IWA VISION FOR SUSTAINABLE PROPULSION ON THE INLAND WATERWAYS

EXECUTIVE OVERVIEW

1. Recognising the UK Government's strategy to reduce emissions from diesel and petrol engines, IWA formed its Sustainable Propulsion Group in 2019 to identify and monitor developments which will enable boats on the inland waterways to fully contribute to the Government's stated aim of zero CO_2 emissions by 2050.

2. The Group has identified a number potential solutions that it recommends should be progressed in order to ensure that boats used on the inland waterways do not get left behind in technological developments. These are outlined in more detail in this paper.

3. To ensure that the inland waterways continue to be sustainable for future generations, and continue to deliver benefits to society and the economy, IWA has concluded that national, devolved and local government should progress the following initiatives:

- Investment in infrastructure through the installation of 300 shore power mains connection charging sites across the connected inland waterways network. This would improve air quality by reducing the emissions from stoves for heating and engines run for charging batteries, as well as enabling a move towards more boats with electric propulsion.

- Working with navigation authorities, investment in a national dredging programme across the inland waterways to make propulsion more efficient. This will also have additional environmental benefits on water quality and increasing capacity for flood waters.

- Research and investment into the production, use and distribution of biofuels. This will be necessary to reduce the environmental impact of existing diesel engines which, given their longevity, will still be around until well after 2050.

- Research and development of alternative forms of propulsion for use in future and current new build boats; including hydrogen production and distribution, fuel cells (proton exchange membrane, solid oxide, methanol/ethanol) and the use of supercapacitors.

The Inland Waterways Association
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1. Background to the Inland Waterways Association

1.1 The Inland Waterways Association (IWA) is the membership charity founded in 1946 that works to protect and restore the country's 6,500 miles of canals and river navigations[1]. IWA is a national organisation with a network of volunteers and branches who deploy their expertise and knowledge to work constructively with navigation authorities, government and other organisations.

1.2 IWA has a network of local branches that champion inland waterway navigation and restoration issues across the country. IWA members are passionate about all the ways in which people can enjoy the waterways, such as boating, angling, cycling and volunteering, as well as simply walking along the towpath to enjoy the heritage and wildlife.

1.3 Recognising the Government's strategy to improve air quality by reducing emissions from diesel and petrol engines as part of reaching zero CO_2 emissions by 2050[2], IWA formed its Sustainable Propulsion Group, a small group of volunteers with qualifications and experience in engineering, chemistry and technical knowledge of boats (see Appendix 3). It is this Group's work to date that forms the basis of this paper which aims to set out a vision for future propulsion which will keep the inland waterways viable for all.

2. Introduction

2.1 The value that inland waterways bring to our nation includes improved health and well-being for the whole population through opportunities for holidays, exercise and recreation, and financial benefits to local economies through tourism, employment and regeneration[3].

2.2 There is an expectation that the maritime sector, including inland waterways, will transition away from fossil fuels, as outlined in the Department of Transport's Maritime 2050 Strategy[4]. The Government's Clean Air Strategy[5] also outlines

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[1] The Inland Waterways Association, *IWA Waterway Directory.* Available to download from: https://www.waterways.org.uk/waterways/iwa_inland_waterways_directory

[2] HM Government, *Reducing emissions from road transport: Road to Zero Strategy.* Available online: https://www.gov.uk/government/publications/reducing-emissions-from-road-transport-road-to-zero-strategy

[3] The Inland Waterways Association, *Value of the Waterways* report, 2019. Available online: https://www.waterways.org.uk/iwa_publications/pdfs/valueinlandwaterways

[4] HM Government, Department for Transport, *Maritime 2050.* Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872194/Maritime_2050_Report.pdf

[5] HM Government, Clean Air Strategy. Executive Summary. Available online: https://www.gov.uk/government/publications/clean-air-strategy-2019/clean-air-strategy-2019-executive-summary

specific measures to tackle air pollutant emissions from the UK's maritime and inland waterways sectors, with a long-term transition to low and eventually zero emissions.

2.3 Just as various people from all walks of life utilise the land-based infrastructure of the waterways there are also various different craft used on inland waterways. The inland waterways offer navigation to a variety of boats, tugs and barges; the principle categories of powered craft are described in Appendix 4.

2.4 There are estimated to be 80,000 powered craft[6] on the inland waterways of England, Scotland and Wales, with the majority of these having hydrocarbon engines. Although suitable technology exists, and continues to be developed, very few boats currently use any alternative methods of propulsion.

2.5 The majority of these boats are on waterways which are funded directly or indirectly by central Government: approximately 34,000 boats[7] are on waters controlled by Canal & River Trust, the largest of some 30 or so navigation authorities[8], and funded by Government contract. The next largest navigation authority is the Environment Agency, directly funded through Defra, with around 14,000 boat registrations[9], followed by the Broads Authority (funded as a National Park by Defra) with approximately 12,000 boats. Other navigation authorities are in private, local authority and charity ownership (See Appendix 2).

2.6 Fuel usage and emissions from boats on the inland waterways is relatively small compared to total use and emissions from other sources countrywide, but cannot be ignored if the UK is to reach zero CO_2 emissions by 2050. As an example, it is estimated that the operation of vessels on the tidal Thames accounts for 1% of emissions in London[10], where there are greater numbers of high speed and commercial craft compared to most inland waterways. This percentage will increase as emissions from road vehicles decreases, and this pattern will be replicated across the UK's inland waterways. Contributory sources include wood-burning and solid fuel stoves and boat engines used for propulsion and electricity generation.

2.7 The key objective of the Group's work is to identify ways of reducing, and ultimately eliminating, emissions from propulsion on the inland waterways. The Group's work has so far focused on craft designed primarily for use on Category A and B waters[11], due to the large number of existing boats and the similarities of

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[6] Boat Safety Scheme, Examiner Training Course, 2017. Available online: https://www.boatsafetyscheme.org/media/293875/A2i-BSS-Examiner-Training-Course-Intro-overview-and-background-7Dec2017.pdf

[7] Canal & River Trust, 2020, website. Available online: https://canalrivertrust.org.uk/enjoy-the-waterways/boating

[8] The Inland Waterways Association, *Waterway Directory*. Available to download from: https://www.waterways.org.uk/waterways/iwa_inland_waterways_directory

[9] Environment Agency boat registrations. Available online: https://data.gov.uk/dataset/9baaf5b2-c554-4387-9ea6-23db50bc7174/boat-registration-boats-registered-by-year

[10] Port of London Authority, Air Quality Update, June 2020. Available online: https://www.pla.co.uk/Environment/Air-Quality-and-Green-Tariff/Air-Quality

[11] Maritime and Coastguard Agency Categorisation of Waters. Available online: https://www.gov.uk/guidance/inland-waterways-categorisation-of-waters

basic designs. The principles established will be applicable to other types of craft. Non-cruising boats present different issues so are not considered in detail.

2.8 This paper sets out a vision of what sustainable propulsion on inland waterways might look like in the coming decades by considering technologies that are available or close to being available now. Research currently being undertaken, particularly in the motor industry, will inevitably develop the technology, possibly in ways that are not currently envisaged.

3. Stakeholders

3.1 National, devolved and local government and navigation authorities are among the key stakeholders, along with a number of diverse groups covering waterway users, amateur and professional bodies and businesses. A list of stakeholders can be found at Appendix 1.

3.2 Some stakeholders will be required to make a significant investment to resolve the issue. It is hoped that a vision for the future, if ultimately validated, will allow the various stakeholders, particularly those who will need to invest financially in the future, to move forward with a degree of confidence.

4. The Problem

4.1 As with road vehicles, the problem can be conveniently divided into four parts and these are looked at in more detail below:

- Current New build
- Future New build
- The existing fleet including historic craft
- Refuelling or recharging

4.2 As with road vehicles, the problem is how to carry the energy around. Hydrocarbon liquids are a very efficient and effective method of transporting energy. The only technologies identified as having the potential to be both practicable and clean at the point of use are batteries charged using renewable electricity and fuel cells powered by 'green' hydrogen.

4.3 Until more infrastructure and equipment is available to fully support such technologies, there are interim solutions, which, while requiring the use of hydrocarbons initially, offers a significant environmental improvement over existing diesel propulsion systems and provides a practical upgrade to battery, hydrogen or both when the infrastructures are available.

5. Current New Build

5.1 The most sustainable propulsion system to have been implemented so far is the battery electric boat (also known as serial hybrid) in which a small diesel generator charges a large battery bank which, in turn, powers an electric motor. Such a system naturally benefits from the intermittent use and greater efficiency of its small, hard-working generator engine and, if fitted with an appropriate motor and propeller, the experience of the Group's members suggests that this can reduce fuel consumption by 50-70%. Cost is the principal barrier to its wider adoption; a system bought from a single supplier typically costing double what a diesel drive does. A mix and match approach can reduce this on-cost to about 50% and two other cost reduction options have been identified which could make such a system more competitive.

Energy Storage - batteries

5.2 There are very few problems installing a battery bank in a boat. Weight is not a problem and space is much more available than in a car. Power requirements are well within the range of the current technology and less than most road cars. The main drawback of batteries is range and recharge times, but both will improve as technology develops. Batteries can be recharged using a shore power mains connection, by onboard photo voltaic (PV) cells or small wind turbines. Onboard PV cells and wind turbines, given the current state of development, will probably not be able to provide all the energy required so onboard generators or fuel cells will be necessary for the foreseeable future.

5.3 This technology is of course, only carbon neutral if the electricity used to charge the batteries is from a sustainable source. This is a national problem and is only partially addressed here. There are also environmental issues around the manufacture, recycling and disposal of batteries.

5.4 As an example, an average narrow boat of 15-18 metres, cruising for 6 hours/day on a 1 lock/mile canal, is likely to need 9 kWh/day for propulsion, up to 9 kWh/day for domestic use, and (for those using their boats during the colder months) up to 34 kWh/day for electric space heating, a total of 52 kWh/day. The space heating figure can be reduced to 12 kWh by fitting a heat pump, reducing the daily total to 30 kWh.

5.5 Three days between charging is the minimum necessary to make a battery-based system viable so this must be tripled to 90 kWh. This is 90 kWh of usable power so, allowing for depth of discharge limitations, it equates to 180 kWh of lead-acid batteries or 110 kWh of Lithium batteries. The lead-acid option, at 3 m3, needs more space than is available on a typical boat, though the Lithium option (0.6 m3) is more realistic but expensive. The weight of the batteries required can offset the amount of ballasting that a new boat requires.

5.6 The possibility of using the much higher voltage systems used in cars (compared to the 48V system currently used in boats) could be explored but presents more dangers.

Energy Storage - Supercapacitors

5.7 Batteries are not the only devices capable of storing electrical power. Capacitors can do so but have never been widely used because the energy densities that could be achieved were very low. The recent advent of supercapacitors, with the addition of management electronics, as an energy storage device[12], has achieved volume energy densities similar to those of lead-acid batteries. As they exhibit virtually no charging/ discharging losses, giving potential further savings of 5% (relative to lithium batteries) or 15% (to lead-acids), and are claimed to have lives of 40 years/1 million cycles they should be a perfect match for a fuel cell, though their bulk and complexity is an issue.

Fuel Cells - Hydrogen

5.8 Hydrogen is an efficient method of transporting energy although it is not as good as hydrocarbon liquids. The technology is well developed (and will develop further) and the size of existing cells is well within that required for most boats on the inland waterways. Hydrogen, while potentially dangerous, can be engineered to be no more hazardous than a petrol system, although it is unlikely to be as intrinsically safe as a diesel system.

5.9 Hydrogen engineering is well understood and mature. The US has nearly 8,500 hydrogen cars as at August 2020[13] while Germany has hydrogen trains[14] and they will be on the UK rail system in a year or so[15] [16].

5.10 Hydrogen is totally clean at the point of use, but it is not necessarily green when being manufactured from hydrocarbon liquids and gases. This could be made ‘semi green’ with CO_2 capture. It can also be manufactured from ‘green’ electricity if available in sufficient quantity. This is a national problem not confined to the waterways and so not considered here.

5.11 There is no doubt that boats can be powered successfully by hydrogen fuel cells, Birmingham University having done so as long ago as 2007 when they built the *Ross Barlow*. To avoid the need to store hydrogen under high pressure it was stored as a metal hydride. This worked but was not as convenient as the hydride had to be heated to ambient to recover the Hydrogen (by a simple circulation pump)[17].

Fuel Cells - Solid Oxide

5.12 Solid Oxide cells can operate on gaseous hydrocarbons, such as propane, as well as hydrogen. Suitable storage tanks are readily available from the autogas

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[12] Kilowatt Labs, website. Available online: https://kilowattlabs.com

[13] California Fuel Cell Partnership, *Fuel cell cars sold and leased in US.* Available online: https://cafcp.org/by_the_numbers

[14] The Guardian, 17th September 2018. *Germany launches world's first hydrogen-powered train.* Available online: https://www.theguardian.com/environment/2018/sep/17/germany-launches-worlds-first-hydrogen-powered-train

[15] Alstom, press release, 14th May 2018. *Alstom confirms plans to bring hydrogen trains to the UK.* Available online: https://www.alstom.com/press-releases-news/2018/5/alstom-confirms-plans-to-bring-hydrogen-trains-to-the-uk

[16] Global Railway Review, 18th June 2020 *DfT award funding to development of UK’s first hydrogen – powered train*. Available online: https://www.globalrailwayreview.com/news/101959/dft-funding-development-uk-hydrogen-train/

[17] Taken from slides presented by Dr David Book of Birmingham University at a conference in Venice on 14/06/13

market and propane is regularly delivered to homes by tanker. This suggests that fitting and operating a solid oxide cell should not present too many problems. As they are more efficient than generators, such a change could increase the fuel saving to something like 80%. Better use could also be made of the cell's heat output, possibly meeting all heating requirements of a well-insulated boat.

5.13 A boat fitted with a solid oxide cell would enjoy significant environmental benefits immediately while being hydrogen-ready, making this a very attractive intermediate step. It would appear that the only suitably sized solid oxide cells available on the retail market are built into domestic heat and power units.

Battery Electric Boat

5.14 This is an arrangement whereby the boat is propelled by an electric motor powered by a battery which is charged by on-board power sources or by temporary shore power mains connection.

5.15 Using currently available technology the battery would be charged by a combination of shore power mains connection, PV cells and a small marine generator, probably diesel powered, which could use 100% biofuel, see below. Charging from shore power may be adequate for craft making short trips and then returning to a home mooring but is currently not practical for extended cruising, hence the need for the hydrocarbon powered generator.

5.16 This set up offers significant fuel usage advantages over a conventional diesel drive for the following reasons:

- An electric drive uses no energy when the propeller is not turning, unlike a diesel which is left idling in many cruising situations.
- A small generator, which can run at its optimum load whenever needed, will be much more fuel efficient than a large diesel engine running at part load.
- An electric battery drive allows the contribution of renewable energy sources such as solar panels to the charge.

5.17 The experience of members of the Group suggests that such an arrangement can save between 50% and 70% (and sometimes more) of the fuel needed by a conventional diesel propulsion unit.

5.18 A further advantage of electric drive is the much reduced noise levels for those on board and in the vicinity of the boat.

Parallel Hybrid

5.19 This is an arrangement whereby the boat is able to be propelled by either an electric motor powered from a battery or a conventional diesel engine. Although it can only offer about half the savings of the battery electric boat, this technology has been heavily promoted and there are a number of such boats in existence.

Government policy to move away from self charging hybrid cars should, however, be noted.[18] [19]

6. Future New Build

6.1 Our current vision for a new build future boat built primarily for use on Category A and B canals and rivers would be a Battery Electric Boat along these lines:

- Powered by an electric motor.
- Equipped with a battery bank large enough for cruising and to give a range suitable for a day's reasonable cruising.
- Equipped initially with a small bio-diesel powered generator and later, when the infrastructure is available, with a hydrogen tank and a fuel cell to keep the batteries charged during longer cruising. A solid oxide fuel cell initially running on hydrocarbons may also prove to be an interim solution.
- Charging of the batteries would be by shore power mains connection, onboard PV cells, the diesel generator or the fuel cell.
- Both the diesel generator and the fuel cell will produce waste heat which could be used for domestic purposes, as is the case with current diesel propulsion units.

6.2 The cost of this future boat could be higher than a diesel set-up, but this will reduce in the future. The batteries would be adequate for short trips. The generator or fuel cell system would give range and fast refuelling capability.

Fuel Cells

6.3 Future boats could well be equipped with a fuel cell running on hydrogen. The technology exists and is practical but hydrogen as a fuel is not currently readily available. Therefore, an alternative to hydrogen is needed in the short term.

6.4 Fuel cells come in a number of forms, with the following being most widely available:

- Proton exchange membrane, which can only be run on hydrogen.

- Solid Oxide fuel cells which can operate on hydrogen or hydrocarbons, typically propane, butane or natural gas. They are not as well developed for transport as hydrogen only cells, but a vehicle has been built using one[20].

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[18] Car Buyer, 4th February 2020, *Sales of petrol, diesel and hybrid cars to be banned from 2035*. Available online: https://www.carbuyer.co.uk/news/159524/sales-of-petrol-diesel-and-hybrid-cars-to-be-banned-from-2035

[19] BBC News, 4th Feb 2020, *How will the petrol and diesel car ban work*. Available online: https://www.bbc.co.uk/news/uk-40726868

[20] Nissan Motor Corporation, 4th August 2016, *Nissan unveils world's first Solid Oxide Fuel Cell Vehicle.* Available online: https://global.nissannews.com/en/releases/nissan-unveils-worlds-first-solid-oxide-fuel-cell-vehicle?source=nng&lang=en-US

- Methanol and/or ethanol fuel cells, which already exist in small installations. These can provide domestic supply; current small yacht installations are capable of producing 210Ah @12V; not enough for propulsion but enough for most domestic electric loads, excluding heating. They offer potential as an easily transported fuel which would be easier to store and refuel boats with.

6.5 Although fuel cells running on fuels other than hydrogen can never be fully carbon neutral, they offer a significant improvement over diesel engines or diesel generators and, more importantly, offer a practical conversion route to hydrogen when it becomes available.

6.6 The high electrical efficiency of fuel cells, coupled with the ability of boats to use the waste heat, should result in high overall efficiencies. The fact that fuel cells work best if run continuously means that a cell need have no more than 1/4 of the output of a generator, possibly even less, and battery banks, being charged continuously, can also be much smaller. If the cost of fuel cells is about the same per kW as marine generators, this would reduce the cost penalty of the adoption of electric drive.

7. The Existing Fleet

7.1 The existing fleet mainly comprises leisure boats with relatively modern diesel engines but there are a significant number of boats equipped with older, more traditional, diesel engines and a valuable cohort of historic ex-working craft, often with their original engines. IWA would not wish to lose the sight and sound of the preserved historic boats, as these are an important part of the inland waterways heritage. The majority of these boats are registered with National Historic Ships UK[21].

7.2 Research shows that the greatest ecological and environmental damage is in the manufacture, rather than in a lifetime of running, hydrocarbon engines[22]. There is no benefit to the environment in seeing otherwise sound vessels scrapped prematurely and, as both boats and engines can have lives of over 50 years and conversion to alternative drive systems is difficult, a sizeable proportion of the existing fleet is likely to remain diesel-powered until well after 2050. It is uneconomic for perfectly serviceable boats to be made obsolete by legislation or for owners to be forced into expensive conversions. Therefore, a way needs to be found to significantly reduce the environmental impact of the existing diesel engines.

Biofuels

7.3 Biofuels, while not 100% carbon-neutral, offer a significant improvement over hydrocarbons. Most powered craft currently use mineral diesel which could be

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[21] National Historic Ships UK Register. Available online: https://www.nationalhistoricships.org.uk/registers

[22] The Guardian. *What is the carbon footprint of a new car.* 23rd September 2010. https://www.theguardian.com/environment/green-living-blog/2010/sep/23/carbon-footprint-new-car

replaced by biodiesel.

7.4 Using biodiesel at 100% concentration has several potential disadvantages and problems which are capable of being mitigated or overcome in the inland waterway's environment. These are:

- Biodiesel can be manufactured from almost any vegetable oil. Waste cooking oil[23] is by far the most common but this produces a product which thickens in UK winter temperatures. This is not a problem when used at low percentages in mineral diesel, as in current road diesel but is definitely a problem at 100%, particularly when fuel lies unused in tanks for a significant period. Proprietary biodiesels are now being produced which can resist northern Europe winter temperatures, using additives.

- Biodiesel is more hygroscopic than mineral diesel, attracting water formation and hence when left unused in tanks for long periods, will be more susceptible to microbial contamination than current fuel. This can also be addressed through the use of additives.

- Pure biodiesel burns at a slightly slower rate than mineral diesel and hence high revving turbocharged road diesels can struggle on 100% biodiesel. High-pressure injection systems, using common-rail or unit injector systems, can also suffer from lacquering of injectors leading to blocked injector nozzles. However, most, if not all, canal boat engines are low revving, are not turbocharged and do not employ high pressure, common-rail fuel injection systems, so biofuel would not present a problem for inland waterways craft.

- Some older engines have rubber seals and similar components – mainly in their fuel systems – which are not resistant to 100% biodiesel. There are various measures that can be employed to mitigate against this: but at a cost. Work would need to be done to identify and convert these engines. Engines manufactured from the mid-1990s onwards use synthetic seals which are fully biodiesel resistant.

- The manufacture of biodiesel, regardless of the process employed, requires the use of a small quantity of hydrocarbon and is hence not 100% carbon-neutral. It is significantly better, however, than using mineral diesel.

7.5 The above shortcomings relate specifically to biodiesel produced by a process known as transesterification. The Sustainable Propulsion Group has identified a proprietary biodiesel[24], manufactured using hydrogen, which eliminates all the

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[23] HM Government, Department for Food, Environment and Rural Affairs. *Crops grown for bio energy in the UK 2018*. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/856695/nonfood-statsnotice2018-08jan20.pdf

[24] Crown Oils' hydrotreated biodiesel. Available online: https://www.crownoil.co.uk/products/hvo-fuel-hydrotreated-vegetable-oil/

above problems and carries OEM[25] endorsements. This is currently undergoing further evaluation, within the marine environment, by members of the Group.

7.6 A relatively small number of boats on the inland waterways system are propelled by petrol outboard engines. Petrol will soon contain up to 10% ethanol which might cause older petrol to experience problems with rubber components as highlighted in 7.4 above. Some generators and newer outboard motors can be easily adapted at point of manufacture to run on nearly pure ethanol.

8. Refuelling and Recharging

Refuelling - the existing fleet

8.1 Assuming this can be converted to biofuel, the current refuelling infrastructure can be used. It may be necessary to replace rubber seals and components on some engines. Engine manufacturers should be consulted prior to carrying out modifications to ensure that any guarantees or other cover will not be nullified.

Charging – access to shore power mains connection

8.2 In order to ensure adequate access to all parts of the canal network by boats with 3-day batteries IWA has an aspiration for shore power mains connection charging sites ideally no more than 5 hours cruising apart, which would mean around 430 charging sites across the 4700 miles of navigable waterways[26]. Less than this could lead to congestion and the sites themselves will need to vary in size between a minimum of 2 and a maximum of, maybe, 20 sockets. Other than on the Brecon & Abergavenny Canal where a fleet of electric hire boats is well established[27], and on the River Thames where the Environment Agency has installed nine charging sites along the non-tidal Thames[28], current provision of shore power mains connections is mostly limited to some permanent moorings and most marina berths.

8.3 Most charging is likely to take place overnight as this will permit much simpler, and cheaper, facilities at shore power mains connection charging sites and onboard. However, 16A 230V systems will only permit partial overnight charging, and so 32A would be better although 16A might be all that is possible in remote locations.

8.4 A recent example of such investment is the London based scheme by Canal & River Trust and Islington Council in creating an 'eco-mooring zone' for visiting

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[25] Original Equipment Manufacturer. For definition see: https://www.jjsmanufacturing.com/blog/what-is-meant-by-the-terms-oem-ems-cem-odm-and-why-should-you-know

[26] Based on 4700 miles of navigable inland waterways and approximately 1800 locks - The Inland Waterways Association, *IWA Waterway Directory*. Available online: https://www.waterways.org.uk/waterways/iwa_inland_waterways_directory

[27] Castle Narrowboats have operated both diesel and electric narrow boats for over 20 years. More information available online: https://castlenarrowboats.co.uk/electric-boats/

[28] Environment Agency, *River Thames electric charging points*. Available at: https://www.facebook.com/notes/canal-network/river-thames-electric-charging-points/375801932471570/

boats between York Way and Danbury Street on the Regent's Canal. Supported by funding from Defra, the zone will include shore power mains connection charging points to provide boaters with an alternative to running boat engines to generate energy.[29]

Charging – solar

8.5 The possibility of using solar panels for direct charging of batteries from the sun during daylight hours is tempered by capital cost and free roof area required (and also seasonal considerations). However, a vast range of perceived applications and therefore size is possible when combined with appropriate battery capacity, which can reduce fuel consumption at other sources.

8.6 Each kilowatt of solar power requires at least 5 square metres of panel (at nominal i.e. max. rating), suggesting that batteries must be large enough to store energy over all daylight hours to contribute to any propulsion or other use. The cost of panels at present being at least £800 per kilowatt (at nominal rating, June 2020). There is no doubt however, that in some applications (depending on the type and use of boat) the solar contribution for propulsion can be considerable or even exclusive, as has been proved by The Electric Boat Association[30], and also by some passenger carrying boats in summer-time. The principal use in current practice however, is to provide power for domestic use including lighting and power for domestic appliances, etc, thereby avoiding the use of portable generators or a boat's engine when moored, as well as general reduction in fuel consumption.

Charging – wind generation

8.7 Unlike with coastal vessels where yachts, both sail and motor, are often seen using a small wind turbine to charge batteries, it is more difficult to apply this technology in a fixed position on each inland vessel, because of frequent bridges. However, when considering moorings and marinas, especially those in open or higher ground, there is often opportunity to generate electricity in a useful way, and this is sometimes done. The smaller sizes available (a metre or so diameter providing up to 200W) are suitable for individual boats/moorings, whereas up to 3m diameter offer 10 times the power at only 3 times the cost, for a larger or more permanent installation.

8.8 Larger marinas have the opportunity to install even larger wind turbines to connect to the grid (as with solar). Small-scale wind generators must be considered in conjunction with another source of energy, due to the variability of the wind, but wind can also occur at night, unlike solar power. This is existing technology, which should be encouraged where deemed appropriate, as energy so generated reduces the consumption of fossil fuels.

Hydrogen Production, Distribution and Storage

[29] Canal & River Trust *Eco Moorings, Islington*. Available online: https://canalrivertrust.org.uk/about-us/where-we-work/london-and-south-east/islington-eco-mooring-zone-trial
[30] The Electric Boat Association. Information available online: www.electricboatassociation.org

8.9 Most commercially-available Hydrogen is made by thermal re-forming, a process in which a lot of energy is used to extract it from a mixture of steam and natural gas. Carbon Dioxide is still formed so the energy is expended simply to leave the problem behind. It is therefore anything but 'green'.

8.10 Hydrolysing water is better, particularly if done using renewable energy at times of surplus. However, because Hydrogen cannot easily be liquefied it requires a lot of energy to compress, transport and store it, with end-to-end efficiencies as low as 30% having been reported. Current automotive work is focussed on high pressure storage, typically 350 bar for heavy goods vehicles and 700 bar for cars[31].

8.11 Work is in hand to develop more efficient adsorption media than that used in the *Ross Barlow*, with some promising results reported, though commercialisation seems likely to be quite some time away[32]. What happens on the waterways will depend entirely on how the automotive system develops, though the possibility of eliminating the transport element by having small, hydrolytic plants at the filling points can't be discounted.

8.12 When considering battery or hydrogen powered craft, refuelling is the major problem and it is economic and logistical rather than technical. Whether considering an electric recharging infrastructure, or a hydrogen refuelling infrastructure, significant capital investment will be required. Commercial operators will not invest until the boats to use it exist and private owners will not invest in the boats until the infrastructure is available. Government investment is therefore required to avoid this chicken and egg situation.

8.13 Currently electric recharging is slow whereas hydrogen refuelling can be accomplished in a similar time to hydrocarbon liquid refuelling.

8.14 There would need to be a distribution system, probably using road vehicles, to service any hydrogen refuelling stations. They will be more costly than diesel pumps and tanks, but the technology is available. Work is currently being done to develop a hydrogen infrastructure in the UK, for road and rail transport and for domestic use, but this is some way off. The natural gas industry is actively looking at using the gas grid to distribute hydrogen for domestic use. This may ultimately develop into a partial solution.

8.15 It may be possible to develop a network of hydrogen refuelling stations around hire fleet bases if enough hire companies could be persuaded to use hydrogen boats. Hire boats are typically refuelled at base, sent out for one or two weeks and refuelled at the same base on their return. Hire boats are also replaced and sold on to the private market at relatively frequent intervals. This combination could make installing a hydrogen fuelling station at a hire base reasonably

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[31] Office of Renewable Energy and Energy Efficiency. *Hydrogen Storage.* Available online: https://www.energy.gov/eere/fuelcells/hydrogen-storage#:~:text=Hydrogen%20can%20be%20stored%20physically,pressure%20is%20%E2%88%92252.8%C2%B0C

[32] NCBI, *Record High Hydrogen Storage Capacity in the Metal–Organic Framework Ni_2(m-dobdc) at Near-Ambient Temperatures*. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7067217/

economic with a hydrogen fleet being available in a reasonably short period of time.

8.16 If enough bases could be ‘converted’ this would provide a basic network for private boaters to use and hence encourage the purchase of hydrogen boats, leading to further developments of the hydrogen refuelling infrastructure. This would only apply to the ‘central’ part of the system where hire bases are common and leave a problem for outlying waterways, at least initially.

8.17 Ex-hire hydrogen boats would find their way into the private market in a fairly short time, but the residual value to the hire company would probably be reduced until there is a wider hydrogen infrastructure available.

9. Non-Propulsion Issues

9.1 The Sustainable Propulsion Group, as its name implies, is looking primarily at how inland waterways craft can continue be propelled in a low carbon or carbon free future. There are other environmental issues associated with boats and boating that need to be looked at, such as domestic power requirements and the use of solid fuel and wood burning stoves. While these are not addressed in any detail here, the widespread introduction of shore power mains connection charging sites will enable significant improvement in air quality by allowing boats with suitable 240v electric wiring systems to charge their batteries instead of running a diesel engine, and to use electric heaters instead of relying on solid fuel stoves for heating.

Behavioural Changes

9.2 There are a few things boaters could do immediately to reduce carbon emissions from existing craft, such as reducing the running of engines as well as the installation of solar panels if practicable. In order to reduce running hours boaters could turn engines off when not actually travelling (e.g. when waiting at locks etc) as well as when manoeuvring (using ropes and poles). Although not a proven trial, a few boaters within the Group compared overall travelling time against minimal engine running hours (along the lines detailed above) with the saving being in the order of 25% to 30%. In the confines of marinas and boatyards, shore power mains connection charging should be utilised instead of running an engine solely to charge batteries.

Channel Maintenance

9.3 The power needed to propel a boat depends in part on the dimensions of the channel in which it is cruising. A member of the Group with an electric-drive boat has observed that about 30% more power is needed to maintain 3 mph in a well-maintained broad canal than in open water, while even doubling the power failed to achieve 3 mph in a poorly-maintained narrow canal, however even these limited figures suggest that better dredging could afford large fuel savings.

9.4 Navigation authorities should be encouraged to dredge or otherwise restore the nominal, historic, or at least maximum practical profile of navigable channels –

for the express purpose of reducing fuel consumption by all users, as well as making more reliable the use of canal transport whether goods or passengers, thereby protecting waterway-based businesses. This could be defined by national, regional or local standards as appropriate, but the essence of the request is to achieve some catching up of the acknowledged back-log of maintenance (in dredging), which would have a beneficial effect on the environment, fuel consumption and safety. The potential for new or enlarged waterways should also not be dismissed, and each possible scheme which could emerge should be examined for its merits.

Hull design

9.5 Modern boats tend to have short swims (the tapers at the front and back). Longer ones would serve to streamline them, making them more fuel efficient. Compound curvature would maximise this benefit. There would be a small (<5%) loss of interior space in both cases and a small cost penalty (which can't be quantified) in the latter.

9.6 The fitting of a larger diameter and coarser pitch propeller can be more efficient, but this requires a boat to be built with a deeper draught. This further supports the argument above for dredging to original profile.

10. Potential Solutions

Provision of shore power mains connection sites

10.1 IWA's aspiration is to see shore power mains connection sites across the navigable inland waterways system, ideally situated no more than 5 hours cruising apart. Allowing for usual travelling speeds and the time taken to operate locks, IWA has identified that on the 2700 miles of connected inland waterways the installation of approximately 300 shore power mains connection sites (between 2 and 20 sockets per site) would be required.

10.2 Although there are another 2000 miles of navigable waterways that form part of this system (including the canals in Scotland, the unconnected waterways operated by Canal & River Trust, the Norfolk & Suffolk Broads, and a number of other waterways run by other navigation authorities), investment by government in installing this infrastructure on the connected network initially would allow the widespread adoption of the use of electrically propelled boats, as well as reducing emissions from engines being run to charge batteries. Investment across the other 2000 miles should then follow.

10.3 220 of the 300 shore power mains connection sites should be installed across the 1710 miles of connected navigable waterways operated by Canal & River Trust. This should be funded by Defra as a separate exercise ahead of the re-negotiation of Canal & River Trust's current contract with Government which runs to 2027. Of the 80 further sites, half of these should be installed on the Environment Agency navigations which are funded directly by Defra and should be included in future grant-in-aid allocations for the Agency. The remaining 40 sites will be located on a mix of privately owned, charity-run and local authority owned waterways and funding could again be administered by Defra as the Government body with overall responsibility for the inland waterways, or through local authorities.

Channel Maintenance

10.4 Government should address the current backlog of dredging that currently exists, particularly across those waterways funded by Defra (Canal & River Trust and the Environment Agency), in order to realise the benefits of reduced fuel consumption and less emissions which would both have a beneficial effect on air quality.

Biofuels

10.5 The widespread use of biofuels in place of hydrocarbons would go a long way to making the existing fleet of boats in the UK more sustainable. Research into the production, use and distribution of biofuels should be commissioned by Government and the findings promulgated to boat owners in order to encourage use of these alternative fuels.

Fuel cells

10.6 Proton exchange membrane, solid oxide and alcohol fuel cells offer real potential for future solutions in inland waterway boats and more research, development and trialling of the use of fuel cells should be commissioned by Government.

Supercapacitors

10.7 Further research into energy savings of supercapacitors with the addition of management electronics, as energy storage devices for boats, is required. Government should commission such research, development and trials.

11. Conclusion

11.1 IWA asks that the following actions, based on the solutions identified above, should be progressed by relevant Government Departments:

- Investment in infrastructure through the installation of 300 shore power mains connection charging sites across the connected inland waterways network. This would improve air quality by reducing the emissions from stoves for heating and engines run for charging batteries, as well as enabling a move towards more boats with electric propulsion.

- Working with navigation authorities, investment in a national dredging programme across the inland waterways to make propulsion more efficient. This will also have additional environmental benefits on water quality and increasing capacity for flood waters.

- Research and investment into the production, use and distribution of biofuels. This will be necessary to reduce the environmental impact of existing diesel engines which, given their longevity, will still be around until well after 2050.

- Research and development of alternative forms of propulsion for use in future and current new build boats; including hydrogen production and distribution, fuel cells (proton exchange membrane, solid oxide, methanol/ethanol) and the use of supercapacitors.

11.2 Much of the research and development recommended above will apply equally to road transport and will already be taking place. IWA wants to ensure that boats used on the inland waterways do not get left behind in technological developments in order that the waterways can fully contribute to the UK meeting the Government's stated aim of zero CO_2 emissions by 2050.

The Inland Waterways Association
September 2020

APPENDIX 1 – Sustainable Boating Stakeholders

Boat User Groups

- Association of Waterway Cruising Clubs
- Commercial Boat Operators Association
- Electric Boat Association
- Historic Narrow Boat Club
- National Association of Boat Owners
- National Bargee Travellers Association
- Residential Boat Owners Association
- Royal Yachting Association

Navigation Authorities - see also Appendix 2

- Association of Inland Navigation Authorities
- Navigation authorities funded by central/devolved Government: Canal & River Trust, Environment Agency, Scottish Canals, Broads Authority
- Navigation authorities in local authority ownership
- Navigation authorities - in private or charity ownership/management

British Marine, representing Hire Fleets, Boat Builders, boatyards and marinas

Boat Safety Scheme

Boat Safety Examiners/surveyors

- Association of Boat Safety Scheme Examiners
- National Association of Boat Safety Examiners
- Yacht Designers & Surveyors Association

Boatyards

Chandlers/equipment suppliers

Government

- Department for Environment, Food & Rural Affairs
- Department for Transport
- All Party Parliamentary Group for the Waterways
- Scottish Government
- Welsh Government
- Local authorities (Local Government Association)

Boat owners

APPENDIX 2 - Main Navigation Authorities in England, Scotland and Wales

Navigation Authority	Miles	Authority type/additional information	Waterways
Avon Navigation Trust	45.5	Navigation authority (charitable trust)	River Avon (Warwickshire)
Basingstoke Canal Authority	31	Navigation authority (municipal)	Basingstoke Canal
Bridgewater Canal Co Ltd	39	Navigation company	Bridgewater Canal inc Runcorn Arm
Bristol City Council	7.5	Navigation authority (municipal)	River Avon (Bristol) - Hanham Lock to Cumberland Basin, including Bristol Floating Harbour
Broads Authority	124	Navigation authority (public)	Norfolk & Suffolk Broads
Canal & River Trust	1799	Navigation authority (charitable trust)	The canals and rivers which were nationalised in 1948 (with a few changes since) (mileage excludes un-navigable waterways but includes mileage in Wales)
Cardiff Harbour Authority	5.3	Harbour authority (municipal)	Rivers Ely and Taff
Cheshire West and Chester Council	13.2	Navigation authority (municipal)	River Dee
City of York Council	1.3	Navigation authority (municipal)	River Foss
Conservators of the River Cam	7.5	Navigation conservancy	River Cam
Cornwall Council	2	Navigation authority (municipal)	Bude Canal
Derbyshire County Council	5	Owner/lessee of land/structures	Chesterfield Canal
Devon County Council	11	Owner/lessee of land/structures	Grand Western Canal
Driffield Navigation Trust	12	Navigation trustees	Driffield Navigation
East Riding of Yorkshire Council	1	Navigation authority (public)	Beverley Beck
Environment Agency	628	Navigation authority (public) (waterways where they are the navigation authority or manage the waterway under byelaws)	All waterways where they are the navigation authority or manage the waterway under byelaws
Essex Waterways Ltd (subsidiary of IWA)	14	Waterway management company operating under a management agreement with Company of Proprietors of Chelmer & Blackwater Navigation Ltd	Chelmer & Blackwater Navigation

Exeter City Council	5	Harbour authority (municipal)	Exeter Ship Canal
Folkestone & Hythe District Council	5	Owner/lessee of land/structures	Royal Military Canal
Lake District National Park Authority	26.5	Navigation manager (byelaws)	Coniston Water, Derwentwater, Ullswater and Winderemere
Manchester Ship Canal Co (Peel Ports)	39	Harbour authority (company)	Manchester Ship Canal and parts of rivers Irwell, Mersey & Weaver
Middle Level Commissioners	95	Internal Drainage Board	Middle Level Navigations
National Trust	20	Charitable trust	River Wey
Port of London Authority	27	Harbour authority (trust port)	Tidal Thames through London (mileage shown refers to Teddington to the Thames Barrier only)
Scottish Canals	141	Navigation authority (public)	Caledonian, Crinan, Forth & Clyde and Union canals
Sleaford Navigation Trust	8	Charitable trust	Sleaford Navigation
Stroud Valleys Canal Co	5	Navigation company	Stroudwater Navigation
Witham 4th District Internal Drainage Board	36.5	Internal Drainage Board	Witham Navigable Drains

Notes This list excludes: derelict waterways, short isolated lengths of restored waterways (unless there is a navigation authority); most tidal waterways (even where there is a body responsible for navigation); docks, lakes/reservoirs where boating takes place but which are managed by a water supply company; and most harbour authorities.

APPENDIX 3 – Members of the Sustainable Propulsion Group

The Inland Waterways Association's Sustainable Propulsion Group is a sub committee of the Association's Navigation Committee. The following members of the Group have contributed to this paper:

Bowman Bradley, CEng, FIMechE, is the Chair of the Sustainable Propulsion Group. Bowman is a retired professional engineer and Fellow of the Institution of Mechanical Engineers. He has 45 years of experience on the UK canal system and is the owner of a modern leisure narrow boat.

Malcolm Bridge BSc, Ph.D is a retired Research & Development manager. Trained initially as a Chemist, he spent most of his working life in the Technical Textile industry where his work increasingly involved mechanical and control engineering. His boating experience goes back to the 1950s and he has owned canal boats since 1975. His current one, completed in 2015, is the first of what might be considered to be a new generation of fuel efficient electrically-propelled boats.

Peter Fisher MEng (Hons), MIET lives on a narrowboat (since 2005) with a modern diesel engine that is rarely used as almost all domestic electricity needed is provided by on board solar PV and is converting to electric propulsion. Wood burner fuelled by sustainably sourced wood. He studied Hydrogen, Fuel Cells and their applications at PhD level at The University of Birmingham where Ross Barlow is based. These studies also included work on UK hydrogen train and (Microcab) cars

Jonathan Mosse MSc Conservation and the Historic Environment (Distinction). Technical Teacher's Certificate. Jonathan is an ex-farm manager and agricultural lecturer who spent 25 years running his own conservation building business. He is a qualified Buildings Surveyor and Domestic Energy Assessor. He is also a waterways writer and photographer and has 16 years experience running vehicles on biofuel.

Alison Smedley MBE, FdA, is IWA's Campaigns and Public Affairs Manager. Alison is a life-long boater and a boat owner for over 30 years, with several years spent living afloat. She has been involved with IWA for 27 years as volunteer, trustee and now employee. Alison was awarded an MBE in 2010 for voluntary services to the inland waterways.

Rupert Smedley, BSc (Hons), MIET, ABSSE, is a Boat Safety Scheme Examiner (since 2003) and Technical Writer for Waterways World (since 2004) following a career in electronic design. He has owned a historic narrow boat for over 30 years and is a committee member of the Historic Narrow Boat Club.

Peter Stacey is the Group's representative from the Royal Yachting Association where he is a member of their Inland Navigation Panel. Peter is the owner of a modern leisure narrow boat extensively cruising the inland waterways with over 60 years varied boating experience.

David W Struckett, BA (Hons), LCGI, Cert Ed., I.Eng., MIQA, ABSSE, is a retired Engineering Lecturer having a life-long interest in boats and waterways of a wide range of sizes and types. With early experience at the former Ship Hydrodynamics division of the National Physical Laboratory, he remains interested in what is possible to improve performance, economy or sustainability. David is also a Boat Safety Scheme Examiner.

APPENDIX 4 – Types Of Boats that use the Inland Waterways

The inland waterways offer navigation to a variety of boats, tugs and barges; the principle categories of the powered craft can be described as follows:

1. Commercial carrying vessels, tugs, dredgers and navigation authority or contractor's maintenance vessels. These can be barges, tugs or narrow beam depending on the waterway.

2. Passenger carrying vessels – can be narrow or broad according to waterway, but also can be commercially operated, or charity run (which are sometimes restricted to 12 passengers but not necessarily).

3. Historic craft, often ex-commercial craft (1, above) maintained with traditional engine or for other heritage purposes. Some of these are in use on small-scale commercial operations, some privately operated, and some operated by museums or other heritage sites.

4. Residential boats. Some have permanent moorings but can cruise sometimes, and some are registered as 'continuously cruising' – a class which avoids using a permanent site for mooring except seasonally, by separate agreement (as opposed to 'houseboats' – which are usually permanently moored on either private waters or on a navigation, and not able to move).

5. Hire craft: cruising boats operated commercially for hire in the leisure market. These are usually cruisers or narrow boats, see next.

6. Privately owned boats for leisure cruising. These can be of steel, aluminium, wood or GRP construction. Many have a 'narrow' beam (meaning a maximum of 2.1 metres wide) in order to make use of the 'through-route canals' to cross England in several directions. Wider craft are limited to a river system or region, unless sea-worthy enough to go round the coast.

Note: the categories shown may not be exclusive – and navigation authorities may sub-divide specifically for licensing purposes, e.g. regarding type of power. There are also many kinds of small craft not with accommodation, which may be propelled mechanically if fitted with a motor or engine (eg outboard motor, electric launch), or otherwise for oar or sail.