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FEB 2022

Transport

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Charging Infrastructure for Near-Shore Electric Vessels

Part 2: The infrastructure considerations for the UK's near-shore maritime sector

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Contents

Documents in this Series

This document is the second of three documents in this series entitled "Charging Infrastructure for Near-Shore Electric Vessels" authored by Cenex for Plymouth City Council.

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Part 1: Background to the Electric Maritime Industry and the Opportunity for the City of Plymouth.

This document:

Part 2: The infrastructure considerations for the UK's near-shore maritime sector

Subsequent documents in this series:

Part 3: Site survey and deployment checklists

2 Introduction to Charging Infrastructure Considerations for Electric Boats

Road transport industry stakeholders have learnt from the growing Electric Vehicle market that progress with uptake of vehicles and charging infrastructure can be a somewhat chicken and egg situation as to which should come first. The electric maritime industry is in its infancy and the market for infrastructure designed for use in a marine environment for electric boat (e-boat) recharging is even less mature than that for electric vessels.

The following sections will cover the key considerations that need to be made by industry stakeholders to design and implement fit for purpose hardware and successful charging networks. The discussion is centred around the use case of electric ferries, given that this is the leading vessel type in terms of number of electrified vessels (43% of the world's known battery ships [1]), however applicability to charging infrastructure for public use by other electric vessel types (likely to be leisure craft) is discussed and many of the requirements are applicable to all vessel types.

These considerations are also consolidated into checklists in the third and final document of this series which are designed to be easy to use for someone shortlisting potential charging locations, procuring hardware and conducting site surveys.

3 Technical

3.1 Charging Power and Battery Size

The power required for e-boat recharging depends on numerous variables, the most important of which are:

- **Vessel.** The displacement, length at water line and type of the vessel will clearly have a direct impact on its propulsive efficiency.
- **Battery size.** A larger battery will need to be recharged less frequently, or at lower power.
- **Vessel purpose/operations.** The distances covered, environment (for example, is the vessel used in sheltered waters (harbours, ports or marinas), or in open sea?) and time spent manoeuvring will all affect the energy intensity of the vessel's operations.
- **Auxiliary systems.** If the battery is powering energy intensive auxiliaries (for example lifting mechanisms, or hotel-loads) the auxiliary energy requirements impact the battery and charging system design.

If the e-boat and charging system are being designed at the same time then they must be considered together, taking account of the vessel's operations. Likewise, where charging infrastructure is being deployed that is for wider public use, the dwell times of the targeted use cases must be considered. There are three options for scheduling of charging, each of which have been applied to a hypothetical use case as an example.

1. Out-of-operation charging

Many ferries perform daytime operations only. This gives an opportunity to recharge the battery overnight when the ferry is not being used. In this charging operation type, the recharging system power needs to supply the battery with sufficient energy to complete the entire day's worth of operations in the available downtime. Given that maritime vessels can require large amount of energy for operations, this can lead to large battery sizes. However, the required charging power may still be relatively low if there is a long downtime available for charging.

Example: Ferry A is operational between 6 am and 8 pm daily. The operations require 200 kWh of energy, accounting for some reserve, which can be delivered by a 10-hour recharge at 20 kW overnight to fully charge the useable battery capacity of 200 kWh.

2. Top-up charging

In top-up charging, the e-boat seizes opportunities to recharge during its hours of operation. In an electric ferry example, the vessel recharges at any one or all the ferry's terminals, whilst berthed and passengers or vehicles are embarking and disembarking. Given that the length of time spent at terminals for some local ferry operations can be a significant proportion of its overall operational time, opportunity charging at ferry terminals can provide scope for top-up charging.

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For e-boats that are either operational continuously or do not have access to charging infrastructure outside of operational hours, the charging power available must recharge enough energy to make the next journey.

Example: Ferry B, a small electric passenger ferry, makes a crossing in 9 minutes that requires 10 kWh of energy, and the ferry is then berthed whilst the passengers embark and disembark for 6 minutes. A more powerful 100 kW recharging system would be sufficient to recharge the system in the available time and in theory the useable battery size could be limited to just 10 kWh.

3. Mixed Charging

In the mixed charging scenario, the two previous options are combined. This might be useful when out-of-operation charging is possible, but the amount of energy used during a day of operations also requires top-up charging to ensure the battery size remains manageable. Clearly, this also requires top-up charging to be operationally feasible.

Example: Ferry C, as with Ferry A, is unused from 8 pm to 6 am. However, the ferry has a smaller battery size of 100 kWh which is fully charged overnight at 10 kW. Therefore, the battery must be "topped-up" during the day at one or more of the ferry's terminals in order to complete the ferry's operations. Two potential recharging profiles, using high powered (120 kW) charging either in regular 10 minute or less frequent half-hour windows, to support such an operation are shown in Figure 1:

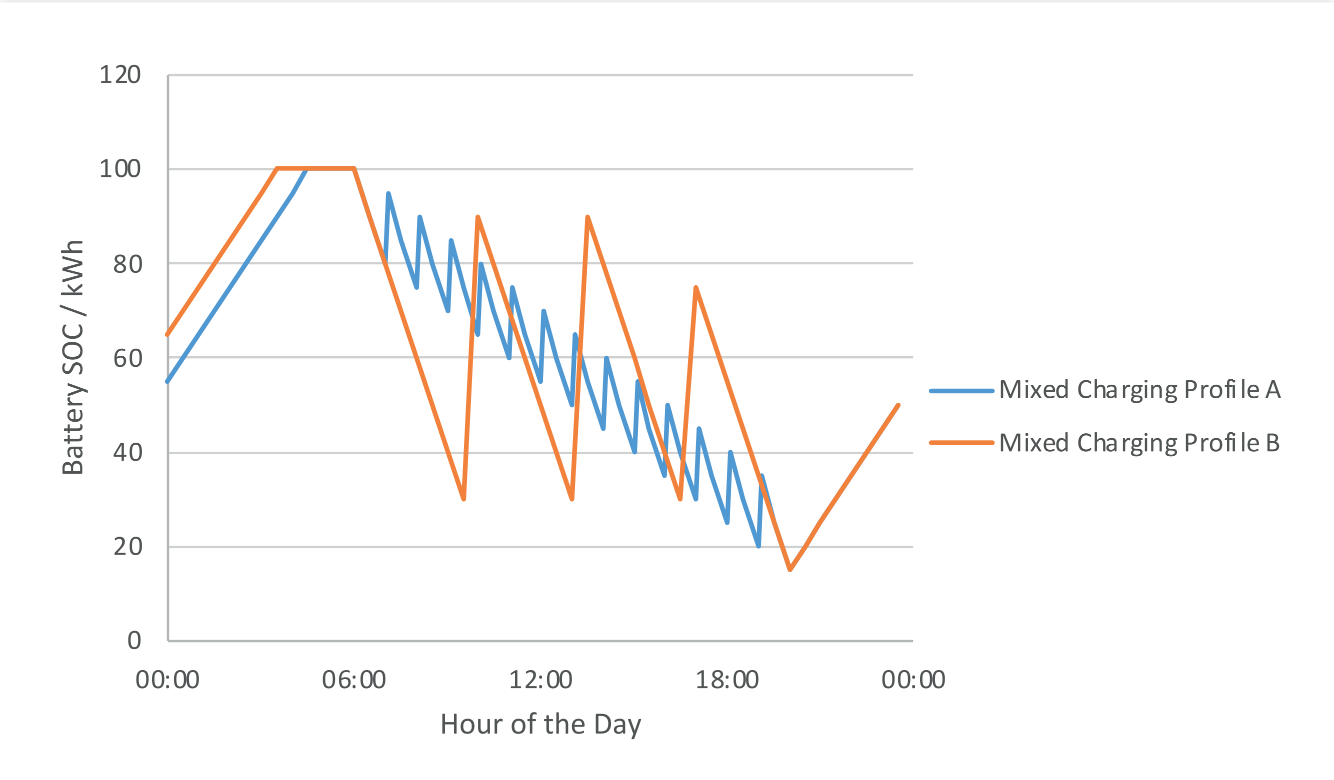

Figure 1: Example recharging profiles - mixed charging

3 Technical

Each of the three examples are simplified but used to illustrate the compromise between battery size and charging power. In reality, the system design will depend on the constraints of the specific operations and energy requirements of the vessel.

Battery sizing and charging infrastructure selection should be done to minimise total lifecycle cost. It is recommended that the top-up charging option is explored first. If it is feasible to recharge during operations, a system of regular charging can lead to smaller battery sizes and as a result a lower total cost of ownership (TCO). This is because battery size reduction saving can outweigh the cost of the higher power charging infrastructure. However, this is not always the case; if expensive grid infrastructure reinforcement required, a larger battery and out-of-use charging system may be preferable. Therefore, it is imperative that the charging system is considered at the outset of any maritime electrification project.

A Note on Public Charging Infrastructure

If providing public charging infrastructure, for example for electric leisure craft that have long periods of downtime (many hours or even days) between uses, either high or low power charging could be useable.

With low power charging, each vessel would require an outlet at its mooring position to charge slowly when not in use as per the out-of-operation ferry charging scenario.

For high power charging, as per the electric ferry top-up scenario, a few charging outlets in a publicly accessible position could provide a “rapid” charge at the start or end of the electric boat’s period of use.

Which is more suitable will likely depend on local mooring arrangements and power availability. Note that high power charging infrastructure is more costly and therefore multiple low power chargepoints will be deployable for equivalent cost. It is necessary to understand the local use case to know which system would represent best value.

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3.2 AC vs DC Charging

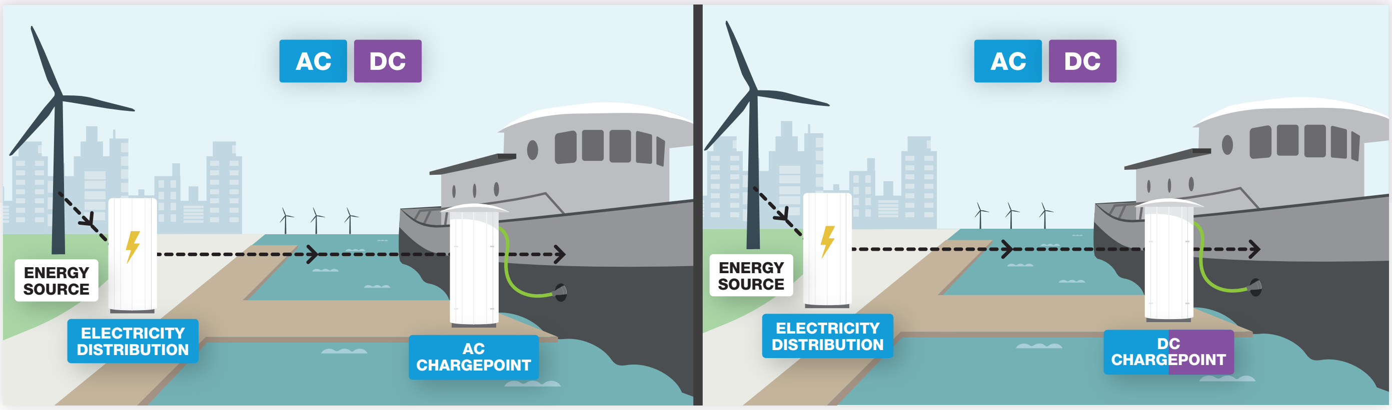
E-boat recharging systems can be further classified depending on the type of energy supplied to the vessel.

• AC Charging

In an AC (alternating current) charging system, the charging infrastructure supplies AC energy to the vessel. An on-board charger is installed as part of the boat's electrical system which converts the AC supply to DC (direct current), in a process known as rectification, to recharge the battery.

• DC Charging

In a DC (direct current) charging system, the charging infrastructure supplies DC energy to the vessel. The supply to the charging infrastructure may be AC or DC, depending on the overall system design. In a typical system where the chargepoint is supplied with AC energy from the Grid, the rectification from AC to DC is done by the chargepoint. This DC energy is then supplied directly to the boat's Battery Management System (BMS) to charge the battery.



For road transport in the UK, AC charging is used for power ranges of 3.7 – 22 kW, with DC based charging systems preferred for higher power charging. The reason for this is that as power increases, so does the cost, size and weight of the on-board charger required to rectify the incoming AC supply.

The energy use for all but the smallest electric vessels is comparatively high, and therefore it is anticipated that the charging power required to support operations of electric ferries will be high. Even boats with operations that support out-of-operations charging (despite the size and weight of an on-board chargers being less important for electric boats than for road transport) are likely to adopt DC based charging systems.

This is particularly true if the charging infrastructure is to be used by multiple vessels as the overall system cost is reduced as the costs are borne by the shared infrastructure instead of requiring costly on-board chargers for each vessel.

Power requirements will clearly depend on the size of the vessels to be charged and their operations. For boats that top-up charge only, there may be no need for an on-board charger if the vessel is reliant on a DC charging system only. However, those that charge when out-of-operation (either uniquely or as part of a mixed charging case) may require an on-board charger to facilitate AC charging.

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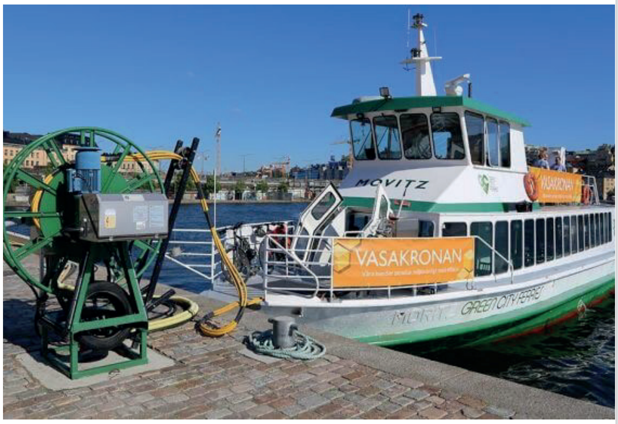
Table 1: Electric Ship Movitz [2], [3]

Case Study: Top-up DC Charging System

Name:	Electric Ship Movitz
Location:	Stockholm, Sweden
Status:	In service from 2014, upgraded in 2019
Vessel(s) Description:	100 passenger ferry, 120 kWh battery
Operator:	Green City Ferries
Suppliers:	Echandia Marine, Vattenfall, Nilar



Charging infrastructure	Operational Description
Charges at 500 kW DC to recharge battery in 10 minutes at Riddarholmen. AC to DC conversion on quayside, cable reel retraction system.	23 m, 100 passenger ferry in central Sweden. Twice daily tours from Riddarholmen to Solna Strand (approx. 10 km)

Table 1 shows an example of a medium sized electric ferry that is recharged with a high-powered DC based top-up charging system. A DC system is the viable choice given the size of the power electronics required for 500 kW rectification. A top-up charging system is used as charging occurs during the 10-minute wait before the ferry makes a return journey. Vattenfall, the recharging system suppliers, have opted for higher powered charging over a larger battery and lower powered charging when the ferry is not operational. Part of this decision may be due to having an eye on future proofing – there are plans for electrifying additional ferry routes in Stockholm as part of Boatplan Stockholm [4].

3.3 Design for a Near-Shore Environment

Charging infrastructure for maritime use will be exposed to near-shore maritime conditions. Therefore, for the hardware to achieve an acceptable lifetime – 10 years is often the minimum benchmark but for bespoke high-cost maritime charging systems a longer lifespan may be desirable – it is imperative that chargepoints are designed for near shore environments.

Salt-water ingress protection, corrosion protection and sand ingress must all be considered. Environmental suitability applies to not just the chargepoint, but the entire charging system including all cables, mountings and fixings.

The Ingress Protection (IP) rating of an electrical enclosure is a measure of its resistance to intrusion of solid objects and water, as defined by IEC 60529.

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SOLIDS			LIQUIDS		
IP0X	-	No protection against contact and ingress of objects	IPX0	-	
IP1X	> 50 mm	Any large surface of the body, such as the back of the hand, but no protection against deliberate contact with a body part	IPX1	Negligible	Probability of presence of water is negligible
IP2X	> 12.5 mm	Fingers or similar objects	IPX2	Drops	Possibility of falling drops, water vapour
IP3X	> 2.5 mm	Tools, thick wires, etc.	IPX3	Sprays	Water falling as spray
IP4X	> 1 mm	Most wires, screws, etc	IPX4	Splashes	Splashes from any direction
IP5X	Dust		IPX5	Jets	Jets of water from any direction
IP6X	Dust tight		IPX6	Waves	Water waves
			IPX7	Immersion	Flooded or immersed to limited to certain depths
			IPX8	Submersion	Permanently submerged

Table 2: IP ratings

3 Technical

The UK, as well as having some of the largest tidal ranges in the world, is often exposed to severe storms due its situation in the North Atlantic. It is possible that the charging systems will be immersed and exposed to sand during its working life.

It is recommended that all charging infrastructure housings containing electronics are rated to IP65 as a minimum, preferably IP66 or IP67. The need for higher ingress protection is less if the infrastructure is to be located in a sheltered near-shore location such as a marine or port where there is zero risk of waves in storm conditions. Alternatively, there are examples of in-pavement charging systems in the EV charging industry designed to withstand water immersion. One such example is the diving bell principle used by Streetplug.nl to protect critical electronics of their underground charging station [5].

Ingress into the enclosure is only one environmental design consideration for a near-shore environment. Regardless of the hardware standard used, the physical connection between the shore infrastructure and the e-boat (assuming a conductive charging system) is likely to be a point of weakness for ingress protection. For comparison, electric vehicle charging systems (designed to BS EN IEC 61851) are only required to have connectors designed to IP24 when not mated and IP44 when mated. Commando connectors to IEC 60309 are available with different ratings from IP44 to IP66 or IP67 which makes use of gaskets to provide a waterproof seal when mated. The equivalent maritime connection when mated must comply with IP66 as a minimum. IP66 is advised regardless of where the inlet socket is located on the vessel.

The connector and vessel inlets, when not mated, may not need such a high level of ingress protection, since it is acceptable for water ingress to occur when the system is not energised. However, unmated connectors designed to lower ingress protection level would need to be designed to allow the connector and inlet to both freely drain or be purged before a connection is made. This may be a useful feature if the connector is handled manually and therefore prone to being dropped. However, it may be simpler to explore designs that maintain a high level of ingress protection when both unmated and mated. Note that standard electric vehicle connectors do include an optional drain hole as part of the IEC 62196 specification.

Charging connectors either need to be designed to a high level of ingress protection, IP67 is recommended as a minimum, or provided with a purging mechanism to remove water before plugging in.

If connectors are not protected against ingress, then understanding limitations of saltwater corrosion for connector pins is imperative otherwise connectors may need to be frequently replaced.

For the charging cable and other metal enclosures, it is necessary to select hardware making use of materials designed for saltwater environments to ensure the entire system is survivable.

3 Technical

3.4 Grid Connection, On-site Generation and Battery Storage

The conventional method of supplying power for charging infrastructure is to connect the system to the electricity grid. There are two potential issues:

- **Proximity of grid infrastructure**
- **Capacity constraints on nearby primary and secondary substations**

Whilst the availability of power in some major ports is improving to reduce air pollution from large shipping vessels whilst docked, others have capacity constraints. Additionally, many coastal areas suffer from weak grid connections, both in terms of constrained capacity and a lack of available infrastructure near-to-shore.

Case Study: Out-of-Operation AC Charging and Grid Connection

Name:	e-Voyager
Location:	Plymouth, UK
Status:	Built, awaiting start of operations
Vessel(s) Description:	Small (## m) electric ferry, ## kWh battery, ## passengers
Operator:	Plymouth Boat Trips
Project Partners & Suppliers:	University of Plymouth, University of Exeter, Plymouth Boat Trips, Teignbridge Propellers, EV Parts, EV Charging Solutions

Charging infrastructure	Operational Description
Three 22 kW eVolt Electric Vehicle chargers installed at Barbican Landing for out-of-operation charging.	Local ferry operations and cruising in Plymouth sound. Daily usage with daytime operations only.

Link
https://www.plymouth.ac.uk/news/uks-first-sea-going-electric-ferry-launches-in-plymouth

Table 3: e-Voyager Case Study [6]

3 Technical

Taking the e-voyager example in Plymouth, three 22 kW chargepoints have been installed at the Barbican Landing as shown in Figure 2.

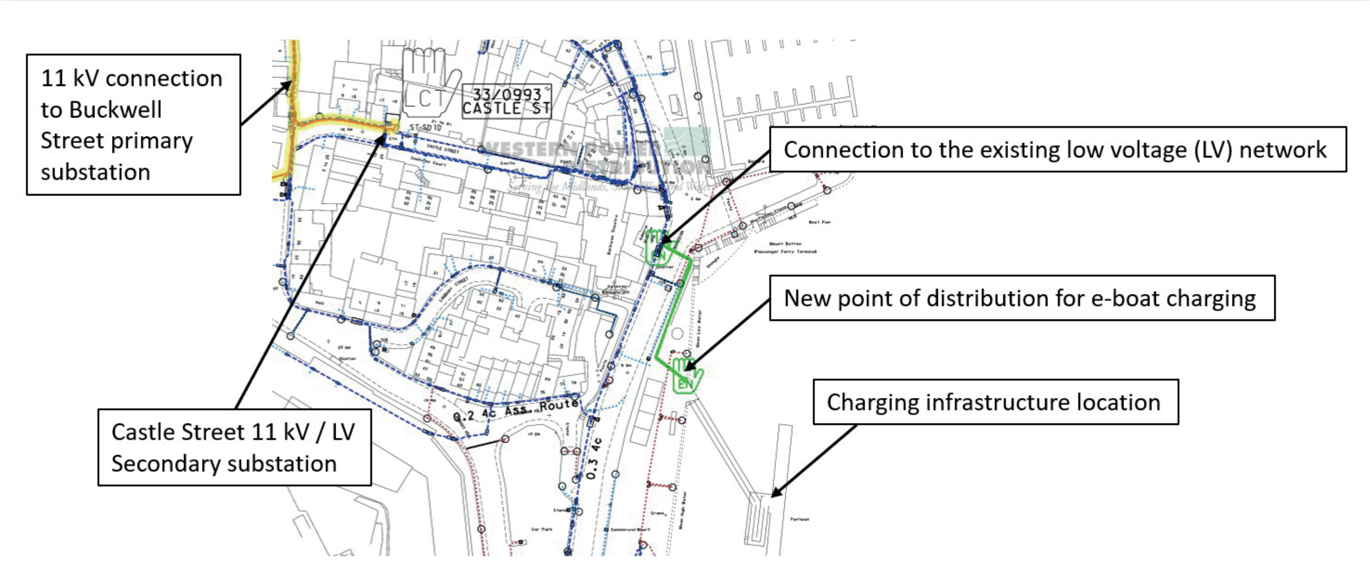


Figure 2: e-Voyager Charging Infrastructure Grid Connection [7]

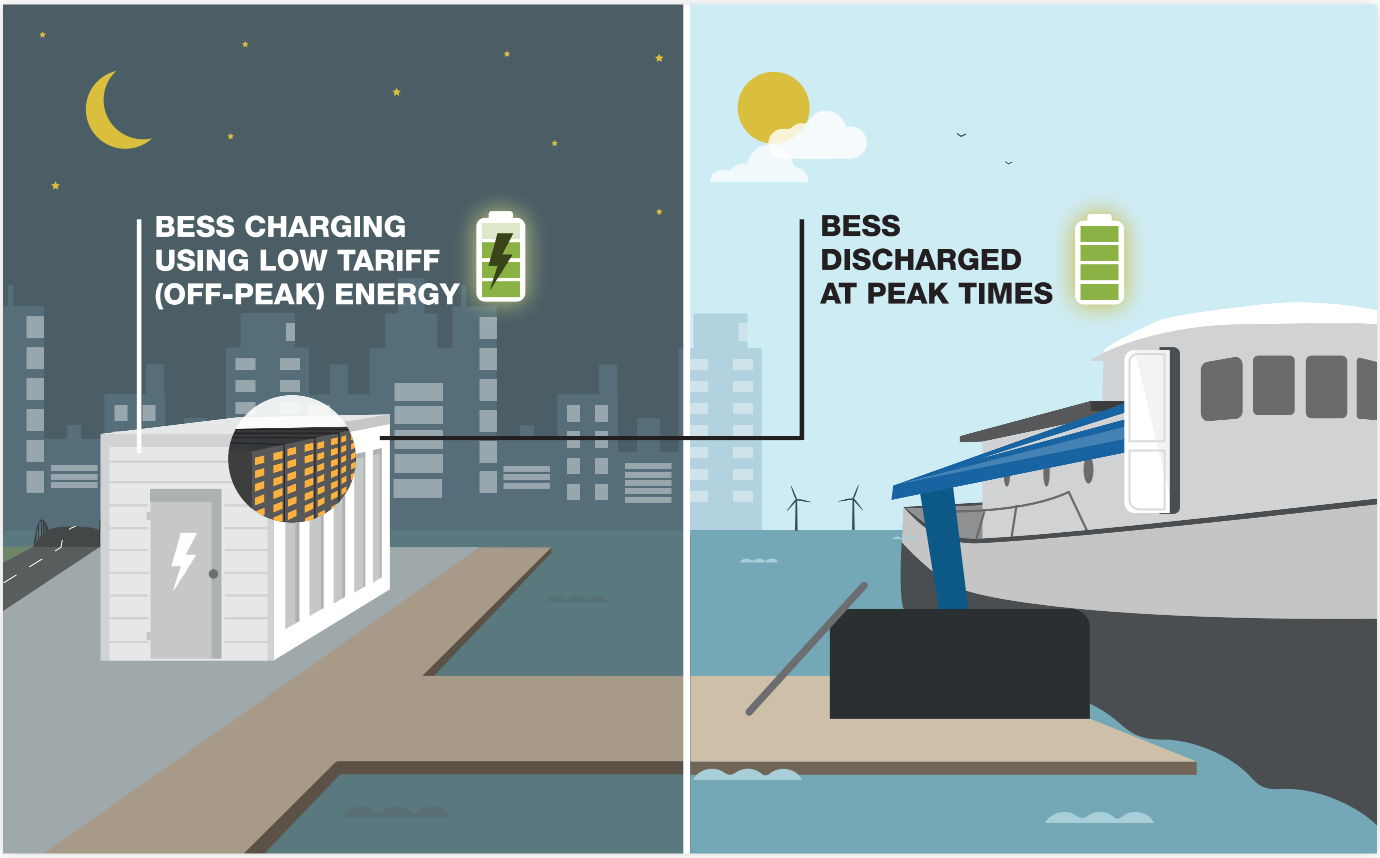
Neither of the primary or secondary substations (or indeed the local Bulk Supply Point (BSP) at Milehouse) are constrained on capacity[1], however a new point of connection was required to bring the low voltage (LV) grid supply closer to the intended charging infrastructure location. The new point of connection added cost and complexity to the installation. This is likely to be an issue for many e-boat charging infrastructure projects, particularly where there is little or no flexibility in the charging infrastructure location. High-power connections made at medium voltage (MV) level will be even more restrictive.

The availability of grid connections near-to-shore can be a complication for the connection of e-boat charging infrastructure, especially if there is no flexibility on situation of the charging infrastructure due to the target vessel(s)' overnight mooring or in-use berthing positions. It is important to understand these limitations at the start of any e-boat charging project.

Even when the proximity of grid infrastructure is not an issue – or can be readily solved – network demand constraints may cause challenges, particularly where higher power infrastructure is required for top-up charging. These constraints may be overcome by supplementing the grid connection with a Battery Energy Storage System (BESS). In such systems, the peak demand for charging is met by power supplied by the grid augmented by the BESS. The BESS is then recharged at lower power from the grid.

[1] According to Western Power Distribution open data "Electric Vehicle" and "Network Capacity" maps as of January 2022.

3 Technical



Employing a BESS can reduce energy costs by charging the BESS using low tariff (off-peak) energy and discharging at peak times. Of course, this depends on the specific use case of the e-boat. However, it is likely that smaller, lower range vessels (such as near shore ferries and fishing vessels) can power daytime operations with the assistance of BESS charged with low tariff energy overnight.

Renewable on-site generation may also play a role. The primary function would be to charge the BESS at low power when charging is not required, although on-site renewables may also supplement the Grid and BESS power to meet the charging demand. This is likely to be a solar PV system (but could also be small-scale wind, tidal or wave generation), which when paired with BESS reduces the environmental impact of the target vessels' operations by providing a clean energy supply.

However, physical space constraints will limit the size of PV arrays for charging locations in many areas. A business case assessment would be required to predict the lifecycle costs and payback period accounting for the combined PV, BESS and e-boat system. To provide a positive return on investment, reduced operational costs must counterbalance an increased up-front investment. However, the environmental benefit should also be considered.

Supplementing the grid connection with battery storage and renewable generation can help overcome network constraints and reduce the environmental and financial cost of operations.

3 Technical

Case Study: Mobile Battery Energy Storage System (BESS)

Name: Skoon Energy

Location: Amsterdam, The Netherlands

Status: Operational

Vessel(s) Description: Various electric boats and shore power for larger vessels.

Description

Skoon Energy is supporting Amsterdam's electric maritime revolution with its containerised deployable battery solution. Their Skoonbox 2 AC product is a 638 kWh battery that can be deployed to provide AC power to charge e-boats in areas with weak or even no grid connection. As the solution simply provides a standard industrial AC power supply, to charge from this the vessel would need an on-board charger.

The container can be lifted onto the shore or left on a barge vessel, which allows the battery to be mobile and moved to where it is required and to be taken away to be recharged for short-term applications without a grid connection. This solution is being used to provide power for electric boats as well as shore power to larger vessels (where the container can even be lifted onto the vessel itself) or even for temporary events.

In addition to this, Skoon have developed a marketplace with access to third party batteries, in doing so providing an energy-as-a-service proposition for electric boat operators as an alternative to investing in their own hardware.

Table 4: Skoon Energy [8]

An extension of the Skoon Energy concept would be a battery swap system whereby the electric vessel's battery is removed once discharged and recharged on the shore and replaced with a fully charged battery. The multiple batteries are used sequentially to keep the boat operating. Although such systems are being deployed by companies such as Zero Emission Services [9], this is unlikely to be the optimal systems design for smaller vessels and would create multiple additional challenges, and hence is not discussed further in this paper.

3 Technical

3.5 Protection from Galvanic Corrosion

A key consideration for e-boats is the need to protect against galvanic corrosion when charging. Galvanic corrosion is a result of differing underwater metals of vessels connected to a common earth provided by the shore connection, which is necessary for fault protection, irrespective of whether the boat is connected for charging of a battery or simply for shore power. There are three possible methods that can be employed to protect against this:

- **Protective coatings applied to the hull of the vessel.**
- **Connecting the system to a sacrificial anode which will corrode in preference to the hull of the vessel.**
- **Galvanic isolators in the shore power connection.**

The corrosion caused can significantly damage a boat's hull and it is therefore imperative to protect against.

E-boat charging infrastructure should include galvanic isolation that is suitably rated, by default. If an operator wishes to install charging infrastructure that has not been designed for maritime use and therefore does not include a galvanic isolator, then galvanic isolation needs to be provided as part of the installation.

4 Practical and Operational

We have seen how the availability and constraints of the local network will be key factors in choosing where to site charging infrastructure for vessels with operations – such as ferries with multiple terminals – where there are multiple potential sites. There are also important practical considerations to be made.

4.1 Installation Location

The installation location chosen for the charging infrastructure can be influenced by both the availability of, and constraints on, the local electricity network. The target e-boat's charging (top-up, or out-of-operation) will add further constraints. Physical berthing infrastructure will also impact how the chargepoint is installed and how charging connectors are managed.

Berthing infrastructure can be sub-divided into two categories:

- **Fixed, permanent structures such as marinas, ports, quays or harbour walls, or jetties or fixed piers.**
- **Infrastructure, that may be less permanent, and is floating such as pontoons or floating piers.**

The two types are differentiated by the relative movement between the infrastructure and water line. Tides, swell, waves, and the load carried by the vessel can all influence the relative positions of ship-to-shore charging infrastructure. In fixed systems, adaptability will be required between the chargepoint and the vessel on charge. For example, for a simple system using flexible conductive charging cable the cable must be long enough to account for the local tidal range.

Conversely, if the charging infrastructure is mounted on a floating berth – such as the installation completed at the Barbican Landing for the e-Voyager - the power supply cable to the chargepoint must accommodate the relative movement (note that there may also be some relative movement between the berth and the vessel), both in terms of the system design and the selection of an appropriate flexible cable standard that is also appropriate for a marine environment. Additionally, if the weight of the charging infrastructure is significant, floating berthing infrastructure may need to be reinforced or made more buoyant.

In addition to this, it is unlikely that the mooring position of the target vessel(s) will be consistent in all cases. The berth may be shared with other vessels. Even if the berth is dedicated to a single vessel, there may still be variability in the mooring position. Exact mooring location will change due to tidal movements for fixed infrastructure, with boats mooring at different positions along a sloping pier depending on the tide. Additionally, if the chargepoint is to be used for multiple vessels, then where the charging socket is located on the vessel may necessitate additional flexibility in the charging system (chargepoint to vessel.)

It is imperative to consider the mooring position of the target vessel(s) as well as any potential relative movement for both fixed and floating berths when designing and installing charging infrastructure.

4 Practical and Operational

4.2 Cable Management

It is likely that a significant length of charging cable will be needed for the reasons discussed. With increased cable length, combined with a thicker cable to accommodate the greater current of high power charging systems (irrespective of whether the supply to the vessel is AC or DC and/ or requires a cooling system), it is probable that cable management will be required to support manual handling of charging cables. Cable management systems can reduce the risk of injury due to dropped cables, lifting heavy cables or slips and falls, as well as making the charging system easier to use. The maximum practical cable length will depend on the charging power; 10 m is likely to be an upper limit for charging in the region of 100 kW to avoid significant cable losses. Alternatively, a higher voltage system (chargepoint to vessel) would reduce the current for the equivalent and power and help to reduce the necessary cable cross-sectional area.

The case study shown in Table 1 and again in Figure 3 shows the cable management system used for the charging of the E/S Movitz. A reel is used to stow the cable away neatly when not in use. This reel also supports the weight of the cable (the 500 kW charging system requires substantial conductor cross section and a cooling system). The reel is motorised to allow paying out and recoiling of the cable. Note that this system appears to be bespoke and not a productionised product; its safety may be improved by the installation of guards to prevent crew or passengers being injured by moving parts.

4 Practical and Operational

Gantries are an alternative cable management system which suspends the cable above the berth, supporting much of the cable weight. Gantry systems may allow for assisted pay out and retraction of the cable, allowing flexibility on berthing position.

When the risk of relative movement between the vessel and the charging system is high (whilst connected), tearaway charging connectors that disconnect the charging power before mechanically disconnecting under a designed mechanical load should be investigated to minimise damage to either the vessel and/or the charging system. Clearly, any potential health and safety impact of a connector being disconnected in this emergency situation would need to be understood.

4.3 Automated Charging Systems

Robotic, automated charging systems are of particular interest where one or more of the following is true for the target vessel(s)' operations:

- **Where the charging power is so significant that manual handling of the cable is infeasible.**
- **The time available for charging in a top-up charging scenario is minimal, and therefore making a connection quickly is key to avoiding delays to the boat's schedule.**

In addition to this, an automated charging system can be highly convenient for boat's with only a small crew. Crew tasks include embarking and disembarking passengers, loading cargo and vehicles, and manoeuvring and mooring the vessel. Crew may not have time to spare for charge cable handling, especially in a top-up charging scenario. Automated charging systems can also give greater choice for the designed location of the charging inlet on the vessel, as hard to reach or inaccessible areas are possible. This can also increase overall safety of the charging operation.

Automated e-boat charging systems are analogous to pantograph charging systems. Pantographs are commonly used for top-up charging of electric buses and power supply to trams in urban road transport. There are already a number of very successful case studies of automated charging systems being deployed for larger ferries that charge at one or more of the ferry's terminals.

4 Practical and Operational

Table 5: Forsea Ferries Aurora and Tycho Brahe Case Study [11]

Case Study: Automated Charging System 1

Name: Aurora, Tycho Brahe

Location: Helsingborg (Sweden) to Helsingor (Denmark)

Status: In operation since 2017

Vessel(s) Description: 2 x retrofitted 111 m electric ferries for 240 car, 1250 passengers. 4100 kWh battery capacity

Operator: Forsea Ferries

Project Partners & Suppliers: ABB

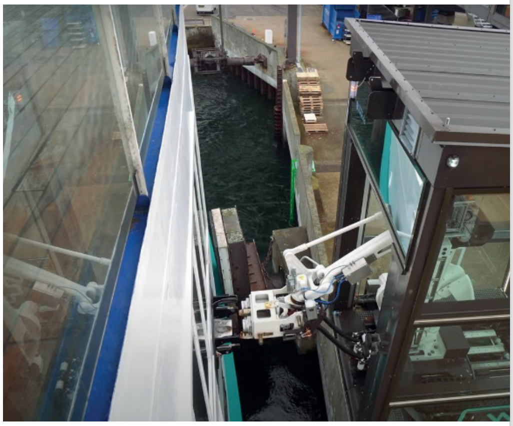


Figure 4: Charging system (from Fully Charged Show [10])

Charging infrastructure	Operational Description
Automated connection of 6 MW charging. 9 minutes charging at Helsingborg, 6 minutes at Helsingor. 45 seconds to connect charging system.	4 km crossing made 46 times a day. Battery sized to maintain state of charge between 40 and 66%.

Table 6: Ampere Case Study [14]

Case Study: Automated Charging System 2

Name: Ampere (formerly ZeroCat)

Location: Lavik, Oppedal, Norway

Status: In operation since 2015

Vessel(s) Description: 1 x new 80 m electric ferry. 120 cars, 260 passengers. 1000 kWh batteries.

Operator: Norled

Project Partners & Suppliers: Fjellstrand (ferry), Siemens (propulsion, batteries), Cavotec (charging system), Corvus Energy (BESS)

Figure 5: Charging system from Cavotec [12]

Figure 6: Charging connector lowered into ship

Charging infrastructure	Operational Description
Charging infrastructure (unspecified power) located at both terminals, supplemented by 260 kWh battery storage system. 10 minute charging duration.	20-minute journey of 5.7 km made 34 times a day. The world's first electric ferry.

4 Practical and Operational

Table 7: Ellen Case Study [15]

Case Study: Automated Charging System 3

Name: Ellen

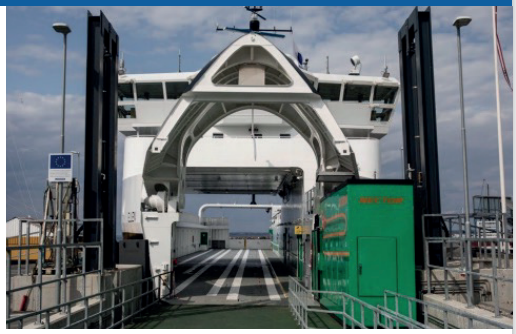
Location: Southern Denmark (mainland to Aero island)

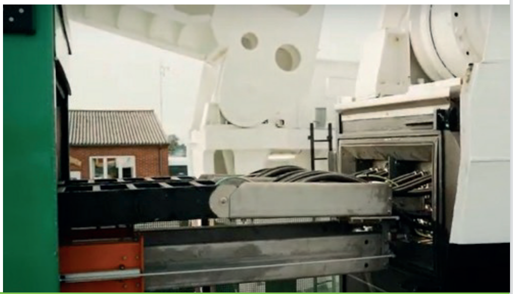
Status: In operation since 2019

Vessel(s) Description: 1 x new 30 car, 200 passenger electric vessel

Operator: Aero Ferries

Project Partners & Suppliers: Result of Horizon 2020 project E-ferry. Danfoss (Charging station), Mobimar (charging connector), Editron (Propulsion system)





Charging infrastructure	Operational Description
Charging station located on the ferry ramp at one terminal only (Soby, Aero island). Up to 4 MW charging power.	22 nautical mile crossing made 5 times a day.

Each of these three case studies has a different bespoke system, with varying levels of flexibility on mooring. The system designed for the Tycho and Aurora ferries has a reasonable amount of vertical freedom to compensate for changing tide. Likewise, the Ampere ferry's system, which lowers into the connection point on the ferry from above, is designed to accommodate some variability in the vessel's mooring position as well as relative movement with the charging station whilst connected.

4.4 Wireless Charging

Until now, only conductive charging options have been explored. An extension of automated systems is to charge without a physical connection between the charging system and the e-boat; a wireless charging system.

Wireless charging systems, of which there are various types, use a pair of coils to transfer energy from a transmitter located on the shore-side to a receiver installed on the vessel The vessel and the charging station need to be well aligned and typically at a controlled, close distance from one another (to minimise the air gap between the coils). Wireless charging is of particular interest to maritime charging, as there are several possible benefits:

4 Practical and Operational

1. **Both the charging system and vessel-side infrastructure can be sealed giving an inherently high level of ingress protection in comparison to conductive methods.**

2. **Although most efficient when perfectly aligned, wireless charging allows for relative movement between the vessel and the charging system, reducing the risk of damage of a physical connection.**

3. **Wireless charging lends itself to automation; charging may be initiated more quickly as there is no need to make and verify a physical charging connection. This can benefit top-up charging operations which have minimal time available for charging.**

Table 8 and Table 9 show two examples of operational ferries with wireless charging systems. Although different in terms of scale, both case studies show the potential benefit of a wireless system to maximise available charging time.

The small air gaps that can be needed for efficient, high power wireless charging could be difficult to maintain without the risk of a collision, which would damage the vessel and/or the charging infrastructure. Charging locations with large swells or waves pose the greatest collision risk. This risk is mitigated in the case studies shown by using a mechanical system that extends and retracts the transmitter coil as required. Nevertheless, it is unlikely that this would be sufficient for locations where rough seas are possible.

Table 8: Fredrikstad Wireless Charging Case Study [16]

Case Study: Wireless Charging System 1

Name: Fredrikstad River Ferry

Location: Fredrikstad, Norway

Status: In operation

Vessel(s) Description: 1 new 15 m electric ferry, 50 passengers.

Operator: Ostfold

Project Partners & Suppliers: Swedship (Ferry) and IPT Technology (Wireless charging system)

Charging infrastructure	Operational Description
100 kW wireless charging system on one side of the River Glomma. Transmitter coil on retractable mounting system. 145 charging sessions per day of 112 seconds.	24/7 operation. Very short river crossing.

4 Practical and Operational

Table 9: Folgeffon Wireless Charging Case Study [18]

Case Study: Wireless Charging System 2

Name:	Folgefonn
Location:	Jektavik, Norway
Status:	In operation since 2014
Vessel(s) Description:	Retrofitted ferry for 199 passengers and 76 cars. 1000 kWh battery.
Operator:	Norled
Project Partners & Suppliers:	Wartsila (integration and wireless charging), Fjellstrand (shipyard), Corvus Energy (BESS)

Figure 7: Wartsila wireless charging system for the Folgeffon [17]

Charging infrastructure	Operational Description
1.5 MW automated wireless charging, mounted on retractable arm supporting air gaps of up to 0.5 m. Paired with a mooring unit which is used to stabilise and position the vessel independent of other mooring	3.5 km route between Jektavik, Nordhuglo and Hodnanes in 10 minutes.

Both automated charging systems and wireless charging systems can offer benefits over conductive charging systems and are used for high power charging systems where the time available to charge is limited.

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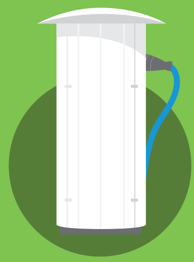
It is important to note that wireless charging is a relatively immature technology even for road transport. Therefore, an e-boat wireless charging system is likely to be a bespoke system and would need to mitigate the risk of human exposure to electric and magnetic fields (EMF) that are used for wireless charging.

4.5 Impact Protection

As with charging infrastructure designed for use by road transport, the installation of impact protection can be a simple means of reducing the risk of damage to valuable infrastructure assets. Simple devices for smaller vessels such as fenders that are attached to the shore or the vessel itself offer some protection. However, it is also important to consider protection on the land-side of the infrastructure; damage protection from a collision with most types of vehicles in this context can be achieved with bollards, kerbs or barriers.

5 Creating a Charging Network



The case studies discussed have all focussed on charging systems that are dedicated for use by either a single vessel, or a fleet of vessels under the control of a single operator. As electric boats become more prevalent, there will be a growing need for public charging infrastructure. In fact, the provision of a public network may incentivise other operators, particularly private leisure craft owners who are unlikely to have the necessary land ownership rights to install their own charging infrastructure, to transition to electric vessels.

There are several additional requirements and considerations that are applicable to charging infrastructure designed for public use, which shall be covered in this section. There are very limited numbers of public e-boat charging networks worldwide, however two case studies are provided.

5.1 Chargepoint Management System

A chargepoint management system (CPMS) – also referred to as a "back-office system" is key for public chargepoint networks. **The CPMS will handle functions such as:**

- **User authentication and management;**
- **Billing;**
- **Data capture; and**
- **Chargepoint monitoring, remote control and preventative maintenance.**

The CPMS is provided by the Chargepoint Network Operator (CPNO). The CPNO may or may not be the hardware owner, depending on the business model used for the chargepoint network (see "Ownership Models").

The data collected on chargepoint use by the CPNO can be used to provide additional services to e-boat operators (and other interested parties). These services include providing information on the location of chargepoints, displaying real-time chargepoint status (for example in-use, available, or out-of-operation), or even booking of the chargepoint for a charging session to guarantee availability. These services are provided by entities known as e-Mobility Service Providers (eMSPs). eMSPs are not restricted to a single form of mobility. For example, an eMSP could provide an application to access both e-boat and electric vehicle charging networks. Some entities will act as both eMSPs and CPNOs, whereas others will be uniquely eMSPs or CPNOs.

5 Creating a Charging Network

There are a number of chargepoint communication protocols, as shown by Table 10, already established by the EV charging industry that can be adopted by the maritime industry for public networks.

OCPP	Open charge point protocol. A common standard that allows electric vehicle charging equipment to communicate with back-office management systems. When tendering separate contracts for chargepoint installation and chargepoint operation, the equipment installed should be OCPP compliant. The current version of this standard is OCPP 2.0, but version 1.6 is still widely used.
OSCP	Open smart charge protocol. A common standard that allows electric vehicle charging equipment to communicate with energy management systems and/or electrical distribution network operators, for the purposes of grid management. If chargepoints are intended automatically respond to stresses on the grid during peak periods of electrical demand, the chargepoint back-office systems used should be OSCP compliant. The current version of this standard is OSCP 2.0.
OCPI	Open charge point interface protocol. A common standard that allows chargepoint back-office systems to communicate with eMobility Service Providers. When tendering separate contracts to a chargepoint operator and a chargepoint network provider, the chargepoint management system should be OCPI compliant. The current version is OCPI 2.2.
OCHP	Open Clearing House Protocol. A common standard that allows communication between service providers and chargepoint operators for the clearing operations (payments). When tendering to multiple chargepoint operators (e.g. using a framework) that are intended to be accessible through multiple payment platforms, the chargepoint operators and network providers should be OCHP compliant. The current version is OCHP 1.5.

Table 10: Open data protocols associated with EV charging infrastructure

Since 2009, the Open Charge Alliance has promoted the benefits of the OCPP in order to make EV networks open and accessible. OCPP is now the de facto protocol for EV network communications.

5 Creating a Charging Network

5.2 Chargepoint User Authentication

In addition to a working CPMS, unless the chargepoint is intended for open-access use, a method will be needed to authenticate and bill users of the chargepoint. The two most common systems are mobile app authentication or Radio Frequency Identification (RFID) cards or fobs. Alternatively, pay-as-you-go card payment options can be used, although such systems do not offer as rich data collection as those which require the user to create a billing account.

Case Study: Public Charging Network

Name:	Aqua Supercharger Network
Location:	Côte d'Azur, Mediterranean, South of France
Status:	1st generation – in operation since 2019 in Monaco, Cannes, St Tropez 2nd generation – in development with strategic partner, Tritium [20].
Vessel(s) Description:	Used by customers with Vita Power yachts but also accessible by others for top-up charging.
Operator:	Aqua Superpower
Project Partners & Suppliers:	ABB (first generation infrastructure) and various host locations including Yacht Club de Monaco. Second generation infrastructure being developed by Aqus engineering supplier.

Figure 8: Aqua Superpower charger [19]

Charging infrastructure

The first-generation charging infrastructure is 75 kW DC via CCS connector and lower powered AC charging via Type 2 connector. User is authenticated using an RFID card. Have been installed on permanent hard standing shore-side infrastructure and floating pontoons.

The second-generation infrastructure will be a dual CCS connector (2 x 75 kW), with a fully marinised and air-conditioned casing.

Table 11: Aqua Supercharger Network Case Study [20]

5 Creating a Charging Network

5.3 Dual-use Chargepoint Hardware and Networks

In niche locations, it may be possible to deploy hardware that can be used by electric vehicles and e-boats. Targeting multiple users may improve the business case of the chargepoint network. Any business case improvement assumes there is no competition for chargepoint use between e-boats and EVs.

For example, if the e-boat is solely charged overnight but its berth is adjacent to a car park it could be possible to allow the charger to be used by EVs during the day. Clearly there will be limited cases in which this is feasible. However, Table 12 shows an example of charging infrastructure that has been designed for use in such a market in Amsterdam.

Case Study: Dual-Use Case Charging

Name:	Amsterdam Canal Boats
Location:	Amsterdam, The Netherlands
Status:	In operation
Vessel(s) Description:	Various electric canal boats. 75% of which are now electric ahead of upcoming 2025 diesel ban.
Operator:	Various
Project Partners & Suppliers:	Various

Figure 9: Simple industrial socket chargepoint and Type 2 chargepoints for both e-boats

Charging infrastructure

The majority of Amsterdam's electric canal boats are charged using simple AC industrial sockets or Type 2 electric vehicle sockets.

However, there are various innovations appearing in the city, including the mobile battery provision solutions such as the one offered by SKOON detailed in Table 4. Another example is the dual-purpose charging solution offered by Bootladen, which has industrial outlets for use by electric boats and a Type 2 outlet for use by electric vehicles.

Table 12: Amsterdam Electric Canal Boat Infrastructure Case Study [21]

5 Creating a Charging Network

5.4 Ownership Models

The preferred ownership model for a charging network depends on its intended use case. There are four commonly used models. In each, elements of the capital cost, operating cost and revenue are shared differently between the landowner and the "supplier" – a chargepoint network operator.

OWNERSHIP MODEL	HARDWARE	GROUNDWORKS	BACK-OFFICE	ELECTRICITY	MAINTENANCE	REVENUE [2]
Own and Operate	100%	100%	100%	100%	100%	100%
External Operator	100%	100%	0%	100%	100%	90%
Lease	0%	0%	0%	0%	0%	20%
Concession	0%	100%	0%	0%	0%	30%

*Table 13: Proportion of costs incurred and revenue retained by **landowner** across ownership models*

When making decisions on chargepoint ownership models, it is important to also consider the non-financial implications of each model. The most obvious distinctions between each ownership model are in how costs and revenue are shared. There is also a variable share in the contractual control over how the chargepoints are operated. In most cases, the greater the investment made by an external supplier(s), the greater the control of the supplier(s). In turn, this means that the landowner will have less control over the quality and type of service(s) provided to e-boat and EV users on their site which, in a worst-case scenario, could create a negative perception of the landowner that they cannot easily address. Regardless of the ownership model pursued, contractual terms should be sought that ensure both financial and reputational risk are distributed fairly, and that the level of service to EV users is maintained to the satisfaction of the landowner.

[2] Note that the revenue share percentage for the external operator; lease and concession models is indicative only and is representative of the EV industry. The exact revenue share would need to be agreed with the landowner and supplier. At the time of writing, given the nascency of the UK e-boat market, it is highly unlikely that suppliers would be willing to offer fully funded ownership models.

5 Creating a Charging Network

Own and Operate

The "Own and Operate" model represents the most involved level of intervention for the landowner. All costs are covered and all revenue is retained by the landowner. The landowner prepares the site, including groundworks and electrical connection, procures the charging equipment, funds the installation of the equipment and purchases a back-office system to manage the chargepoint. All revenue is hence retained by the landowner. By comparison with other ownerships models, own and operate offers the greatest revenue opportunity but also the greatest risk to the landowner. In this model, the landowner has control over all aspects of how the chargepoint is operated, including tariffs and network compatibility.

External Operator

The "External Operator" model is identical to the "Own and Operate" model in all regards except that the operation of the chargepoint is agreed with an external supplier. The supplier then provides the back-office system at no direct cost, in return for a share of net revenue gathered by the chargepoint. This ownership model removes some of the operating expense associated with the chargepoint, therefore reducing the risk whilst retaining most of the revenue gathered by the chargepoint. The capital investment is still entirely provided by the landowner and, in all regards except for network compatibility, the landowner retains control of how the chargepoint is operated.

Lease

The "Lease" ownership model represents the lowest level of investment from the landowner. In this model, all capital and operating costs are covered by an external supplier, with a small share of revenue retained by the landowner in return for making their land available to the chargepoint supplier. This model involves the least exposure to financial risk but also the least opportunity for revenue generation.

The "Lease" model is not without other risk or challenges, however. The success of this model relies on sourcing an external supplier with the appetite to accept the financial risk, which will be dependent on the type of site being offered and the revenue generating potential that it presents. In less ideal sites, external suppliers may seek additional contractual assurances to mitigate long-term risks, such as having autonomy over usage tariffs, a longer lease period, 24-hour access and/or favourable contract termination conditions. Another key risk to the landowner is that, as the external supplier has ownership of the electrical connection point, the landowner may incur additional costs associated with asset transfer of the connection point at the end of the contract period.

Concession

The "Concession" model is similar to the "Lease" model but much of the risk to the landowner is mitigated in exchange for a lower share of revenue. The key difference between the "Concession" and "Lease" models is that the landowner provides the capital investment to establish an electrical connection point for an external supplier to install and operate a chargepoint. The benefit of this model is that, as the landowner retains ownership of the connection point, there is no lasting obligation to the external supplier, beyond the terms of their concession. This increases the control of the landowner over the quality of service.

5 Creating a Charging Network

Given that the e-boat industry is still in its infancy, there are very few active chargepoint operators. Table 11 gave the case study of the Aqua Superpower network which is a public network, however the foundation of the Aqua Superpower business model is its own superyacht customers. It is highly likely that early chargepoint networks will be established in a similar vein by opening up chargepoints that have been deployed for a particular use-case for public use. Alternatively, the public sector may wish to incentivise the uptake of electrified maritime in their local region by deploying a charging network where the business case is unsustainable in the short or medium term.

5.5 Interoperability

In the short-term, if a charging network is to be deployed to be used multiple e-boats operators, a standardised connector is required to ensure connection is physically possible. This is where existing standards or the development of a new e-boat charging infrastructure standard, as discussed in the following section, can be advantageous.

In the EV charging industry, the term interoperability refers to the ability of a user to “roam” between different networks without the need for multiple accounts. This simplifies and improves the customer experience. In the UK there are a large number of charging networks and, although agreements are being created, there is some way to go before the public network is fully interoperable. Whilst this is not currently a concern for the maritime industry, with very few established public charging networks, as the industry matures there are lessons that should be learnt from the EV industry.

An extension of this concept would be to ensure that “roaming” is possible between EV and e-boat charging networks. This would allow an EV driver to use e-boat charging infrastructure using the same account that they use for public EV charging. To ensure this, a designer of a public charging network for electric vessels could assess the interoperability agreements with existing EV networks that potential suppliers have in place as part of the procurement process.

6 Existing Standards and Solutions

The previous case studies that have shown that there are currently three options for e-boat charging connections:

1. Use of existing industrial connectors to standards such as BS EN 60309 (Plugs, socket-outlets and couplers for industrial purposes), commonly used in marinas, or IEC 80005 (Utility connections in port).
2. Use of chargepoints and connectors designed for charging of electric vehicles, typically Type 2 AC or Combined Charging System (CCS) DC connections as per BS EN 61851 (Electric vehicle conductive charging system) and BS EN 62196 (Plugs, socket-outlets, vehicle connectors and vehicle inlets. Conductive charging of electric vehicles)
3. Provision of bespoke infrastructure designed for a specific use case. This is particularly common for larger electric ferries that require higher power connections.

Table 14 contrasts the advantages and disadvantages of each option:

	ADVANTAGES	DISADVANTAGES
1. Standard industrial and shore-power connector	Include standards that are designed for high power connections and marine use. Standardised connectors. Also facilitate power supply for auxiliary systems.	Not designed for the charging of batteries. AC, and therefore require the vessel to have an on-board charger. This limits the charging power.
2. EV charging standards	Designed for battery charging. Designed for repeated connection and disconnection. Standardised connectors.	Charging infrastructure and connectors not designed for a maritime environment as standard. Designed for battery charging and therefore will not support auxiliary loads if these are not powered by the e-boat battery.
3. Bespoke infrastructure	Designed specifically for the use case	Not a recognised standard and therefore not appropriate for a charging network with multiple users.

Table 14: Comparison of available e-boat charging infrastructure options

There are disadvantages for each of the available options and therefore a clear need for an equivalent of the EV charging standards for electric boats to support the development of the industry.

7 Recommendations

STAKEHOLDER		RECOMMENDATIONS
GROUP	EXAMPLE STAKEHOLDERS	
Regulatory Bodies	**IEC, BSI, IET**	Lead the creation of the necessary e-boat charging standards in conjunction with DfT
National Government	**Department for Transport**	Provide research and innovation funding for e-boat and charging infrastructure projects via Innovate UK and MarRI-UK such as the recently released Clean Maritime Demonstration competitions [22]. Develop a grant scheme specifically for the installation of charging infrastructure for e-boats – to be managed alongside the OZEV schemes
Local Government	**Plymouth City Council**	Set target dates for zero emission ferry operation in Plymouth Sound. Provide funding to develop local charging networks (e.g. Plymouth and its local ferry network). Include e-boats and e-boat charging as part of local air quality and environmental strategies. Provide leadership to the local maritime industry for e-boats and e-boat charging. Provide a focused business support programme to enable the maritime sector in Plymouth to diversify and develop low carbon products and services.
Other Funders	**MarRI-UK**	Provide funding opportunities for the development of e-boat charging infrastructure solutions and networks, in addition to electric vessels. Advocate and support the development of necessary standards.
Other Policy Makers	**International Maritime Organization**	Support the development of the e-boat charging infrastructure industry through the Marine Environment Protection Committee by sharing best practice and advocating the development of the necessary standards and funding streams with members and affiliated bodies. Inclusion of e-boat charging infrastructure as part of strategies. E.g IMO strategic direction 3 – "respond to climate change".
Chargepoint OEMs	**e.g. from this white paper - Wartsila, ABB, Swarco, IPT Technology, Bootladen**	Work with the regulatory bodies to develop e-boat charging infrastructure standards. Use information provided in the considerations section to inform design decisions.
Boat Operators	**e.g. ferry operators**	Refer to the key information in this document when making procurement decisions on e-boat charging infrastructure
Landowners	**e.g. port & marina operators**	Work with Local Government and boat operators to deploy e-boat charging infrastructure to support the uptake electric boats. Refer to this document when making procurement decisions, designing the charging network and selecting sites, and selecting business models.
Trade Associations	**e.g. UK Major Ports Group**	Support the development of an e-boat charging standard. Share best practice.
Distribution Network Operators	**e.g. Western Power Distribution**	Provide open data to allow stakeholders looking to deploy e-boat charging infrastructure to make good site selection decisions. Work with stakeholders to support rollout of infrastructure at least cost.

8 Case Study Map

Ten case studies are used in this report to highlight key aspects of infrastructure used for e-boat charging. These are shown in Figure 10.

Figure 10: Case Study Map

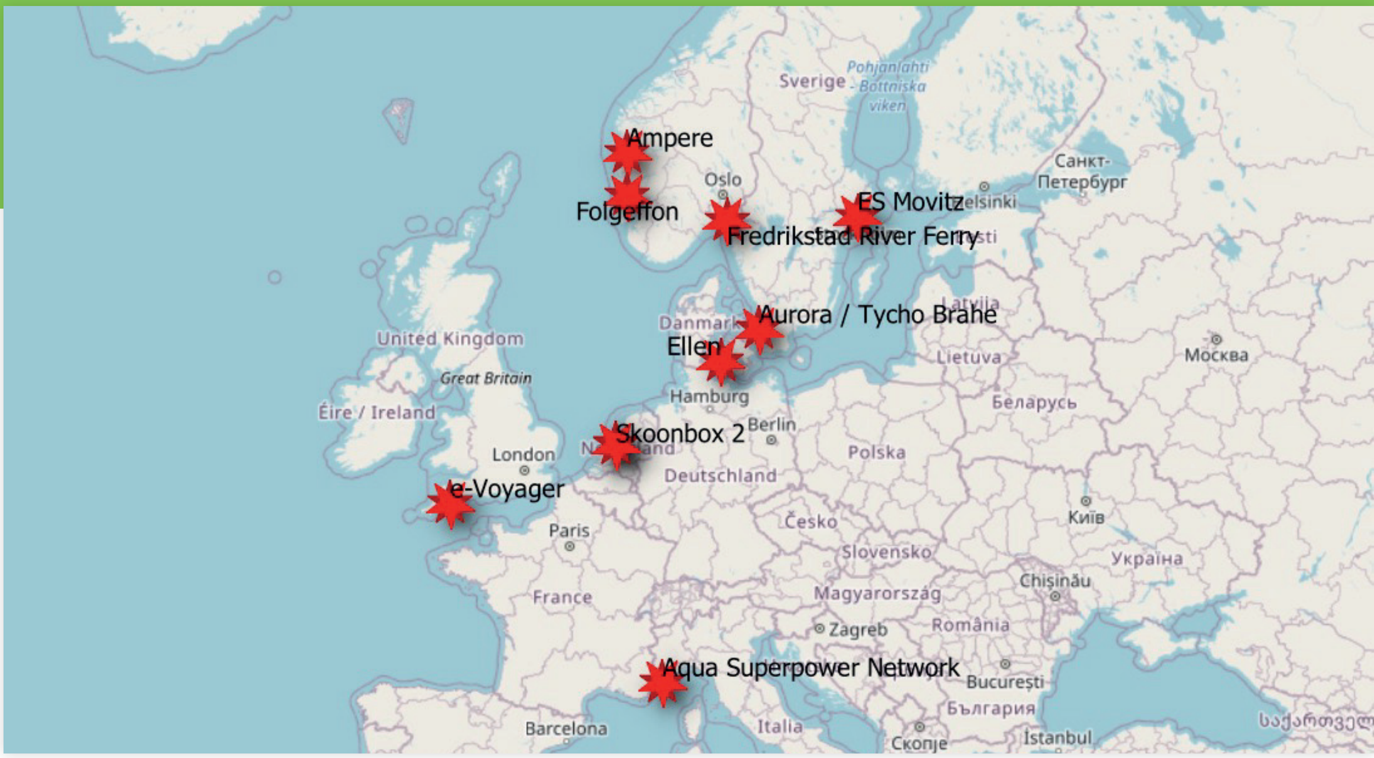


Table 15: Case Study List

	NAME	OPERATOR	LOCATION	TITLE
1	ES Movitz	Green City Ferries	Stockholm, Sweden	Top-up DC Charging System
2	e-Voyager	Plymouth Boat Trips	Plymouth, UK	Out-of-Operation AC Charging and Grid Connection
3	Skoonbox 2	Skoon Energy	Amsterdam, The Netherlands	Mobile Battery Energy Storage System (BESS)
4	Aurora / Tycho Brahe	Forsea Ferries	Helsingor, Denmark and Helsingborg, Sweden, UK	Automated Charging System 1
5	Ampere	Norled	Lavik, Norway	Automated Charging System 2
6	Ellen	Aero Ferries	Aero Island, Denmark	Automated Charging System 3
7	Fredrikstad River Ferry	Ostfold	Fredrikstad, Norway	Wireless Charging System 1
8	Folgeffon	Norled	Jektevik, Norway	Wireless Charging System 2
9	Aqua Superpower Network	Aqua Superpower	Cote d'Azur, France & Monaco	Public Charging Network
10	Amsterdam Canal Boats	Various	Amsterdam, The Netherlands	Dual-Use Case Charging

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10 About the Author

Cenex was established as the UK's first Centre of Excellence for Low Carbon and Fuel Cell technologies in 2005.

Today, Cenex focuses on low emission transport & associated energy infrastructure and operates as an independent, not-for-profit research technology organisation (RTO) and consultancy, specialising in the project delivery, innovation support and market development.

We also organise Cenex-LCV, the UK's premier low carbon vehicle event, to showcase the latest technology and innovation in the industry.

Our independence ensures impartial, trustworthy advice, and, as a not-for-profit, we are driven by the outcomes that are right for you, your industry and your environment, not by the work which pays the most or favours one technology.

Finally, as trusted advisors with expert knowledge, we are the go-to source of guidance and support for public and private sector organisations along their transition to a zero-carbon future and will always provide you with the insights and solutions that reduce pollution, increase efficiency and lower costs.
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