DELIVERING SHORE POWER TO SHIPS

A white paper

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Why Shore Power is Needed

Shore power is becoming critical to ports and the vessels they serve for three main reasons:

1) Improving air quality in port cities. Although emissions affecting air quality are often quantified at national or regional levels, the impact is local. Traditionally, ships use on-board generators for power when they are at berth. Depending on their age, these can generate very large emissions of NO_x and particulates, contributing to poor air quality in adjacent areas.
2) Meeting carbon reduction obligations. Ships running on-board generators at berth produce CO_2 emissions that contribute to the port's carbon footprint. Shore power provision is a significant factor in ports' overall carbon management strategy.
3) Increasing vessel electrification. All-electric ships and some hybrid ships will demand shore power in order to recharge their batteries.

What are the Challenges?

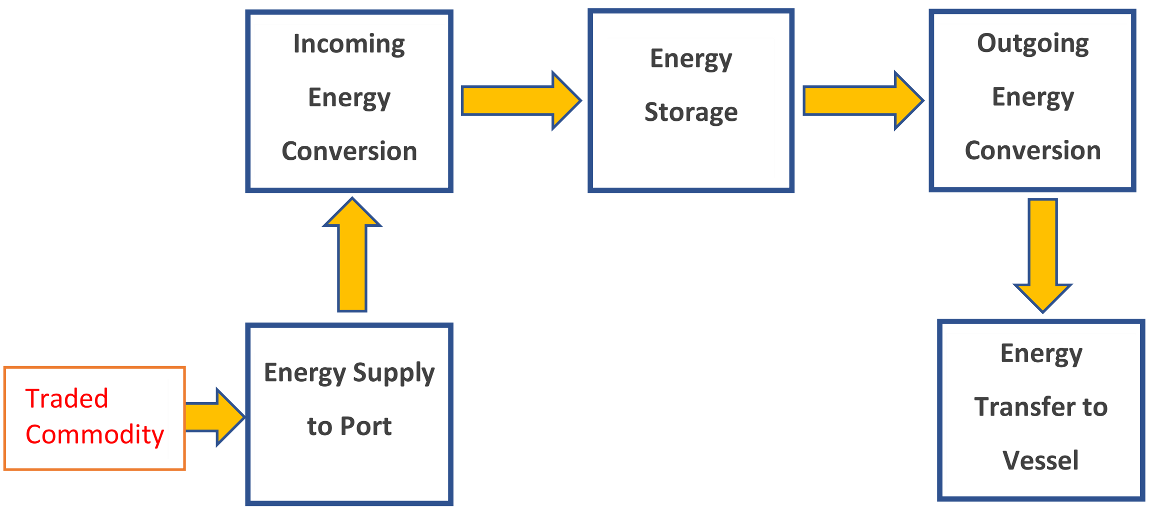
In order to achieve the rate of decarbonisation required to meet net-zero targets (eg in the UK Clean Maritime Plan and the EU 'Fit for 55' strategy) workable solutions are needed now. The roadmap towards maritime net-zero is beset with uncertainty and will involve a range of novel fuel and power solutions in ports. As vessels decarbonize in line with national and international net-zero policies, many ports will become unable to access all the required power from their grid connection cost-effectively, so other solutions are needed. However, ports need to start investing now in the infrastructure they will need.

The question is: what should that investment plan include in order to minimize the risk of creating 'stranded assets' which become obsolete as decarbonization options mature? A range of factors need to be considered:

- Security of supply – will the port be able to access sufficient energy and power to meet the needs of visiting vessels and in-port facilities at times of high demand?
- Compatibility – how will shore power facilities work alongside other fuel systems needed in the port (eg for bunkering)?
- Cost – will vessel operators be willing to pay the price of energy offered by the port, taking account of future pressures within the market for fuel?
- Risks – are there significant risks of technological obsolescence or failure to meet future safety standards?
- Efficiency – losses incurred in converting energy resources procured by the port into on-board energy will determine costs and increase the capacity of supply chains needed.

The ModOPS Project

MSE has carried out the ModOPS project with support from DfT's TRIG programme. The project has analysed the complete energy flow from source to vessel, under a range of use cases and for different energy vector options. The system under consideration has been broken down into modules to determine losses and costs at each stage in the supply chain, as shown below:



Energy processing and conversion systems needed in each module are defined, depending on the energy vector being used to bring the energy resources into the port (the 'Traded Commodity') for which a market price is available. The complete system is then modelled to determine the overall system efficiency, the cost (of buying energy and of financing the capital investment) and the net carbon impact.

The performance of a shore power system depends strongly on its use case: not only the energy throughput but also the intermittency of provision. In order to cover a wide range of sizes and duty cycles, six real-world use cases have been defined and modelled:

UC1	Short-distance passenger ferry (eg Gosport ferry) with all-electric propulsion	Batteries need recharging at each berthing, drawing typically 250kW during 6 minutes at berth, with four crossings per hour.
UC2	Medium-sized cruise ship (eg Noble Caledonian), hotel load only	Average 450kW drawn over 8 hours berthing time, with weekly ship visits in season
UC3	Short/medium-distance RoPax ferry (eg Victoria of Wight), hotel load only	Average 350kW drawn over a 30min berthing time, with vessels berthing at roughly 1 hour intervals

UC4	Cross-channel ferry fleet (eg Brittany Ferries), hotel load only	Average 1.5MW power draw for a typical duration of 2 hours at berth, with 2 or 3 services per day on average
UC5	Windfarm support offshore vessel (SOV), hotel load only	Average 250kW power draw over a 24 hour period to replenish crew and inventory, every ten days typically
UC6	Nearshore fishing vessel, hotel load only	Average power of 15kW over a period of 12 hours at berth, every day

Potential Solutions

Although direct electrical connection of shore power systems to the port's grid connection is the default solution, several alternative options have been considered:

- Electrical connection with in-port battery storage;
- Hydrogen in-port energy storage with conversion into electrical energy;
- Methanol in-port energy storage with conversion into electrical energy;
- Diesel, HVO or DME in-port energy storage with conversion into electrical energy.

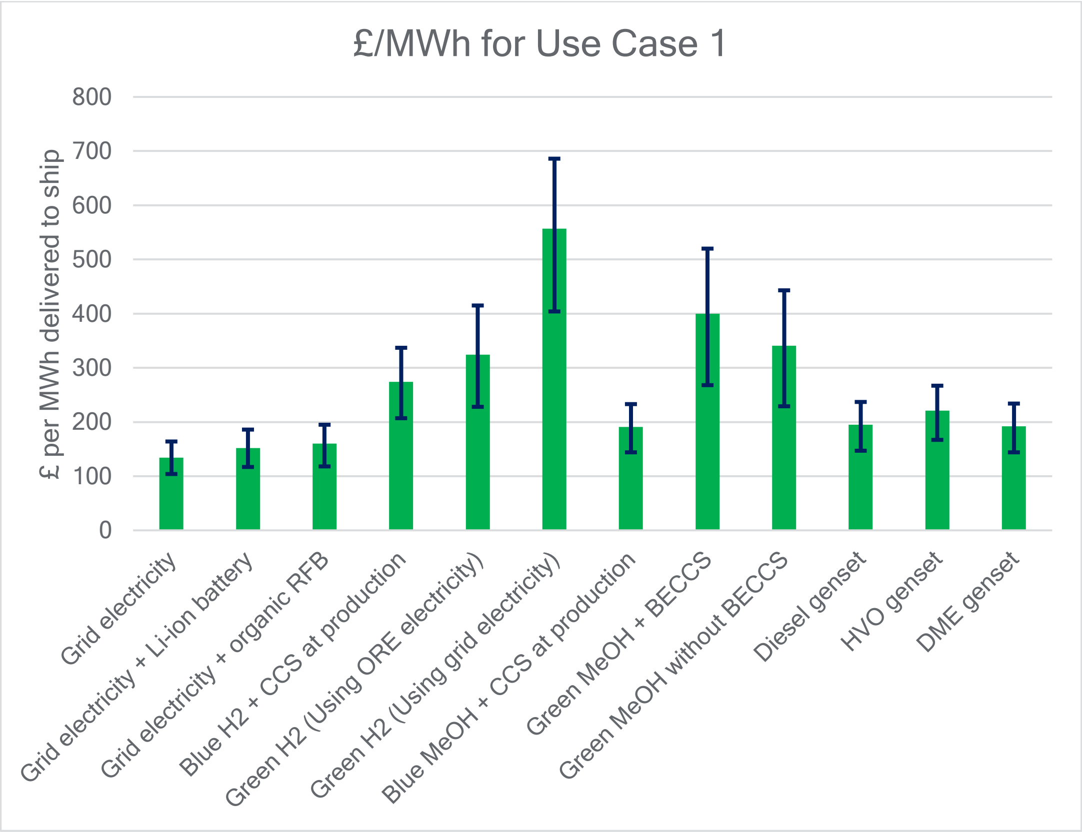
The economic and environmental performance of such shore power systems depend significantly upon the details of how the energy resource is delivered to the port and stored ready for use. To understand these dependencies, the following system configurations have been modelled:

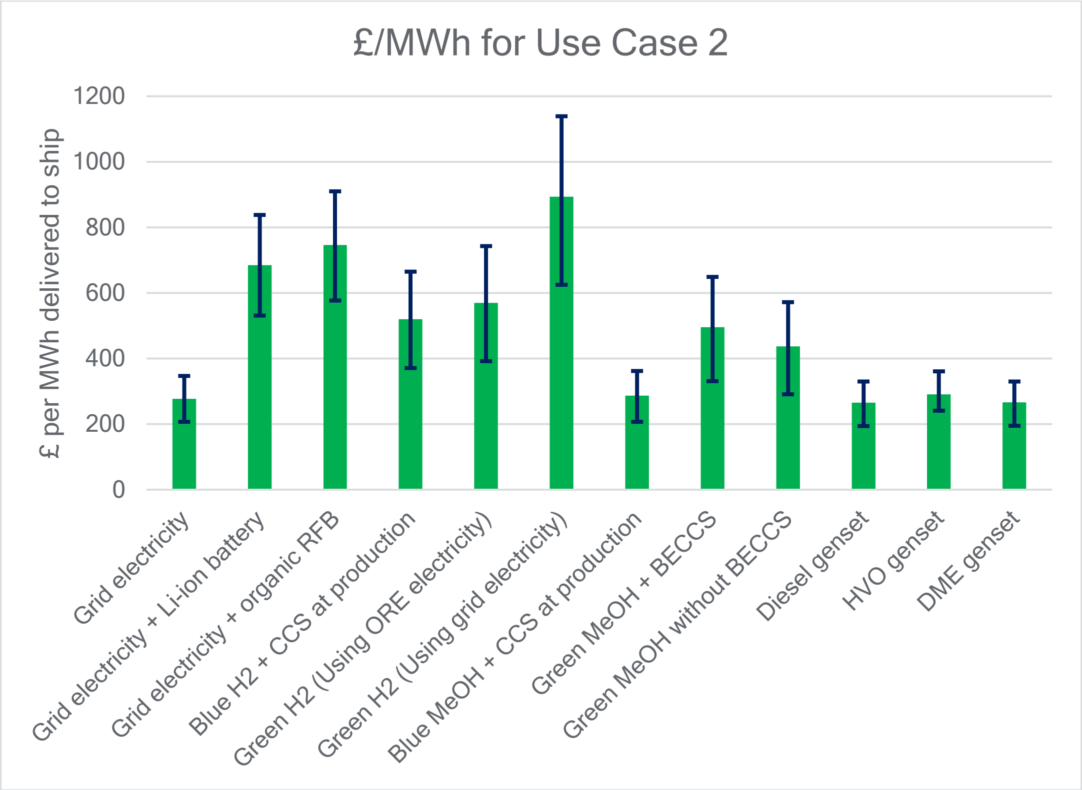
E0	Grid electricity	Electricity from the grid or local DNO connection supplied directly to ships
E1	Grid electricity + Li-ion	As for E0 with a Li-ion battery in the port to minimise peak power demand on grid
E2	Grid electricity + RFB	As for E0 with a flow battery in the port to minimise peak power demand on grid
H0	Blue H2 with CCS	Hydrogen produced off-site from natural gas with carbon capture at production plant, and tankered to the port
H1	Green H2 from ORE	Hydrogen produced off-site from 100% renewable energy (eg at offshore wind sub-station), and tankered to the port
H2	Green H2 from grid	Hydrogen produced and stored in the port from grid electricity coming from the port's DNO connection
M0	Blue methanol with CCS	As for H0 with additional off-site process for production of methanol which is then tankered to the port
M1	Green methanol from ORE	As for H1 with additional off-site process for production of methanol which is then tankered to the port

M2	Green methanol with BECCS	As for M1 but using carbon generated from biomass plant
S0	Diesel genset	Conventional in-port generator module burning diesel fuel which is tankered to the port
S1	HVO genset	As for S0 but burning commercially available Hydrotreated Vegetable Oil instead of diesel
S2	DME genset	As for M0 but with additional off-site process for production of DME

Analysis

The economic and financial performance of these 12 energy vector options have been modelled for each of the 6 use cases, creating 72 sets of results. Some important conclusions can be drawn by comparing the results for two extreme use cases, namely:
UC1 – a short-distance passenger ferry that berths very frequently and is therefore drawing relatively small amounts of energy many times during the day;
UC2 – a medium-sized cruise ship that berths very infrequently and is therefore drawing large amounts of energy at intervals of at least a week.

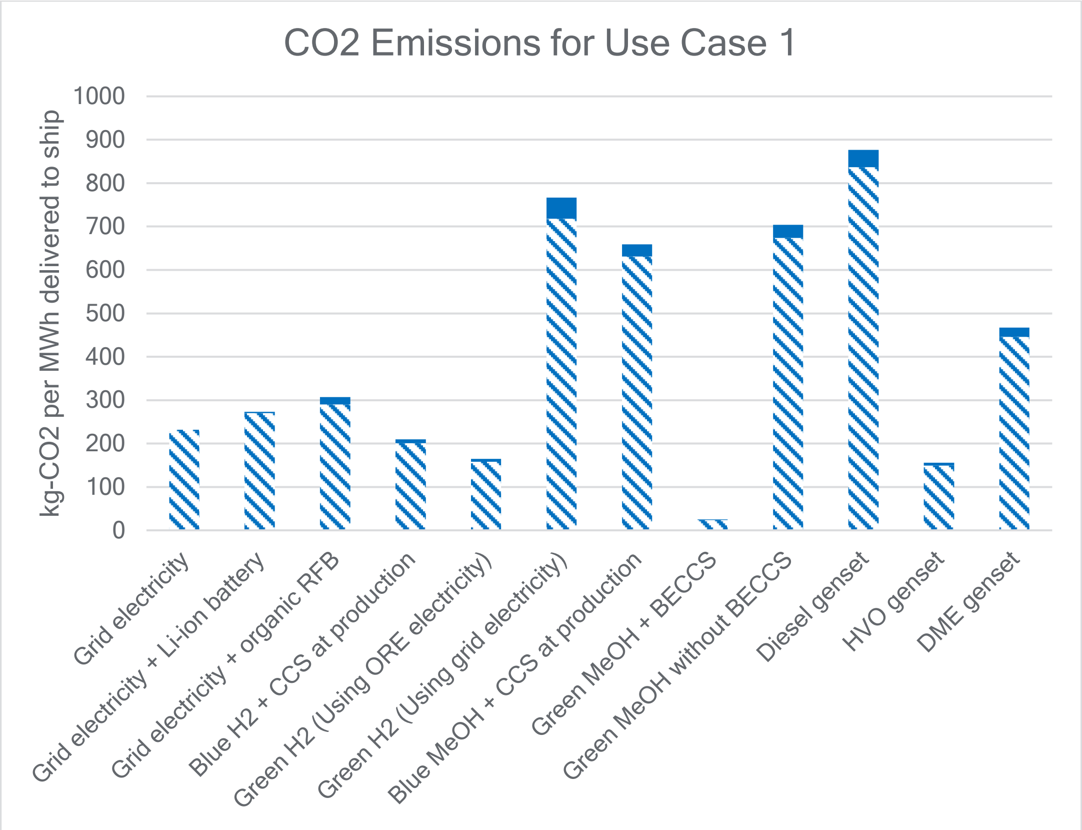




For use case 1, the role of energy storage is rather limited because the power draw is more or less continuous. Costs are dominated by the cost of procuring energy from the market, where established energy suppliers (grid electricity and liquid fuels that can be burned in well-established combustion engines) are cost-effective.

In contrast, use case 2 benefits from large, long-term energy storage. Costs are dominated by storage costs where liquid fuels are advantageous. The exception is the direct grid connection option where costs would normally be dominated by sub-station/grid reinforcement costs that have NOT been included in the ModOPS model. For most ports, the costs of finance for such reinforcement would be substantial making the direct grid connection option unattractive.

The CO2 emissions are the same for all the use cases since emissions are determined by the amount of input energy consumed with negligible dependence on energy storage duration. The energy vector options showing greatest CO2 emissions are those using input energy with high carbon content (grid electricity, diesel, blue methanol etc). Hydrogen generated in-port using grid electricity is especially unattractive due to a combination of losses (in the electrolyser and genset) coupled with relatively high carbon content of grid electricity (using National Grid figures).



What Solutions are Best?

Every port is different and there is no single 'best' solution that would suit the circumstances of all ports. However, the results emerging from the ModOPS study suggest a number of front-runner solutions that could usefully be considered by ports.

All-electric shore power systems

Any port which already has a substantial grid connection capacity sufficient to meet peak power demand should consider one of the electric options. Direct grid connection without storage appears to be cheapest, but in reality the opportunity for peak-lopping and arbitrage to optimize the price paid for energy in the wholesale market could realistically make battery storage a cost-effective option. The battery also offers more flexibility to exploit on-site renewables and to avoid excessive peak power by load-shifting.

Hydrogen-based systems

Production of hydrogen at major renewable energy hubs (eg offshore wind sub-stations), or from natural gas with carbon capture as an intermediate stepping stone, offers reasonable costs and carbon emissions performance. However, transporting the hydrogen to the port (using road tankers) represents a major overhead. Conversion of the hydrogen into methanol makes the transportation more efficient and allows easier energy storage in port. Generation

of hydrogen in-port, using grid electricity, appears to be unattractive on both economic and environmental grounds.
Large-scale production of methanol from green hydrogen using carbon captured from the biosphere (eg in a biofuel facility) performs extremely well and is effectively carbon-neutral. It is still quite expensive (delivering shore power at around double the cost of a diesel genset) but this is likely to reduce as economies of scale are achieved.

Retrofit Options

Hydrotreated Vegetable Oil (HVO) is an attractive option as a drop-in replacement for diesel, allowing ports to use existing assets and to deploy gensets using very cheap diesel engines. This is the 'low hanging fruit' of decarbonization as it can be deployed today. Widespread adoption would, however, overwhelm the available resource, so HVO should be viewed as an intermediate stepping stone solution for as long as a secure source of supply can be assured.

Avoiding Stranded Assets

For ports that are unable to access sufficient grid power for the all-electric solutions, and where HVO presents a security-of- supply risk due to insufficient availability, a methanol solution could offer a robust longer-term solution. Much of the shipping sector views methanol as a promising bunker fuel, so use of methanol-fuelled gensets for shore power would simplify ports' supply chains. As methanol production migrates from blue methanol (increasingly with carbon capture) to green methanol to carbon-neutral methanol, shore power solutions would progressively decarbonize without fresh investment by the port.

Operating Shore Power Solutions

A stand-alone shore power generator fuelled by HVO or methanol could be owned and operated by the port, supported by a third-party maintenance service. This module would include a variable frequency capability within the generator to serve vessels at 50 and 60Hz.

Shore power solutions that are integrated with the port's (50Hz) electrical network are more complex. The optimization of energy storage in batteries, taking account of variable wholesale electricity pricing and serving highly variable shore power loads, is a complex and specialist role. It seems likely that ports will contract in this capability from a specialist provider. In-port generation of energy for shore power could displace the need for back-up generators.

Some ports may elect to appoint a third-party contractor to build and operate their shore power facilities. This is the standard business model for EV charging and for charging of electric leisure craft. The viability of this model will depend, however, on the nature of the port's commercial relationship with its shipping customers and on the regulator drivers for vessel operators to use shore power.

Ports where the same company owns terminal and vessels (eg Stena Line at Hook of Holland) present a simpler case, avoiding the competing interests of vessel operator and port.

Conclusions

As demand for shore power expands to meet air quality and carbon emissions targets, ports will increasingly function as major energy hubs, managing incoming energy resources to deliver the shore power services demanded by visiting vessels. This will require new infrastructure and new capabilities to manage it.

There is no one-size-fits-all solution to build this infrastructure. The optimal solution for a port depends on multiple factors including: proximity of access to high power grid connection; easy access to secure supplies of other energy resources (hydrogen, methanol etc); types of vessel requiring shore power and their duty cycle. The shore power facility will generally form part of a wider port energy network: fuel bunkering for vessels and electric power for port assets, as well as battery storage for optimizing use of on-site renewable generation (eg PV solar) and back-up power generators.

This diversity limits the potential for a standard in-port modular shore power solution. More standardization benefits are likely to arise within the energy supply chain: transition by shipping towards novel low-carbon fuels will drive supply chain scale-up and cost reduction. Some shore power solutions could align with this transition, to piggy-back on cost savings and simplify procurement.

Ports that are proximal with major energy supplies (high capacity grid connection, hydrogen generation hub etc) are likely to benefit from using these supplies for shore power. In particular, an existing high power (some 10s of MW capacity) grid connection allows the port to achieve all-electric shore power at low risk. In most cases, battery storage will also be beneficial: to allow the port to optimize its procurement from the wholesale electricity market and to integrate on-site renewable generation.

The options are much more limited for ports lacking convenient access to energy at the capacity dictated by their shore power demands. Battery storage can maximise shore power capacity from a fixed grid connection capacity, especially for serving vessels that impose a very intermittent load. However, longer term growth in shore power demand is very likely to exceed the limitations of existing grid connections for most ports.

Where an all-electric solution is not feasible or unattractive, on-site generation of electricity using fuels transported into the port is an alternative option. Using compressed or liquified hydrogen as the energy vector is generally unattractive due to the overheads of transport and storage. Conversion of the hydrogen into a liquid fuel such as methanol (ideally at scale to minimize the additional process costs) appears to be a more cost-effective solution, since the liquid fuel can be transported and stored safely using proven technology. Hydrotreated vegetable oil (HVO) is also a useful transition fuel as a drop-in replacement for diesel.

Liquid fuels like HVO and methanol can be conveniently burned in a conventional diesel engine (with some modification for 100% methanol or aquamethanol) with significantly lower emissions than diesel. An in-port genset can therefore be used to generate additional electrical energy which, alongside grid energy, could meet a port's shore power requirements.