The Inland Waterways Association
Sustainable Boating Group

An Introduction to Electric Narrowboating

[Revised July, 2026]

NB Ampère

NB Tenacity

NB Free Phase

NB Firefly

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Contents

Notes:

The IWA's Sustainable Propulsion Group was formed in 2019 with the objective of identifying and publicising ways of reducing emissions from internal combustion engines in inland waterways boats. It morphed into the Sustainable Boating Group (SBG) in recognition of the indivisibility of propulsion and domestic energy use on boats. At the time of writing, it comprises about a dozen volunteers, all boat owners and most with scientific or engineering backgrounds.

Recognising that, as with cars, the way forward will inevitably be the use of battery electric power this guide has been prepared by the owner of nb Ampère, now in his 12th year of electric boat ownership, with input from other members of the Group. Its objective is to provide unbiased advice in order to reduce the risk that people lacking the Group's expertise will be disappointed as a result of purchasing boats with unsuitable electrical systems.

The opinions expressed in this guide are offered in good faith, based on the experience of the author and other members of the IWA Sustainable Boating Group.

Nothing in this guide is intended to recommend or promote equipment from any specific supplier.

1 Scope

The guidance offered in this document applies directly only to narrowboats as other boats on the canal system vary so much in size and design that any attempt to cover all in a single document would be very difficult. That said, the basic engineering principles are universal so much of the advice is adaptable to other types of boat, such as broad-beams and cruisers, though that adaptation must be done by those with relevant expertise.

It must also be pointed out that this document is based on technologies available at the time of writing, many of which are still evolving so may quickly become outdated. This is the largest, revision to date, recognising recent battery developments, adding more detailed consideration of solar panels and correcting previous over-estimates of the efficiency of electrical systems, though it should be noted that, while system monitoring has advanced greatly since the first version, electrical propulsion technology has barely changed.

It will be revised again whenever further significant changes are recognised by the Group but it is recommended that readers check the revision date and seek further independent advice before proceeding with a purchase.

2 Introduction

The prospect of near silent cruising is probably what attracts most people to electric boating in the first place though its environmental benefits and potential for completely CO_2-free cruising in the future are arguably of greater importance. In the absence of alternatives capable of meeting the current Government's equivalent of the last government's Maritime Decarbonisation Strategy (whenever it appears), electric propulsion may, for all practical purposes, become mandatory for new-builds within 10 years. At the moment we are in a transitional phase during which minimising the use of internal combustion engines without wasting their embedded carbon content by scrapping sound units is the best that can be achieved.

3 Capital Cost

This is the main barrier to the adoption of electric drive because, although running costs will be lower (see 5), the capital cost of an electric drive system, while falling (see 9.3-9.5 & 9.7), is still higher than that of a diesel one. However, it must be emphasised that it is not, as is often claimed, necessary to buy a complete system from a single supplier to ensure compatibility and mixing and matching products from different suppliers can afford big savings. Doing so should present few problems to anyone with reasonable electrical knowledge as it involves little more than ensuring that voltages and power ratings match and that, if needed, components share a common communications protocol. As most modern ones offer several, finding a common one is not difficult.[1]

Using non-marine products can give even bigger savings. For example, narrowboats rarely, if ever, see salt water or heel at crazy angles so don't really need specialised marine generators. Equivalent industrial units typically cost about half as much, though

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[1] The major components of the author's boat came from 5 suppliers, at least in part because no single one could offer all at the time of building. There have been no compatibility issues.

suitable ones rated at less than 10 kVA are no longer as readily available as they were when the first version of this guide was written. Slightly second-hand ones, often former stand-by units with very few running hours, can be even cheaper. Both will need slight modifications (see 10.5) and extra soundproofing, but these will cost hundreds of pounds while saving thousands.

4 Buyer beware!

The basics are clear. **Maximising propulsion efficiency requires the largest possible propeller turning at the lowest possible speed.** This has been known since soon after the invention of the propeller some 200 years ago but is often ignored, or even denied, particularly by companies selling motors which, though no doubt suitable for other applications, are far from ideal for narrowboats (see 7). The Group has also identified a few cowboys though it obviously can't name them here. **The Group strongly recommends a maximum propeller speed of no more than about 1,000 rpm.**

The more detailed advice offered below should enable intending buyers to ask questions which should, in turn, prompt a responsible builder to produce a sound, efficient boat. If you are offered something which conflicts with this advice, challenge it. If your prospective builder persists, find another builder.

5 Overall System Design

***Firstly, a correction**. Information then available led earlier versions of this guide to overstate the efficiency of electric drive systems relative to diesel propulsion. Analysis of diesel power curves by a Group member and re-evaluation of battery charging efficiency made possible by the advances in system monitoring mentioned in Section 1 suggest that end-to-end electrical efficiencies are not as high as was believed then, though diesels were equally found to fall significantly short of their theoretical efficiencies in a 2021 trial.*

Nevertheless, unless it is extraordinarily badly specified, any electric-drive (Serial Hybrid) boat[2] will be significantly more efficient than a comparable diesel because:

5.1 Electric-drive boats use no power when stopped while diesels continue to tick over, typically using about 2/3rds as much fuel as they do while cruising. As about a third of total 'cruising' time on 1 lock/mile canals is spent stopped this is very significant.

5.2 Their ability to turn propellers from virtually zero rpm (rather than the 400 rpm minimum of a typical diesel system) permits the fitting of larger, more efficient, propellers to electric motors without unacceptably increasing a boat's minimum speed (see 6.5).

5.3 Solar power can significantly reduce the need to use shore power or a generator.

Taken together, 5.1 and 5.2 should result in fuel/CO_2 savings of at least 30% relative to a modern diesel boat. 5.3 depends on the number and size of panels and the times of year when the boat is used but could easily double these. Solar power is discussed in more detail in Section 11.

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[2] A Serial Hybrid's only means of propulsion is an electric motor powered by batteries charged by an onboard generator, solar panels and/or a shoreline.

As the benefits of 5.1 are more-or-less automatic, attention must be focussed on 5.2 and 5.3 to maximise the benefits of electric drive.

Parallel Hybrids[3] are inherently less efficient than Serial Hybrids as they cannot benefit from 5.2 because the propeller must be sized for the diesel engine and they only benefit from 5.1 if electric drive is used appropriately (in stop/start situations such as locking). Their ability to benefit from 5.3 is also likely to be lower because they tend to have smaller battery banks so can't store as much energy for later use.

That said, if used appropriately they are more efficient than straight diesel engines so the Group welcomes the introduction of kits for converting existing diesels to what are sometimes termed 'Inline Hybrids'[4]. While ongoing CO_2 reductions will not be as great as they would with full Serial Hybrid conversions, upgrading existing engines avoids discarding their embedded carbon so this approach can be a good option for an existing boat with a sound diesel engine.

6 Power Requirements

6.1 The power needed to propel a boat depends principally on its underwater cross-sectional area, effectively a narrowboat's draft as its beam is more-or-less fixed. 18" is probably the practical minimum draft for a conventional, steel narrowboat, with 22" currently typical of new, diesel engined ones.

For any boat, the shallower the draft the less power will be needed, and this is particularly significant for electric drive. However, reducing draft does have downsides which include reduced stability (all other things being equal) and increased air draft if internal headroom is to be maintained.

6.2 The power needed can be reduced by having a more streamlined hull, meaning one with longer swims than the 8' norm, the rear swim being particularly important as it affects the water flow to the propeller. 'S'-shaped rear swims are also claimed to do this but the author has been unable to find any scientific evidence. 'V' bottoms and angled chines reduce the cross section at any given draft so can reduce the power required and two hull designs with lower power requirements exist, though only one is in production.

6.3 Thermoplastic-hulled narrowboats have recently been introduced. These were originally very shallow drafted so needed much less propulsion power than a typical steel boat and offered other environmental benefits, though their shallow draft inevitably translated into a greater air draft, restricting their cruising range. Recent reports on the Internet[5] suggest that they are now ballasted to about 18", largely overcoming that problem but losing a significant part of the original propulsion efficiency advantage in the process.

6.4 **Tank trials have shown that for maximum fuel efficiency a narrowboat should be ballasted to be as level as possible in the water.**

6.5 Diesel engines cannot be fitted with propellers large enough to optimise propulsion at canal speeds because doing so results in an increase in the minimum speed

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[3] Parallel Hybrids comprise a conventional diesel engine and an electric motor (which may, or may not, double as a generator) working in an either/or relationship.

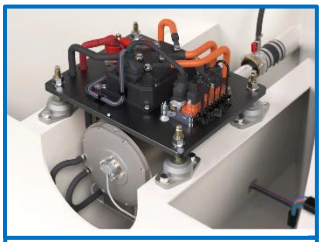
[4] These are similar in concept to Parallel Hybrids but with the option of the diesel engine and electric motor working together rather than only in an either/or relationship.

[5] https://www.youtube.com/watch?v=C0DWVy5RiUc&t=170s

possible (that with the engine on tick-over) which makes manoeuvring and boat passing speeds too high. Electric motors can turn propellers from zero rpm so do not suffer from this problem. Consequently, as commonly fitted diesels rarely, if ever, use more than half their available power, electric motors with only half their power are entirely adequate. About 10kW is suggested for boats up to 45’, 15kW for ones of 45-60’ and 20kW for full-length boats. Ironically, these are almost exactly the powers of the diesels that were commonly installed in narrowboats 50 years ago when they ran slower but had higher torque and larger propellers

6.6 **Beware of under- and over-powering.** While only 2-3 kW is needed for normal canal cruising, more is needed for stopping quickly and coping with faster river and tidal flows so boats with smaller motors than those suggested might struggle in such situations. Having said that, don't be swayed by claims that vastly more power is required to cope with adverse conditions. If a narrowboat can reach 6 mph it should cope with any conditions in which it is safe for it to cruise.

7 Motors



PMAC Motor with the Cover Removed

7.1 The greatest efficiency is likely to be obtained from a permanent magnet, alternating current (PMAC) motor with inverter control. Including controller losses this is likely to afford a battery to propeller efficiency of about 85% *(previously believed to be over 90%)*. The Group welcomes the fact that PMAC motors with maximum speeds of about 1,000 rpm are now available from at least two suppliers in the UK[6], though the majority on offer run at about 1,500 rpm so have 1/3rd less torque and must be fitted with smaller, less efficient propellers. This has been a weakness of many electric drive boats built since those shown on the front page.

DC Motor with Belt Gearing

7.2 Brushed DC motors have a long and honourable history and modern ones, helped by lower controller losses, can approach PMAC motors in efficiency. They come in a range of powers but are too fast for direct drive so must be geared down, usually done using toothed belts. They are similar in cost to PMACs.

7.3 A few suppliers offer AC induction motors. These are considerably cheaper than PMACs but are larger and less efficient so are not recommended.

7.4 Most manufacturers supply controllers pre-programmed to match their motors.

8 Propellers

Because of the different torque characteristics of electric motors and diesel engines suppliers have struggled to specify propellers for electric-drive boats, meaning that many, including the author’s, have had to have their original ones changed. It is worth taking the trouble to get it right first time as a prop change is likely to cost about £1,000 and the Group knows of one boat which is on its 4th.

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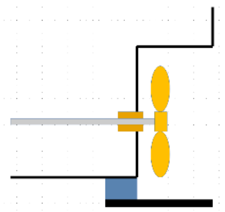
[6] The author’s boat’s motor was imported from Croatia as no suitable ones were available in the UK in 2014.

Most modern boats are built with a draft of about 22”. This limits the diameter of propeller that can be fitted to about 18” as a 10% clearance around the blade tips is necessary if efficiency is not to be adversely affected. This diameter is about right for 3-bladed propellers on boats with maximum shaft speeds of 1,500 rpm, typical of modern diesel engines with 2:1 reduction gearing and most electric motors currently on the market. However, 22” draft doesn’t allow for the larger, 3-bladed propellers required to optimise lower speed electric drives.


4-bladed Propeller

However, if a boat’s draft will not permit the fitting of an optimal 3-bladed propeller there are a number of options. These are not mutually exclusive.

8.1 Fitting a 4-bladed propeller. This will transmit a given amount of power within about a 10% smaller diameter, albeit with a small loss of efficiency relative to a 3-bladed one. It will also give less tiller shake.


Dropped Skeg

8.2 Lowering the prop shaft and fitting a ‘dropped skeg’. This has minimal impact on drag while allowing the propeller diameter to be increased (to a maximum of 19.5” on a 22” draft boat) without its extending below the boat’s base plate or compromising tip clearance. This is a viable, if rarely used, option.

8.3 Increasing the pitch of the propeller. This is standard practice for making small adjustments but, as the rule of thumb is to add 2” of pitch for every 1” of diameter lost, it would require an unrealistic, 4” increase to match the previous options.

8.4 Several websites generate propeller specifications if given boat details (weight, power, shaft speed, etc). However, if given an electric motor’s **continuous** power they invariably suggest propellers which are too small. This arises from the fact that they prop match at the maximum speed that the motor can sustain rather than the (invariably lower) one requested. Entering the higher **instantaneous** power often produces more realistic suggestions, albeit ones which now err on the top side.

To exemplify this, entering the continuous power (15 kW @ 1,000 rpm) of the author’s boat’s motor into the popular VicProp website produces a recommended 3-bladed prop size of 18.2 x 11.4”, significantly smaller than the original 19 x 12” with which it was clearly under-propped. Entering the instantaneous power (29 kW) produces a recommendation of 20.7 x 13.5”, comparable to the current 20 x 14” with which it is now equally clearly over-propped, reaching only 850 rpm, though working better (reduced cruising revs and prop-wash) at canal speeds and still being able to reach 6 mph. This experience, *plus* anecdotal evidence from other electric boat owners, suggests that modest over-propping is desirable, though the Group has been unable to quantify this on a theoretical basis. A purely empirical approach which seems to give sensible results is to overstate the actual continuous power by about a third

9 **Batteries**

9.1 The capacity needed depends on how fast and for how many hours per day a boat will cruise. Allowing for locking time, a well-designed boat on a 1 lock/mile, canal will use 1.5-2.0 kWh per cruising hour so a boat cruising for 6 hours/day is likely to use 9-12 kWh/day. Gentler use and/or shorter days will obviously reduce this, as will solar input. As the power required increases rapidly with speed, a 10% increase in speed needing 33% more power for example, so anyone wishing to cruise faster may need to install more battery capacity to avoid the need to charge frequently. Of course, the converse is equally true; modest slowing can give large power savings.

Domestic use is likely to add 25-50% to the above.

9.2 48V has become the norm for electric-drive boats for the very good reasons that, being widely used in other applications, ancillary equipment is readily available while motor currents remain manageable. 24, 72 and 96V are also options but all present problems, a shortage of suitable motors and very high currents for 24V, a lack of ancillary equipment and being subject to the more onerous wiring requirements of the Low Voltage Directive for 72V[7] and 96V.

9.3 **The battery situation has changed dramatically since the last revision of this document. In that it was said that "2V Lead-acid traction cells ... should probably be considered first." This is no longer true.**

9.4 Lithium Iron Phosphate (LFP) batteries have always been the best choice from a technical point of view but, although relative costs have been reducing slowly, they have remained too expensive for many would-be purchasers. However, the introduction of 'rack' form LFP batteries has stood the cost situation on its head, with these now the cheapest option by some margin. Ones from reputable manufacturers cost about £200 per usable kWh while Lead-acid traction cells cost £300 and conventional LFPs £400. Even cheaper rack batteries are advertised but their quality is unknown.

A 5kWh Rack Battery awaiting fitting in the Author's Boat

9.5 An even cheaper option is to build your own. Kits, including Grade A cells from a reputable manufacturer, are available to build (vertical or horizontal) 15 kWh batteries for about £120 per usable kWh. Online videos suggest that assembly is straightforward but make sure that you know what you are doing before attempting such a build.

9.6 **Be aware that LFP batteries can be damaged by charging at low temperatures.** The minimum charging temperature varies from manufacturer to manufacturer, but most are in the 0-5°C range, making them potentially vulnerable in UK winters. Some batteries are available with built-in heaters; others require external heating, though mounting them directly on a boat's baseplate will offer some protection against sub-zero temperatures. The author has found 10W per battery to be plenty for his unheated rack batteries, but this will vary depending on the installation.

9.7 This change contributes to the potential for a very significant reduction in the cost of electric drive systems. Internet searches by the author suggest that the components for a basic system using rack batteries, an industrial generator and a 15 kW/1,000 rpm motor can now be bought for £20-25K. Parts for a more conventional 'mix and match' system come in at £30-35K while one with a marine

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[7] Although nominally below the 75V at which the Low Voltage Directive applies to DC systems, 72V systems are actually 76.8V, with higher system voltages while charging.

generator from a single supplier will cost well over £40K. Note that these figures do not include installation or solar panels.

> ***Warning:***
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> *The term 'Lithium Ion' is widely used for all Lithium battery chemistries but it is important to distinguish between LFP (Lithium Iron Phosphate), the type usually used in boats, and other chemistries, the most common of which is NMC (Nickel Manganese Cobalt)*[8]*, used in products as diverse as electric vehicles and mobile phones. In the event of faults or damage. NMC batteries are prone to thermal runaway*[9] *and the resultant fires cannot be extinguished with standard extinguishers*[10]*, if at all.*
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> *The risk is particularly great if using repurposed ex-EV batteries (something the Group does not recommend) as their original battery management systems (BMSs) must be replaced with lower voltage proprietary ones, some of which are reported to be of dubious quality. LFP batteries are not subject to thermal runaway so are inherently safer, though even these can emit gases which are toxic and flammable if they overheat. Their Battery Management Systems should prevent this, but* ***it is important to eliminate any risk of overcharging in the event of BMS failure by setting the charger according to the battery manufacturer's recommendations****.*
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> *The Group is aware of the explosion on an ABC Dayboat at Gayton Marina in August 2025. The cause has not been made public at the time of publication of this guide, though there has been a lot of speculation, much of it ill-informed. We would not wish to add to that but are hopeful that a full investigation will uncover the facts. When this is available, we will assess its findings and incorporate any learning into this guide as appropriate.*

9.8 For anyone looking to purchase an existing boat which already has Lead-acid batteries (including Lead-Carbon ones), the following guidance is retained.

A weakness of all lead-acid batteries is what is termed 'memory', loss of capacity due to sulphation if not fully charged regularly. The final stages of charging a large LA battery bank using a generator can be particularly inefficient as it can take several hours during which time most of the energy in the fuel goes to warming the canal. On an all-electric boat this can be mitigated by arranging domestic loads while charging but, in the absence of a large solar installation (and then only at the right time of year), an occasional plug-in is preferable as the charger can then take only what it needs.

9.9 20 kWh of usable power requires about 40 kWh (830 Ah @ 48V) of Lead-acid or 25 kWh (500 Ah @ 48V) of LFP batteries. For an all-electric boat these figures need to be increased by about 50% to cover domestic use. A further 25% for Lead-acids, 10% for LFPs, is suggested to compensate for loss of capacity with age.

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[8] NMC batteries are also environmentally undesirable as the mining of Nickel, Molybdenum and Cobalt are all notoriously polluting. They are also more difficult to recycle than LFP ones.

[9] Thermal runaway occurs when a faulty battery gets hot enough to emit flammable gases and ignite them.

[10] Extinguishers which are claimed to work on Lithium battery fires are offered on the Internet but the Group's judgement is that none will work on boat size batteries, if at all.

9.10 Promised for some years and finally close to being commercialised[11], are Solid Electrolyte Batteries. These have higher energy densities and could be game changers once they become available, potentially providing enough energy storage for boats to manage a week, or more, between charges. This could make purely shore-based charging viable and, by removing the need for generators, bring capital costs down to the point where electric-drive boats could become as cheap as diesel-engined ones.

10 Generators

10.1 Generators should, in general, be water-cooled as they are quieter and can be more efficient. However, even in an efficient diesel engine only about 30% of the energy in the fuel does work while 50% is lost through the exhaust and 20% goes into the engine's cooling system. Recovery of at least some of this last for domestic use can make a useful contribution to overall efficiency.

A Small Marinised Generator

10.2 If you are planning only electric drive, you only need your generator to charge your batteries and a DC unit will be slightly more efficient. However, if your boat is all-electric, an AC unit will allow you to share the domestic load between your generator and inverter.

10.3 For the sizes of battery bank mentioned above a generator with a **continuous** rating of 4-8 kVA is suggested. Read the small print carefully. Most require downrating to 80%, or even 70%, of their nominal outputs for 'extended running', which can mean as little as 20 minutes!

10.4 The final choice requires the balancing of opposing factors. A larger generator (likely to be 1,500 rpm) will charge more quickly so, being run for fewer hours, will disturb your peace less, require less frequent maintenance and probably last longer. However, a smaller one (likely to be 3,000 rpm) running for longer should be more fuel efficient as more waste heat will be available for domestic use and it will be less wasteful if fully charging LA batteries.

10.5 If buying an industrial generator, the critical features are that it must be water cooled, have electric start and a 230V AC output (some have only 110V). Removing its diesel tank and replacing its radiator with a skin tank or secondary raw water circuit with a Bowman-type heat exchanger is all that is required to install one on a boat.

10.6 If space restricts you to a smaller battery bank than suggested, you may want your generator to start automatically so that your cruising isn't curtailed. If so, it is best to opt for skin cooling and a dry exhaust as running a water-injected one while cruising increases the risk of blockages. Otherwise, dual circuit cooling with a raw water secondary has a lot to commend it as not only is it cheaper, but it permits the use of rubber hoses, thereby avoiding the embrittlement problems of metal exhausts.

10.7 Fuel cells are potential generator substitutes, technically developed but with only one suitable product known to be on offer in the UK at the time of writing. They

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[11] Several impending introductions of solid electrolyte batteries in cars have been announced since the last revision of this document. Free standing batteries suitable for boats will inevitably follow.

Hydrogen Fuel Cell Unit

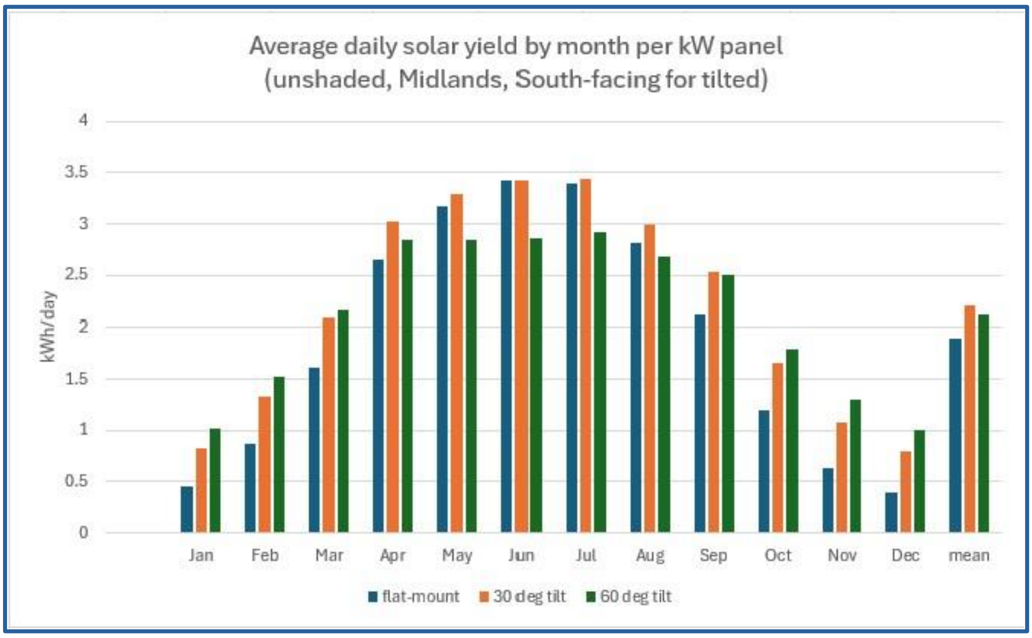
produce electricity directly by the chemical reaction of fuels with Oxygen, the principal types being Proton Exchange Membrane (PEM), which can use only pure Hydrogen, and Solid Oxide (SO), which run hotter and can also use Methane. At about 50%, both types are nearly twice as efficient electrically as generators and, with most of the other 50% of their fuel's energy available as heat, can potentially provide virtually all the water and space heating for a narrowboat, affording a significant saving in domestic energy use.

Unfortunately, almost all the Hydrogen currently available is made by the steam reforming of Methane, an environmentally damaging process. It is also very expensive. 'Green' Hydrogen, if/when it becomes available, is likely to be even more expensive and, with an end-to-end efficiency of less than 30%, will be much less efficient for charging batteries than using power from the grid. Nevertheless, there could be niche applications for Hydrogen.

Combined heat and power units using SO cells running on natural gas alongside conventional c/h boilers exist but are too large for use in narrowboats.

11 Solar Power

Over and above their environmental benefits, solar panels can be worthwhile financially[12] so capturing as much solar power as possible is a given for any electric narrowboat, isn't it? The basic answer is 'yes' but solar power has limitations, and these must be recognised as decisions on the number and types of panel and how they are to be fitted will influence both costs and benefits. This graph provides data useful for the discussions which follow. Note that the figures are for 1 kW nominal.



11.1 Two types of panel, rigid and semi-flexible, are regularly fitted to narrowboats. In the former the Photo-Voltaic (PV) cells are located behind glass within aluminium

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[12] This is particularly true when the only other means of battery charging is using a propulsion engine while moored, where costs can easily exceed £3/kWh.

frames and are mounted clear of the boat's roof. In the latter the cells are sandwiched between two layers of plastic and usually bonded to the roof.

11.2 The left-hand lines on the graph show that a narrowboat with a 2 kW installation (which would have to be semi-flexible), moored in an open situation in the Midlands could, on average, expect about 7 kWh/day. This will reduce, typically to a bit over 5 kWh, because of shade from trees, buildings, bridges, etc, while cruising. This is an average so there will be better days – and worse. Importantly, reference to the cruising power figures in Section 9 shows that even such a large solar installation is likely to support only domestic use and modest cruising during the Summer. At some point in Spring or Autumn the solar yield will no longer suffice and plugging in or using a generator is likely to be necessary. Exactly when this happens will obviously depend on panel size and energy use but by the middle of Winter solar energy will only contribute a fraction of the likely demand.


Rigid Solar Panel

11.3 **Rigid panels** tend to have slightly higher conversion efficiencies and longer lives than semi-flexibles (see 11.6) and being cheaper, offer better financial returns. However, the areas that can be fitted are smaller and they can interfere with ropes, poles and the ability to walk on a boat's roof, potentially affecting safety.

To look at some numbers, rigid panels can be bought for less than £0.50/Watt, though £1/Watt is more typical. Each Watt will produce 1.0-1.5 kWh/annum, worth 25-50p (at generator/shore-line cost) so will pay back within 2-4 years, well within their expected lifetimes of 10-15 years.


Walking on Solar Panels

11.4 **Semi-flexible panels** permit larger areas to be fitted as they can, within reason, be walked on, though, as they cost about 3 times more than rigids, their pay-back times are proportionately longer. There also appear to be more durability issues than with rigids (see 11.6). Full roof coverage also creates problems with the storage of poles, boat hooks and planks. Nevertheless, most electric-drive boats now have large semi-flexible solar arrays, typically a nominal 1.5-2 kW.


Angled Solar Panels

11.5 **Angling** panels towards the sun, only possible with rigid ones, can increase their solar capture though, as may be seen from the graph, 60° angling, the best during the Winter, results in a reduction during the Summer. Maximising the return requires re-setting of the panels from time to time.

In practice, the benefits of angling are not large (see the 'mean' lines on the graph) so, bearing in mind that (I) the area of rigid panels that can be fitted is less than that of semi-flexibles, (ii) that angling isn't practicable while a boat is cruising and (iii) the benefit is dependent on its (probably random) orientation when moored, the Group's opinion is that the additional complexity and cost is difficult to justify.

11.6 **Longevity.** Panels can get very hot on sunny days and, while the outputs of both types of panel fall with increased temperature,[13] rigids appear to suffer little permanent damage while at least some semi-flexibles do, meaning that they may not last long enough to recover their capital cost. Prompted by the failure of his semi-flexible panels after 3 years and those of a friend after 4, the author carried out an Internet survey in 2019, finding that 5 years was the most commonly reported time to failure, with 8 the longest. Products may well have improved since then and will almost certainly do so in the future. but the Group knows of a number of failures (many denied by the builders who fitted them) so **make sure to get a good warranty.** As semi-flexible panels are likely to take 6-12 years to repay their cost 10 years should be the target.

The vulnerability of semi-flexible panels almost certainly derives from the thermal movement of the polymers used to encapsulate the cells and one builder, who has had boats with large semi-flexible solar arrays in service for 7 years without any failures, attributes that longevity to the fact that the backing layers of the panels he uses are reinforced with glass fibre. This seems plausible as such reinforcement will restrict the thermal expansion of the polymer.

11.7 The Group knows of attempts to reduce damage to semi-flexible panels by providing under-panel ventilation using hollow-section plastic sheets. Results are likely to take some years to come through though the Group is sceptical about this approach as it is premised on the idea that the boat's roof heats the panels, an idea which is almost certainly wrong in most cases as panels are usually black, meaning that the heat flow is more likely to be the other way. The author suggests that cooling the roof by passing cold water through capillary matting[14] mounted on its underside is likely to be more effective.

11.8 Another product which might be of interest is the hybrid panel, a combined PV and water-heating unit. These are only available in rigid form and, as the water circulating will get hot in sunny weather, will still lose some PV efficiency. However, as a rigid panel it is likely to be quite durable and not needing to use electricity to heat water should more than compensate for any loss of efficiency.

11.9 Yet another product is the bifacial panel. These are rigid panels which absorb light from both above and below so can increase the capture from a limited area, though the surface under them must be made as reflective as possible to maximise the benefit. In most cases this means painting a boat roof with solar reflective paint, though the Group knows of one boat with such panels successfully mounted on a polished stainless-steel roof.

The Sustainable Boating Group hopes that this document will prove useful and wishes you safe, enjoyable and efficient electrical narrowboating.

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[13] The fall in output is typically 0.2-0.5 %/°C, meaning a loss of up to about 15% on a sunny day.

[14] The type used in wet ceiling heating systems rather than that used for watering greenhouse plants.

Appendix 1 – Propulsion Layout of a Typical ‘Electric Drive’ Narrowboat