1}, Scenario B requires up to 7,093 m^3 of electrolyte to be stored onshore.

This equates to 4 tanks (discharged anolyte, discharged catholyte, charged anolyte and charged catholyte) sized at 15 m high and 17 m diameter.

These would need an area of ~ 30 x 90 m. The power stacks and pumps need an area of 25 x 50 m; making total of 2,750 m^2, around 1.5% of the existing port area (210,000 m^2).

Transfer of energy to the ship

In considering the requirements to transfer energy to the ship inside its berthing time. We assumed that 20 minutes in total would be required to connect and disconnect the pumping systems. The electrolyte would be stored in 10 tanks, 5 tanks of each electrolyte on board, allowing filling of the first tank to commence as soon as it has been emptied and avoiding waiting for all the spent electrolyte to be removed before commencing filling, which would dramatically increase the required pumping rates.

In Scenario A, the most challenging vessel to replenish is the CAP FINISTERE traveling to Bilbao in Spain on 09/09/2018. There is a 105 minute window to transfer 720.7MWh of energy for propulsion. Replenishing by pumping fresh electrolyte onboard from shore tanks would require a pump flow rate of 915 L s^{-1}. For comparison, if the CAP FINISTERE were electrified using a lithium-ion battery, it would require a charge power of ~484.5 MW (85% charge efficiency) to achieve the same energy transfer: the equivalent of the entire peak output of an offshore wind farm. This is an order of magnitude larger than the ~50 MW charge power required for the studied flow battery scheme.

In Scenario B, the most challenging vessel to replenish is the ARMORIQUE traveling to Roscoff in France on 26/03/2018. There is a 58 minute window to transfer 169.3 MWh of energy for propulsion. Replenishing by pumping fresh electrolyte onboard from shore tanks would require a pump flow rate of 389 L s^{-1}. This is viable for 1 pump per electrolyte.

For comparison, if the ARMORIQUE were electrified using a lithium-ion battery, it would require a charge power of ~206.0 MW (85% charge efficiency) to achieve the same energy transfer. This is an order of magnitude larger than the ~24 MW charge power required for the studied flow battery scheme.

Conclusion

With the organic electrolytes of energy density of 75 Wh L^{-1} flow batteries will be able to power ships on cross channel routes of up to 200 nm. The port will need a significant grid connection.

However, flow battery energy storage ensures that this is considerably smaller than that required with conventional batteries such as LIB. The infrastructure is of a reasonable size that could be incorporated within the existing port. The charging and discharge rates for electrolyte fall within acceptable norms.

Acknowledgements

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