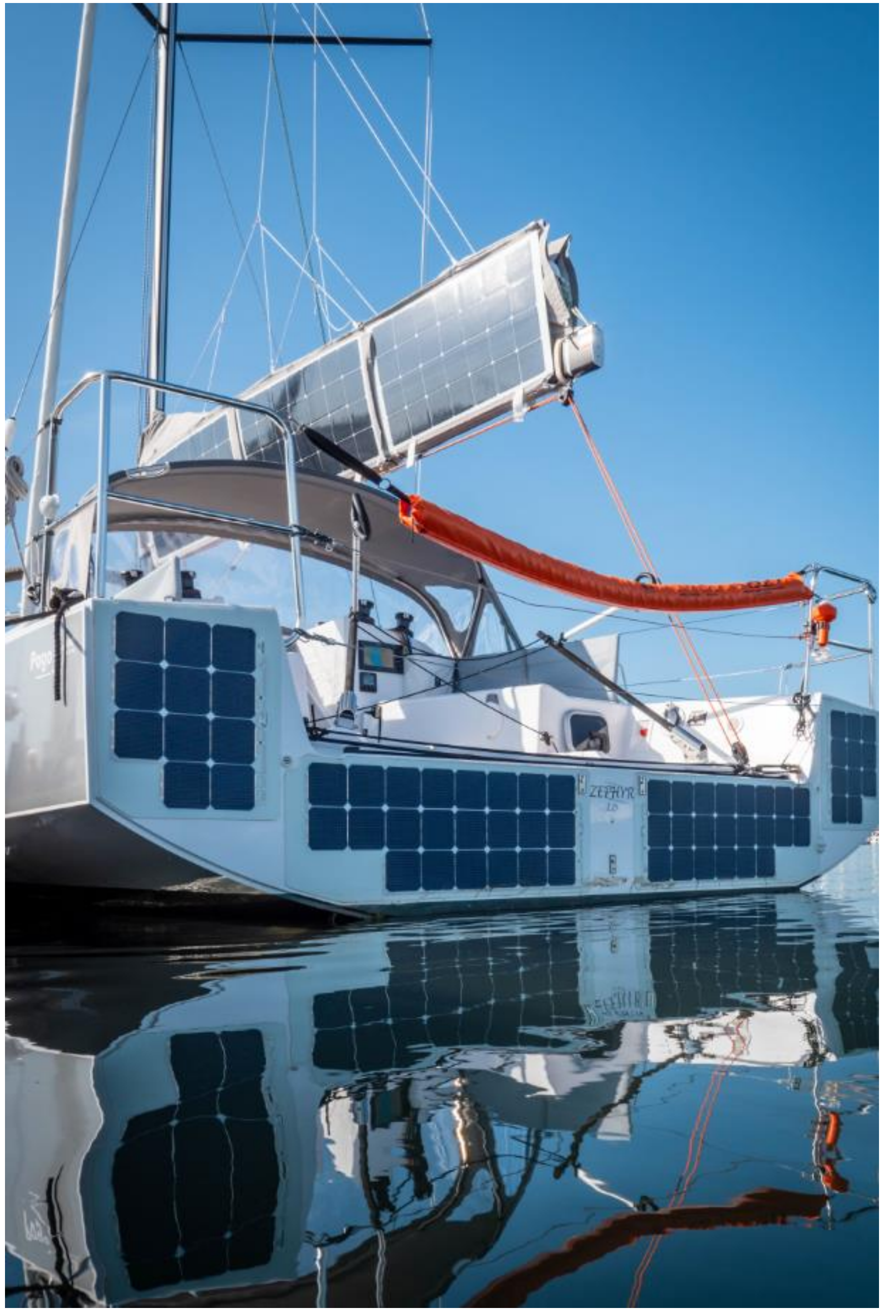


Solar sailing with Zephyr, a fully electric Pogo 30

By Mark Johnson

July 2019

7 week summer trip sailing the all-electric Pogo 30 between France and the UK with mostly cloudy windy weather UK side. All good, no technical problems, no power shortages. The keys to this successful trip were:

- Good weather forecasting: the forecast was sufficiently accurate that we could plan around the weather so we never needed to motor long distance. The children are happy about this, in previous years we have had some long motoring spells which nobody enjoyed.
- Plenty of solar power: the 1kW arrays (see photos) produced 50W to 500W all day long, keeping the batteries topped up, so when we needed our batteries we always had a full charge
- Efficient boat: the Pogo30 sails very well (even fully loaded for family cruising, thanks to the 200kg saving of the electric system), making it easier to work around the weather and reducing the need for motor power
- There was only one occasion when our speed felt limited, coming out of Audierne harbour against 15kts of wind and 1.5kts of current. With a bigger motor we would have got out 5 minutes quicker, but the 4kW pod still delivered >4kts of boat speed which was acceptable. Otherwise the electric power was all for the good: quiet, clean, no refueling, valuable space gained and weight saved, infinite power for the fridge and electrics, no need to run the motor to charge the batteries or run the windlass/keel-lift motor.
- The interface with Raymarine was 100% reliable and the display of battery and charge/discharge status, time to go etc makes it easy and builds confidence.

July 2020

3 week summer family cruise from Vannes to La Rochelle and back in mostly continuous sunshine:

We had no technical problems, no range anxiety, and no need to plug into shore for a recharge. Our 10kWh Torqeedo Lithium battery remained above 75% most days and we never dropped below 50%, indeed the instant availability of power (the Torqeedo system has no delay like when starting the diesel engine) helped us on a few occasions.

Family holidays are about sailing not motoring and like all sailors we optimized our trips, timing our departure for a fun sailing breeze. But we had some light winds and did some motoring and motor-sailing. Running the motor at 1kW provides the ideal fishing speed of 3.5kts and the electric motor is efficient, so we rarely need more than 2kW. On sunny days, the Solbian 1kW solar array was peaking at 600W around mid-day so the battery topped-up quickly with the SNA by Guardtex solar lazybag allowing us to pop the panels out to the horizontal, maximizing power output and providing welcome shade in the cockpit. We benefited from unlimited silent power for the fridge, electronics, and keel lifter. Understanding and planning for energy was made easy by our Raymarine Axiom display which kept us effortlessly up to date with the battery status and power flows.

This summer trip demonstrated again that solar sailing can be perfectly compatible with family cruising in an efficient sailboat like a Pogo 30. The space gained from eliminating the diesel engine means that we have the equivalent usable volume of a Pogo 36, so the electric solution provides significant cost as well as weight savings. Life on board is quieter and cleaner and it's now two years since we visited a diesel dock - now that's something to celebrate.

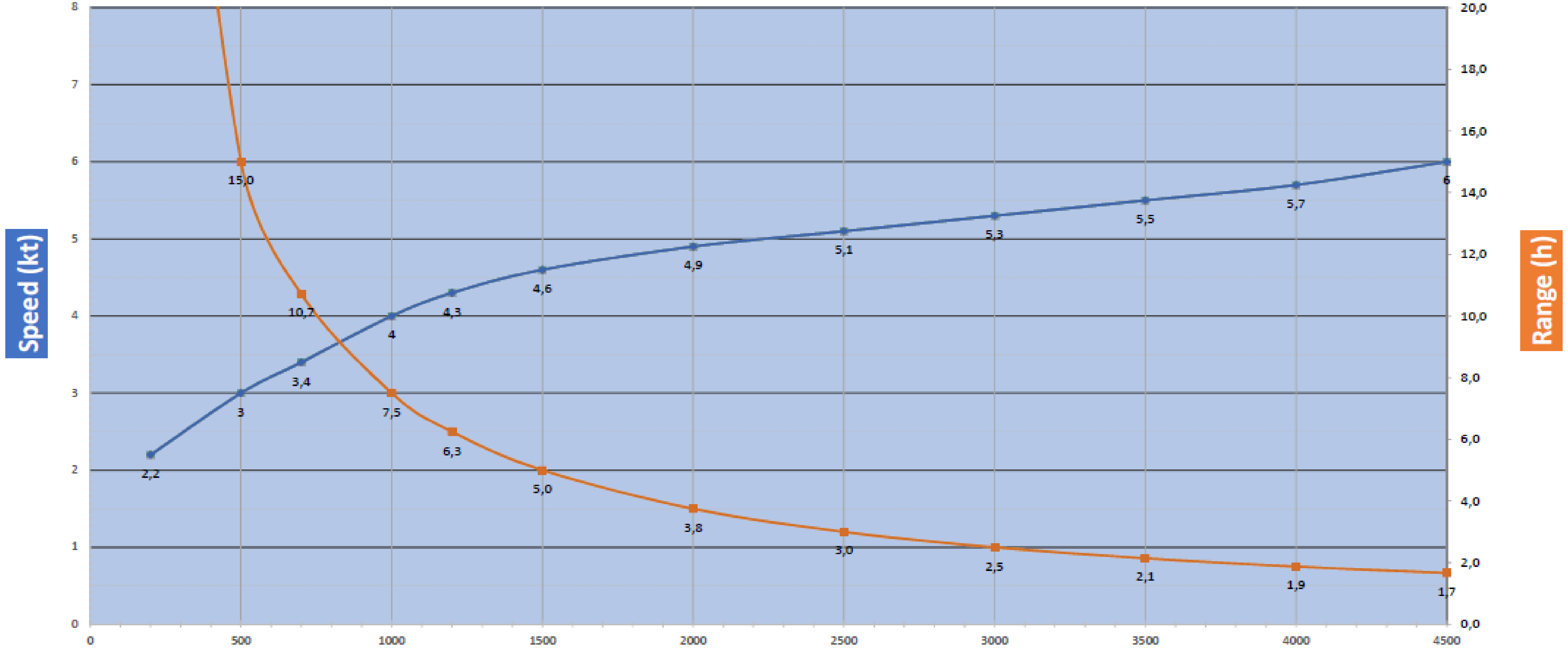
Clean, space-saving, weight-saving installation

Electroinics in clean engine bay

And the liferaft too!

Torqeedo lever & display

Motor pod installed with safety bulkheads above water level



Pogo 30
Displacement 2,8T
2 x Power 48-5000 & CR4.0 FP

WARNING:
Average speed.
Speed may vary with sea conditions,
loading of the boat and cleanliness of the hull.

Electric sailing: key factors for success

- **Good weather forecasting**: plan around the weather and avoid the need for long distance motoring
- **Plenty of solar power**: 1kW can produce 50W to 500W depending on conditions. This is generally enough to keeping the batteries topped up, so that a full charge is available when needed.
- **Avoid fixed dates and destinations**: need to be flexible either on destination or on timing, delivery trips on fixed dates may not be feasible. Solar charged electric propulsion works best with sunshine and minimal motoring and in many cases (eg family sailing) this is in alignement with the objectives of the crew.
- **Efficient boat**: the sailing boat needs to perform well, making it easier to work around the weather and reducing the need for motor power (an electric installation can save 200kg or so, which is noticeable on light-weight cruising yachts). Combining motor and sails is a great way to extend range and enjoy a silent sailing experience in light airs. The hull must be clean
- **Good integration:** with electronics giving a clear view of the battery and charging status is essential

Why boom-mounted solar panels?

The optimal angle for a solar panel is facing the sun but this is hard to achieve on a sailboat. Horizontal (sky facing) is a good compromize but shading is a big issue:

- The panels have ~60 cells in series, each producing 0,5V creating an output voltage of over 30V.
- Each cell is capable of producing up to 9A
- Think of this like a production line with workers passing electrons from one cell to the next, each cell upping the voltage. If one worker is shaded and works at 20% of full capacity, then the ENTIRE production line slows by 80%, current and output falls to 1/5th – that's a big drop in output from shading just one cell.


Saint-Martin-de-Ré 2020

There is a tradeoff between shading (making sure that a bank of series cells is not partially shaded) and optimum angle to the sun. The difference between being horizontal and vertically mounted is about 50% ie you get half the daily harvest from vertically mounted verses horizontally mounted installation. The loss from partial shading can therefore be more significant than the loss from vertical mounting.

Zéphyr's solution of mounting solar panels on the lazy bags has many benefits:

- Large surface area, where else would you find 4m² onboard a sailboat without partial shading?
- Easy to retrofit without impacting the deck
- Can be folded to the horizontal if extra power is required, can angle to the sun and track the orientation by positioning the boom
- When zipped closed vertically, the solution is very robust (proven in storm Alex with >100km/h winds)
- We really appreciate our mobile cockpit shade in hot weather, in fact this is probably the biggest benefit of all

Boom-mount carrier design

The solution was provided by SNT of Arzon (south brittany, France). It is very robust, we have sailed in all weathers and the boat has survived storms with no movement or vibration of the solar system.

SNT modified their standard lazy bag in the following ways:

- Rectangular rather than tapered, with the upper fibre rod running parallel to the boom.
- Three sets of zips (one top, one bottom) allowing the panels to be removed or lifted by unzipping the lower zip
- Aluminium posts to prop the solar panels into the open position. The posts fold in behind the panels when not in use.
- Weight carried by the lower zip, with siffened zip carrier which is bolted into the underside of the boom:

Due to the elevated access of the upper zip, we have added a block and tackle to raise and lower the lazy jacks which control the boom height. This also allows the solar panel angles and tension of the lazy jacks to be adjusted whilst reefing. We have a small elastic crossing between the two arrays at the upper aft end to prevent reefing pennants looping around the solar panels.

The aluminium posts which support the panels when opened are telescopic so that the lift height can be optimized depending on the sun's elevation. The white post cloth receptables seen hanging below the panels have now been moved to the inside so they are no longer visible when the panels are zipped closed.

Solar panel and charger matching

Each boom array is made from 3 panels of 28 cells connected in series (84 cells total). The Solbian SX cells are ~20% efficient which means they deliver 200W/m² at the AirMass1.5 reference point ie 1000W/m² inbound. They produce 9A and 42V at their maximum power point.

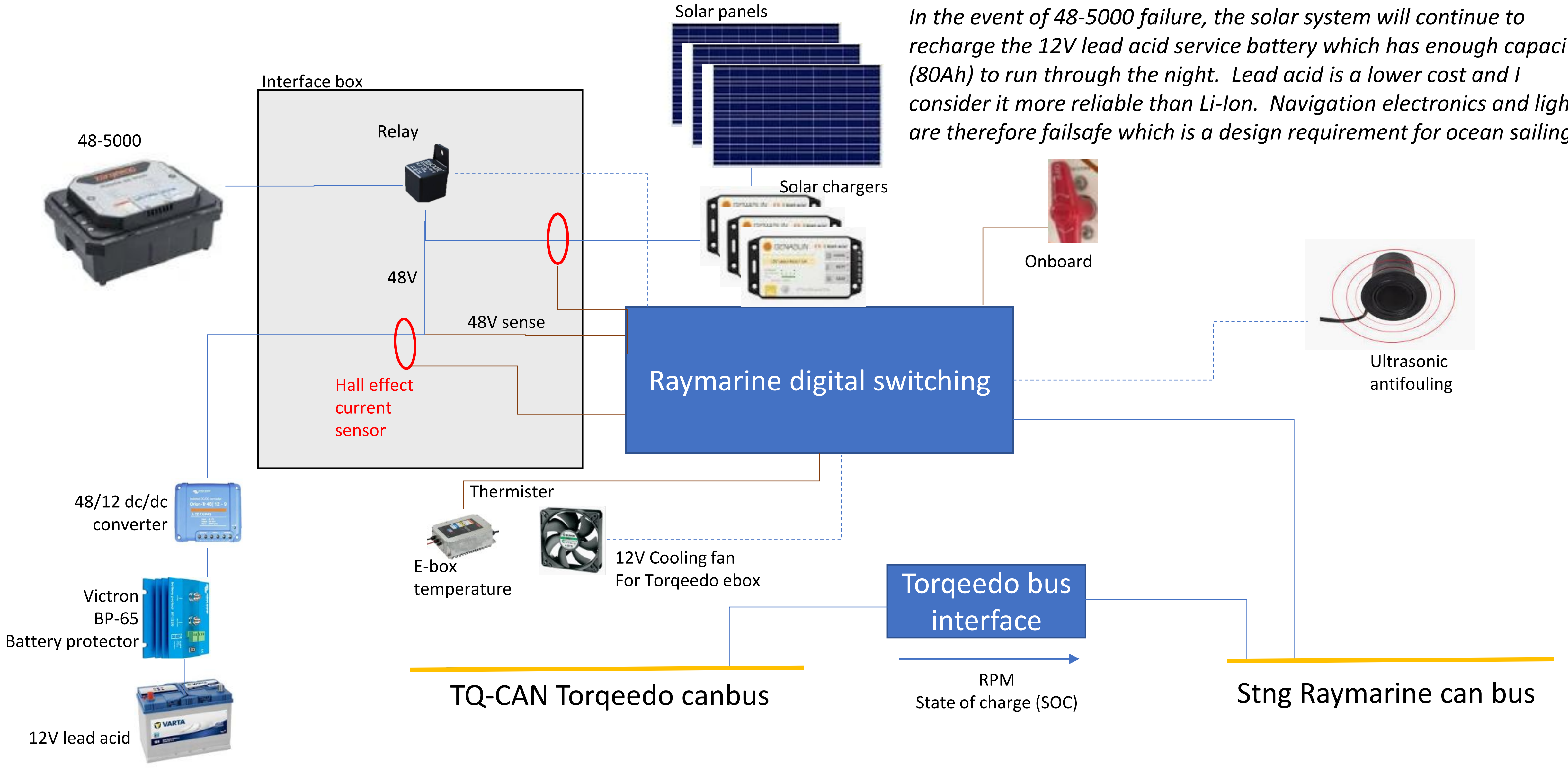
There are two Torqeedo 48-5000 batteries wired in parallel. The voltages range from 50V (full charge from the Torqeedo shore chargers), to 38V. The batteries need a shore charge from time to time for cell balancing and so we shore charge once every couple of months but solar does the rest.

There is one Genasun GVB8 maximum power point tracking charger per array ie a port, starboard and aft charger). They continuouly modulate the voltage point of the solar panels to maximise output. The optimum voltage will generally be below 42V since it's rare to have optimum insolation. The chargers are therefore working essentially in boost mode, pushing the voltage from the solar cell voltage up to the battery voltage.

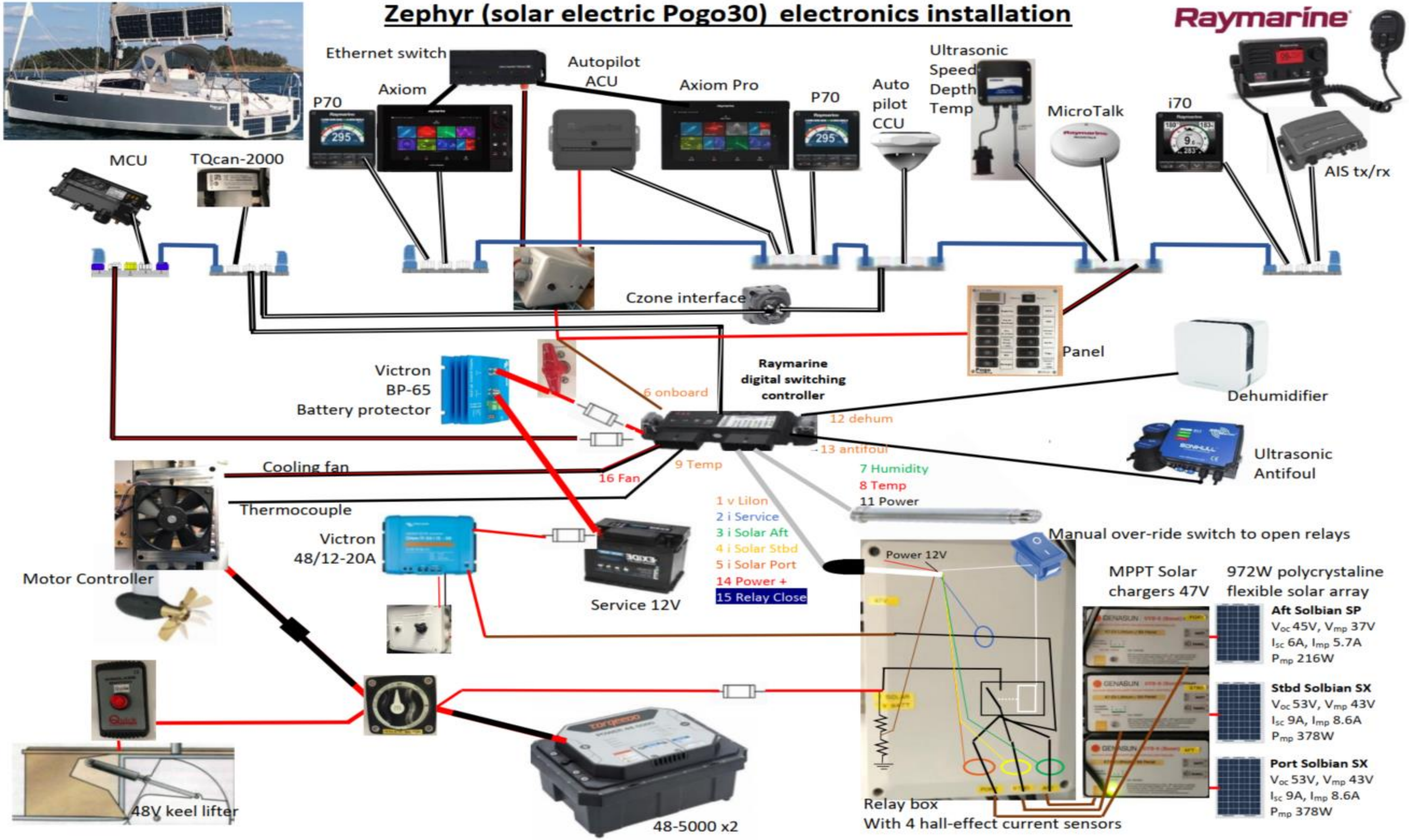
The Genasun charger upper voltage limit is set to 47V not 50V, since the life of the Torqeedo batteries is extended by charging to 90% of a full charge (47V) rather than 100% (50V)

Torqeedo integration with Raymarine digital switching

In the event of 48-5000 failure, the solar system will continue to recharge the 12V lead acid service battery which has enough capacity (80Ah) to run through the night. Lead acid is a lower cost and I consider it more reliable than Li-Ion. Navigation electronics and lights are therefore failsafe which is a design requirement for ocean sailing



Zephyr (solar electric Pogo30) electronics installation



Electric is an on-cost but space saved is valuable

On cost: 15 000€
Range 25Nm*

*doubled from butane outboard, not counting solar or hydro generation, or wind assistance

Annual running costs: 750€
Space saved: 50 000€*
Self charging, no refuelling
Quiet & clean

*cost difference between a Pogo 30 and diesel Pogo 36 which has similar internal space

INSTALLATION COSTS (retail prices inc VAT)	Diesel	10kWh Torqeedo 4 FP
Motor, propellor, controls & chargers	10 000€	6 000 €
Batteries (12V 200Ah & 48V 200Ah)	1 000 €	10 000 €
Ultrasonic antifouling	0 €	1 500 €
Solar (boom panel 2000€ x2 + Transom panel 2299€ + Genasun 200€x3)	0 €	7 000 €
Digital switching	0 €	2 000 €
Total	**11 000€**	**26 500 €**

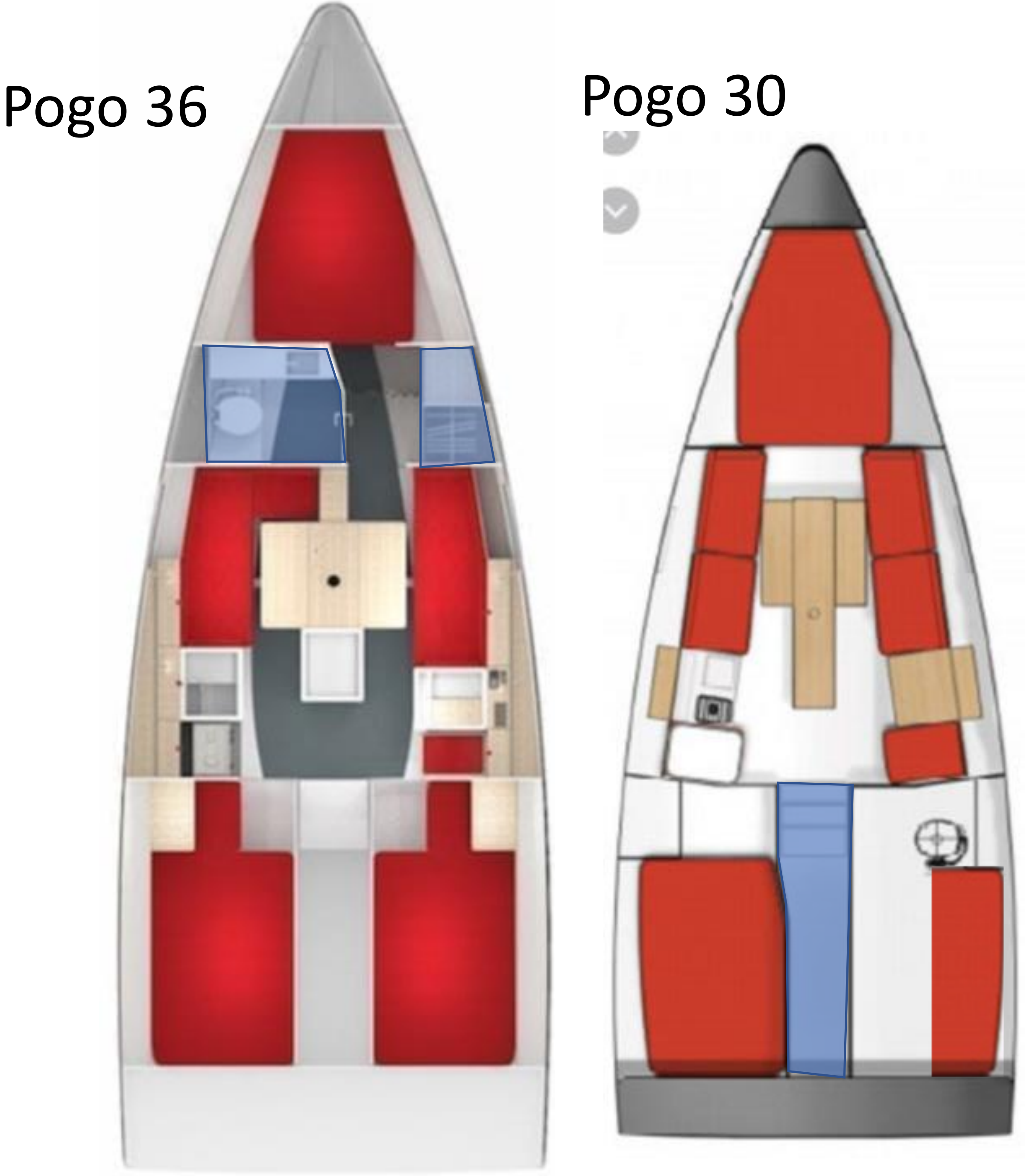
ANNUAL COSTS	Diesel	Electric
Engine servicing + fuel	800 €	50€

Space saving

The blue area left is the loo and hanging locker on the Pogo 36

On the Pogo 30, right, the electric engine releases the blue area for other use. We use it for hanging waterproofs and storing the liferaft (as well as motor, batteries and electronics).

The living space then ends up the same, with a boat 6 foot shorter, making the overall package less expensive despite the on cost of electric propulsion & solar system.



The weight savings are substantial

178kg saving !

Diesel Volvo D1-20	Mass Kg
Motor & saildrive	144
House batteries (2 x 12V AGM)	60
Motor battery (12V AGM)	30
Oil and cooling water	28
Exhaust system, oil filter, water cooler	8
Fuel tank (full)	40
Total	**310**

Torqeedo 4FP with 2x 48-5000 Li-n	Mass Kg
Motor pod	16
House battery (12V AGM)	30
Traction batteries (2x 48-5000 Li-Ion)	73
Electronics	5
Shore chargers	8
Total	**132**

Environmental impact

CO_2 footprint recovery time

Manufacturing a Li-Ion battery is energy intensive, involving material extraction and processing. It takes some time to recover the 'CO_2 footprint' ie the CO_2 emissions from manufacture:

- Lithium battery production: ~50kg CO_2 per kWh*
  battery manufacture has become more efficient since 2018 when Zéphyr was designed
- Pogo uses 10kWh Li-Ion, so emissions at fabrication are 500kg
- Typical annual fuel usage: 150L, producing 500kg CO_2
- A solar sailboat's Li-Ion CO_2 footprint can be neutralized in 1 year

Automotive comparison ASSUMING **ZERO CO_2** ENERGY which is close to true in France but not in other countries:

- Renault Zoe or Nissan leaf (mk2 40kWh) 0,7 years
- Tesla 90kWh 1,5 years (which doubles if the energy grid is only 50% carbon free)

Figures ignore the carbon footprint of manufacturing diesel and electric engines and the rest of the boat!

Carbon savings could be ~5 tonnes of CO_2 over the battery life (10 years)

*https://cen.acs.org/energy/energy-storage-/Northvolt-building-future-greener-batteries/97/i48

Energy harvesting predictions vs reality

Predicted daily energy demand

		24H sailing		Cruising		Moored		Limp home
		24		7				24
Digitally switched device	**Current A**	**Hrs/day**	**24h Wh**	**Hrs/day**	**Cruising Wh**	**Hrs/day**	**Moored Wh**	**LimpHome Wh**
Antifouling	1	24	0	0	0	24	312	0
Total	**1**		**0**		**0**		**312**	**0**
Manual switched device								
Fridge (peak = 3, average= 1)	1	24	312	24	312		0	0
Nav lights	0.5	7	46	7	46		0	6
Cabin lights	0.5	3	20	3	20		0	0
Total	**2**		**377**		**377**		**0**	**6**
Navigation Device	**Current A**							
p70 x2	0.24	24	75	7	44		0	150
i70	0.15	24	47	7	27		0	94
Axiom 9" & Axiom Pro 9"	2.5	18	585	7	228		0	30
Ray70	0.60	24	187	7	55		0	187
EV1 CCU	0.03	24	9	7	3		0	9
ACU200 standby	0.30	24	94	7	27		0	94
ACU200 operating	2.00	24	624	0	0		0	0
MicroTalk	0.03	24	8	7	2		0	8
UDST800	0.13	24	39	7	11		0	39
Total	**6**		**1668**		**397**			**610**
TOTAL Wh from service battery			2045		774		312	616
TOTAL Wh from propulsion battery			2405		910		367	725

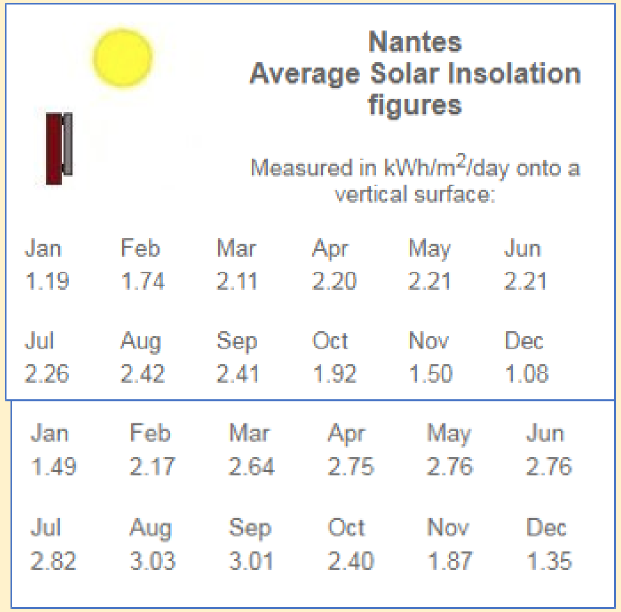
Heater 48V 500W only deployed at pontoon, or when spare capacity available

efficiency of 48/12 85%

Predicted daily energy production from vertical panels

Area per solbian cell/m²			Sea reflection gain &					
0.017				Derating for	kWh/m²		Wh/day	
Power rating	Area (m²)	Efficiency		Shading	August	Decemb	August	Decemb
Transom	0.85	24%		0.8	2.0	0.9	326	143
Solar lazy bags	4.0	20%		0.8	2.0	0.9	1280	562
Total		**2**					**1606**	**705**

In reality, summer average harvest is about 1.5kW, winter harvest seems lower than predicted



http://solarelectricityhandbook.com/solar-irradiance.html

<--Facing East/West

<--Facing south

Positive power balance when sailing, self-recharging when offboard

1st generation

CIGS flexible panels didn't seem to produce sufficient power in low light and need stiffening backers to avoid pinch points. Typical power was less than the 80W base demand (fridge+electronics)

Nominal power 250W + 2 x 120W = 500W

2nd generation

Solbian panels can be shaped to maximise available area, and seem to work well in all conditions (they also need stiffening backers). Typical power 50W to 250W, which typically doubles when folded out.

Nominal power 250W + 2 x 370W = 1kW

Lazy bags designed and made by SNA, Arzon, France

Transom design

We use a propane/butane outboard for our dinghy. The plug-in butane cartridges can be removed and the motor can be put on the transom and run from the cooking gas, providing a backup motor in case of an electrical system failure. We only use the motor a few times a year for the dinghy as the kids are good at rowing so one butane cartridge lasts all year. We've never had a motor failure or zero wind so we've needed to use our outboard to power the boat but we've tested it and it works. The 2,5HP outboard delivers 3,5 knots in flat water (when there's no wind the water is flat).

This solution avoids carrying petrol and eliminates refuelling spillages. It's also more robust than a standard diesel installation where a motor failure can leave a yacht stranded in zero wind. 1kg of propane contains 10kWh which is equal to all of our electrical storage in 70kg of LiIon*, so we think it makes sense to have a high energy-density emergency store, especially when we use propane for cooking and carry a spare bottle anyway, so we're not carrying any more propane than we would normally for cooking. It's not possible to cook on electric because the cables to the cooker would be too thick for a heeling sailboat, so eliminating the propane seems to be impossible for now.

** Combustion engines lose ¾ of their input power to heat, whereas electric engines loose far less*

The three-point mounting system with center bolt fixing (just visible beneith the 'Lo') is used to attach the custom plywood motor bracket or the steps for bathing (permanent steps would produce partial shading).

We worked hard with Pogo to clean up the transom. There was no exhaust so that was the easy part but gas drains, lifting rings, emergency step ladder all had to move a little vs the standard design.

Anchoring

Pogo put a great deal effort into keeping the boat weight down:

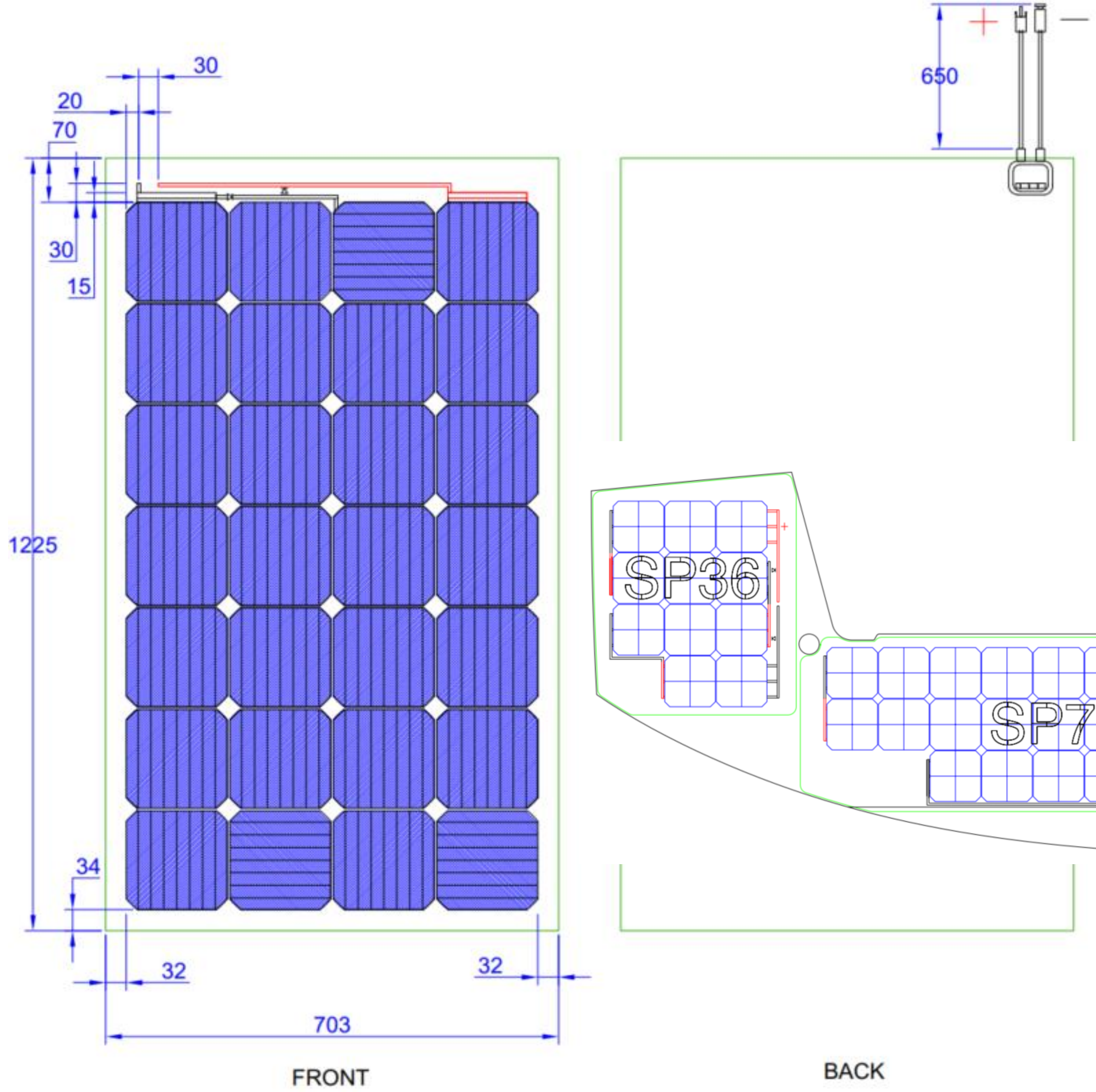
- Sandwich construction
- No floorboards –> low decks and reduced hull height & materal
- Carbon fibre mast
- No doors (cloth separators)
- Lead inside at the bottom of a moulded keel 2,5m deep
- We took out 200kg with our 100kg replacing the 300kg deisel system

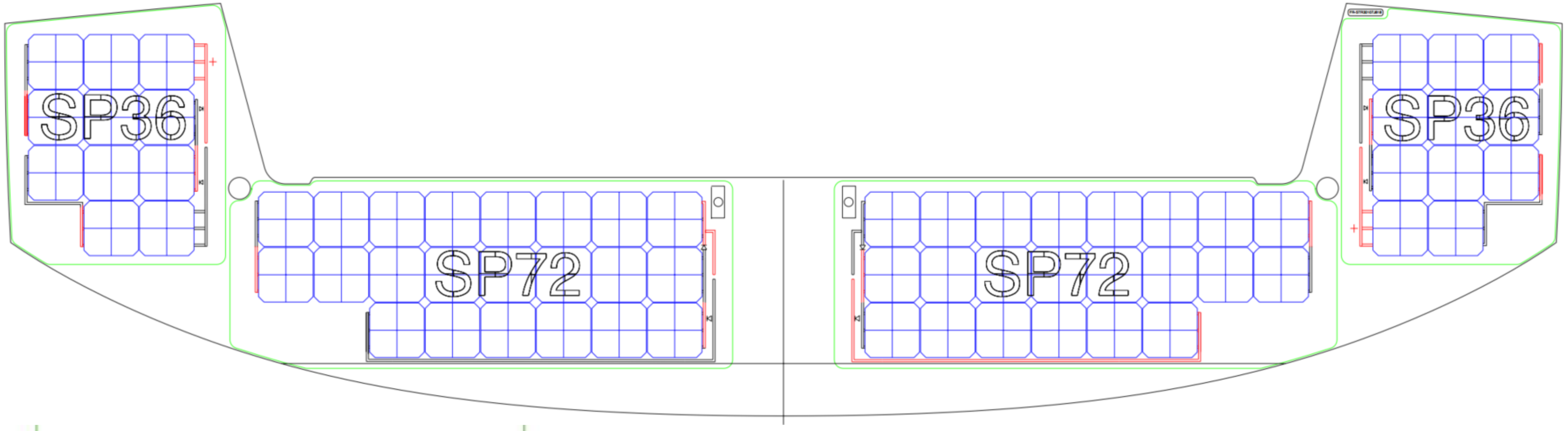
We could have added a 48V windlass and this would be compatible with the 48-5000 Torqeedo 48V batteries; we have a 48V keel lifting hydraulic motor which works well taking only ¼ the current of a 12V system. It would have been a shame though to add the weight of a windlass and the fat cables that go with it, anyway they often seem to be a source of technical trouble and lost fingers. Instead we picked the best and lightest anchor availble which is the aluminium Spade. It wins all the magazine competions for holding and is light as a feather. Anchoring in 4m takes no effort, but sure, if we anchor off in deep water then hauling up the chain weight gets me puffed but it keeps me fit and beats going to the gym!

Example digital switching display

Prototype, not currently available for sale

Solbian solar panel designs





Lessons learned

- For reliable Torqeedo start up, must have a relay to cut out solar & 48/12 chargers
- E-box can get hot, we added a fan which maintains <40°C.
- Charging 48V from 35V solar panels requires a boost charger, there is only one supplier (Genasun, who are excellent)
- To feel comfortable, net current needs to be positive when sailing, so 1kW of solar is a good idea. Solbian make an excellent product.
- Sweet spot for motoring is 1.5kW giving 4,5 kts though we get more speed for less power by combining with the sails and playing with the apparant wind.
- Boom-mounted open/close solar panels are effective as an energy source and provide valuable cockpit shade