E4E

Report for ‘Energy for Everything’

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Overview

In regards to the “Energy for Everything” challenge
(http://www.blottmatthews.com/what-you-have-to-do)

This document contains our theoretical plan for a carbon neutral city within the Solent area. We have researched many methods of energy saving and energy production that combined would support the needs of a population of 2,000,000. The energy plan we have devised is intended to explore new ideas on how electricity could be provided and used by a very large and dense city. The current population of the fully urban zones of the solent area is estimated at 500,000. From taking into account the needs for energy at home, industry and transport.

Who we are

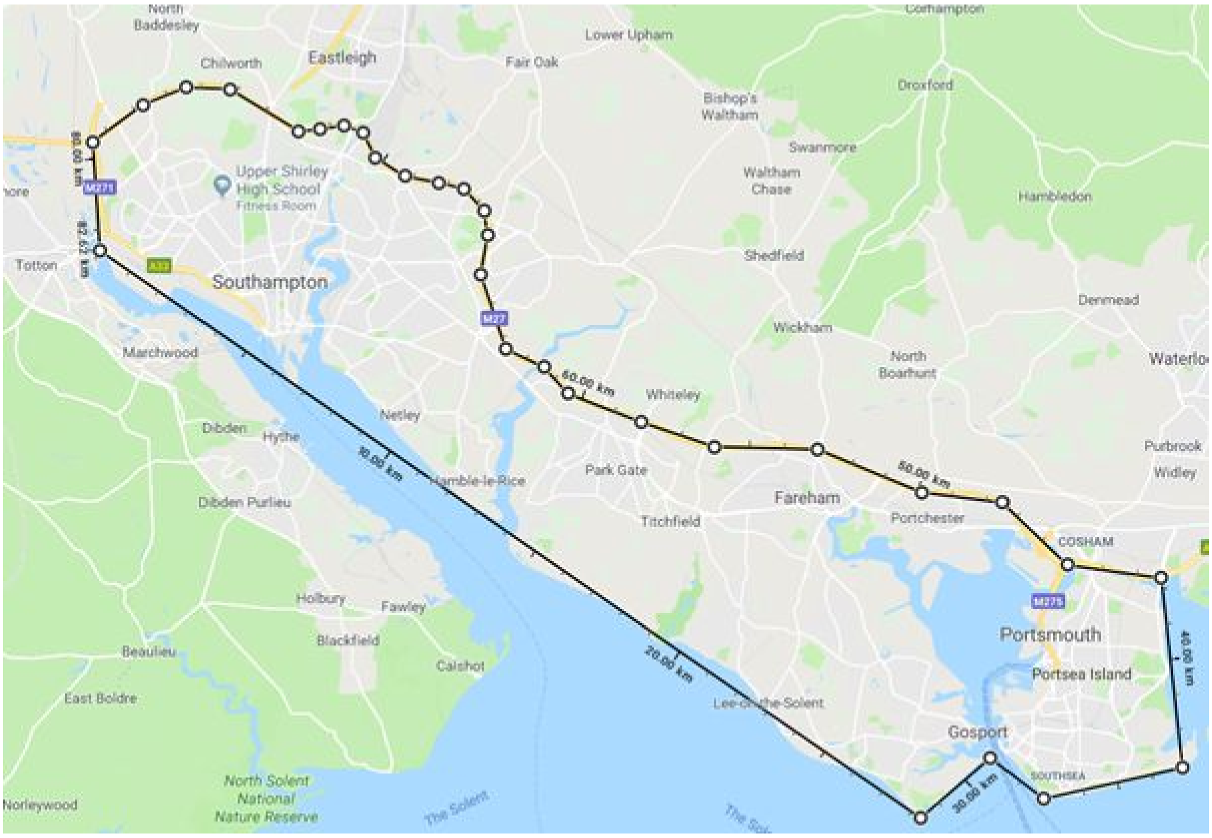
Our team is made up of:
Thomas Hayter, a student of Maths, Chemistry ,and Physics.
Katherine Brocklesby, a student of Maths, Physics ,and Product Design.
Samuel Cook, a student of Engineering, Product Design, Photography.
Euan Murray, a student of Maths, Biology, and Law.

Geography of Solent area

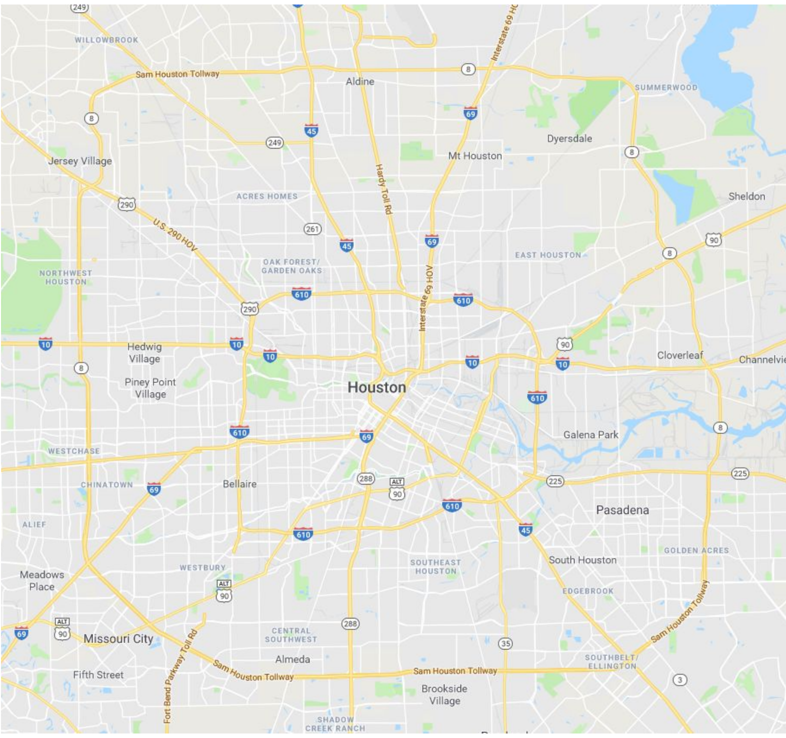
The Solent area is on the south coast of England and is mostly urban, containing two large cities; Southampton and Portsmouth. It is key for this area to improve its environmental impact as not only are the two large cities large emitters of greenhouse gases, but also the trade and export at Southampton docks produces a huge amount of carbon dioxide waste.

In this project we will use the geography of the Solent area to inspire the decisions made for Solent City, however will not allow this to be a limiting factor to our ideas for Solent City.

The Layout of Our Solent City



Our Solent City, instead of being comprised of 2 cities, Southampton and Portsmouth, will instead be one major city, with a centre in between the two existing cities and spreading out the further away you go. The area of the enclosed region above is $210km^2$.



We have gauged an idea of how our population's needs can be met based off the current city of Houston, which has a population of roughly 2.2 million and is a well built up area, which is what we aspire to.

Our city will be centered near Netley as this is half way between Southampton and Portsmouth, the centre of our solent area (see right). The city will be much larger than this, and the surroundings will be made up of many suburban areas, spreading to the M27 and possibly beyond.

Energy:

How Much Energy Will We Need:

In 2015, the population of the UK was 65.13 million. The amount of energy used in the UK in 2015 was 145,653 ktoe (kilotonnes of oil equivalent). These figures have been taken from the government national archives. This can be split into these many areas:

Industry: 23,594 ktoe
Transport:54,809 ktoe
Domestic Activity: 42,061 ktoe
Services: 18,301 ktoe
Heating: 58,801 ktoe (in homes, service, industry and transport)
Cooling: 1,103 ktoe (in homes, service, industry and transport)
Commerce: 3,290 ktoe
Infrastructure Operation: 7,900 ktoe

145,653 ktoe is equivalent to 1,693,944,390,000 kWh for the entire population of the UK in 2015. Therefore, we would need 52,017,331,184 kWh of energy to power our Solent City of 2 million population. This rounds to 52 TWh of energy needed per year.

The problem of stability

Most traditional forms of energy production follow the idea of using heat to turn water into steam, to be forced through a turbine, creating a large mass that is rotating. This allows for a very constant rate of generation and will smooth over fluctuations, however renewable energy sources such as solar and wind do not have large amounts of system inertia. This creates the problem of unstable power levels, so we will have to use other methods of filling in small glitches or covering for long enough for a control room to detect, evaluate, and inplace counter controls in case of a major power failing happens.

Solutions for this problem are not yet integrated in the current grid. Suggested solution to this problem include using bodies of water on different elevations (pumped storage)[1]; water would be pumped up at times of excess power and allowed to run down through a turbine at times of low power. The problem with this system is that it is very slow and would not be able to smooth out the second by second fluctuations. We would not use pump storage for dealing with stability as it would not be able to react fast enough, however it may be suitable for extended periods of time of low energy product for example in the event of a major failing (as explored later in the report).

A newly developing technology is replicating the large spinning turbines found in traditional power stations for wind turbines. Synthetic inertia[2][3] can be imagined as the gears of a car, where a high input RPM with a high gear ratio, could result in the same output as a low input RPM with a low gear ratio; although the input is different the output could stay the same. The challenges with this technology is the potential large amounts of torque that could be put on the wind turbine, however we believe that technology within the next ten years will advance wind turbine design a sufficient amount for this not to be a problem. In solent city we would want to use this technology within wind turbines that we build as it will make them equivalent to a contributor to system inertia.

It is likely that we will not have the capability of producing batteries that greatly surpass Lithium ion batteries within the next 10 years, despite common media gathering behind Solid Electrolyte Batteries, we view this technology as highly unlikely within the next 10 years[4]. However, with a overhaul of the grid we do have the technology to potentially utilize millions of small batteries, such as from electric vehicles, industry and homes that are connected to the internet to have the ability to sell energy back to the Grid/ local substations.

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[1] [https://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity] Article for pump storage.

[2] [https://community.dur.ac.uk/supergen.wind/docs/presentations/3rd_Seminar_Presentations/Day1_02_Stock.pdf] Presentation created by Loughborough University–12th september2011

[3] [http://www.marinet2.eu/wp-content/uploads/2017/04/MARINET_SYNERTIA-PLUS_Report_Olimpo-1.pdf] Olimpo Anaya-Lara, Universityof Strathclyde.

[4] [https://youtube/8RbwOhM6PUk] A video essay by Phil Mason, debunking solid electrolyte batteries. Published on November 23, 2017

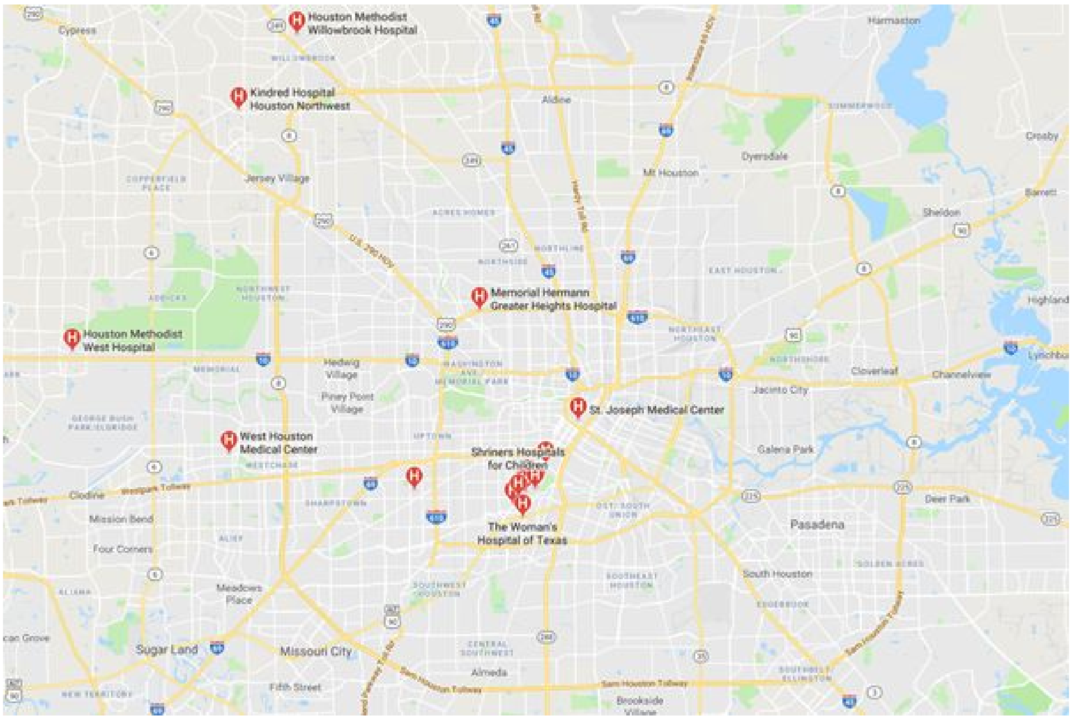
A system like this would be extensive and challenging to create but would be able to create stability and allow for decentralised energy storage that would keep power going in major failings. Furthermore a smart grid like this could reacted quicker to failings; important for a system that is founded on less predictable energy production.

Power Loss

Due to unforeseen circumstances, power loss is entirely possible, perhaps caused by a natural disaster, or system failure. This could take out up 80% of our power supplies, which could have a devastating effect on citizens and services alike. We must be able to compensate for this loss, and be able to get critical services back up and running as fast as we can.

Our Critical Services:

We have decided that the most critical place to get power back to are hospitals, as they have life support machines and ICU units that need a constant supply of power to keep people alive. The next most important thing to get power to would be police and fire stations, to mobilise emergency services if needed. We may need to sustain this emergency powering for up to 24hrs, before the problem is fixed, or a semi-permanent solution is figured out. We've decided our city is going to have four hospitals to cater for the population. Looking at Houston, they have many more than this, however that's taking into account that health care in the US is privatised, thus they'll have more hospitals as they're all different businesses.



We looked at Southampton General Hospital as an example[5] of the kind of power we need, which is classed a category C hospital (When A is classed as good, and D as bad for energy efficiency), meaning “average but could do better”. The maximum demand of Southampton General is around 7 MW, and as we are planning to use four hospitals, we will need 28 MW of power for all of the hospitals.

To calculate the energy consumption of a police station, we used the figures from the hospital, and scaled it down, due to the lack of specialist equipment you’d find in a police station as oppose to a hospital. We also used employee figures, with Southampton General having 10,500 employees, and Hampshire Constabulary with 5,000, roughly half of that of the hospital’s. The population of Hampshire is just under 2 million, therefore we know that we would need the same number of officers for our city as are currently required for Hampshire. Therefore if we know the maximum demand of Southampton general is about 7 MW, we can safely assume that the maximum demand of a police station would be around 3.5 MW, which would be spread across several stations around Solent City.

There are 51 fire stations in Hampshire, which covers a total area of 3,700km^2. However, Solent City covers only an area of 210km^2 , so therefore we have estimated that Solent City would only need 25 fire stations, because they would cover a much smaller area. Over a month, each fire station would use roughly 2,500 kWh[6], relating to roughly 85 kWh for a 24 hour span of time. Consequently, for 25 fire stations, we would need 2.2 MWh for the same 24 hour period.

Overall, to power all of our emergency services for 24hrs we need 254.2 MWh, rounded to 250. After we’d found the total energy we needed for fire, hospital and police services we looked into energy generation methods that seemed viable.

Planned Solution:

One method we could invest in would be pump storage, as with natural energy sources we are bound to get surges, as, for example, wind and sun levels are not constant. We can put these surges to use transporting the water up to a high level reservoir, so that during shortages and possible losses of power we can let it run to a lower level reservoir through an underground tunnel. This tunnel forces the water through a turbine, and the velocity of the water rotates the turbines, generating energy. This can then be transported through the grid to places that need it most. This will allow essential services to remain active, while we work on dealing with the power loss. An advantage of this method is it that it utilises an issue we may encounter using renewable sources (non-stable energy levels), however something we will need to think carefully about is that this method does largely depend on geographical features, as you will need a steep hill or slope to allow it to work, and even then it will take extensive work to allow it to be functional, as you need to tunnel

[5] Page 57: http://www.uhs.nhs.uk/Media/SUHTInternet/AboutUs/TrustBoard/DocumentsArchive/200802FebruaryTrustBoard/EnclosureBii.pdf
[6] Based on the Energy Consumption of this Fire Station in Windham North: https://www.windhammaine.us/DocumentCenter/View/420

underground. This in turn brings another environmental consideration to our attention, as we'd need to ensure the ground was stable enough to be tunneled underneath and not collapse.

We decided to start looking at numbers to help us decide whether it would be worth looking into using pump storage for power generation, as if it was not viable for the energy we needed, there is no point researching conditions needed any further. Bearing the amount of energy we needed in mind, we then researched into existing pump storage stations, and found Dinorwig Power Station in Wales to be a good example of one. The station can get started in 12 seconds, which would allow almost instantaneous power generation. It can produce 9 GWh, so if we divide that by 250 MWh then a power station similar to Dinorwig would give us 36 hours of energy. This would be comfortable enough to keep emergency services going for 24 hours, and some extra if we need longer to sort out the problem, or any more energy than estimated is needed.

Energy decentralisation

The near future is likely to see houses fitted with 240v AC outlets (mains) and lower voltage such as 5v DC outlets that would be both sourced from the home's independent solar panels. Theoretically you can do everything with DC, however transport is less efficient. A completely decentralised network could run on only direct current.

By the nature of renewable energy sources you can't just place them anywhere, for example the optimal location for a thermal plant is likely not a suitable location for wind turbines. We do not consider a primary non grid system where each building is energy neutral, as solar panels are the only method that don't really matter where they're placed, and they alone would most likely not be enough to power the house. This is an advantage of having a grid, as you can gain power from lots of different resources and pool all of it together, allowing you to make maximum use of different renewable sources. However, renewable energy sources create problems as well as solve them, as they are not usually stable sources of power, and lack inertia, as discussed earlier. Therefore an advantage of non-grid power is that homes can help by feeding back excess power they generate into the grid, thus utilising power surges, and power that would otherwise go to waste.

Overall, a combination of the two would be best, as then we could still utilise resources such as wind and geothermal, but also have the means to smooth out minute power fluxuations as necessary.

Energy Saving Techniques

As well as using carbon-neutral and renewable sources for energy generation, we'll also install as many measures as we can to ensure that energy is saved in little ways, throughout the home.

One way would be through wall cladding, as this would minimize heat loss through walls, and therefore minimize the heating needed for houses. We estimate that having every home have cladding would save 15% of total electricity needed for heating, exterior for homes with solid walls, and interior for homes with cavity walls.

	ACH	Ventilation loss coefficient c_v	Required space heating (kWh)
Single-glazing	0.8	65	9,072
Double-glazing	0.3	24.5	7,031
Save			2,041

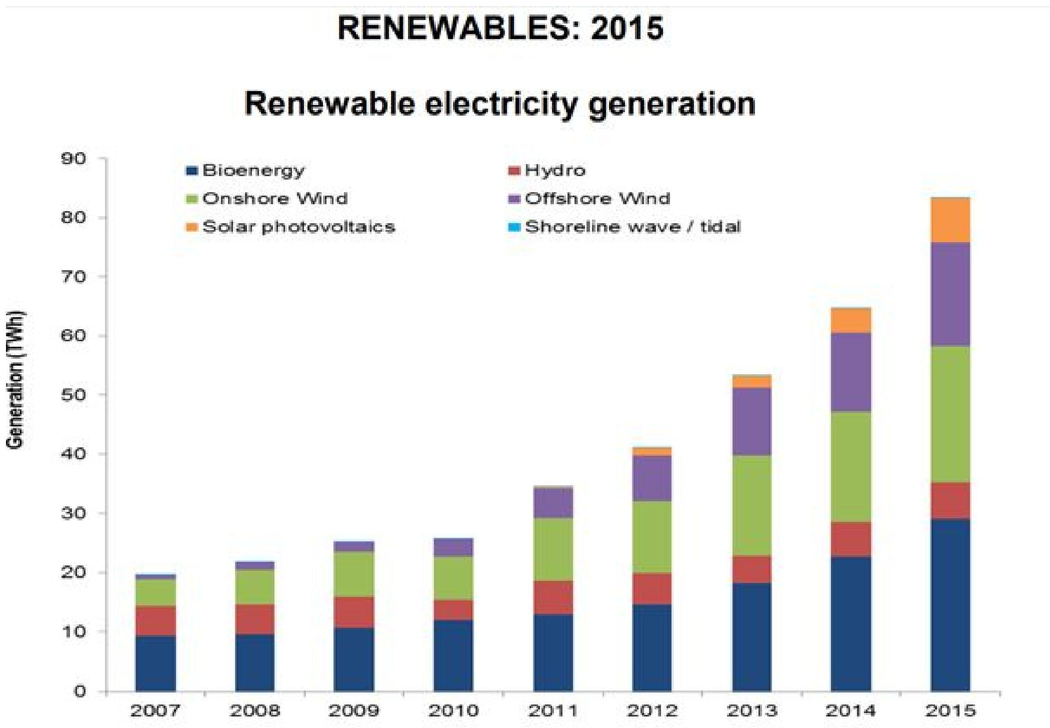
Another energy saving technique would be to install double glazing in every house. Roughly 15% of houses do not have double glazing[7]. 15% of the 850,000 houses in Solent City is 130,000 homes, which we would save energy by installing double glazing in these houses. Overall this would save roughly 2 MWh over a year, making it definitely worth investing in.

Energy Production

We are using four main means of producing energy, all from renewable sources, to ensure carbon-neutrality; Wind, Solar, Geothermal and 'Sea'. 'Sea' power covers both tidal and wave power. We have researched each way of production greatly, the conditions that are necessary for it, the energy that it will produce and the machinery that enables it. Also the storage and distribution.

This table shows how much the UK produced from different renewable energy sources in 2015:

7 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/345141/uk_housing_fact_file_2013.pdf

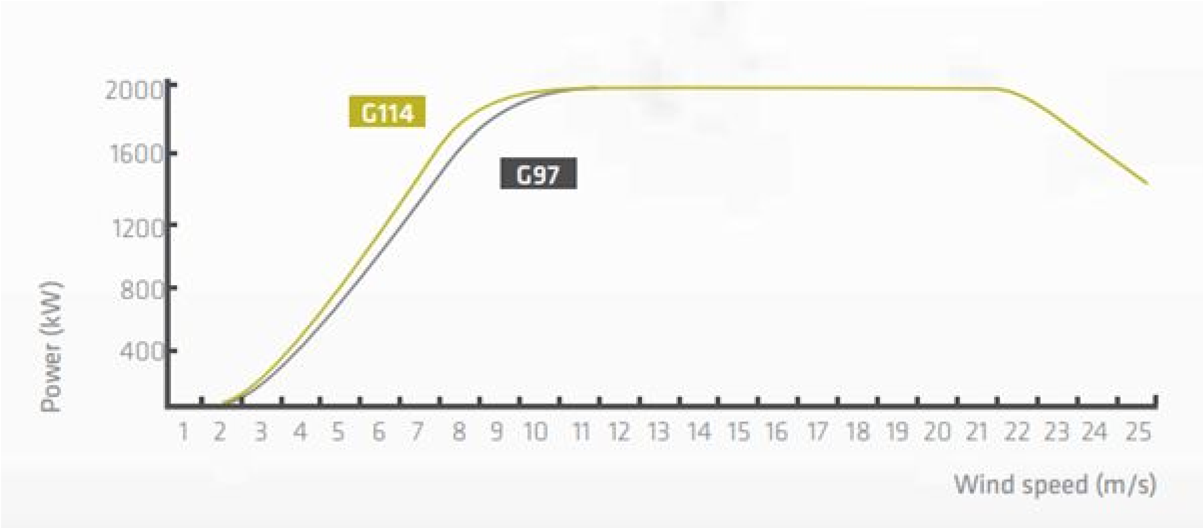


Wind Power

An overview of wind power is that it requires large open spaces, with as little obstructions as possible, to allow max airflow. The turbines themselves have large rotor spans, and are very tall, so need lots of space. This points toward placing them on the outside of the city, as although small, mounted turbines could be put on top of residential or commercial buildings, the bigger turbines would need more space, and even in suburban areas, it would be best if they were away from people, as some may object due to the visual appearance, or the noise they make when running.

In terms of how they work, there are, essentially, two different types of wind turbines; vertical and horizontal axis turbines. How both of these work is that when the blades of a wind turbine turn, they rotate the axis which feeds into a generator. This creates a DC current which can then be passed through an inverter that changes it to AC, suitable for energy transportation. However vertical and horizontal axis turbines differ in terms of how they pick up the wind to spin their blades, and various advantage and disadvantages. Vertical, although are able to generate energy from all directions, they are not as effective at generating power, and are more likely to be used in smaller scale developments. They are also better with heavy wind, so could be used in areas with rougher conditions. Horizontal turbines are better for large scale developments, as they do not need to be so wind efficient as they are able to be higher up, and are better for producing large amounts of energy. Therefore I think we should choose to install large developments in swathes, and if we need more energy, we could always install domestic wind farms on rooftops, with small vertical axis turbines, as this is the purpose they are specialised for.

We did some research into different wind turbines to find out how much power you could get from one and over what time scale. The best company we found, at present, is Gamesa, using their model G114-2.0, as it has the greatest efficiency of all of their products.[8] Wind speed averages in southampton are 12.7mph during the more windy months (October through March) and 10.5mph during the less windy months (April through August)[9]. This means that on average we'll be generating 2000 kW of power, which comes out to 17,520,000kWh of energy per year per turbine, rounded to 17.5 GWh.



Although we couldn't find an exact price on the Gamesa website, we found for other wind turbines of the same capacity[10], the wind turbine alone would cost 2.14 million.

Solar Power

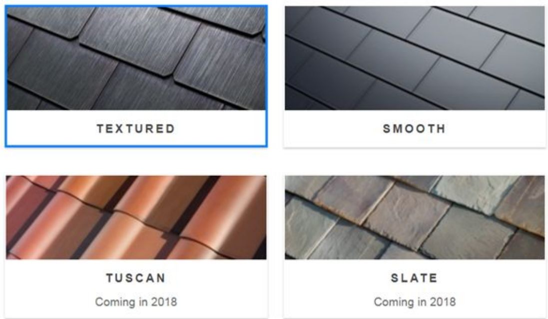
Most sources of renewable energy are very big. Solar panels are very thin, relatively light, make a negligible amount of noise and are low maintenance. This makes them suitable to be mounted on buildings or just to be arranged side by side in a large area or field with direct sunlight. A large area of land would be ideal, that has no covering from agriculture or other patches of land like mountains or hilly areas. There are many possible areas that the solar farm could be placed at in the Solent area, so an abundance on solar power energy is possible.

The issue with solar panels is the energy they produce and the total capacity from an average sized solar farm. As we've already discussed, area for a solar farm would not be problem, even though one of the largest solar farms in the world at this point covers an area

[8] Graph from G114-2.0 brouchure
http://www.siemensgamesa.com/recursos/doc/productos-servicios/aerogeneradores/nuevas-fichas/g114-20-mw-eng.pdf
[9] Using averages from wind data
https://weatherspark.com/y/41541/Average-Weather-in-Southampton-United-Kingdom-Year-Round

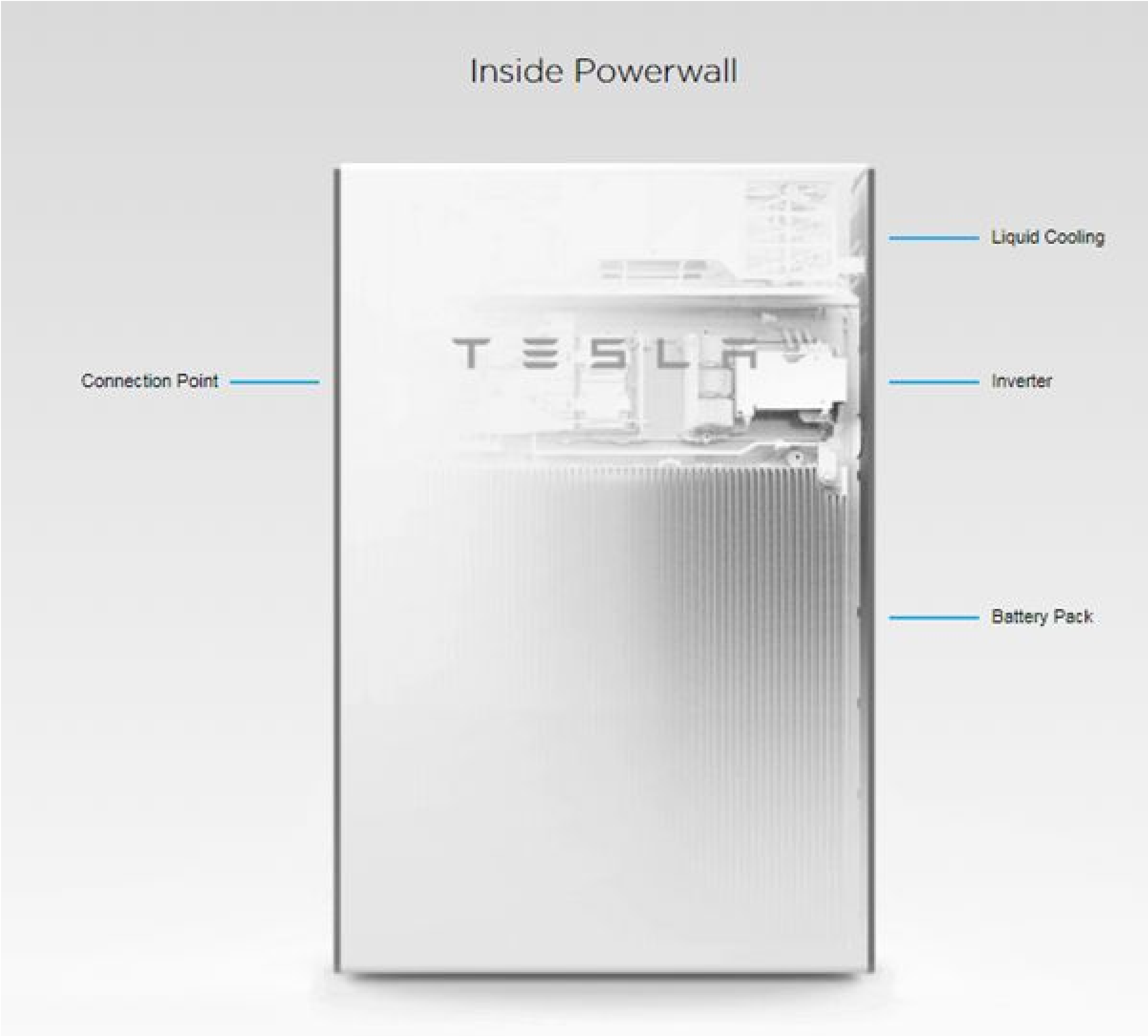
[10] Info on Turbine prices
http://www.renewablesfirst.co.uk/windpower/windpower-learning-centre/how-much-does-a-farm-wind-turbine-small-wind-farm-turbine-cost/

of 247 acres of land. This solar farm produces around 20 MW of energy a year, which is the equivalent to around 20,000 homes powered for a year.



Tesla, one of the big names in the world of science these days, are selling Solar Roofs and Powerwalls. These Solar Roofs will produce enough energy to run a household during day and night. From an aesthetic point of view, these Solar Roofs are designed to look like ordinary tiles (see right). These tiles have also been tested and designed to resistant to strong rain, winds and hailstorms.

The Powerwall is a home lithium-ion battery that charges over the day (via the Tesla Solar Roof mentioned above) for use whenever required. These batteries are rechargeable and will store the power you create. When the Solar Roof is generating more power than the home is using, it stores this power for later use. When the home is using more power than the Solar Roof is producing, the Powerwall will subsidise the required energy. If more power is needed than the Powerwall has, this will be taken from the grid.



In Houston, 2010 (when the population was 2.1 million), there were roughly 900,000 households. For Solent City, we would have about 850,000 households. The average house size is about 100 square metres. According to the Department of Energy & Climate Change (DECC), in 2014 the average electricity consumption per UK household was 4,000 kWh and the average gas consumption per UK household was 12,400 kWh[11]. Since all of our energy will be produced by electricity, the average consumption per UK household will be 16,500 kWh. This means that all 850 thousand houses would produce 14 TWh over a year.

Each Solar Roof and Powerwall would cost £10,000 combined (including costs for installation), so for all 850,000 homes, this would cost us £8.50 billion.

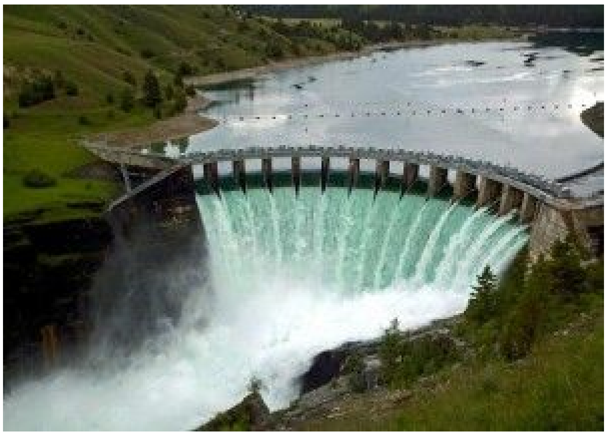
[11] https://www.thegreenage.co.uk/how-much-energy-does-my-home-use/

Geothermal Power

By using the natural heat found in the crust of the earth both electricity and heating can be provided to homes. Water is piped down in a web of pipes that have a large surface area. The water warms up due to the temperature of the earth under the surface, and the water is then pumped back up to the surface. It is not very efficient to turn the steam from this into electricity, however it is easy to pump the water to homes to be used as heating. The Geothermal power station in southampton has 11 km of pipes, and is producing 40 GWh of heat, 26 GWh of electricity and 8 GWh of cooling per year. The plant costed £4 million to set up.

Hydroelectric Power

There are many possibilities and techniques to harness energy from the sea. However, a lot of these methods are dangerous, as their turbines pose a danger to the sealife. They are very rewarding in the amount of energy they produce, so we have decided to implement them. The Solent water is lucky enough to have a double tide, two high and low tides a day, which allows us to greatly increase the amount of energy we can capture.

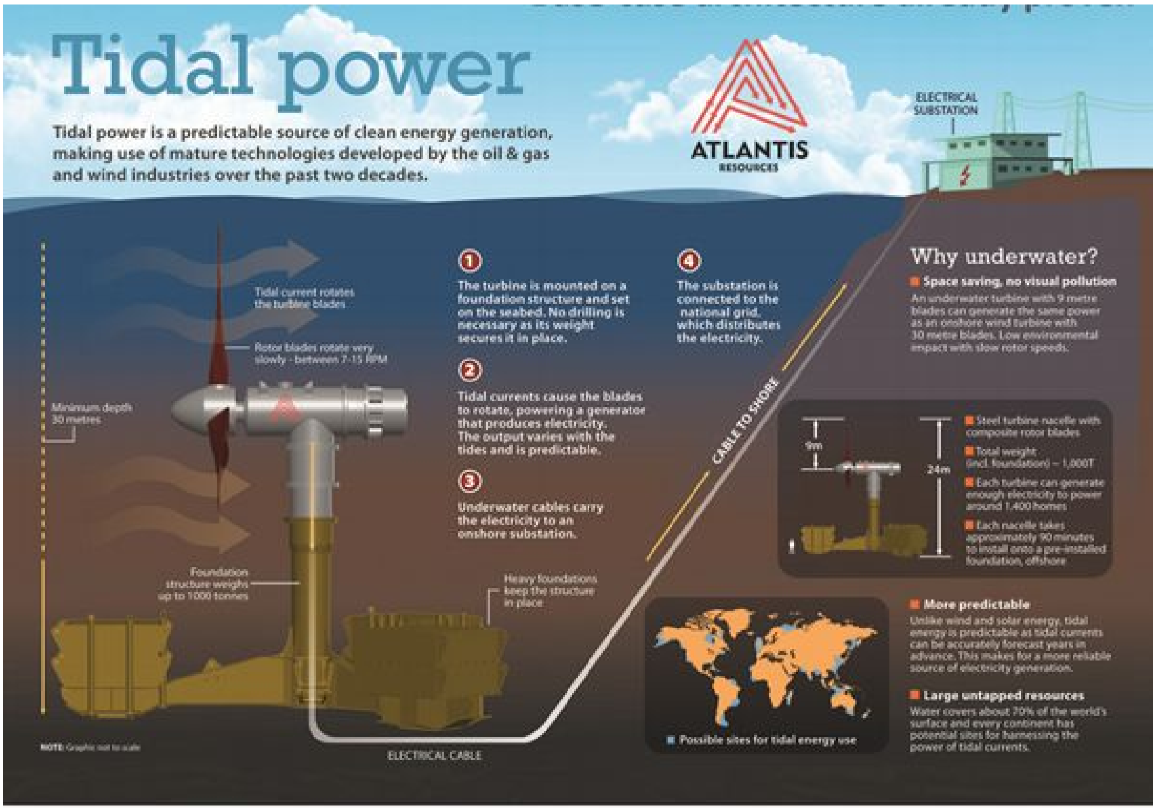


The geography of the Solent Area would make building a hydroelectric dam not overly rewarding as there is no place to store the water in a reservoir. As the reservoir would need a large area, we would not be able to encompass one into our city. We would also need the Solent water to remain deep to allow ships to arrive and depart. This would be ruined by the drastic drop in height in the solent.

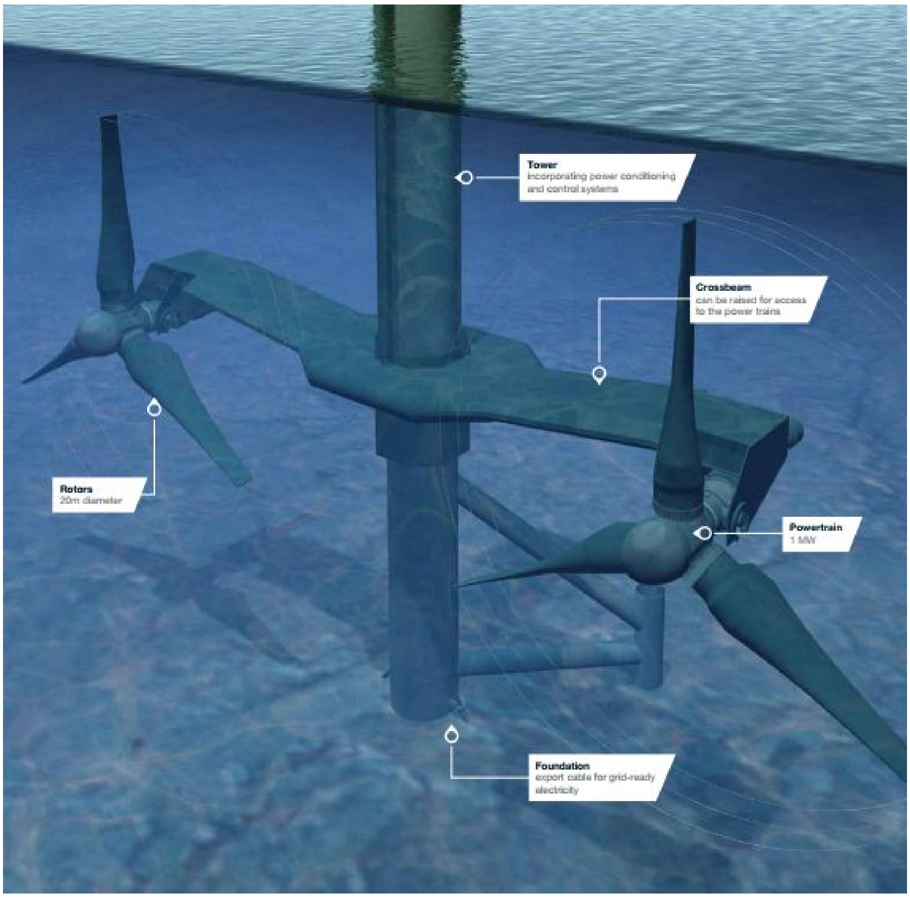
Another option is to install tidal turbines. There are very few companies in the world who install tidal turbines and there are very few hydroelectric power stations in the world (not including hydroelectric dams), so it proved difficult to research. However there are many proposed plans for the future.

Atlantis Resources were one company we found who install tidal turbines. They have two types of turbine, the AR1500 and the SeaGen.

AR1500 Turbines:



SeaGen:

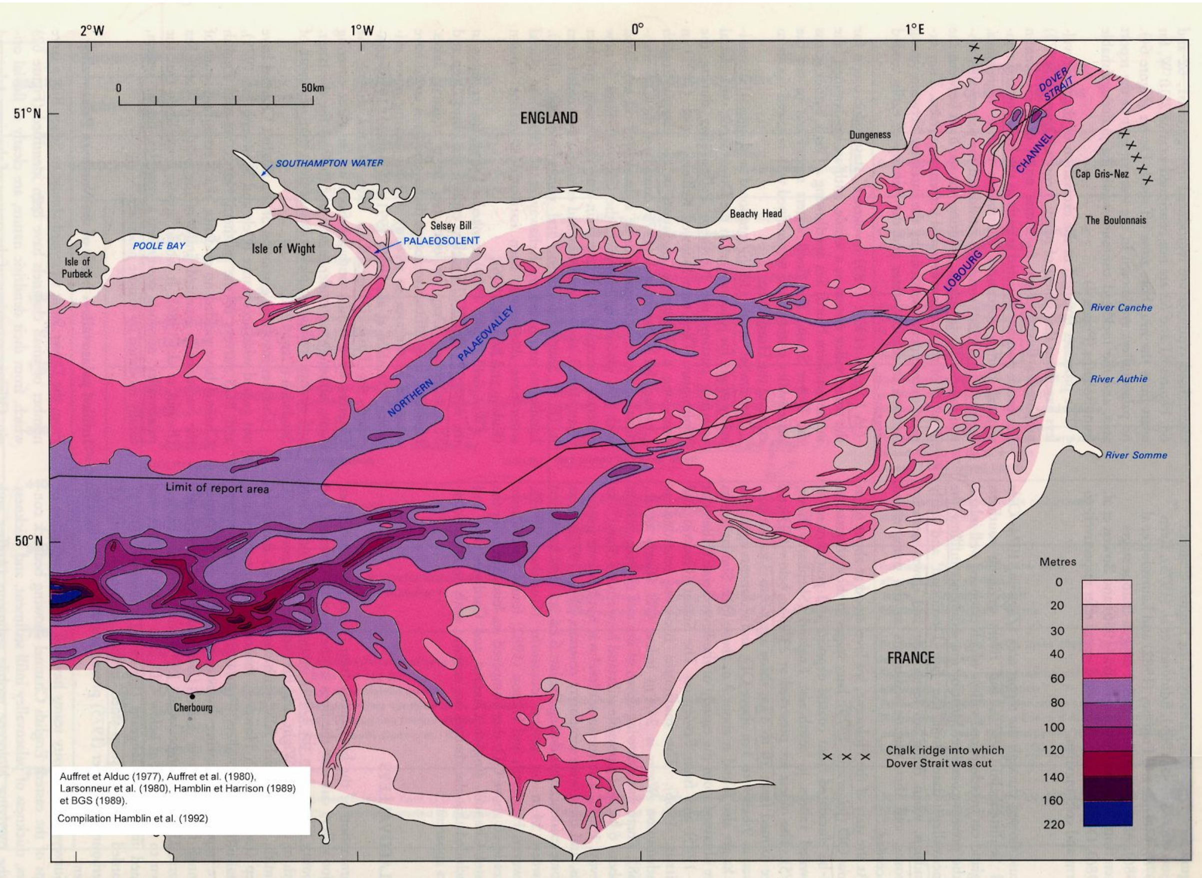


The AR1500 can only produce 1.5 MW, wheres the SeaGen's two turbines can produce a total of 2 MW. Though this does of course take up double the amount of space. For every one SeaGen, you would be able to fit AR1500's. Moreover, the AR1500 does not protrude above the water's surface, whereas the SeaGen does and therefore would face some criticism for obstructing the scenic ocean view.

Atlantis Resources have an operation currently in progress called the MeyGen project in Pentland Firth, Scotland, which is the largest tidal energy project in the world[12]. For this project, Atlantis are using the AR1500 turbines and phase 1A, 1B and 1C plan to install a total of 57 turbines, which could produce 86 MW while the tides are over 3ms^{-1}.

In the past, they have also successfully installed a prototype of the SeaGen (only 1.2 MW capacity) in the Strangford Lough, Northern Ireland.

Both tidal turbines require roughly 30m depth. This chart beneath shows the depths of the solent area and the English Channel. To install these turbines, they would need to be placed a fair way out to sea into the Channel.



12 http://www.independent.co.uk/news/business/news/pentland-firth-tidal-power-station-electricity-generation-energy-renewables-a7922141.html

The maximum speeds of the tides in the Solent and English Channel are around 5 knots, which equates to roughly 2.5 ms^{-1}. The AR1500 will produce its maximum energy output of 1.5MW at speeds of 3 ms^{-1}, whereas the SeaGen will produce its capacity of 2MW at speeds of only 2.5ms^{-1}.

We have decided to use the AR1500's. While they might not be working at their full capacity, they would still produce around 1 MW each. As we could place 2 AR1500's in place of every SeaGen. This would be just as effective as having the SeaGen, only the AR1500 would allow for energy surges when the tide speed rose above the average 2.5 ms^{-1}.

Transport:

Transport overview

The ability to travel is one of the top factors for a city being prosperous and so will be a strong focus for the design of our Solent City. An interesting quote from the University College London is "Travel offers the means to reach essential opportunities such as jobs, education, shops, and friends, which affect the quality of life. Lack of mobility is inextricably linked to social disadvantage and exclusion."[13] , confirming our thoughts on the importance of an efficient and well organised transport system. Travel is also something which, presently, has a terrible effect on the environment, due to the amount of carbon dioxide transport contributes. For example in the US cars and trucks alone contribute ⅕ of the total carbon dioxide emissions. Within our city we will try and promote other methods of transport, such as bicycles, which have numerous benefits for the environment as well as the people riding them.

Personal Transport

The primary function of personal transport is to offer freedom of travel to a user and to transport personal belongings. Personal transport can be broken down into two categories, road vehicles (Cars, motorbikes) and pedestrian convences, with inclusion of cycles (A pedestrian conveyance is any human powered device by which a pedestrian may move other than by walking or by which a walking person may move another pedestrian.)[14] Road vehicles, most commonly a car, are currently a vital part of everyday life, and greatly widen the opportunities available to the individual for both socialising and employment.

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[13] https://www.ucl.ac.uk/transport-institute/pdfs/transport-poverty] A report created by Univerity College London looking to the effects of transport on poverty from 2014
[14] [http://www.nber.org/mortality/1995/docs/ecodes.txt]
Definitions of transport categories.

However, they are also a major problem for carbon emissions, due to their abundance and over-use, so we have decided within our Solent city we will have policy that will only allow electric powered personal vehicles to be on the road. These vehicles will have a range of 200 miles giving the driver plenty of freedom to travel. Although electric vehicles are going down in price, they may be more expensive than petrol or diesel cars, so public transport will be very important to most of the population.

We have researched electric vehicles and found a model called the LightYearOne[15], which is a solar powered car that has no need for charging points, as it charges from the sun. Assuming everyone in the solent city would have one of these cars, this would both be carbon neutral and also mean that we would not have to supply power for the cars.

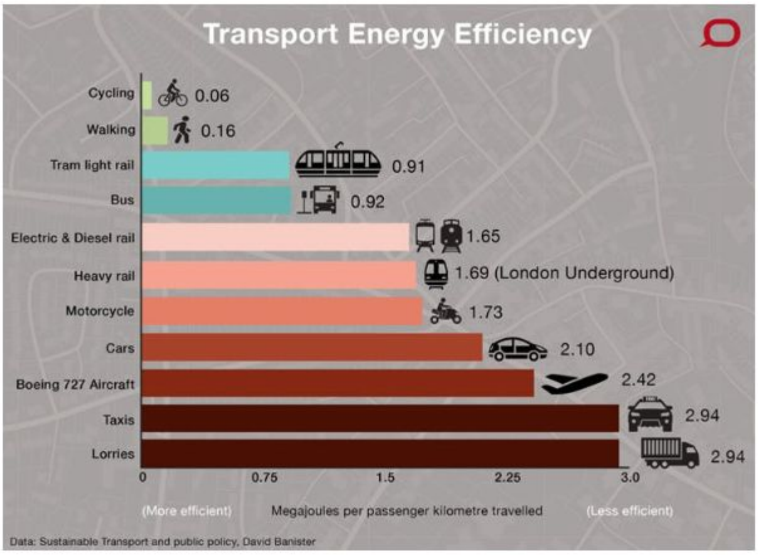
Light transport will be an alternative for commuting short distances. There are many products that are increasing rapidly in popularity, including self balancing scooters, mono-wheels ,and electric bikes. Although all of these need electricity to run, all of them can be charged from the home, and use much less electricity than cars. Nationally people who commute to work by cycling travel an average of 7 miles, however, we could encourage people who might have a little further to go by creating cycle paths, that were well-upheld, so to provide more safety, and hopefully popularise that form of commuting.

Another aspect of personal transport to consider are taxis. They offer an alternative for direct travel (as opposed to bus routes), however come with all the negatives of regular cars on the road. Self driving taxis would be able to provide safety and select routes based on traffic information to reduce the problem of added traffic, however we still believe that public transport it a preferable option, and so will try and encourage that more than taxis.

Public Transport

The two most effective ways of public transport are buses and trams, as shown by research, so we are going to use one of them as our main system. After considering both options,we concluded that buses have more advantages that would be beneficial in this situation. The advantage of buses is that you do not need to lay tram lines, making them more flexible and able to go more places. Furthermore they are usually higher capacity (especially double deckers), therefore reducing the number of them needed on the road at one time. However trams are less affected by traffic or accidents on the roads, making them faster and thus more efficient. They are 0.01 more efficient than buses in megajoules per passenger kilometre travelled, with buses being 0.92 and trams 0.91 .

[15] https://www.lightyear.one Info on solar cars



[16]Overall, due to the circumstances of their use, we value the flexibility of buses more than the fact trams are not affected by traffic, as we are aiming to reduce road traffic anyway, so there should be less traffic on the roads for buses to be affected by, thus making this advantage not very influential. Furthermore buses have higher flexibility, which is always valuable, as you never know when you will need to change a route due to a road blockage or another unforeseen incident.

Once we had decided on buses we needed to think about numbers, and companies. We have decided to stick with a single bus company, for sake of simplicity, and also as we want only as many buses as we need, as we don't want to be producing any excess carbon dioxide that we don't to need to be. Although having multiple companies has it's advantages, for example the competition between them keeps the companies improving and makes sure they always run at their best, in this instance we are deciding to go with one. We will layout the bus system similarly to the london, making zones, with zone one being the most central area, decreasing in numbers outward. Passes can be purchased to travel within one zone, or inter-zone. This, we believe, will make sure people think about their traveling, and encourage them to only use transport from zone to zone, and walk or cycle within their zone. In terms of numbers, we have used data from a city of a similar size to the imagined Solent city, to gauge the number of buses we might need for our population. In Houston, Texas, a city with a population of 2.2 million, they have a fleet of 1,211 buses, so we've decided to round that down a little, to 1,100.

We also considered how much energy this would all take to fuel. Diesel engines are the most common for buses, but are not very good in terms of how much carbon they emit, and the fact diesel is non-renewable makes it a very bad choice for which engine to use. There is however, a developing industry of buses using electric motors with lithium ion batteries to power a light-weight chassis. This lightness helps the buses achieve fuel efficiency equivalent to more than 20 miles per gallon. Furthermore they also come with active safety features and wireless internet built in, and since there are so few moving

[16] http://theconversation.com/which-transport-is-the-fairest-of-them-all-24806 Graph Source

pieces, minimal excess heat, and little material at risk of rusting, the maintenance costs come way down compared to diesel.

If we have a fleet of 1,100 buses, then we'll most likely be running 1,050 per day, due to some being serviced, and having them as reserves in case they're needed for other things. Assuming average bus route is approximately 20 km, which is what we've found for local bus routes we've looked at, and each bus route takes approximately an hour to complete, with an extra 15 minute margin for traffic and change over. This means the bus would complete this route approximately 18 times, as we could fit 14 routes into the 18-hour working day, and then we would have a few late night buses running also. There would be more than four late buses running in zone one, but less running in say zone five, so we've decided to average it at four.

If we have 1,050 buses running a 20 km route 18 times a day, that means each day 396000km will be travelled in total. I found that electric buses use between 0.42-0.99 $kWh \cdot km^{-1}$ dependant on recuperation strategies. [17]If we take the power usage to be 0.99 kWh/km, rounded up to 1.0, then 378000 kWh will be used by public transport each day. Per year, assuming buses won't run on approximately 7 days per year, to account for different public holidays, then that's a total of 135.324GWh per year, rounded to 135 GWh.

In terms of cost, we've researched and found figures that compare the lifetime costs of diesel vs electric buses, taking into account maintenance, fuel and purchasing cost; £841,174.80 for an electric bus, and £960,935.28 for a diesel bus. This would make the total cost of our electric bus fleet around £925,292,280. This doesn't include for unforeseen breakages and replacements, but gives us a good idea of cost.

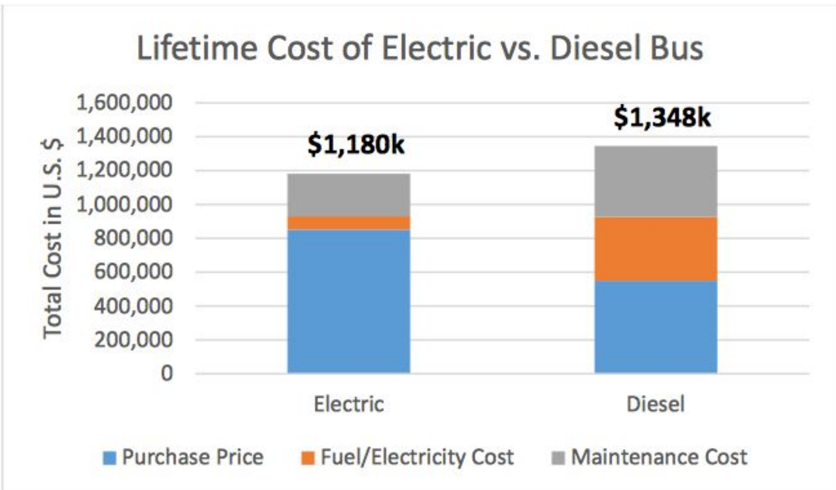


Figure 7: Lifetime Cost of Electric Buses vs. Diesel Buses in U.S. $ Excluding Cost Savings Associated with Health Benefits

[18]

[17] http://tf.llu.lv/conference/proceedings2015/Papers/060_Graurs.pdf
Paper on improvement of rural transport

[18] http://www.columbia.edu/~ja3041/Electric%20Bus%20Analysis%20for%20NYC%20Transit%20by%20J%20Aber%20Columbia%20University%20-%20May%202016.pdf
Costs of buses

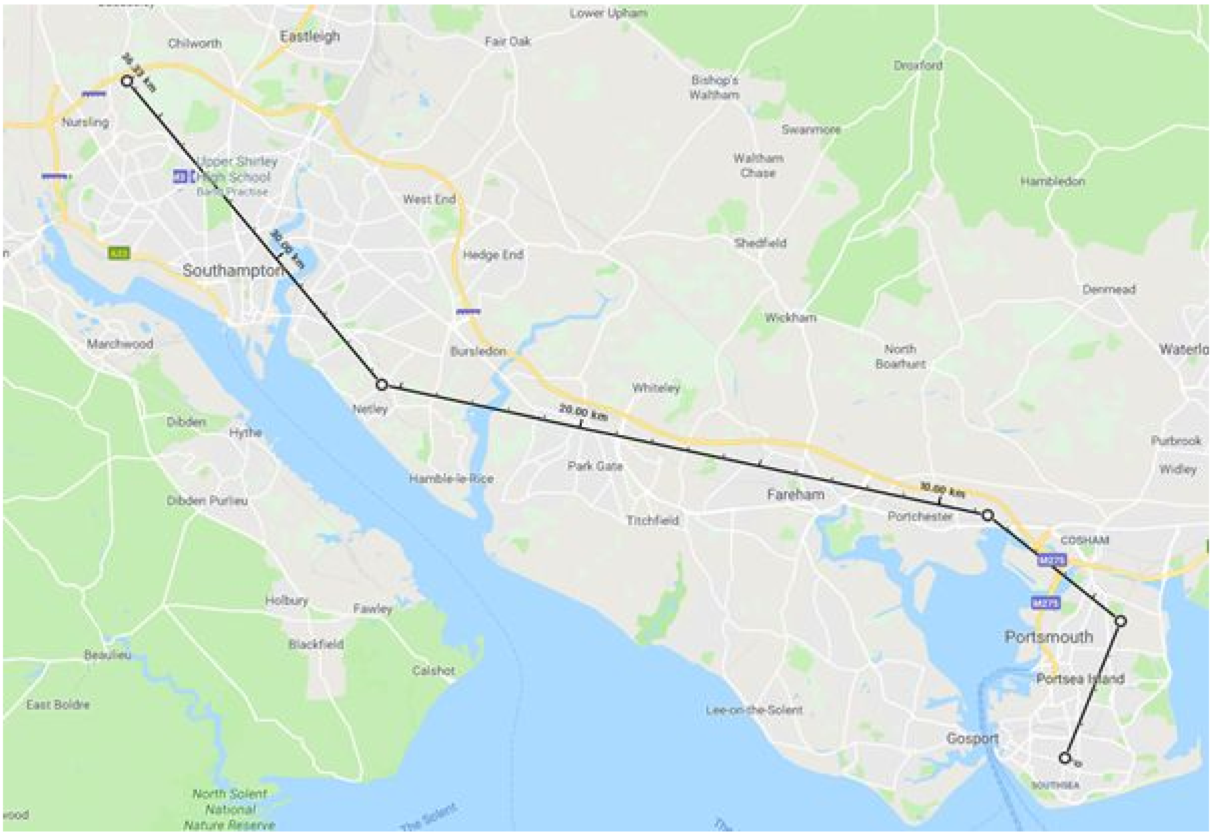
Transport In and Out of the City

To arrive and depart from Solent City to other places around the UK and the world by air, land and sea, while achieving carbon neutrality is not easily achievable. With the technology currently in place, this is an impossible task. However, these industries are currently researching ways of making carbon neutrality possible. Despite trains being mostly electric these days, especially in the UK, all planes and the significant majority of boats still run off fossil fuels.

Land

For passengers, we would use electric trains as oppose to diesel trains. Electric trains are lighter because they are not required to carry fuel, their power is supplied by an overhead line or ‘third rail’. According to the Telegraph, the cost of maintaining electric trains is 40p (20p cheaper than diesel), fuel cost per mile is 26p (opposed to 47p) and track wear and tear is only 8.5p per mile, compared to 9.8p per mile for diesel. Electric trains also emit less carbon into the atmosphere.

We are working with this as our train line:



This line would cover around 37km, which we would round up to 40km to allow for extra track needed to work around buildings and to stations. Our central station would exist by the small white dot by Netley, in our city centre.

We've found that electric trains in Portugal[19] can do 1km per 8.5 kWh of energy, so if we have a route of 40km it will mean 680 kWh of energy per round trip. If we have trains making 144 round trips a day, as we're assuming one train will go through our central station every ten minutes, this means that per day 97,920 kWh will be used by trains. This rounds to 10,000 kWh a day, which then, times by 360 (we can assume for at least five days of the year the trains won't be running) means 3.6 GWh will be used by trains each year.

Sea

Boats are a difficult thing to fuel using renewable energy, as most of them are engine run and therefore currently use diesel or petrol. However several companies are currently working to try and make high-capacity boats such as ferries, able to run off of renewable energy, by using electricity.

XALT energy has partnered Plan B Energy Storage to produce ferries that run entirely off of electricity[20]. Each ferry will carry a 4.16 MWh battery pack, enough to power the whole ferry's propulsion and services on board. We have decided to use these ferries for transport outside the solent city via sea, as they'll be able carry over than 7.4 million passengers and 1.9 million vehicles annually with zero emissions, which would more than cover the average number of people who would want to leave or enter the city by boat. These ferries would have extra advantages also, the engine would last longer due to the engines having a thermal management system, which allows the batteries to always be at optimum temperature. Furthermore the lack of diesel fumes will make using the ferries more pleasant, and reduce long term health risks.

We estimate that we'd need around ten ferries, as disincluding comercial cruise liners, the only current routes that ferries travel is to the Isle of Wight from Southampton port, and to France from Portsmouth Harbour. We'd need two ferries to cover the Isle of Wight route, as one ferry could do the daily route comfortably, by just going there and back however many times a day as is needed. However two would mean that they could rotate the route, so that if one needed any repairs we'd simply swap them out to perform them, so scheduled travel could continue as normal. For the cross-channel route we might need a few more, as currently the ferries run to four different places in France, therefore we'd have one ferry for each route, and then a reserve for each ferry additionally. This would be eight ferries for the French route, and therefore ten in total.

We found an existing ferry route that uses the technology we;ve planned to, and they used 150 kWh for a 6 km journey, meaning it's 25 kWh per km. For an Isle of Wight round trip it's 64km and for a French round trip 350km. If we multiply these figures by the amount of times we'll do each trip, then it gives us a total of 2,424km to travel every 24 hours, which we'll round to 2,500. This times by 25 is 62,500, meaning transport by sea will need 62.5

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[19] https://en.wikipedia.org/wiki/Energy_efficiency_in_transport#Trains

[20] Xalt Energy Article
https://cleantechnica.com/2016/09/27/xalt-energy-supply-worlds-2-largest-battery-powered-ferries-lithium-ion-cells/

MWh per 24 hours, which will mean per year (assuming two weeks total of days of no ferries for various reasons) transport by sea will take up 22 GWh.

Air

Aeroplanes require lots of energy to run, so making them electric would prove to be very challenging due to the huge amount of energy that would be needed for the journey. One solution would be use biofuels to power the boat. This would require a ridiculously large amount of plants, and powering the big number of planes that are around, we would need a number of plants that would have serious consequences, and to grow this many plants on top of the existing crop would use an area of land too large.

Another possibility is making planes electric. This requires a huge amount of energy. For a Boeing 747 to take off, assuming:

- Engine Thrust = 284kN
- Takeoff speed = 170 knots
- Takeoff power = 90% max power

Using P = Fv, we get a power of roughly 90MW[21] for a plane to take off, let alone fly to its destination and land. However, EasyJet have teamed up with Wright Electric, a company whose aim it is to reduce all emissions from planes to 0% in 20 years. They believe that by 2027, electric planes will be ready for action.

An alternative for air travel that isn't planes is using an airship, (similar to a blimp, only with a rigid body) which perhaps is viewed as outdated technology, but several companies are working hard to bring it into the modern age. Blimps can easily be carbon neutral, as with solar panels mounted on the top, they can power themselves. There is a model in the testing phase currently utilising 24,000 square feet of thin-film solar cells on the top of the blimp, resulting in 62.7 KW of rated power. Once this blimp is up and running, speed estimates come to around 182 MPH during the day (utilizing a 96 MPH average Jet Stream wind speed) and around 165 MPH at night. This is whilst carrying around 60 tons of cargo, which could also translate to around 300 passenger capacity. 30 tons would most likely be taken up with seating and furnishings, which gives us room for 300, with an allowance of 100 kg of baggage each.

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21 https://aviation.stackexchange.com/questions/19569/how-many-kilowatts-to-get-an-electric-747-8-airborne

For an idea of passenger numbers, I looked at the number of passengers that went through southampton airport in 2016[22], which came to just under 2 million, which is roughly 170,000 per month. This would mean approximately 570 trips a month, departure and arrival, using the figure of 300 people per blimp. Rounding this to 600 trips a month, that's 20 trips a day, so we'd most likely need a fleet of ten airships. Seeing as they'd be near enough self-sufficient, the energy we'd need to provide them can be regarded as negligible. Furthermore they would be an efficient and exciting travel option, so we would definitely invest in a ten airship fleet for our solent city.

Total Transport Energy Needed

We have determined both cars and airships will have a negligible energy usage, buses will use 140 GWh per year, trains 3.6 GWh per year, and ferries 22 GWh. In total that's 165.6 GWh per year, rounded to 170 GWh.

Energy Plan

First of all, we would install Solar Roofs and Powerwalls on each and every house. This would produce 14 TWh of the 52 TWh that we need for the year, powering all of the houses in Solent City. This leaves us with 38 TWh to produce.

We would install double glazing in the remaining 15% of houses that do not currently have it installed. If 130,000 houses all save 2,000 kWh per year from double glazing, this means that we can save 260 GWh of energy per year. This reduces us to 37.74 TWh.

We would also install cladding in each home in Solent City. 11 TWh a year would be used to heat 850,000 homes. If we could reduce this by 15%, we would could reduce this number by 1.65 TWh. This lesses our production need to only 36.09 TWh per year.

In terms of transport, for city of 2 million based off the UK values for 2015, the transport would use 20 TWh per year. However, in our solent city, we only need 170 GWh per year. This means we would save 19.83 TWh of energy, reducing our total figure for the year to 16.26 TWh.

If we used a Geothermal plant double the size of the one in Southampton, this would reduce the total energy required by 148 GWh, taking it down to 16.11 TWh.

[22] https://www.southamptonairport.com/about-us/facts-figures/ Passenger Numbers

If we installed 200 AR1500 tidal turbines in the English Channel, this would produce 1.75 TWh of energy, reducing our target to 14.36 TWh.

14.36 TWh divided by the 17.5 GWh capacity of a wind turbine equals 820 wind turbines, which we would place on the hills around Solent City and also offshore in the sea.

Costs

Cost of energy production units; an installation of 200 tidal turbines would cost 500 million pounds, and an installation of 820 wind turbines would cost around 1.7 billion, a geothermal planet would cost 8 million, an installation of solar panels would cost 8.5 billion pounds.

This makes the total cost of energy productions means 10.7 billion pounds.