A quest for sustainable narrowboating

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The problem

- Britain's inland waterways are heaven! But….
- The 38,000 narrowboats on Britain's inland waterways emit >100,000 tonnes CO_2 per annum
- They also have a range of other negative environmental impacts
- The government intends to legislate but most boat owners don't have much money
- Green Narrowboats is seeking real answers to two questions:
  1. How can we address the environmental impact of narrowboats?
  2. How can we do it at a reasonable cost?

Environmental impacts

- CO_2

	kg CO2 p.a.		Total kg CO2 per boat p.a.	Number of narrowboats in the UK	Total Tonnes CO2 p.a.
	Diesel	LPG			
Year-round living plus cruising in the holidays	3,012	266	3,279	9,500	31,000
Cruising only - private	1,672	89	1,761	19,000	33,000
Cruising only - commercial	5,017	133	5,150	9,500	49,000
					113,000

- Most electric power is generated by using the diesel engine really inefficiently; statistically only a small proportion of narrowboats use shore power
- Diesel engines create significant NO_x and particulates
- Over 120,000 litres of fuel is spilt into inland waterways, polluting 120 billion litres of water annually

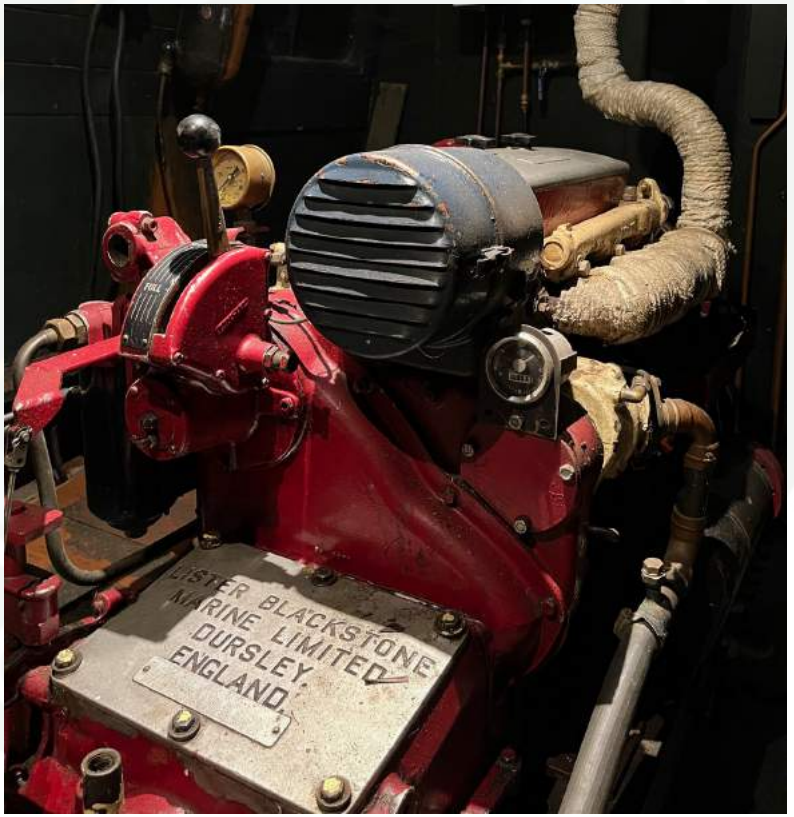
The concept

- Convert a narrowboat to investigate and deliver solutions to the following issues:
  - motive power
  - electricity
  - space heating
  - water heating
  - toilets
  - cleaning agents and other things (all grey water - e.g. the sink - is discharged directly into the canal)
  - construction materials
- Collect data and improve
- Share all the learning!

Introducing Katoomba

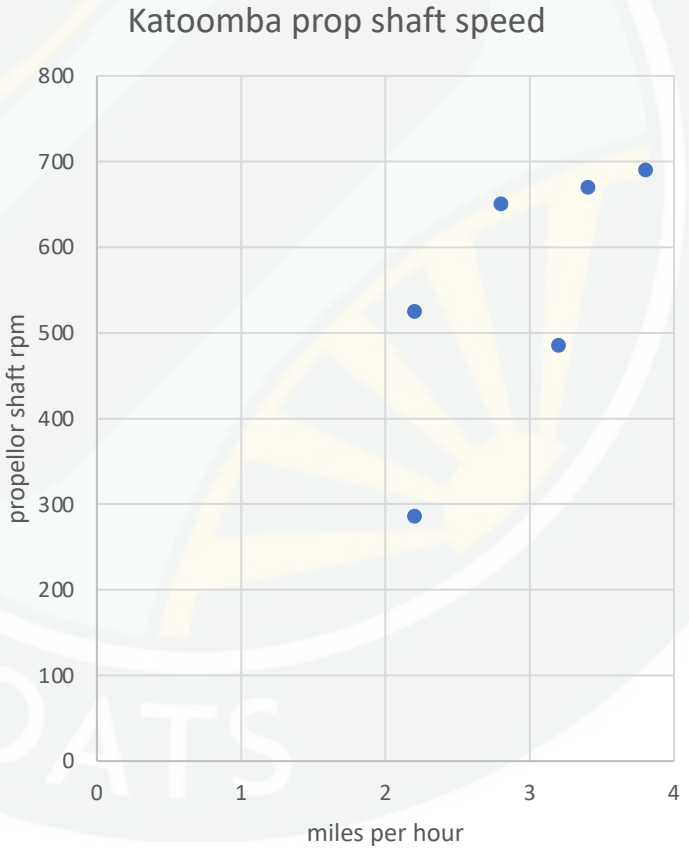
Electric drive

- An electric motor with inverter is 85-90% efficient
- A new diesel engine can be up to about 55% efficient, but:
  - Most narrowboat engines are old, which significantly reduces efficiency, and
  - Diesel engines are only this efficient at full RPM; engines are sized for safety in flowing rivers, but the vast majority of travel is on canals at much lower RPM
  - In practice therefore, most narrowboat engines are used at about 10% efficiency
  - This is also true when they are used to generate electricity (low revs to limit noise)



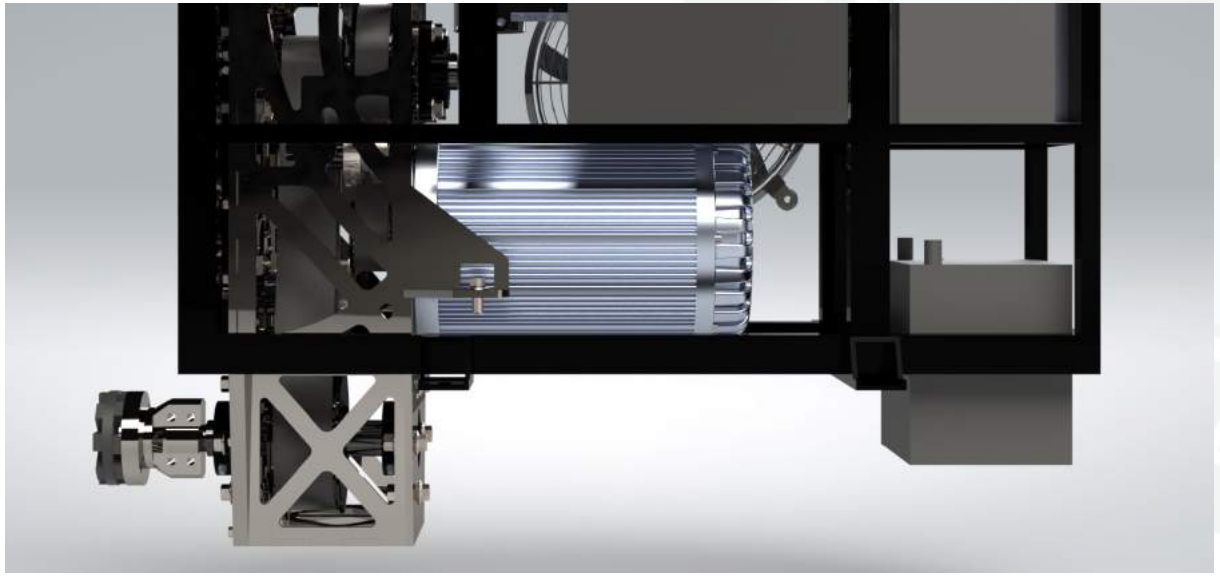
Electric motor considerations

- All available data suggests that normal cruising (4mph) consumes 1kW
- You want at least 10kW to get you out of trouble (just in case)
- Under 60V is “safe”
- Over 96V means your local boat safety officer has to refer to head office
- This implies a nominal working voltage of between 48V and 80V
- Electric motors are relatively fast – so the cost of your gearbox is an important consideration



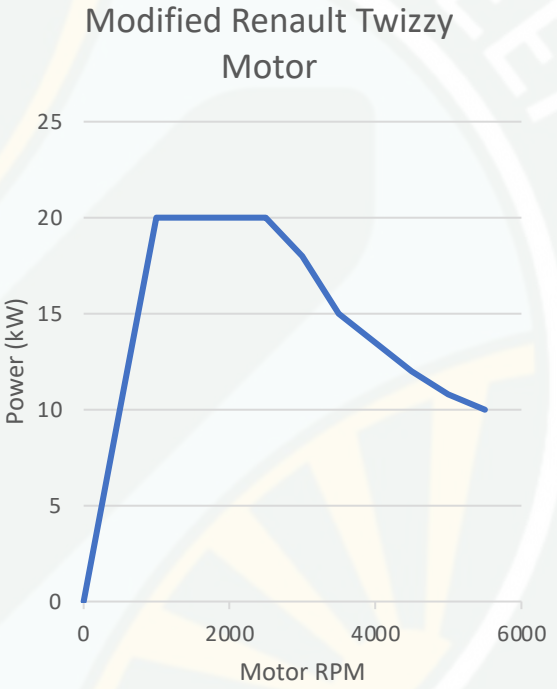
Version 1

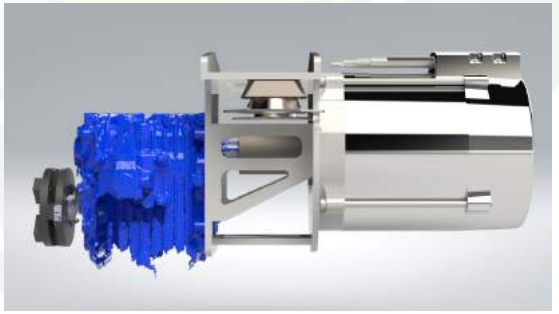
- Commercially available motors cost >£10,000
- A Netgain “Hyper 9” motor and inverter costs £3,500, but it runs at up to 8,000rmp, so…



Version 2

- Renault Twizzy motor + inverter: £1,800 new
- Off-the-shelf 3:1 boat reduction box
- Green narrowboats will modify the power curve of the motor so that max power is available from 1,000 rpm motor speed – 330rpm prop speed = 2mph Katoomba speed
- This will ensure most cruising is at max motor efficiency



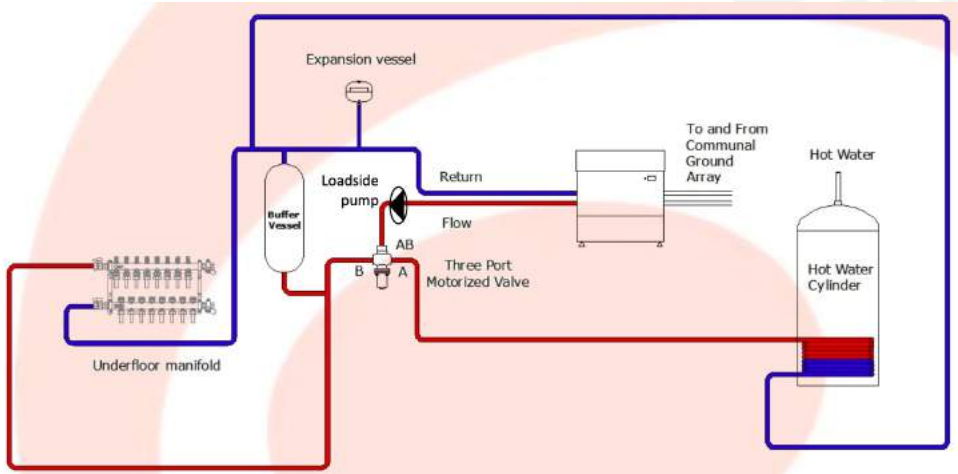


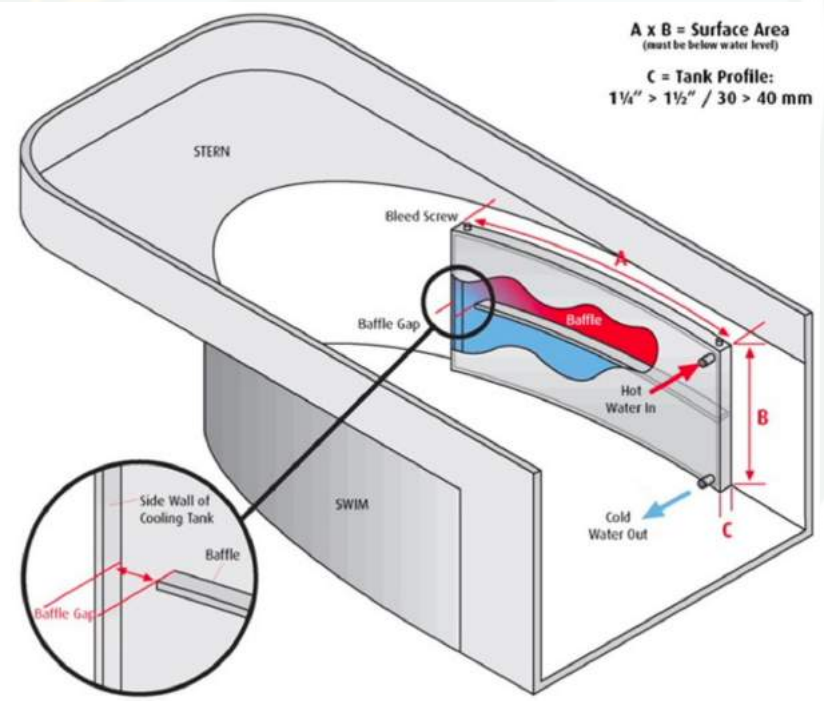
Space and water heating

- Only real options for space heating are diesel and/or a stove with a back-boiler
- Diesel is fossil!
- Stoves with a back-boiler are difficult to live with
- So what about a heat pump?
  - Water is a perfect heat source
  - Output water temperature is circa 35^{o}C at max efficiency
  - Not much floor space in a narrowboat but ideally underfloor heating plus radiators
  - Katoomba is a retrofit, so underfloor heating is not practical
- Heat pump can supply hot water plus background heating but best with a wood stove for added comfort

Heat pump specification

- 4.05 coefficient 3kW Kensa “Shoebox” + 150ltr Hot water Cylinder
- Whole system £5,000 + radiators
- Heat exchanger is easiest by skin tank – 1.5m^2 required for a 3kW heat pump





Insulation

- Insulation is important, and even more-so if you want to use electricity for heating. An uninsulated boat with two people in will take 2 hours to cool to ambient temperature, compared with 12 hours for a properly insulated boat. Here are some rules for insulation:
  - More insulation the higher you go – hot air rises and transmission is proportional to temperature difference
  - Radiative barrier to keep you cool in the summer – Eurothane insulation boards come with one already attached
  - Polyester wool for small gaps
  - Vapour barrier – this is vital to prevent/reduce condensation on the inside of your narrowboat's metal skin – which is where you don't want damp. This requires careful thinking about penetrations, such as types of lighting
  - Cladding – wood looks nice and also insulates!

Forced air ventialtion

- A heating system is not efficient on a boat because of the need to deal with humidity and ventilation…
- Otherwise you will be damp and if you don’t have enough fresh air for your stove, you won’t pass your boat safety examination
- A forced air ventilation system removes warm wet air and uses it to heat incoming fresh dry(er) air
- A dehumidifier can be added but it should not be necessary

- Baluberg Komfort horizontal MVHR heat recovery ventilation system total cost £2,500

Cooking etc.

- Eliminating fossil fuels means eliminating gas for cooking
- Removing the gas also means less need for ventilation to get your BSS
- Induction cooking is the most energy-efficient, but uses high power – so your battery system needs to be up to it
- To fit a cheap induction hob means a 240V AC supply from an inverter
- Plus a combined microwave/electric oven… which is mostly used as a microwave!
- The fridge and other main loads are more efficient at 24V than 12V
- So it’s important to think about loads and supply voltages

Energy loads

Load	Qty	W	battery voltage (V)	supply voltage (V)	Ah	hrs	Ah/day
motor	1	1000	44	44	22.7	8	181.8
fridge	1	12	21.9	24	0.5	12	6.6
TV	1	100	21.9	240	4.6	3	13.7
wifi	1	1	21.9	12	0.0	24	1.1
hob	1	2800	21.9	240	127.9	1	127.9
cooker	1	900	21.9	240	41.1	0.5	20.5
microwave	1	800	21.9	240	36.5	0.10	3.7
washing m/c	1	500	21.9	240	22.8	2	45.7
laptop	1	80	21.9	240	3.7	3	11.0
phone	2	10	21.9	12	0.5	4	3.7
radio/speaker	1	20	21.9	240	0.9	3	2.7
lights	10	8	21.9	12	0.4	3	11.0
hot water h/p	1	500	21.9	240	22.8	4	91.3
radiator h/p	1	500	21.9	240	22.8	8	182.6
							703.2

Batteries

- Lithium Ion batteries are best:
  - No fumes, no maintenance
  - Lasts 4 times longer than AGM or Gel
  - No Perkow's Law
- They need to be properly managed – a battery management system that balances at cell-level
- The inverter will last longer if it is not in parallel with a big load, so have two banks of batteries:
  - one charging + supplying the domestic loads
  - one for driving the boat

  and swap them over (automatically) when the drive battery needs recharging

- 12 x 22V 102Ah batteries = 979Ah storage at 80% capacity
- (best to keep the batteries between 10% and 90% full charge)
- This is plenty more than the 700Ah daily demand with everything on including the washing machine!
- These batteries are £300 used or £600 new = £3,600 or £7,200 total

Power source – solar!

- Green Energy Scandinavia latest-generation MIPV solar panels:
  - walk-on
  - insensitive to shading
  - works when horizontal
  - gathers wide light-spectrum for high-yield
  - Flexible so will curve to fit a narrowboat roof
- They measure 1150 x 350 mm so there is room for 28 of them on Katoomba's roof
- Each panel outputs 6V, so use in groups of 4x to output at 24V for max efficiency
- Batteries will charge at 24V and be used for propulsion at 48V

How far on pure solar?

- There is room for 28x panels on Katoomba at a cost of about £6,000

		YEAR			APR - SEPT INCLUSIVE		
Panel yield		annual hours oxford	No panels	average daily yield (Ah)	total hours oxford	No panels	average daily yield (Ah)
sunshine	2.3 A	1,615	28	280.1	1,114	28	385.1
overcast	1.0 A	2,243	28	176.8	1,037	28	162.9
rainfall	0.5 A	634	28	25.0	612	28	48.1
		4,493			2,763		
				481.9			596.2

- Total load without radiators is 520Ah – so you can cruise continuously for 8 hours a day from April to September on solar only

OXFORD INSOLATION

Month	Sunshine (hours)	Days of rainfall ≥1 mm (days)	Hours daylight
January	63.4	12.1	248
February	81.9	9.4	252
March	118.2	9.1	341
April	165.6	8.9	390
May	200.3	9.6	465
June	197.1	8.0	480
July	212.0	8.3	511.5
August	193.3	9.0	496
September	145.3	8.6	420
October	110.2	10.9	341
November	70.8	12.2	300
December	57.6	11.6	248

Back-up power?

- Solar panels don't generate enough power in the winter to continuously cruise and run the heating and water, so…
  - plug in to shore power, or
  - don't move around so much (cruising for 8 hours is 25% of the daily energy budget), or
  - get used to just using the wood burning stove for space heating, or
  - install a diesel generator
- If you want true independence, then a diesel generator is necessary for an hour a day in the winter. But if you use a purpose-built diesel generator it really will run at 55% efficiency, so as long as you avoid diesel spills your impact on the environment will be a tiny fraction of what it was before

Total costs

- Total cost is about £30,000 fitted
- Annual savings in fuel and maintenance is about £3,000 for a live-aboard (while red diesel is still available), so currently about a 10-year payback for a re-fit
- A re-fit with an equivalent diesel-based system would cost at about £15,000, and the reality is that all boats have solar systems now so the equivalent cost is actually higher than this.
- In a new-build the incremental cost of going all-solar is about £10,000, so a 4-year payback

motor and inverter	£ 2,000.00
reduction box	£ 1,200.00
heat pump	£ 5,000.00
forced air ventialtion	£ 2,500.00
batteries (used)	£ 3,600.00
solar panels	£ 6,000.00
Electronics	£ 1,700.00
Fitting	£ 8,000.00
	£ 30,000.00

And lastly….toilets!

- Nothing to do with energy but sustainable boating means you have to address the subject of toilets
- Cassette toilets are smelly, disgusting to empty and require environmentally horrible chemicals
- Separator (“composting”) toilets are not, but it takes 12-18 months to compost human waste, and the toilet needs to be emptied about once every 3 months. The CRT have banned emptying them into their bins, as it condemns the whole bin to landfill.
- So the next phase for Katoomba is to design an on-board composting facility so that the contents of the toilet have 18months of composting in a controlled environment. A smorgasbord of scatological humour awaits…

Thank you!

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