CROSS RIVER PARTNERSHIP
CLEAN AIR LOGISTICS FOR LONDON

Department for Environment Food & Rural Affairs

NZMS

# A DEEP DIVE: FROM ALBERT TO ALB-E

## Retrofitting for London's first fully electric workboat

## Contents



This Deep Dive was developed by Cross River Partnership (CRP) as part of its Defra-funded Clean Air Logistics for London Programme. CRP would like to recognise and thank Defra as the funder for this document.

Read more about the retrofit from **Albert to Alb-E; London's first fully electric workboat**.

# 01 Overview

In January 2023, Cross River Partnership partnered with Net Zero Marine Services to retrofit their workboat from **Albert to Alb-E; London's first fully electric workboat.**

The project aimed to produce an example of how existing inland vessels could tackle reducing emissions on the Thames. Whilst vessels on the Thames only account for a small proportion (1%) of London's air pollutant emissions, this is expected to grow as road vehicle emissions fall and river freight increases.

The project involved replacing the vessel's diesel-fuelled combustion engine with a carbon-neutral electrification system and conducting emissions testing before electrification to quantify the air pollution that would be eradicated.

The project was developed using lessons from CRP's Mayor's Air Quality Funded project, Clean Air Thames, which focused on selective catalytic reduction which breaks down dangerous nitrogen oxides into nitrogen and water.

**"The retrofit of the Alb-E shows how important organisations such as Cross River Partnership are for the river Thames. The marine sector has taken a step forward here and we hope that many workboats will follow in Alb-E's footsteps."**

**Miles Cole, Managing Director, Net Zero Marine Services.**

From May to July, Albert was dry-docked at Eel Pie Island, Twickenham, where the emissions testing and retrofit were carried out by Net Zero Marine Services, Thames Marine Services and Emissions Analytics.

This CALL Deep Dive will provide background to air pollution on the Thames, outline the process of the vessel retrofit and emissions testing, present key emissions data, and reflect on learnings.

# 02 Air Pollution on the Thames

**Inland vessels and air pollution**

Rivers and canals have long been conduits for freight movement. A network of canals was constructed during the industrial revolution, and along with natural rivers, UK watercourses played an instrumental role in moving goods in and out of UK cities.

Now, over 200 years later, waterborne freight still plays an important role in the UK economy, with waterways moving 24.7 billion tonne-kms in 2020, and accounting for 13% of all goods moved within the UK. The River Thames is by far the most active waterway, accounting for 58% of all goods moved by inland waterway.

Transporting goods by inland vessels brings various benefits, including low noise levels, a relatively low carbon footprint, and easing traffic congestion on strategic road networks and logistics hubs. Across Europe, inland waterway logistics are prominent, with 200 inland ports, 37,000km of waterways, and 17,000 vessels moving 150bn tonnes of cargo each year.

The EU is aiming to shift cargo movement from roads to low and zero emission vessels – there are plans to increase inland shipping by 25% by 2030, and 50% by 2050. This translates to moving 75% of freight currently moved by road onto the waterways and rail. However, the fleet is mostly composed of diesel boats pushing non-propelled barges, which raises issues around air quality particularly in urban areas where nearby areas are often densely populated. For instance, in the the Danube, there are 332 barge pushers, and it is estimated that each barge pusher emits 196 tonnes of $CO_2$ per navigation.

Studies tend to use modelling and estimates to measure emissions along inland waterways due to lack of established monitoring infrastructure. Despite a difference in local context, climate, and urban form, all demonstrate heightened levels of sulphur dioxide, nitrogen oxides, particulate matter, and volatile organic compounds in the areas immediately surrounding the river. More generally, pollution in river-adjacent cities is generally recorded as higher than in non-river-adjacent cities.

**Air Pollution on the Thames**

In 2018 a series of news articles highlighted that vessels on the Thames and other waterways in London are not regulated in the same way as vehicles in London's low emission zone, as the river is governed separately by the Port of London Authority (PLA).

## Air pollution on the Thames

Vessels on the Thames were reported to be emitting 100s times more than the legal limit of emissions for road vehicles, particularly older vehicles and dirtier fuels that are high in sulfur oxides and nitrogen dioxides. A key concern highlighted is the effect on air quality in the area immediately surrounding the river itself.

The PLA's 2018 Air Quality Strategy set out an evidence base which outlines different freight scenarios. These compare emissions from vessels with emissions from lorries:

- Emissions of NOx and PM10 relative to tonnes carried is higher by vessel than by road
- CO2 emissions per tonne carried are significantly lower by vessel than by road
- Concentrations of emissions from the river decrease rapidly due to dispersion, meaning the emissions concentrations at point of exposure on land is significantly lower than the point of exposure from a road vehicle
- The emissions inventory demonstrated that majority of emissions from the Thames occur to the East of Greater London
- The largest sources of pollution are container ships (22%), roll-on-roll-off ships (21%), and inland passenger vessels (14%)

## Alleviating pollution in London

In 2019, the DfT put out a call for evidence aiming to gather information about the extent of emissions from vessels in the UK. This sits within the DfT's Maritime 2050 Strategy which aims to transition to low and zero emissions water vessels.

Several actions have been taken within London to alleviate the pollution from vessels on the Thames and encourage a transition towards low emission river freight.

The PLA's Thames Strategy established the aim of reducing harmful emissions from vessels within the Thames including a 40% reduction in particular matter and NOx by 2031, and a net zero CO2 target by 2051.

Other actions taken to reduce vessel emissions on the Thames include:

- CRP's Clean Air Thames project to retrofit vessels with exhaust treatment
- Thames Clipper introducig hybrid ferries
- PLA purchasing a Leader Hybrid Boat

These schemes indicate that there is appetite for exploring both battery electric as well as alternative fuels in the transition towards low emission vessels and shipping.

Despite these initiatives, the transition to greener vessels has been slow in the UK. Currently, there are no UK laws in place to limit the vessel emissions.* Additionally, operate can reclaim excise duty on mineral (hydrocarbon) oil.

Electrification of vessels is fairly nascent, and the battery technology is not currently at the advancement and cost point required for large scale electric shipping. However, some vessels are suited to trialling new technologies, such as ferries with defined routes and smaller goods ships with fixed routes. Charging can be planned, and energy use monitored and compared effectively.

** The United Nations' International Maritime Organistion (IMO) Tier III emissions standards limit nitrogen oxide emissions from 3.4 to 2 grams per kilowatt hour. However, it does not have legislative powers.*

# 03 Process

## Vessel Retrofit


CRP had conversations with vessel operators and industry experts to identify potential participants to complete the vessels retrofit within eight months. The tight deadline proved to the biggest hurdle for vessel operators and CRP was limited to operators who already had a retrofit underway or who proposed a relatively simple retrofit with access to resources, including parts and labour.

Other factors included:

- Vessel type, use and estimated life expectancy following the refit
- Vessel operations along the Thames
- Supplier quotes for the proposed work
- Financial health of the operator

Net Zero Marine Services' (NZMS) were selected to replace the Albert's diesel engine with an ePropulsion's H-series electric inboard motor powered by an E-Series lithium battery. NZMS collaborated with Thames Marine Services (TMS), a marine engineering service, to complete the vessel retrofit.

## Retrofit Cost

Parts and labour costs to retrofit Alb-E are as follows:

| Item | £ |
|---|---|
| Battery system | 71,400.00 |
| E-motor | 7,200.00 |
| Other parts and accessories | 15,372.00 |
| Drydocking, maintenance | 16,000.00 |
| Material and supplies | 4,500.00 |
| Waste disposal, miscellaneous and consumables | 1,550.00 |
| Labour & Travel | 20,924.00 |
| **Total** | **136,946.00** |

**Vessel Specifications**

Length: 10.30m
Beam: 3.30m
Air Draft: 2.74m
Classification: PLA Category C & D
Stern deck area: 7.29m2
Passenger capacity: 10 pax
Vessel number 4568
Operating from Teddington to Gravesend (Category C and D waters)

Equipment:
- Davit (SWL: 225kg)
- Heated cabin
- Passenger guards
- VHF Radio

| Pre-retrofit | Post-retrofit |
|---|---|
| Speed: 7 knots | Hull speed: 7.8 knots at 40kW<br>Maximum speed:10.3 knots at 60kW |
| Propulsion: Perkins Sabre M130C | Propulsion: ePropulsion H-60 motor |
| Bunker (fuel tank) capacity: 700 litres | Battery system: 14 packs + 1 high voltage box: total 109kWh (202Ah) 540VDC output<br><br>Onboard charger 6kW, 240V, Single phase 12-hour charge 0-100%<br><br>Shoreside HV 30kW, 380V, 3 phase 4-hour charge 0-100% |
| | Range: 75 nautical miles |


## Vessel Emissions Testing

Emissions Analytics were selected as the emissions monitoring provider to gather real-time emissions data, whilst the vessel was docked at Eel Pie Island in Twickenham, Greater London. The monitoring aimed to provide before and after emissions data to quantify how effective the retrofit was in reducing or removing harmful emissions and improving air quality on the Thames.

**“By leveraging the insights gained from both the overall emissions results and the GCxGC-TOF-MS analysis, decision-makers can make informed choices to protect the environment, improve air quality, and safeguard human health.”**

**Emissions Analytics**

Emissions Analytics used Portable Emissions Measurement Systems (PEMS), which facilitated the calculation of average emissions for each duty cycle and fuel economy. Testing was conducted on 26th April 2023, measuring the following air pollution components:

- Carbon dioxide (CO2)
- Carbon monoxide (CO)
- Nitric oxide (NO)
- Nitrogen dioxide (NO2)
- Nitrogen oxides (NOx = NO + NO2)
- Total hydrocarbons (THC)
- Particulate matter (PM)
- Volatile organic compounds (VOC)

## Testing Equipment

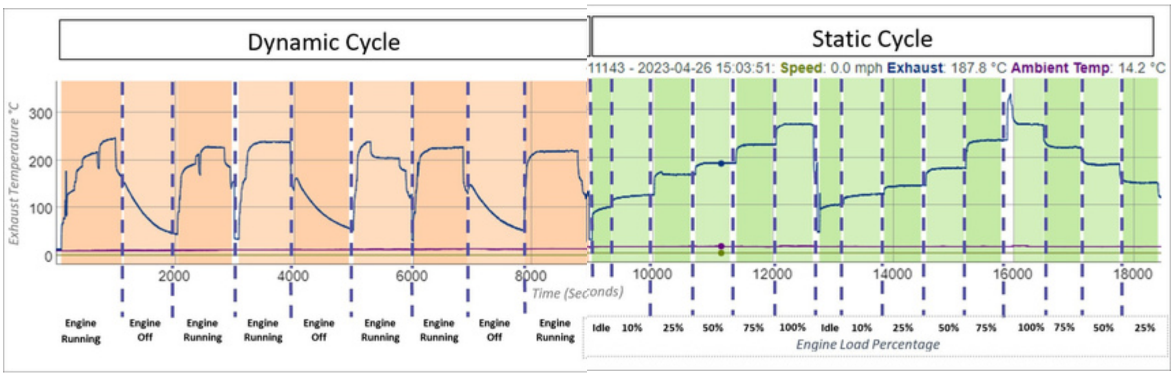
- SEMTECH-LDV, a flow tube mounted on the vessel's exhaust pipe to measure total flow independently of the vehicle’s systems. The analyser measures CO, CO2, NO and NO2 gases.
- SEMTECH-FID, a Flame Ionization Detector that measures THC.
- Pegasor Mi3, a particle sensor that uses a diffuser measurement technology to quantify, in this case, PM.
- Thermal desorption tubes to store exhaust samples that were later analysed in Emissions Analytics' laboratory for VOC.

## Testing Methodology

Tests were run in two cycles:

**1. A dynamic cycle** simulating the vessel's vessel's typical operation of collecting and delivering crew to other vessels or the opposite bank. This cycle involved periods of engine ignition and underload, as well as periods of the engine being off to cool down. To account for this, the simulated drive was repeated five times.

**2. A static cycle** which fully characterised the engine's emissions across its entire rev range. This cycle followed the ISO 8178 "Non-Road Steady Cycle" test, which consisted of multiple load steps at different percentages of engine load. The cycle was conducted twice, with the gaseous emissions' measurements being captured using 10 thermal desorption tube samples in total.





The load steps were as follows:

- 5 minutes for the engine to settle
- 10% load for 10 minutes with VOC sample
- 25% load for 10 minutes with VOC sample
- 50% load for 10 minutes with VOC sample
- 75% load for 10 minutes with VOC sample
- 100% load for 10 minutes with VOC sample

Overall, the emissions analysis provided a comprehensive characterisation of the engine's emissions output across different load steps and operational scenarios and is summarised in the two tables.

# 04 Performance

**Emissions Monitoring Results**

Baseline tests carried out by Emissions Analytics show that by replacing Albert's diesel engine with an electric motor and battery, the following emissions have been avoided.

| | Dynamic Cycle (30-min round trip) | Dynamic Cycle Test | | Static Cycle Test | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cold start | Warm start | Engine Load 0.1 | 0.25 | 0.5 | 0.75 | 1.0 | Overall |
| Carbon dioxide, $CO_2$ *grams per second* | 3.92 | 2.65 | 2.6 | 1.28 | 1.72 | 2.77 | 4.53 | 5.64 | 2.95 |
| Carbon monoxide, CO *milligrams per second* | 17.6 | 14.2 | 10.5 | 7.6 | 11.2 | 15.3 | 19.4 | 19.5 | 14.3 |
| Nitric oxide, NO *milligrams per second* | 62.0 | 43.3 | 40.3 | 10.0 | 18.6 | 43.0 | 71.9 | 93.9 | 43.6 |
| Nitrogen dioxide, $NO_2$ *milligrams per second* | 9.3 | 6.8 | 5.9 | 3.3 | 4.2 | 7.1 | 9.8 | 10.1 | 6.9 |
| Nitrogen oxides, NOx *milligrams per second* | 71.3 | 50.2 | 46.2 | 13.3 | 22.7 | 50.2 | 81.6 | 104.0 | 50.6 |
| Total hydrocarbons, THC *milligrams per second* | 12.0 | 8.5 | 7.7 | 4.7 | 8.8 | 11.5 | 14.6 | 15.8 | 11.0 |
| Particulate matter, PM *milligrams per second* | 0.019 | 0.013 | 0.013 | 0.025 | 0.021 | 0.017 | 0.02 | 0.031 | 0.021 |

The table above compares emissions per second from a 30-minute round trip on Albert compared with simulated dynamic and static tests.

Assuming:

1. Alb-E operates one hour per day, 250 days per year; and
2. Using the most conservative numbers, i.e. results from the dynamic cycle, warm start, as highlighted in the table

switching from diesel fuel to electric power eliminates of **2.34 tonnes of CO2, 41.58 kg of NOx and 0.012 kg of PM annually**.

A less conservative assumption would be to consider the approximate amount of diesel burned during the 30 minute round trip: 2.73 litres. Operating 250 hours a year, this would mean 3.6 tonnes of carbon dioxide equivalent (CO2E)* has been averted annually.

**Calculated using the UK government's 2023 Greenhouse Gas Conversion Factors for mineral diesel at 2.66 kg CO2e per litre.*

## 04 Performance

### Projected Cost Savings

Despite the cost to retrofit Alb-E, the initial investment will lead to a significant reduction in fuel and maintenance costs over time. Although both vary, electricity costs are generally lower diesel costs. This means electricity is cheaper per kilometre than diesel.

In Alb-E's case, as of 27 September 2023, charging costs were approximately £0.52 (or **£56.68** for a fully charged battery). Alb-E has a range of 75 nautical miles.

Assuming the same conditions over the same distance, running a 130 horsepower engine at 7 knots, diesel fuel would cost approximately **£246***, at £1.35 per litre.

Additionally, there will be lower maintenance costs, as an electric motor has fewer moving parts than a diesel engine.

**Based on a typical fuel consumption of 3.74 imperial gallons per hour (approx. 17 litres per hour).*

**"We are pleased to have successfully helmed the creation of London's inaugural carbon-neutral, electric vessel project...Our team designed the electrical package to ensure a speed and range compatible with the needs of a workboat operating on the Thames. Alb-e sets a new benchmark with its capability to traverse the full length of the tidal Thames on a single charge."**

**Jonathan Angus, Director, Thames Marine Services Engineering**


### Learnings

As well as capturing emissions data the retrofit process provided an opportunity to capture key learnings and challenges from the process. Overall, vessel operators would like to operate cleaner vessels. Finding solutions to the following challenges will

- High investment costs is a challenge for struggling vessel operators.
- There are no binding legal requirements for vessels to be cleaner, therefore no real incentive for operators to upgrade their vessels.
- Converting vessels from diesel powered to electric is still rare in UK, and there isn't a standardised licensing system for such vessels. Obtaining licencing for such vessels could prove difficult, but not impossible, for operators of such vessels.

# 05 Conclusion

CRP supported Net Zero Marine services to retrofit their workboat, Alb-E (formerly named Albert), converting it from a diesel- to electric-powered engine as part of our Defra-funded Clean Air Logistics for London project which aimed to improve air quality across London.

Prior to work on the boat starting, an exhaust monitoring exercise was carried out which showed that replacing the diesel engine with an electric motor resulted in 2.34 tonnes of $CO_2$, 41.58 tonnes of $NO_x$ and 0.012 tonnes of PM eliminated each year.

Despite the cost to retrofit the vessel, at approximately £137,000, the investment has resulted in reduced ongoing costs for Net Zero Marine Services due to less maintenance required for the motor and cheaper charging costs.

Additionally, the company has placed itself ahead of the curve pre-empting future legal requirements to cut emissions from vessels. Vessels like Alb-E, in addition to ever-improving infrastructure and services along the river, are a step in the right direction for utilising the Thames to the fullest in a truly sustainable way.


**CRP river and logistics related reports and guidance:**

- Light Freight: Design Solutions for Thames Freight Infrastructure
- River Freight Monitoring: Butler's Wharf and Dartford Pier
- Getting Started with River Freight: A Guide for Businesses
- River Freight Pilot Case Study: Summer 2022
- A Deep Dive: London Light Freight River Trial
- Thames Freight Infrastructure: Design Guidance for Piers

**CRP's Thames Directory:** CRP's interactive web tool that provides information about utilising The River Thames to transport goods into London.

If you would like further information about anything that has been included in this guidance, please get in touch:

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