Ice Truckers

Blott Matthews Challenge
Pole to Pole
Abingdon school

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Contents

Contents

About the team 3
Objective 3
Route 3
Timing 4
Trade-Offs 5
Overall Transport Design 6
Terrain movement method 7
Details and requirements of Crew members 8
Drinking water 9
Food 9
Navigation system 10
Transport vehicle 10
Details 11
Modifications to the Catamaran 11
Storage 12
Mechanical and electrical design 13
Overview of energy production 13
Energy source consideration 13
Flow chart of electrical design 14
Engine 14
Hydrogen fuel cells 15
Electrolysis 17
Compressor 18
Storage Tanks 18
Solar Panels 19
Costs 20

About the team

Our team consists of 5 members, where we all attend 6th form at Abingdon school. Throughout this project, each of us has taken a distinct role. Cai and Alister were joint project managers. Cai focused on the overall description and Alister focused on electrical and power design. Then there is Alex who oversaw the strategy of getting to Antarctica. Then Dennis was our CAD designer and engineer who solved the problem of the caterpillar tracks and made the 3D models. Lastly, there is Gerald Who helped construct the 3D model and worked on the navigation aspect of our ship. We all wanted to do this challenge because it would improve our teamwork skills and it will give us good experience for the future.

Objective

The challenge is to transport a 1-ton non-metallic block from the North Pole to the South Pole. Our only limitation is that we cannot fly, therefore our journey could only consist of land and sea. Furthermore, throughout this document, we will be referring to the 1-ton block as the 'load'.

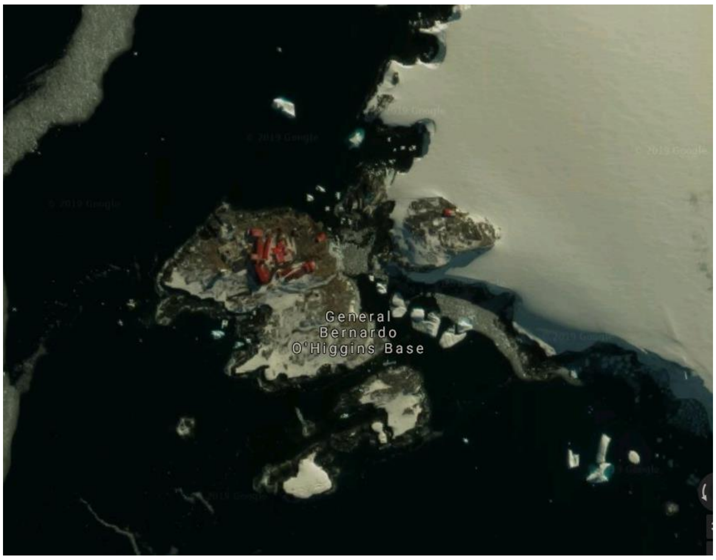
Dimensions of the load = 2m x 2m x 1.5m

General Strategy

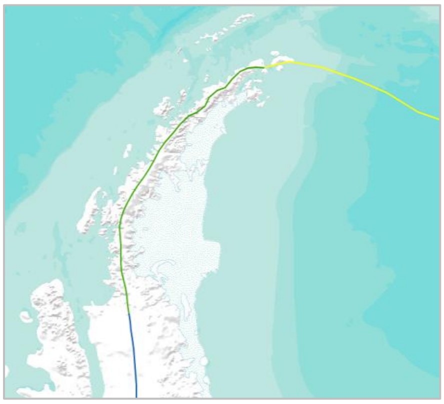
Route

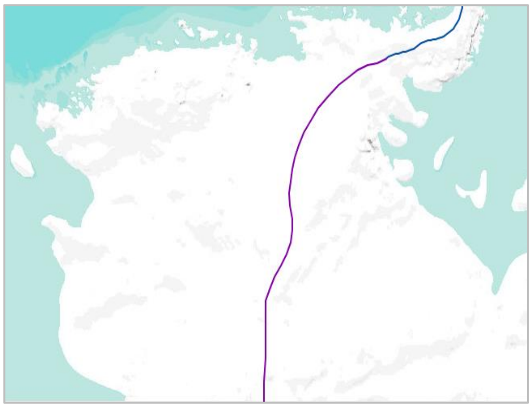
The transport vehicle would start as a land-based vehicle at the North Pole on the Arctic Ice Cap. We would cross this by heading south-east of Greenland. Once we hit the water, the vehicle would retract its caterpillar tracks to form a catamaran and we would continue south. The vehicle would then reach the part of the Arctic Ocean that is open water. We would send it further south via the Arctic Ocean, between Iceland and Scotland. Once past the UK, we would then continue south west of Africa. We would then continue south-east to Antarctica.

Once we reach Antarctica, we would aim to land at the outstretched "arm" part that juts out from the continent. We would not go there via Drake's Passage (the stretch of water that goes from Cape Horn, Chile to Antarctica), since the waters there are very rough, and the waves are often over 5 metres high. The direction of the waves would also be heading eastward, which would make it difficult to cross since we would be travelling westward and into the harsh waves. We would instead head to the coast near the tip of the arm and move alongside the ice until we get to General Bernando O'Higgins Base, which has a good landing spot where the catamaran can be brought onto land.



The catamaran would then deploy its caterpillar tracks, to be able to drive on the snowy terrain of the land. We would head inland via Antarctica's arm, taking caution not to head into the more mountainous part of the arm. Once we reach the flat plains of the mainland, we would drive the vehicle straight for the Pole.





Timing

The Atlantic storm season starts on June 1st and ends on December 1st. To avoid storms we should, therefore, go between January and May. If we started the voyage on January 1st, we would avoid the Atlantic storm season by 1 month and still have a 5-month period for travel until the next storm season. It is also an ideal time because the North Pole would still be especially cold and therefore has more solid ice, which is useful if we are travelling across ground using caterpillar treads on a heavy vehicle.

The Hydrogen-powered catamaran we are taking inspiration from for our vehicle has an average speed of about 8.7 km/h and the distance from pole to pole is 13832.88 km: meaning it would take roughly 1590 hours (66.25 days, or 2 months and 6 days) to travel. Therefore, if we set off on January 1st we would be at the South Pole by March 7th. The 5-month no-storm gap for travel would be more than enough time to go from pole to pole.

Trade-Offs

When coming to our decisions, we had to make multiple compromises for the sake of some features over others. Since we were not allowed to use airborne vehicles in any way, we were forced to travel across land and sea instead. This created a lot of problems which need to be solved or compromised with. The lack of aerial travel means that speed would be quite slow for most of the journey, although faster on land than by sea. However, since there is no continuous land route from north to south (even the Pan-American Highway contains a split in the middle), we concluded that it would be best to travel as much as possible by sea. This also gives us no vehicular traffic, which could be a problem if we were travelling by land.

Another problem is the mode of waterborne transport. Boats of a small size with a single hull are unstable in turbulent waters, which would be a problem for transporting a load, although they can be brought on and off the land with ease and weigh little. Large transport boats, on the other hand, make actually getting onto land impossible, although they would be ideal for transporting the load. They also have great stability due to the size of their hulls. However, we needed a way to get onto land (the South Pole is situated in a location that is unreachable by boat alone). We settled with a catamaran as it provides a balance of these positives. However, space is still slightly limited onboard, and energy would need to be sourced sustainably to provide a long-lasting and compact supply. It also does not weigh as little as a single-hull boat, which makes it more awkward in terms of getting onto mainland Antarctica.

Overall Transport Design

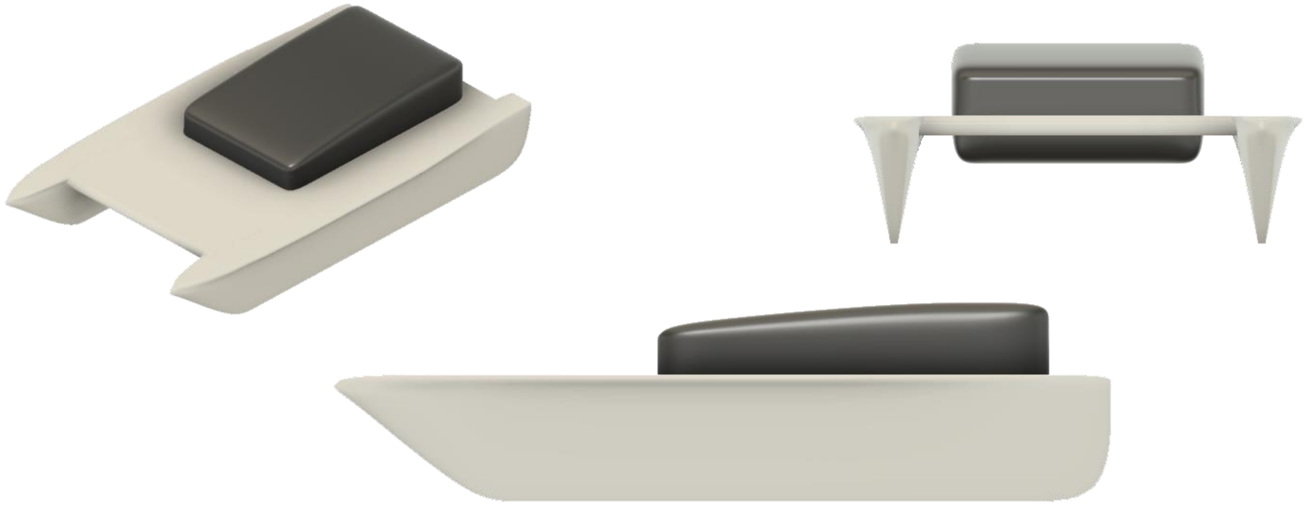
When coming to a decision on our transport vehicle we came across 2 main ideas; boats and submarines. Additionally, the vehicle must be amphibious as it must travel on land and on the sea to go from the Arctic to the Antarctic. As we saw no way for the submarine to get onto land without extreme difficulty, we excluded it from our design. This then left us with our main option, boats. Out of the many types of boats, we could choose from, including; standard sailing boat, yacht, power boat, catamaran and an icebreaker, each had advantages and disadvantages which are listed below.

Type of Boat	Advantages	Disadvantages
Single hull boat	Cheapest option; can hold crew members.	Unstable in rough water; most will be too small to carry the load.
Icebreaker	Built for the conditions of the Arctic.	Too heavy to convert into an amphibious vehicle very expensive.
Catamaran	Stable in rough water; enough space for the load and the crew.	Hard to convert to an amphibious vehicle
Powerboat	High powered engine.	Unstable in rough water consumes lots of power; too small to hold the Load.
Yacht	Large space for crew and the load	Expensive; Slow

As a team, we decided the prime choice for our transport vehicle was a small to medium sized catamaran as its two hulls create stability which will be needed as it will be heading across around 14000km of water, and most likely to encounter rough water along its way. The boat will also need to be capable of carrying the load. To reduce costs and ease the transport design it was decided that a pre-built ship would be bought and then modified with our own components and systems to allow it to survive the journey.

As wind is not a reliable energy source, another viable option needed to be used. Therefore, to ensure the boat can run independently and environmentally friendly we are using two renewable sources. These are solar panels and hydrogen-powered fuel cells. The solar cells will be fitted to the top of the boat for maximum efficiency. However, this will only be able to produce a low power output so we will use the energy from the solar panels to power an electrolysis machine to produce hydrogen which will be placed into the hydrogen power cell. This will power our main electric motors. To allow the boat to run straight away the boat will be fitted with gas canisters to store hydrogen which has already been produced.

Renders of 1st design



Terrain movement method

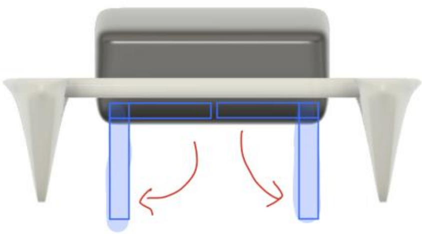
Since the target location is on land (specifically on ice), we need to find a way to allow the boat to travel on land. The methods we came up with include; wheels, screw-propelled or caterpillar tracks.

Method	Advantages	Disadvantages
Wheels	Easy to repair Relatively cheap High speed High manoeuvrability Simplicity	Not suitable for certain types of terrain (e.g. ice)
Caterpillar tracks	Power efficient Supports a lot of weight Aesthetics (looks aggressive) Suitable for many terrains (more grip)	Low speed Difficult to repair Short Life Higher chance of breaking
Screw Propelled	Can travel on both sea and land Relatively high speed	Large and bulky Not power efficient Damages the land Needs to be big to be effective

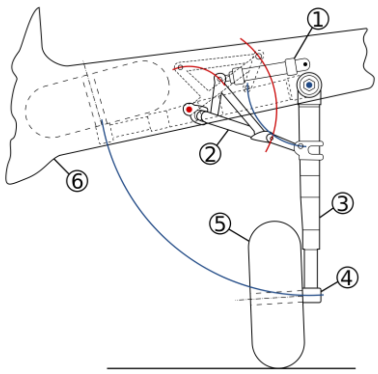
We concluded that using caterpillar tracks is the best option, due to their ability to travel on rough surfaces, power efficiency and grip towards the surface. Since the weight of the entire boat is spread across the tracks, it can, therefore, support a larger weight. Since most of the journey will be on the sea, the caterpillar tracks will last longer, therefore needing less maintenance.

Not deployed

To enable the amphibious characteristic of the transport vehicle we shall use caterpillar tracks on the underside of the two hulls, these tracks will be able to travel across the Arctic and Antarctic. However, we also need to develop a way to conceal the tracks when not in use to decrease drag while on water. We ended up with the idea of deploying caterpillar tracks between the hulls since it doesn't impact the aerodynamics of the hulls when not deployed. The design will be based on the rear landing gears of an airliner. However, the wheels will be replaced with caterpillar tracks, unnecessary parts (e.g. shock absorbers) will be removed and many of the materials will need to be changed due to reducing weight, cost and space. The mechanics of the gears will also be hydraulic powered.



Deployed



Details and requirements of Crew members

On board the vessel there will be two crew members. We have chosen to have crew members on board because they can course correct if need be. This aspect also allows us to have fewer redundancies on board for each system because if one fails the crew should be able to fix any problem. Additionally, we have picked two crew members because the voyage will be at least 2-3 months long therefore to ensure the mental well being for our crew they will need human interaction.

As there will be two people on board, they will need clean drinking water and plentiful food for the journey, plus suitable living quarters for cold and warm weather conditions. However, before we continue these crew members will need to be paid a wage, the average wage for transport boat worker is £27 an hour. Therefore, to pay two crew members for 2 months and 6 days it will be a cost of £26794 (eight-hour work days)
Source - The wage of transport boat workers - The Average Salary of Workers on Deep Draft Vessels (Work.chron.com)

Drinking water

To ensure clean and non-salty water a portable desalination unit will be fitted to the boat. This unit will be outsourced to ensure high quality and reliability. The unit seen below costs £2200

This particular unit performs “Reverse Osmosis”, which can produce between 30L-50,000L. As adult men only need on average 3.7 litres a day (7.4L for two) this machine can definitely produce the necessary output. However, there is a negative aspect to this choice of desalination unit, which is its relatively large size, however, this technology is hard to shrink down and when it does it occur the prices increase rapidly. Therefore, to keep costs down the size of the unit is a compromise.

Food

If both crew members are male, then they are recommended to eat 2500 Kcal every 24 hours. As the ship can not restock supplies, all of the food will have to be put on the boat at the beginning of the journey. The best option that we have available is dehydrated food as it would reduce the weight of the boat which allows it to travel faster while consuming less power. Hot water can then be added to the dehydrated food, which can come from the desalination unit and heated using a boiler, (already installed on the boat). As previously stated in the general strategy the journey will take at least 2 months and 6 days. Therefore to ensure a safe amount of food in case of a breakdown or bad weather conditions 3 months worth of food will be placed inside the boat.

Total food energy requirement = (2 x 2500)/day x 30 (days) x 3 (months) = 450000 kcal. Most sources for dehydrated foods are survival kits. Survival kits are also a good idea as they won’t go out of date any time soon. The company which we will get our supply from is called EVAQ8. It can supply 1 packet (3kg) for £100 for one person over a 7 day time period. Therefore, for our desired 3 months demand we need 3(months)*4(weeks)= 12 of these packets for 1 man, as we have two crew members this will be doubled to 24 packets, costing £2400 weighing in at 72kg.

Source - Survival Food Kit 24 Long Life Meals (Evaq8.co.uk)

Navigation system

For the navigation of the boat, we plan to use GPS to guide it through the route, and to be able to locate the position of the boat at all times. The vehicle would also have an autopilot system installed to ensure that the crew members are able to rest during the journey.
The navigation of the boat is done by GPS, and we will purchase the Garmin GPSMAP 276Cx (£535.28), which has an internal antenna which is suitable for the design of the boat, without needing to make extra space for an external one.
The boat can be both controlled manually and automatically. For the autopilot system, we will purchase the Garmin Reactor™ 40 Mechanical/Retrofit/Solenoid Corepack (£1,459.99). The reactor being able to be powered through multiple means. The autopilot system would help guide the boat through the set route in a much easier and convenient manner.

Transport vehicle

As a team, we decided to go with a catamaran to transport the load. As designing a catamaran and building it ourselves would be cost and time inefficient we will be buying a second-hand boat which we will modify to meet our objective of going from pole to pole. The boat we need must have enough space to hold our two crew members and the block.

From our research, we came across a catamaran called Lagoon – 52 on sale and currently located in Greece (image on next page).

Source - Catamaran seller - Lagoon - 52 for sale in Athens, Greece (Boatshop24.co.uk)

Details

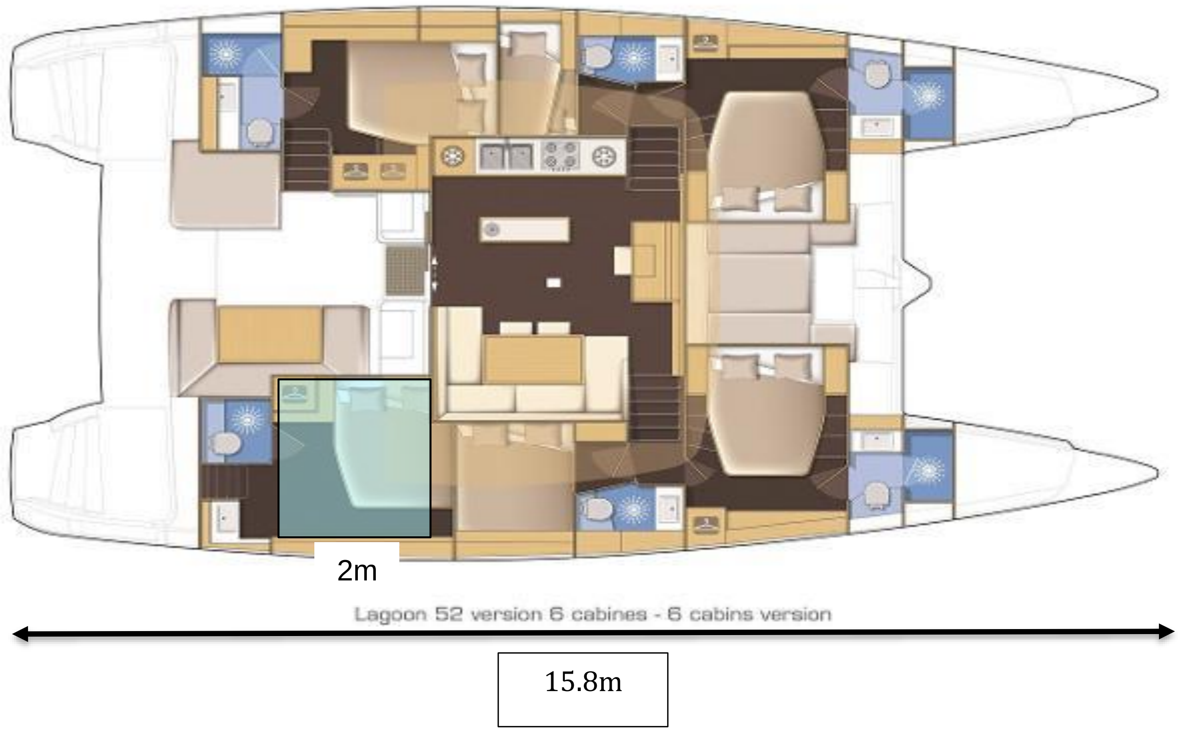
Dimensions:	Length – 15.84m Width – 8.6m
Cost	£688,653
Number of cabins	6
Number of W/C	6
Condition	Used
Manufactured	2013

Modifications to the Catamaran

The catamaran already has some major components including navigation and cabins. However, the power source and engine will need to be replaced. To achieve this we will start by removing the sails as we will be covering the majority of the top deck with solar panels. The twin diesel engines within the boat will need to be replaced with an electric motor to allow it to be powered by the hydrogen fuel cells. The overall plan for these designs will be discussed in the electrical design section. However to give a brief overview: The solar panels will power an electrolysis machine which will turn the sea water into hydrogen and oxygen. The hydrogen will be stored inside compressed gas canisters. These will then feed into hydrogen fuel cells that will be the main source of power for the electric engine as it will require a high energy output which the hydrogen cells can provide

Storage

the catamaran will need to store the non-metallic block in a secure location. This will require us to empty out some of the compartments to make room. As seen below in the diagram we will empty out one of the cabin quarters and the bathroom which will store the load, (the load is the blue box which is in scale to the rest of the boat. To get the cube into the boat a crane will lift it in from the ground, then the compartment can then be removed over the area marked below. The top of the catamaran will be cut into to allow it to be opened



All these Modifications will require us to hire some labour so roughly 5 days and also hire machinery for the workers to use. We estimate a cost of around £10,500 based on the average wages in the UK for this sort of work.

Mechanical and electrical design

Overview of energy production

On the boat we took inspiration for our design, from The Energy Observer, they extract hydrogen through the electrolysis of seawater for fuel. However, they mainly use solar panels for basic navigation and low-level movement and only use the hydrogen when the weather conditions are tough as the hydrogen cells provide extra energy rapidly released to get through these situations which is something that we would like to do as well. This is costlier than producing hydrogen as a by-product of the burning of fossil fuels, but it is 100% carbon neutral and would also work on our boat as there is an abundance of seawater in the sea and we would be unable to use fossil fuels.

Energy source consideration

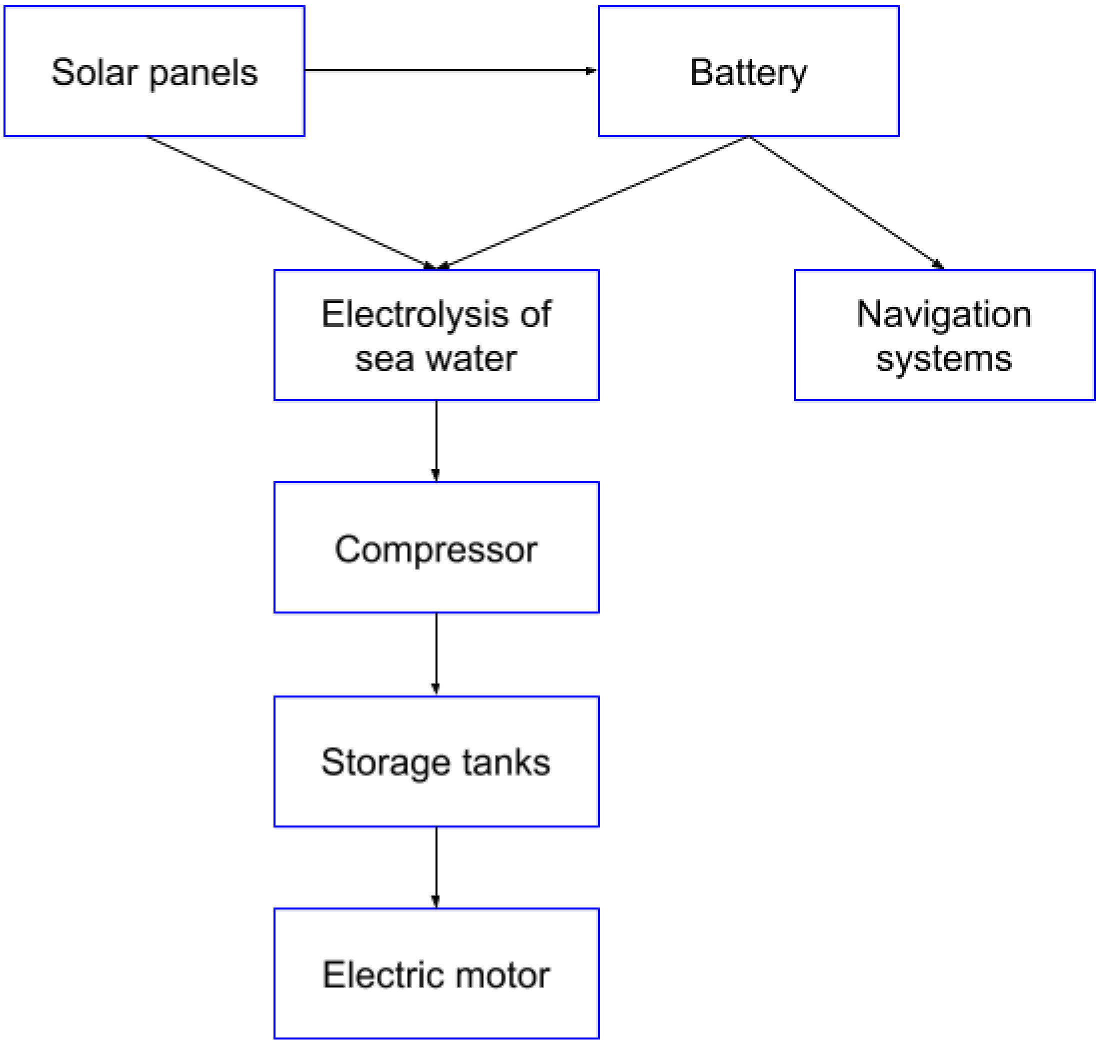
When considering the energy, we are going to use we decided early on that we would use environmentally friendly sources. Outlined below are the fuel sources that we compared.

Fuel Type	Energy Density (MJ/kg)	Produces Greenhouse gases
Coal	24	Yes
Methane	50	Yes
Uranium	83,140,000	No
Hydrogen	142	No
Petrol	46	yes
Diesel	48	yes

Uranium is by far the most energy dense fuel type, however, it is incredibly expensive and to be able to use the uranium in nuclear fission would be unfeasible for our vessel. Apart from this, all the other fuels are nonrenewable and we would need a lot of them to power the vessel all the way to the South Pole so we can’t use them either.

The best option, therefore, would be to use hydrogen fuel as it is relatively energy dense compared to fossil fuels and is renewable as we can produce it from the electrolysis of seawater. As well as using hydrogen as a fuel we would use solar panels as they can be used to do the basic navigation and as they use the energy from the sun's rays and so are carbon neutral. The hydrogen would be used when the conditions are rougher, and the boat needs more energy to progress on its way.

Flow chart of electrical design



Engine

We want our vessel to travel at roughly 9 km/h which would allow the boat to travel the full distance in 2 months. The boat which we are going to buy and modify currently has 2 x 75 BHP diesel engines which we would have to remove and replace with electric engines as that is how we will run the vessel with the electrical energy produced by both the solar panels and the hydrogen fuel. Compared with motor boats of a similar size, most of these have roughly 1200bhp spread over 2 x 600 bhp engines. However, it would be impossible to provide this much power using only solar panels and hydrogen fuel cells. Instead, we can use a 180 BHP electric motor from a company called ReGen Nautic. The motor is called the E180 Electric Outboard and features a 130 kW brushless electric motor which operates at a 95% efficiency. This motor runs at roughly 8,000 RPM and is cooled by a closed loop glycol system which in turn is cooled by seawater which there is an abundance of at sea. Each one of these engines weighs roughly 280kg so they are quite heavy but they are required given how heavy our boat is and may even get us to Antarctica faster than our 2 months estimated time span.

The only downside to this motor is that it would come in at $35000 or £27000 pounds. This is expensive for the motor however it is one of the main parts of the boat and it is one of the best electric motors on the market which has enough horsepower to power our boat compared to the previous best electric motors which only had roughly 75 BHP.

Hydrogen fuel cells

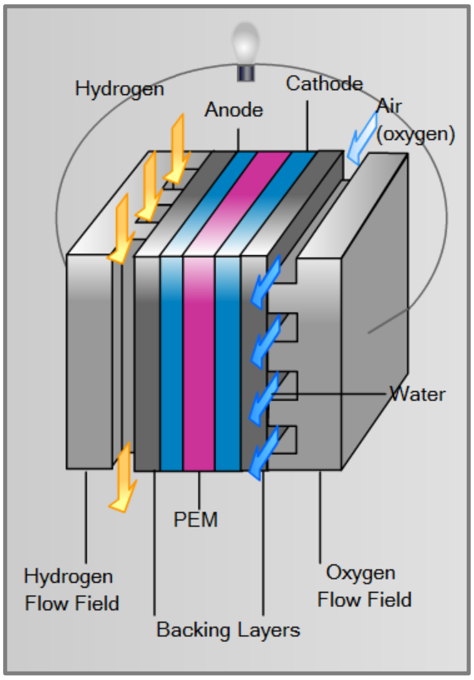
The hydrogen fuel cells react the hydrogen gas with oxygen to produce electricity giving only water, and a little heat as the by-products. They are better than combustion engines as they have no moving parts so they break down less easily. As well as this, as they convert chemical potential energy straight into electrical energy they are more efficient than internal combustion engines which convert chemical potential energy into heat energy and then mechanical work.

There are 5 different types of hydrogen fuel cells which we are going to look at that could power our vessel. With at least 100 kW of power production, we don't necessarily need 130 kW of power as this is the maximum output of the engine and not necessarily the optimal power as this could deteriorate the engine quickly. These have been explained below in the table:

Fuel Cell Type	Operating Temperature /°C	System Output	Efficiency /% electric	Cost per kW /£
Alkaline (AFC)	90-100	10 kW - 100 kW	60 - 70	195
Phosphoric Acid (PAFC)	150-200	50 kW - 1 MW	36 - 42	1150
Polymer Electrolyte Membrane (PEM)	50-100	<250 kW	50 - 60	45
Molten Carbonate (MCFC)	600-700	<1 MW	60	1500
Solid Oxide (SOFC)	650-1000	5 kW - 3 MW	60	12000

From this research, we can see that the PEM fuel cells will be the best for our boat as they are one of the most widely manufactured and understood of all the fuel cell types whereas, given using hydrogen as a fuel is only just coming onto the market, other fuel cell types are less cost-effective.

The PEMFCs (Polymer Electrolyte Membrane Fuel Cells) has four main parts. These are the anode, the cathode, the electrolyte and the catalyst. The anode's main role is to conduct the electrons which are freed from the hydrogen molecules as well as disperse the hydrogen gas equally over the anode with small grooves etched in it. The cathode distributes the oxygen evenly across the surface and also conducts the electrons back from the external circuit to the catalyst where the hydrogen reacts with the oxygen to form water. The electrolyte facilitates the proton exchange. It's a specially treated membrane which only allows the positive H+ ions to travel through forcing the electrons around. Finally, the catalyst is made of platinum nanoparticles and facilitates the reaction between the hydrogen and the oxygen. The diagram of the PEMFC is shown below.



At the anode, the hydrogen molecules are split into protons and electrons. The hydrogen ions are allowed to permeate across the electrolyte and the electrons are forced around the circuit creating a current and powering the batteries. Air is supplied to the cathode which reacts with the protons and electrons to form water. The reactions occur as follows:

At the anode:

$2H_2 \rightarrow 4H^+ + 4e^-$

At the cathode:
$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

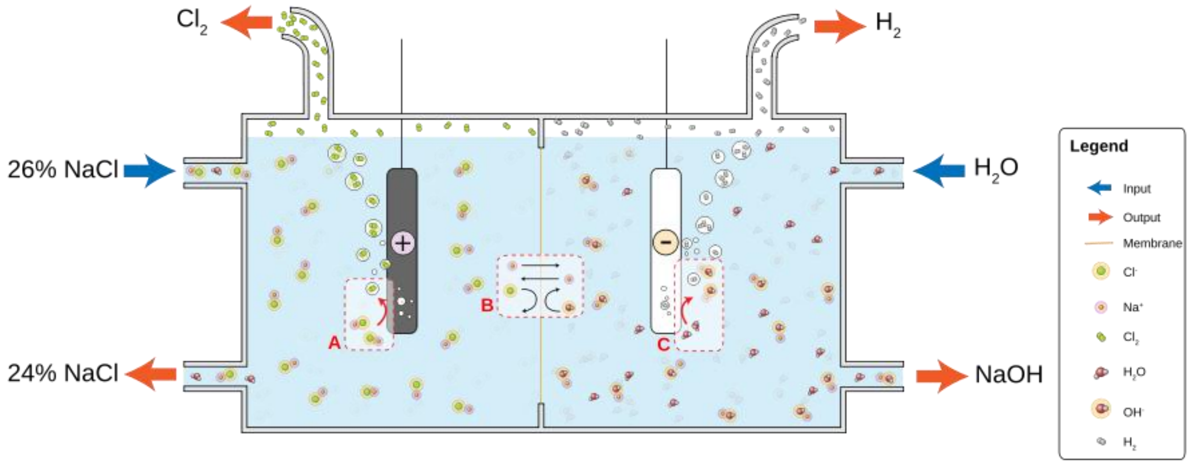
Overall reaction:
$2H_2 + O_2 \rightarrow 2H_2O$ + Heat + Electricity

The amount of energy produced would be 1.2291V per mole of hydrogen.

For our vessel, we would need roughly 107 kW of energy production, therefore, it would cost 107 x £45 = £4815. Which is quite cheap compared to diesel combustion engines.

Electrolysis

To produce the hydrogen which will then be used as a fuel we will pass a current through the seawater which splits it up into hydrogen gas, chlorine gas and sodium hydroxide as shown below.



At the anode:
$2Cl^- \rightarrow Cl_2 + 2e^-$

At the cathode:
$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

Overall reaction:
$2NaCl + 2H_2O \rightarrow Cl_2 + H_2 + 2NaOH$

The hydrogen produced from this will be at 30 bar of pressure and will go straight to the compressor to be compressed to 200 bar. The energy required to do this reaction is the same per mole as what is released ideally in the fuel cells - 1.23V.

Compressor

We need to compress the hydrogen produced from 30 bar of pressure to 200 bar of pressure for storage. We will use a small diaphragm hydrogen compressor which costs £7,742 to do this and weighs 800 kg

It is water cooled so we can just use the water from the sea to cool it.

Storage Tanks

2500L needed for 64 kg of hydrogen as pV = nRT. We will store the hydrogen at room temperature and 200 bar of pressure so the volume required is 3840L of storage.

We will buy a 5000L metal high-pressure storage tank which weighs 1 tonne to store the hydrogen. This means that, as pV = nRT, we can store roughly 80 kg of hydrogen or 40000 moles. This is a lot of long term energy storage. This tank costs £1548.

Battery

We will use a battery for short term energy storage. It will be roughly 100 kWh and there are different types of battery that we could use however lithium-ion batteries are most suited to our system. To do this we would buy 2 x 50 kW lithium-ion batteries. They cost £7,700 each so that is £15,200 total and they weigh 300kg each.

Solar Panels

Our boat is 8.6m wide by 15.9m long which gives us an area of 136.8m^2 . However, not all of this area will be occupied by solar panels as it is not possible to put solar panels on all of it. I estimate we would be able to fit 75m^2 of solar panels on our boat as a maximum. There are different types of solar panels that we could use as outlined below

Solar cell type	Efficiency rate	Cost/W (£)	Advantages	Disadvantages
Monocrystalline solar panels (Mono-SI)	20%	1.00	High-efficiency rate; optimised for commercial use; high lifetime value: low price	
Poly-crystalline solar panels (p-SI)	15%	2.33	Lower price	Sensitive to high temperatures; lower lifespan and space efficiency
Thin-film: Amorphous silicon solar panels (A-SI)	7-10%	2.33	Relatively low costs: easy to produce and flexible	Shorter lifespan
Concentrated PV cell (CPV)	41%	2.33	Very high performance & efficiency rates	Solar tracking & cooler system needed to reach a high-efficiency rate

We need 20Kw of solar panels so we will use the mono-si panels which will cost £20000 and will take up 55m^2 of space on top of the boat.

Costs

System Area	Item	Price/£
Mechanic	Boat	688,653
	Modifications	10,500
Power	Electric motor	27,000
	PEM fuel cells	4815
	Compressor	7742
	Storage Tank	1548
	Solar panels	20,000
Navigation	Garmin Reactor™ 40	1459.99
	Garmin GPSMAP 276Cx	535.28
Crew members	Dehydrated Food	2400
	Desalination unit	2200
	Wages	26,794
Total		793,647