Blott Matthews 2018 Competition

Solent City:

As envisaged by Team Millet.

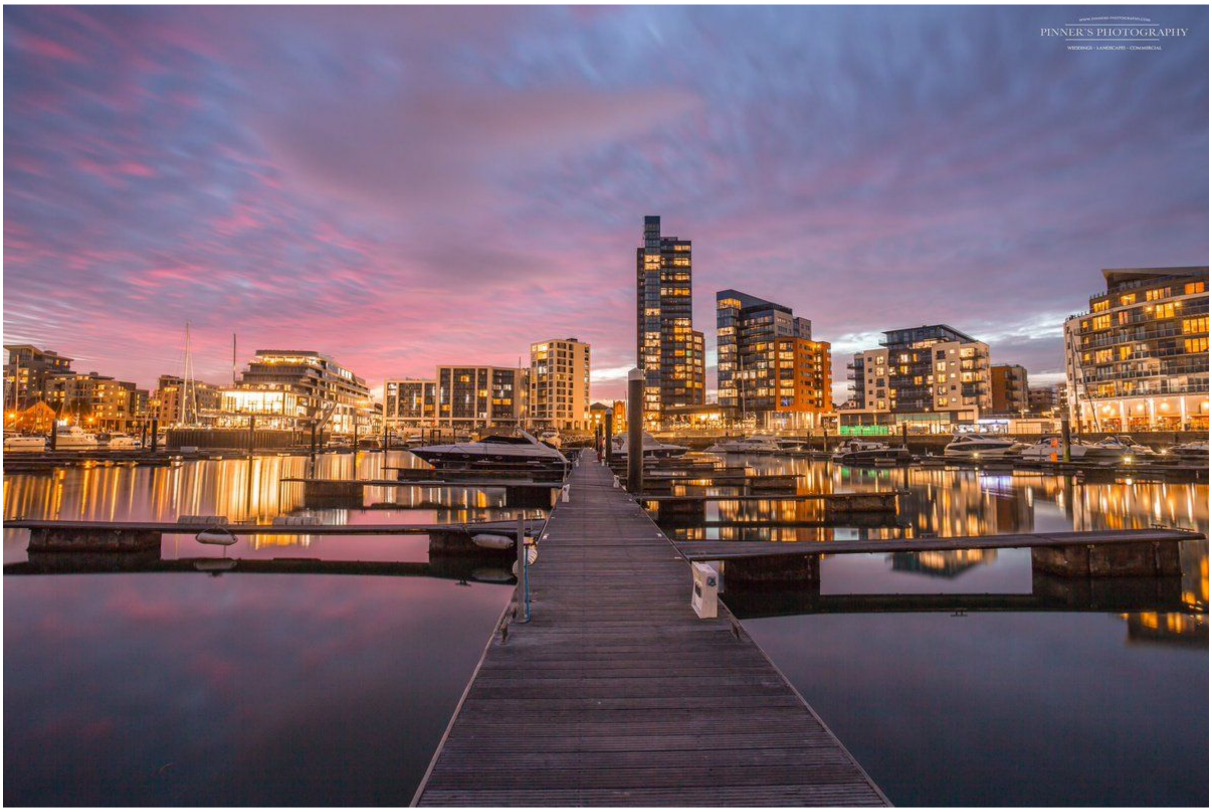
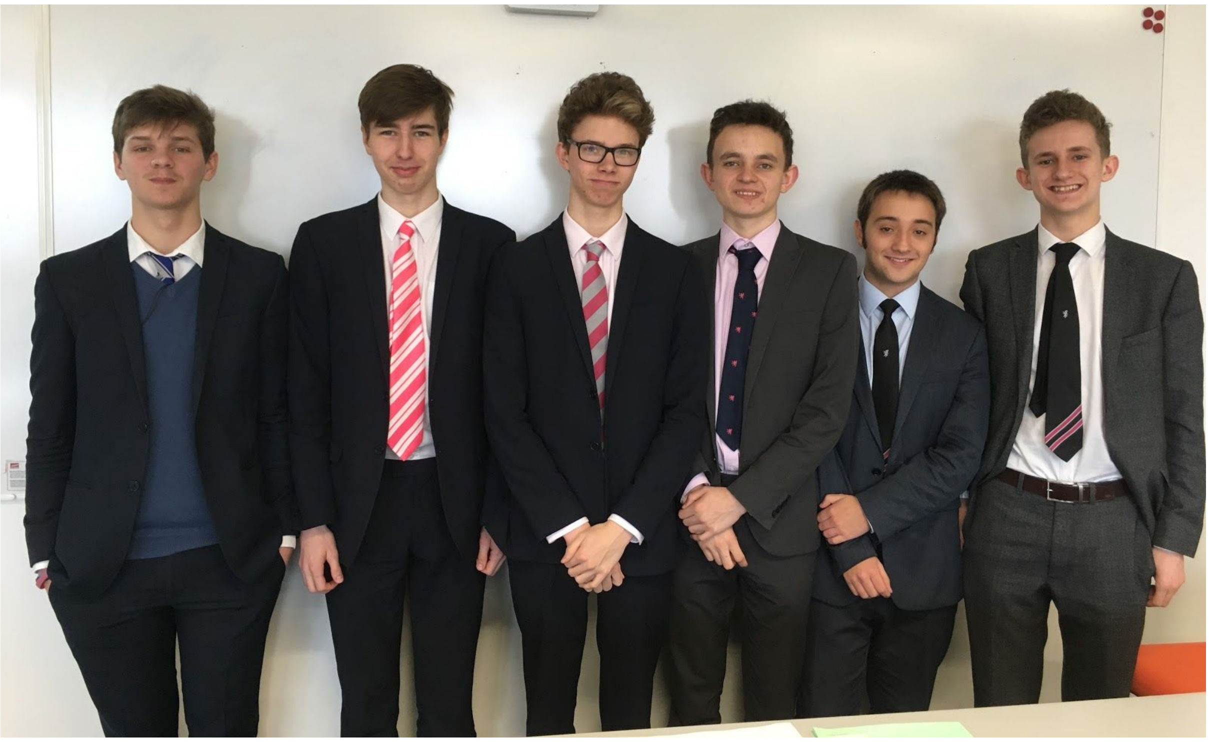


Table of Contents

Introduction:

Who are Team Millet?



- Toby Rowles
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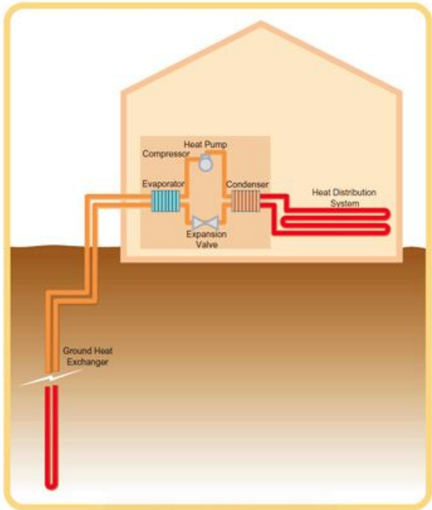
- John Allen

We all study physics A-Level in the Lower Sixth Form at Abingdon School and hope that our vision of Solent City is one that can be creative and innovative, whilst also being achievable within the time period that has been allotted. In the energy section of the brief, the main challenges faced were finding an energy source that was achievable, whilst also being able to deal with the variations in usage that come with a modern city of the size imagined. Another challenge that arose in the energy team was the implementation of energy - where would we put an offshore wind farm to not disrupt one of the busiest shipping channels in the world? In the end a



combination of wind, solar and nuclear energy were deemed the best options to ensure a zero carbon emission city, whilst also using technology such as ground source heating to minimise the energy needed. This allowed us to combat the task of a fully fossil fuel free city.

Similar problems were faced by the transport team, the main challenge being to eliminate all sources of fossil fuels from transport. We did this with a mixture of public transportation schemes, from an innovative AI transportation scheme to rented bikes, we used simple technology and innovative, up and coming hi-tech vehicles. One of the greatest challenges faced was the problem of creating an air travel system that was zero emissions. Commercial air travel is one of the last modes of transportation left to achieve carbon neutrality. We used biofuels and electric drones for

emergency services where we could. Moreover we had a maximum height for aircraft in the city, so that we didn't release any particulates straight over the city.

Overall we feel as though we have managed to create a city that is both innovative and exciting, whilst not using improbable technologies that might be developed far into the future. We feel that a balance of old and new technology will be the only way that a city of this scale will be able to remain carbon net zero, whilst also maintaining the quality of life of the general public.

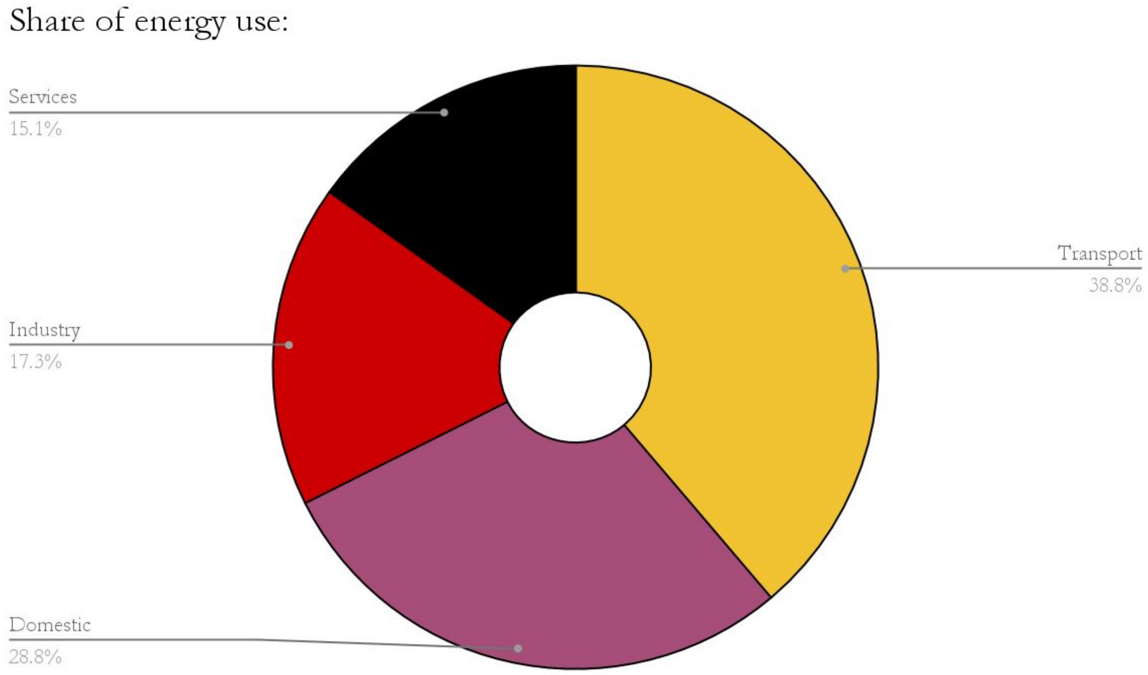
Energy Overview:

"The best energy is the energy we do not use":

Energy efficiency and economisation is at the core of our energy policy. For instance, insulation in all new buildings to reduce the need for heating in winter and cooling in summer. Moreover, the railroads and bus routes will be as efficient as possible being able to serve the majority of the population with the smallest possible distance travelled in an optimised manner. Bikes will also be available for the public allowing a clean way to move around the city itself. Our energy sources will also have an adaptability such as moveable, floating wind turbines and optimised solar panels.

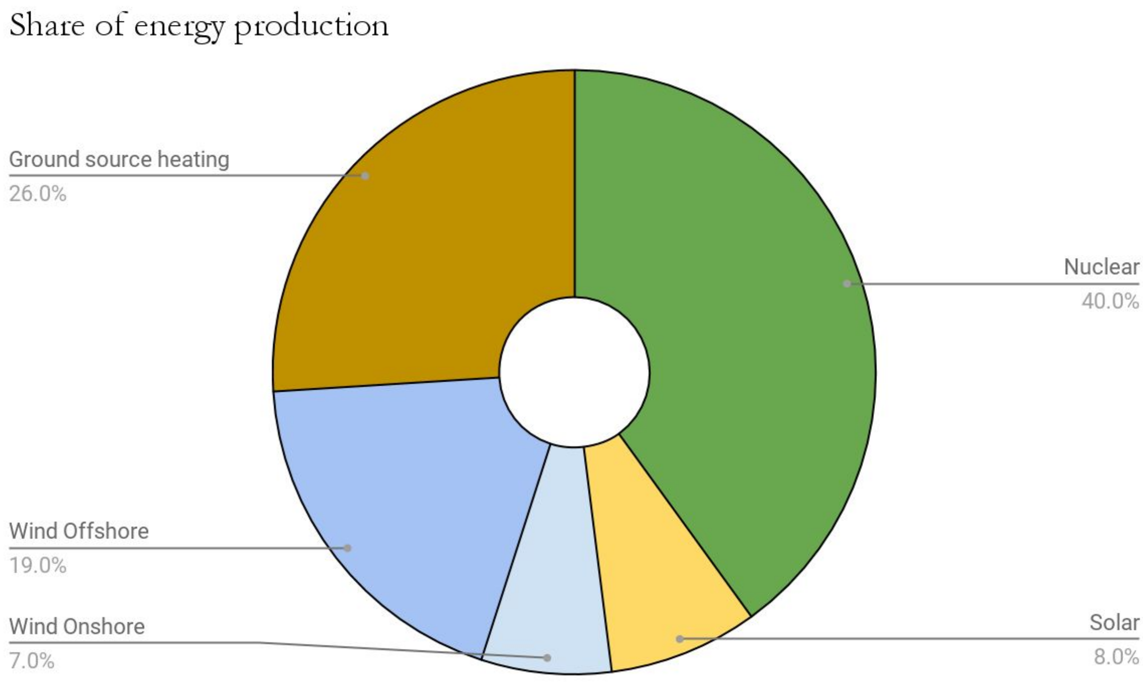
The energy itself:

For 2 million people, services and the industry associated with a large city, we have calculated that we will need **50,500,000,000 kWh per year,** where:



Energy production:

We will use predominantly four sources of energy; wind, solar and nuclear power along with ground source heating. This is done in order to mitigate the over dependence on weather conditions for solar or wind power while still taking full advantage of the immense energy collection potential in the area. There has been much debate about nuclear power and after looking at the numbers it seems that it would be impossible to fully sustain the population on renewable "fully clean" energy.



All of our sources are virtually carbon free to run and as a result we will achieve our goals of carbon neutrality as soon as we have given the National Grid enough green energy back to pay for the instalment of our farms and plants.

In the following pages, we will cover all of our energy sources and give key details to give an overall impression of how we are going to provide power for Solent City.

Wind Energy:

Wind power is clearly one of the main strength of the UK's renewables network and a particular strength of the Solent area as the winds from the English channel are constant almost all year round. We will be placing onshore wind turbines both in and around Solent City in order to minimize the negative impact of "visual pollution". For offshore wind power, we will be using floating wind turbines which will be placed clear of shipping lanes and will be adjusted to be placed in the best locations to maximise energy production. We will be using more offshore turbines as they have almost double the energy efficiency as onshore ones. Both types of turbines can be built within 4 months and as a result, we can assume that our wind turbines (Offshore: 500, Onshore: 400) should take about a year to start operating (after the start of the building in Solent City) and 4 years to be fully functional. The price for each turbine can be expected to be approximately £3M[1].

Floating offshore turbines:

Recent developments in offshore wind turbines mean that we will be able to have an effective fleet of floating turbines, able to be relocated based on weather and wind patterns to optimise their seasonal performance. This means we can maintain fairly constant energy production all year round despite inconsistent wind speeds and direction in different seasons.

[1]http://www.renewablesfirst.co.uk/windpower/windpower-learning-centre/how-much-does-a-farm-wind-turbine-small-wind-farm-turbine-cost/

Power Output:

OFFSHORE: 13,248,000 kWh annually, per turbine[2]
ONSHORE: 6,000,000 kWh annually, per turbine[3]
If we multiply these values by the numbers that we aim to be using for each type of turbine, 500 and 400 respectively, we can produce a total of **26.1%** of our total energy output solely using wind energy.
OFFSHORE: 6,624,000,000 kWh annually, and of total **19.07%**
ONSHORE: 2,400,000,000 kWh annually, and of total **7.03%**

Emissions and Effects:

During its lifetime a single wind turbine will produce 80[4] times more energy than is used to build, install, maintain and decommission it. This means that we are being extremely efficient on an energy production to usage ratio. However, it does mean that we will need some external energy over the course of a wind turbine's lifetime which averages between 20 and 25 years[5]

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[2] http://www.ewea.org/wind-energy-basics/faq/
[3] http://www.ewea.org/wind-energy-basics/faq/
[4]http://www.renewablesfirst.co.uk/windpower/windpower-learning-centre/how-much-does-a-farm-wind-turbine-small-wind-farm-turbine-cost/
[5]http://www.renewablesfirst.co.uk/windpower/windpower-learning-centre/how-much-does-a-farm-wind-turbine-small-wind-farm-turbine-cost/

over the course of which they will run continuously for approximately 120,000 hours[6] of energy production. There is currently a lot of research into extending the lifetime of wind turbines so these values may look even better in the future.

Looking into the future:

This type of energy production is the cleanest and in our area brings the biggest amount of energy per square metre of farm. The growing amount of research indicates that prices will go down and efficiency will increase within the next few decades. As a result we wish to increase our wind farm capacity in the long run in order to provide cleaner energy and replace our dependency on nuclear energy. We believe the wind sector of our energy production should cover about 50% of our energy needs by 2050.

[6]http://www.renewablesfirst.co.uk/windpower/windpower-learning-centre/how-much-does-a-farm-wind-turbine-small-wind-farm-turbine-cost/

Solar energy:

Solar power is also a great resource for any carbon free city. Solar panels come in different sizes and can be fitted almost anywhere with sunshine. Therefore, we intend to cover the largest area possible with panels to increase our energy production. Places like rooftops, cars, and even roads will be fitted with high-tech photovoltaic panels in order to maximise our energy production. These however are still quite expensive and have to be cleaned almost every year to maintain efficiency. We also intend to have a few solar tower farms which are being researched now and will definitely be available in the next 10 years. The main advantage of these is that, they can be built more cheaply than individual solar panels and they also use less non-renewable minerals, present in solar panels, for the same final energy output. More generally, in 10 years time we expect solar panels such as those Tesla is developing to be cheaper and more efficient and as a result there will only be positive outcomes to branching into this type of energy production.

Power output:

For the number of solar panels we are assuming that on average each family will own a 4kW solar panel either on the roof of their own house or at work, or even on their driveway. As a result we can safely assume that even on a bad year weather-wise the solar panels (covering an area calculated to be

24km^2) will be enough to provide 2,950,000,000 kWh. A few solar tower plants should help the solar energy to come to just about **8.00%** of our energy production.

Dealing with expensive technology:

Solar panels are likely to be the least cost effective source of energy. This is mainly due to the need for a thorough and precise construction of each individual panel along with the cost of the materials themselves such as copper and silicon. The average 4kW solar panel can cost about £7,000[7] and only lasts for about 20 years. However the good news is that private investment in solar panels would actually be beneficial for the average homeowner as the energy they can produce with their own solar panel will be "cheaper" for them than if we provided it to them. As a result we plan on having a positive stance towards private investment into solar panels on the new homes that will be built for Solent city, possibly giving out bonuses or small tax cuts to solar panel enthusiasts.

Solar panels research:

The best thing about solar energy is the amount of research and development that goes into it. It seems as if it will turn out to be one of the most important energy sources in the world within the next hundred years. For example, "Perovskites", or small materials with a specific crystalline structure have been researched by a team at Stanford University and allow a regular silicon solar cell of 11.4% efficiency to rise to at least 17%[8]. This research and investment in solar technology means that we would be even less reliant on our nuclear fission energy. One aim could be to have at least 15% of our total energy from the sun as we approach 2050, and to increase a further 5% in the following decade.

7 https://www.theecoexperts.co.uk/4-kw-solar-pv-systems
8 https://en.wikipedia.org/wiki/Perovskite_solar_cell

Nuclear Energy:

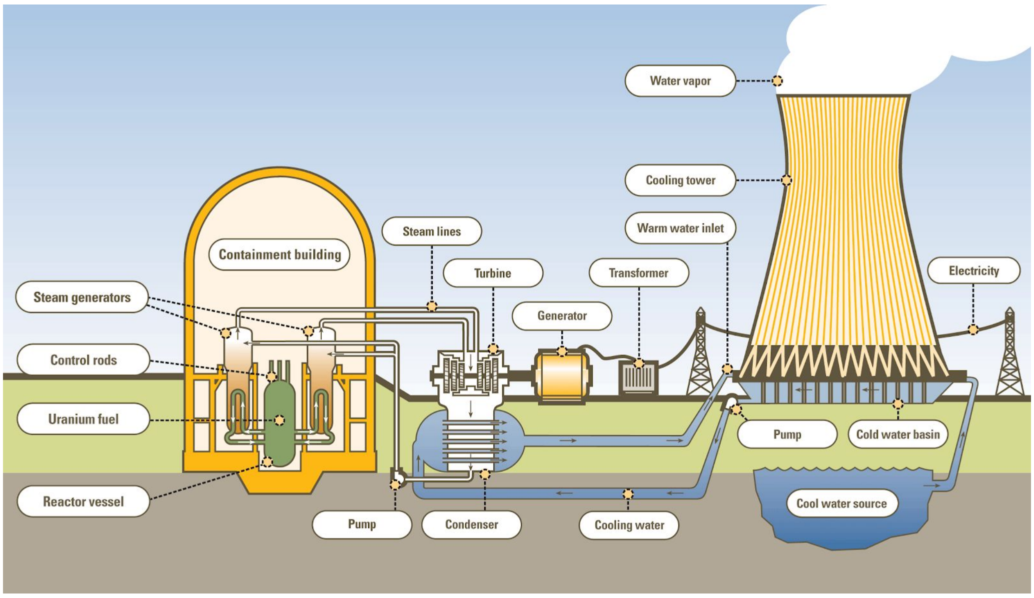
Nuclear energy is the best source for enormous amounts of "clean" energy, as there is, for now, no better substitute. The sheer amount of energy produced by a single small nuclear power plant would be enough to provide for a good 10% of Solent's population. It also provides an excellent base load of electricity as the energy is harvested on a constant basis and does not require any other intervention other than feeding nuclear rods and constant water cooling.
The downside of nuclear electricity is that the reactors are very difficult to turn on and off unlike alternative sources of energy. This means that if we commit ourselves to using nuclear energy, we must also appreciate that there is a base load that will need to be constantly accounted for. This will either need to be less than the minimum amount of energy usage at any given time or we will need to find a sustainable way of storing large quantities of energy over long periods of time.

Power output:

For our nuclear fission, we intend to have three relatively small reactors all within a single plant, which should each give out about 71,937,120,000kWh. Taking into account the time that they will need to be stopped either for routine checks or because we simply do not need as much energy (summer-time mainly), we can expect them to cover a comfortable **40%** of our energy needs.

How nuclear fission works:

Within the reactor, a rod will be lowered and a neutron will be fired at it. When an atom of nuclear fuel (uranium in this case) absorbs the neutron, the uranium will fission into two smaller atoms (waste) and release one, two or three neutrons. The kinetic energy of the waste products is then used to heat the water for the steam turbine which turns and is where the energy is harvested. The neutrons are used to fission the next lot of uranium atoms and the process continues.



<u>Managing the negative view of nuclear power:</u>

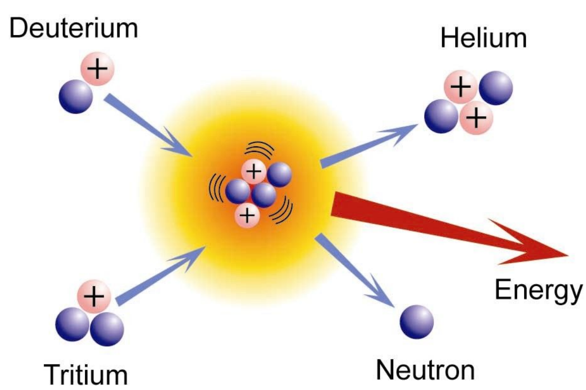
Nuclear energy is the energy source most distrusted by the population, and this is no surprise. Accidents such as Chernobyl and Fukushima are extremely worrying and have turned many against nuclear fission generated electricity. However, it could also be argued that this type of energy, while concerning, is actually less deadly than other sources. Accidents with oil spills or gas tanks exploding are much more common and have caused many more sudden deaths than well controlled nuclear plants. Of course we do not intend to build a nuclear plant right in the middle of the city. It would have to be on the coast for water cooling and as secluded as possible. Areas with non-practicable beaches and low population density would be favored in choosing a location for our plant.

How we will manage nuclear waste:

Another downside to the fission energy is the need to dispose of the nuclear waste produced. This nuclear waste tends to be radioactive for centuries after being used and as a result we would need a solid plan to take care of the waste we accumulate as we produce energy. One of the easier ways to solve this problem is recycling and underground long term storage like the French system. This way of working would be useful for us as it seems to be the most efficient and is less expensive than other ways to secure the radioactive material. We could therefore create a deep underwater storage facility in the English Channel where both recycling of the used rods and their ultimate radioactive decay can take place.

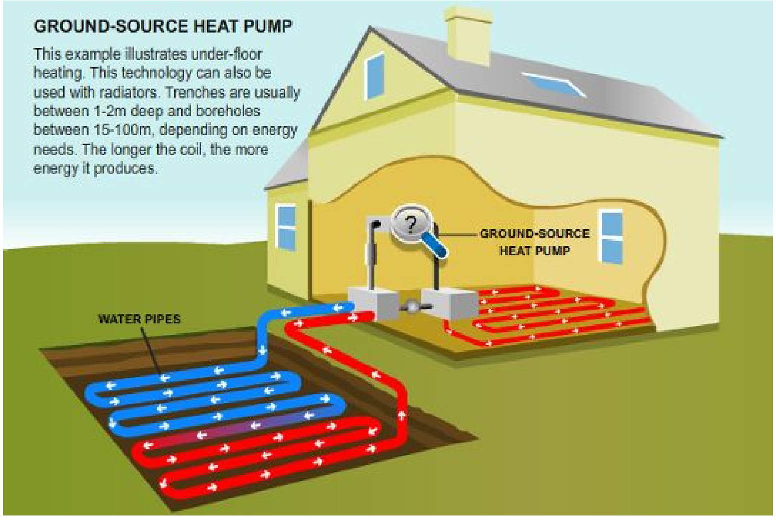
Nuclear and looking forwards:

We do not believe nuclear fission as a long term energy source is a good thing and as a result we plan to slowly reduce our consumption of fission energy after 20 years of Solent City. We will slowly decommission the reactors as technology for other sources improves. We would also look very closely at nuclear fusion, an alternative way of producing a lot of energy but with lower risks, this time fusing isotopes of hydrogen found in sea water. This type of technology will only be available after 2050 so for now, it seems fission is our only hope of providing a stable base load in terms of clean energy.



Ground Source Heating:

Ground source heating is a technology which is able to capture heat from the earth. This is achieved via the use of pipes filled with refrigerant and water which are pumped from hot soil underground to a cold home. This technology also works in reverse in summer as heat can be transferred back into the soil. This type of heat collection allows for a reduction in the demand for energy as there only needs to be a single pump for the whole home to be heated, cooled and maintained at a comfortable temperature. Ground source heating is at the moment used by countries like Canada and Russia where small volcanic activity is enough to increase ten-fold the efficiency of their pumping. Sadly, in the Solent we do not have high volcanic activity so our pumping system will be less efficient. However, that being said, ground source heat can help lower the need for domestic electricity as people are able to produce 60% of what they need. The fact that the heat pump can work at all times provides a backup if the renewable energies such as sun or wind are not producing anything on a cloudy and non-windy day.



Power output:

Ground source pumps will be fitted in every new home, where appropriate, as well as in any type of work sectors, including offices, shops or industry. We have calculated that if our need for heat consumption went down in each of these areas, we could have 30% of our energy produced from the ground. However, taking into account the energy need for pumping which would be considerable over such a large scale, we end up with having our ground source heating accounting for **26%** of the overall energy produced.

Managing our heat reserves:

One of the only problems of ground source heating in a non-volcanic area is that the ground has to be "re-fed" with heat as it would not be possible to pump heat out winter after winter. Multiple solutions have been trialled in Sweden such as the 2,1 year system or the summer heat re-feeding. The 2,1 year system describes how for two winters in a row heat will be pumped but the next one will be left out in order to allow the ground to recover. For our purposes it seems that heat re-feeding is the best option. While the heat pumps will need to be a little more expensive, it is greatly outweighed by the gain of being able to heat every winter and cool every summer.

The future of ground source heating:

Ground source heating technology does not seem to have much more to offer us. Of course better conductors and more efficient pumps would be beneficial but it cannot be further expanded. As a result our plan is to keep this type of technology between our 20-30% mark for the next few decades. We will within this time period be able to produce much more energy from our other green sources and this technology was never intended to support our full energy infrastructure but serve as a supplement to the base load already provided by the nuclear reactors.

Energy demand and management:

Energy demand and management is the most crucial part of the energy sector as it controls when our sources need to be turned on and how much storage we would need for the whole year.

Change during different times:

The first factor to take into account is that energy usage from 0:00 - 4:00 is quite stable at around 50% of total maximum energy consumed; this is due to the fact most people are sleeping. During this time, with only two nuclear reactors running and the ground source heating it would be enough to provide for everyone, however we would be doing much more than this as we could store the energy produced during the night for the day.
It’s also important to consider that energy usage increases gradually from 4:00 to 8:00 to reach 80% of our maximum consumption during the day. Over this time, our solar panels will not be as useful due to the low light levels and occasional fog, however the wind power can start to pick up. At this point, especially in winter, it might be useful to draw energy from our storage.
From 8:00 - 18:00 energy demand levels remain at a constant 70% of the maximum with a slight peak at midday. During this time period it would be wise to have maximum production as it is possible that electric cars will need recharging further increasing our energy needs. This period is going to be particularly hard to manage in the winter when our energy use is 36% higher than in summer. In this aspect, for each £1 million we would spend on insulating, we would save at least £1.4 million in having to create more energy storage and production for the whole winter.
The last factor to take into account is the small climb at 19:00 to 20:00 where energy usage is at the maximum, from our calculations, it would simply be impossible to provide enough from our renewable sources and this is where energy storage is critical which is why our battery equipment is crucial. The demand slowly drops down after 20:00 to reach our 50% at 00:00.

Energy storage plans:

For our energy storage we are going to have two systems working in parallel. One system is going to be a classical centralised battery and the other is going to rely on our fleet of electric cars. For our centralised system we would plan on having two 100MW battery farms like the one Elon Musk recently built in under 100 days in the south of Australia. This battery would be for longer term storage such as preparing for winter. Our other energy storage will be based upon our fleet of electric cars. Using batteries such as the one Toshiba recently announced, the cars would become virtual batteries, charging and discharging to give power to places when and when it is needed. More on them will be said in the transport section.

Cost and Implementation:

Cost of building:

Our nuclear plant with three reactors is an expensive investment but is relatively cheap to run as long as there is an easy way to dispose of the waste. For our nuclear plant we would be looking at about £6.5bn[9]. For our solar energy, if we take into account the fact that some individual people might want to invest themselves in producing their energy (25% of total population), we would have to buy £4.6bn worth of solar panels. Our wind power with 400 onshore wind turbines will be cheaper than the rest as a 100kW onshore wind turbine only costs about £500,000 which would give us a total of £0.2bn. The offshore floating turbines have no exact pricing, but assuming they have the same type of materials as a ground turbine, but with the modifications for outer sea floating and the cable extensions to the coast we could be looking at £800,000 per unit. As a result our 500 turbines would cost us £0.4bn giving a total of £0.6bn for wind. This makes wind power extremely cost efficient and is the reason why we plan to have so many more in the future. The cost of our ground source heating can be estimated to be £13,000 to install[10] and as a result would be just under £10bn to have the whole population covered.

Overall we will need a total of **£21.68bn** to set up our energy sources.

Costs of running:

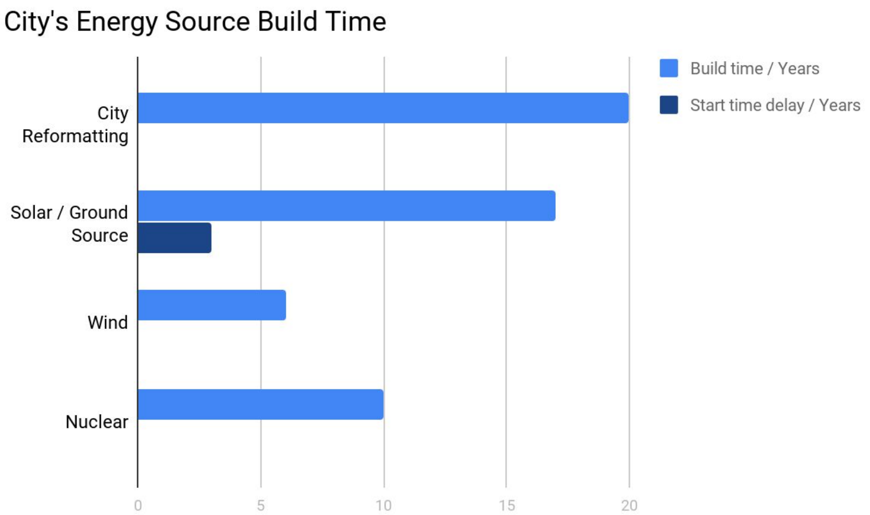
For our type of nuclear plant the best option is to refuel every 18 months costing about £40M. This means that the annual cost will be a little over £26M. If we include the fact that the nuclear waste needs to be stored, (digging the tunnel approx £1bn) over the lifetime of the plant the cost per

[9] https://www.ucsusa.org/nuclear-power/cost-nuclear-power#.Wn62CZ5l-to
[10] https://www.cse.org.uk/advice/renewable-energy/ground-source-heat-pumps

year increases to £46M. For wind turbines, it seems that there needs to be at least twice as much maintenance for those offshore than for those onshore. With the price of running a single 100kW onshore wind turbine being at about 40% of original price over the lifetime of the wind turbine, it would cost £240M to run our 400 onshore and 500 offshore farms. The cost of maintenance and operation for our solar panels would come close to £150 per unit per year and as a result, it would cost us close to £130M to be able to run them perfectly. The ground source heating, with a price of £655 per unit [11], would be approximately £500M per year to fully function both in winter heating and summer cooling.

As a result the running costs of the energy sector is a total of **£916M** per year.

Implementation and building times:



During the 20 years we have given ourselves to reform the city as we would like, we would need 6 years to have the wind industry fully running and 10 years for the nuclear to be operational. As the solar panels and ground source pumping will be fitted within homes, it seems natural that the time it takes for them to be finished is the same as the time for the whole city to be rebuilt. There is a 3 year delay created by the time needed to have space made for the first houses built by regenerating brownfield sites.

[11] https://www.cse.org.uk/advice/renewable-energy/ground-source-heat-pumps

Transport overview

Solent City will rely on four main transportation solutions.
These are:

1. Autonomous BEV network (Battery Electric Vehicle)
2. Solent Line high speed trains
3. Small scale free to use bus routes
4. Bike rental

The main challenges that we encountered when considering the transport of the city was how to integrate a large scale transport network that would be accepted by everyone, whilst also ensuring that our transport was cheap, implementable and available in ten years time. For this we balanced more ambitious schemes, such as our 75,000 strong AI car fleet eliminating all traffic, with pre-existing transport solutions, such as electric buses and bike rentals. By doing this we created a transport network whereby nobody owns a mode of personal transportation, rather everything is rented from the city. We believed that this would be the future of large scale city movement, as the age of internal combustion is coming to a close, to be replaced by autonomous vehicles. Hopefully this 'revolution in transport' that we predict will happen sooner rather than later, so that a zero emission city will be possible in the next 10 years.

The BEV Fleet:

The BEV fleet (standing for Battery Electric Vehicle) is our concept for primary transportation across the Solent city. These AI cars would be completely driverless and operate on an Uber-like app system, whereby nobody would own a car, rather a car would come to you.

This would significantly reduce traffic and the emissions from our city, as direct CO_2 emissions from vehicles would be zero. Moreover there are options for expansion into shared rides, following a similar structure to Uberpool, where for a reduced rate one can share their car with another person. Driverless buses could also be introduced into this system, further reducing the number of BEVs required and further integrating a low emission policy into the city.

Challenges that arose from the investigation into the BEV's was the number required that would simultaneously ensure that there would never be a shortage of BEVs whilst also creating the minimum number of idle BEVs, that were not doing anything. Moreover problems arose from the implementation and housing of the BEV's. Overall however, despite some problems, the BEVs remained the most viable zero emissions transport system available to us.

How many BEV's would be required?

For the number of BEVs required, we chose to use statistics from London.[12] We chose these statistics as London has a similar population density and similar levels of public transportation use.

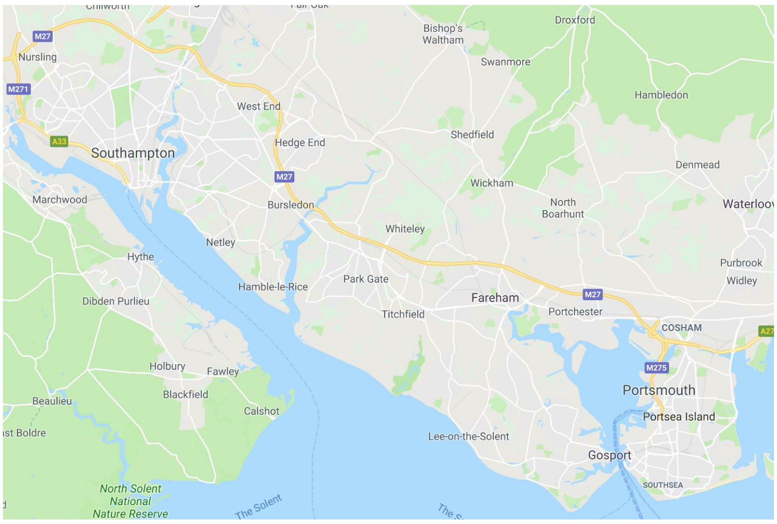
Firstly we would need the number of car journeys that are made on average in peak times - in London people make 6 million car trips on an average day - 20% of these are for work, with the rest being leisure or other. 60% of car trips are made alone, whilst the rest have passengers, and 60% of car trips are used for leisure, commerce and personal business according to the study. If we multiply the number of theoretical trips needed by 0.5, representing the max number of trips needed at one time with some leeway, we can calculate that 600,000 BEVs would be needed, as a theoretical maximum.

This is a very large fleet of cars, that would very possibly result in thousands of cars at a time being idle, without passengers. We wanted the maximum efficiency for the BEVs where ideally less than 10% were not on the roads at a time. This is possible through the emerging technologies of Toshiba - a new electric car battery that lasts for 200 miles, charging in just 6 minutes which

[12] http://content.tfl.gov.uk/technical-note-12-how-many-cars-are-there-in-london.pdf

would be commercially available in 2019.[13] This technology is possible due to a new anode material in the battery - titanium niobium oxide which retains 90% of its energy capacity after 5000 charge cycles making it perfect for the taxi service we have envisaged.

This means that we could significantly reduce the number of BEVs required. If we expect 600,000 car trips in the rush hour zones (6-10 am and 4-8 pm), which are the busiest times of the day, and the greatest distance covered in Solent City taking 30 mins (found using the rush hour travel times from Portsmouth to Southampton) we can multiply 600,000 by 30/240 giving us only 75,000 BEV's. This is closer to our ideal number, as only one BEV would provide transportation for 27 people in the city. Moreover even this number has a lot of leeway for fluctuation, as with AI technology congestion will be decreased greatly, thus the average rush hour travel times would decrease. With no congestion and an average assumed road speed limit of 60 mph, the time taken to travel the distance from Portsmouth to Southampton (23 miles), would only be 23 minutes. This would decrease the number of BEV's required to only **57,500**, or 35 people to one BEV.



13 https://www.toshiba.co.jp/about/press/2017_10/pr0301.htm

How much energy is needed for the BEVs

The problem with using the quick charge is that, whilst it is of paramount importance to the efficiency of the city, it requires large amounts of power to charge a car battery that quickly. Toshiba have not yet published how much power would be required to charge their battery, so we used statistics from the Tesla model S, which had a comparable range and charge time. [14]

The number of charges per BEV could therefore be calculated by using the average miles driven per person, multiplied by the number of people to a BEV. In London 2015, according to the publication listed above, the average person drove 4,200 miles. 4,200 miles average driven in 2015, multiplied by 27 as roughly 27 people per BEV equals 112,500 miles driven per BEV.

This requires 563 charges per year per BEV if each battery holds 200 miles of charge. We can subsequently multiply the number of charges (563) with the energy needed (85 kWh) and the overall number of BEV's (57,500) this gives a value of 3,589,125,000 kWh per year. Fortunately this is less than three times the allowance for transport given by the energy team, thus more energy can be used to fuel the city.

We also would like to use the BEVs as a portable battery storage system. If each BEV holds 85 kWh of energy, then our fleet of fully charged BEVs would have the capability of putting 6,400,000 kWh of energy back into the grid. This is useful for us as the times when a city needs the most energy is in

[14] https://www.tesla.com/en_GB/models

the evening on a cold winter day. This corresponds with almost minimum car usage, thus the BEV's could be efficiently used to restore energy to the grid. Certainly it is true that the BEV usage would increase during the day if it was cold, however this would only have a significant impact on the overall energy of the day, allowing the BEVs to account for sporadic spikes in the energy usage throughout the day. Moreover the BEV usage would realistically decrease significantly during the summer, thus the BEVs could even be used to charge the large batteries that we would need to help power the city.

Overall the energy statistics for the BEVs make them clearly the most sensible choice of transport in order to maintain a zero emission city. This coupled with the convenience of the AI technology made the BEVs the most logical way of powering a modern city with upcoming technology, which would easily be attainable within the next 10 years.

Cost and Implementation of the BEVs

According to a recent study[15], automotive forecasts say that the price for the self-driving technology will add between £5,000 and £7,200 to a car's price in 2025. The cost of the electric vehicles themselves would be closer to £17,800. [16] This means the overall cost of our cars would be £120,230,000, plus additional charging costs as mentioned in the energy section.

This would not be the only cost of the project however, as charging stations capable of housing the BEVs when they are idle would also need to be built. If roughly 14% of BEVs need to be charging at any one point, then we need to have the capability to charge 7,500 BEVs at any one moment. This would be split up into two warehouses away from the city that could hold 2,500 BEVs each, with 250 ten BEV stations across the city.

As we used the Toshiba batteries whether the BEVs were charging or putting power into the grid, this would be sufficient for the number of BEVs on the road. If an average two car garage needs to be 45 m² [17] then our warehouses would need to be 562,500 m², or 750 m by 750 m. This would cost approximately £1,430,000 to build both[18] whilst the 250 BEV stations would cost approximately £71,580, as both are very simple building structures.

This brings the overall cost of the BEV fleet at £124 million which, considering what the BEVs bring to the city in terms of transport capabilities is reasonably cheap. The implementation of this scheme is again fairly

[15] http://www.ihssupplierinsight.com/_assets/sampledownloads/auto-tech-report-emerging-tech-autonomous-car-2013-sample_1404310053.pdf

[16] https://www.parkers.co.uk/best-cars/best-cheap-electric-cars/

[17] http://2-car-garage.coolhouseplans.com

[18] https://www.buildingsguide.com/blog/planning-steel-warehouse-building/

straightforward, as the structures would be built into the infrastructure of the new city.

This once again can bring us to the conclusion that the BEV fleet is the most efficient way of transporting people across the city, as it is simultaneously low energy, cheap and convenient. We hope that in 10 years time public opinion towards AI vehicles would have improved dramatically, so that our BEV fleet would be integrated into a modern community as easily as possible. This depends on how the next 10 years play out, with the opening few years of AI vehicle integration being crucial as people are far more likely to forgive an accident on the 1,000th day of having AI cars on the road, as opposed to the first. Overall it appears as though the general population is moving towards the idea of AI car integration, with giants of the tech industry all involved in this technology, it is hard to see a future where driverless vehicles do not dominate the roads, making them the perfect choice for our primary transportation scheme.

Rail Transport within Solent City:

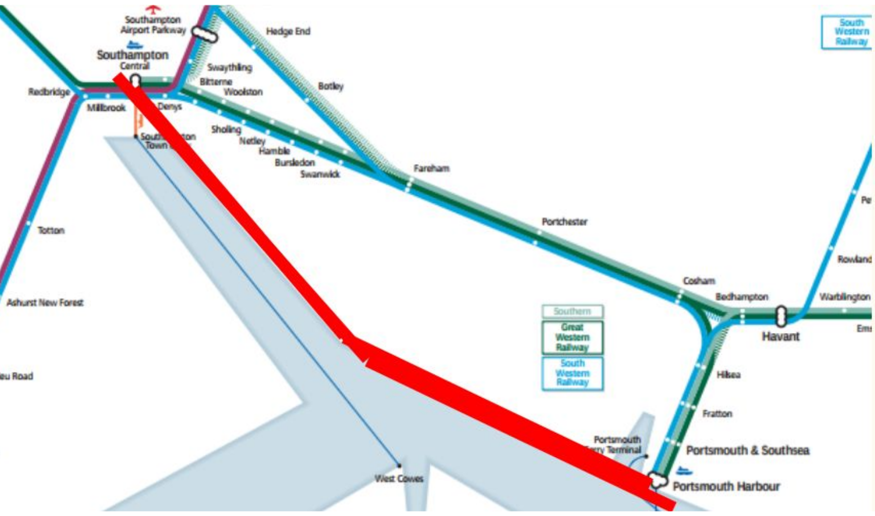
Alongside the BEV fleet in the city, public transport will be a crucial ingredient in making the city run smoothly. This will include trains, light rail and bikes; although predominantly light rail systems, as these are already incorporated successfully into cities in 2018.

"An advanced city is not one where even the poor use cars, but where even the rich use public transportation."

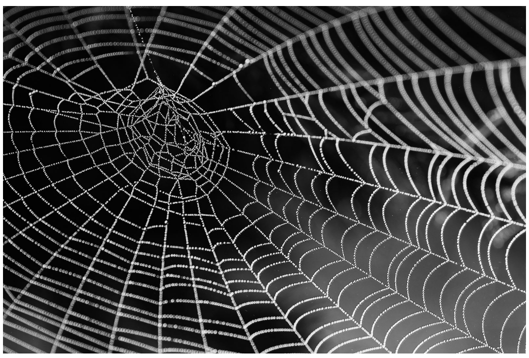
The SolentLine

With looking at the geography of the Solent City area, we decided that it makes sense to build a circle line around the perimeter of the city.
We plan on a circle line transport link that is both efficient and easy to travel around the city. Our criteria were as follows:

- The line must be cheap for the users
- There must be regular stops
- The line must connect with existing transport terminals and hubs in order for fast journeys within the city and the UK
    - Trains leave every half hour from Southampton Central Station at peak times headed to London
    - It should additionally connect with much smaller scale transport infrastructure



Here is the existing rail network that runs along the northern bound of Solent City. The highlighted red section is the planned route for new electric rail lines that run not far from the coast. This comes at quite a cost for the city (this is discussed in the cost and implementation section of the transport section.) Thankfully, the section of new track is only 20 Km in length. We estimate the cost of this new track will be £50.2 million.



"Spider Webbing" and small scale bus routes:
Team Millet plan for a complex tram/bus network to interconnect the areas of the city that are more isolated from larger stations. The population density

of Solent City will sit at a figure similar to that of London's[19]. The majority of people will live a fair distance from the periphery of the city.
The spider's web analogy helps to understand our plans for the public transport network.

- At each SolentLine station on the periphery of the city, there will be a bus/occasionally tram line that runs into one large hub station in the centre of Solent City placed in the existing settlement of Park Gate. (Photo is of an example of part of the existing industrial site in Park gate)

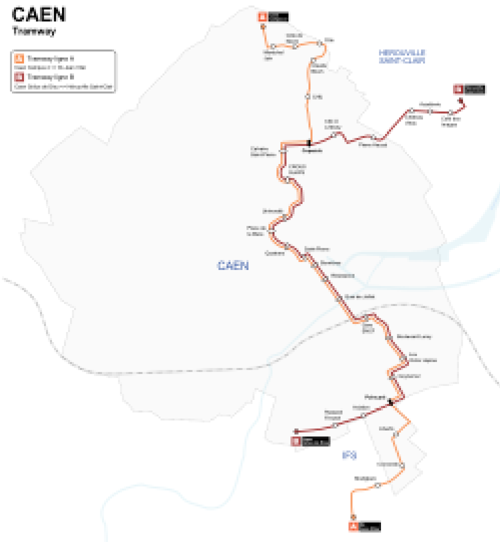
- The lines that run from the periphery into the centre at Park Gate will be much slower than the SolentLine and almost exclusively bus routes
- These services running into the centre will be free to use for only the citizens of Solent City and provide a good alternative for those who don't want to use the BEV system
- Seeing as we will be running the BEV fleet at cost, we understand that those who are in a weaker financial situation will favour using this service. This also means the load of carrying passengers shorter distances will be spread between the BEV fleet and the bus services.

[19] According to the 2001 Census

Details of the SolentLine and buses

Trains

Currently, technology for 2-in-1 electric buses and trams isn't incredibly well developed. However, the city of Caen in France leads the way with this sort of public transport. Their system of the "Caen Guided Light Transit[20]" is similar to what we would like to implement in Solent City. Alternatively to having overhead wires throughout the city however, we would like to build our buses with lithium-ion batteries that means they can avoid damage to the environment as well.



Lithium-ion operated battery buses are already in use all over the world. It is less common for buses to be running on 100% electric without a petrol/diesel generator in 2018. However in 10 years time and by the end of the completion of Solent City, the technology will be available at a significantly cheaper rate than it currently is. In addition - we wanted to implement the same technology as is used in our BEV fleet in the buses. They shouldn't need a driver although we plan on having one member of staff aboard each bus at all times, to ensure smooth running of the service.[21] Eventually this will be able to be phased out however with consequent reduced running costs. The vehicle design would come from Mercedes-Benz, who are creating a market-leading design of self-driving

[20] https://www.twisto.fr/
[21] http://www.bbc.co.uk/news/business-42090987

buses[22]. The advantage of an electric bus comes with the large immediate torque that can be provided with the engine. Current diesel engines are very slow to build up speed and use a lot of fuel when using a lot of engine power. The efficiency that is gained from electric engines is therefore significant. Between 59–62% of the electrical energy from the battery is converted to power at the wheels. Conventional internal combustion vehicles only convert about 17%–21% of the energy stored in the bond enthalpy of the fuel to power at the wheels[23].

Cost and implementation

Since there will be 8 bus routes running in towards the centre, we will need 18 buses to run on them - allowing for the spare buses that may be required to cover any breakdowns. In the time scale of the Solent City construction, the price of an autonomous bus will be £200,000[24]. This gives a cost for the buses alone of £3.6 million. Including an estimated £50,000 for setup costs - the bus network would be £3.65 million. However, the fact that we are using cheaply available green energy means that the buses will pay for themselves in fuel savings in around two years (presuming each bus drives on average 100 miles a day. In reality we think that most buses should be able to do 200 miles in a day.) In terms of costly changes that would need to be made to the existing city - there are very few. The buses would share the roads with the BEVs and would be able to drive at quite a speed while cruising.

Bikes

22 https://www.daimler.com/innovation/autonomous-driving/future-bus.html
23 https://www.fueleconomy.gov/feg/evtech.shtml
24 https://www.mercedes-benz.co.uk/content/unitedkingdom/mpc/mpc_unitedkingdom_website/en/home_mpc/bus/home/new_buses/models/regular_service_busses/citaro_hybrid/facts/economy/tco.html

Recently, in many trendy cities in developed countries, including the UK, bike sharing apps have allowed those living in a city to travel by bike around the city at a very low cost.

Pony Bikes, the scheme in the Oxford area, works as follows[25]:

1. **Find it:** The rider wants to make a journey by bike and so opens up a smartphone app that tells them the nearest location of available bike
2. **Unlock it:** Using a Bluetooth® connection, the rider approaches the bike and unlocks it through the phone. The bikes are left out in public, in areas where they are neither obtrusive nor completely out of sight to other future riders.
3. **Ride it:** Then, the rider takes the bike to wherever they wish to go within the city (it is forbidden to take the bike out of the city.)
4. **Leave it:** After the ride, the rider simply presses the lock button on the bike and acknowledges that the ride has finished on their phone. The bike can be left anywhere within the city which gives them an advantage over traditional bikes like London's so-called "Boris-Bikes"

Bikes within Solent City

[25] http://getapony.com/

Within the context of Solent City, the bikes will be an excellent "Final mile vehicle." Final mile transportation is an issue that has troubled property developers for a long time. Despite the speed and efficiency of a transport network, there will always be a final mile of travel that needs to be completed between the final destination and the station of arrival. For people in Solent City, this final mile of commute will normally be between their place of work and the large train stations, or alternatively, between their home and nearest light rail station. Although the light rail network is versatile - there is no reason why citizens wouldn't be able to complete their whole commute by bicycle - it could take a lot of stress away from the BEV network.

Cost for the users

Most of the current bike rental systems charge the customer per time used on the bike, rather than per distance travelled. A standard rate is 50 pence per half hour of travel.

For Solent City, the standard rate will be 37 pence per half hour.

For the average commuter, there will be 2 final mile journeys per day, each of a length of 1.12 km, totalling 2.24 km of cycling per day. For the average commuter on a bike, this equates to around 9 minutes of cycling per day. This is a total of 11.1 pence per day per commuter. For 260 working days in a year - this works out as £28.86 per year. For the commuters who use the bikes, this seems like a small price to pay - bearing in mind that many more times this amount would be spent on petrol for a conventional type commuter. The payment account for the bike system can be linked to a credit card and making payments would be automatic and easy after a short initial setup. We expect that people will prefer to use the bikes instead of the small scale bus networks and SolentLine if they are travelling a smaller distance and they want to save time - the bikes can travel almost as the crow flies - unlike other journeys by public transportation that may require travellers to go out to the periphery of the city and back in towards the centre after having caught a train.

Cost and implementation of the bikes

The bikes themselves can be manufactured and maintained at a relatively low price. Notoriously, the rental bikes that were put into place in London are very expensive to maintain due to the bike docks.

Each bike when bought in bulk would be available to us at £108[26]. Allowing for 1 bike per 20 people, the cost will be £10.8 million. With this cost, the price of setting up the software for the app and regulating the bike system once it is in place will be almost negligible. The bikes will eventually pay for themselves, with each one making £0.96 a day through rental costs. They will pay for themselves in 112 days and eventually start making a profit from where they will be able to contribute towards improvements for the city. Some of this profit will also be needed in order to keep up the maintenance of the bikes (spare parts etc.) Any person who fails to return the bicycle within 24 hours or causes damages to it at their own fault will be obliged to pay for the damages.

[26] http://www.bbc.co.uk/news/business-40351409

Commercial Air Travel

In Solent City, there are two major airports that are open to commercial use: Southampton Airport and Solent Airport (formerly Daedalus Airport).

Southampton airport is the larger of the two and has an average of 41,000[27] flights per year over the past 6 years, whilst Solent Airport deals mostly with military flights and private air travel, although it is becoming more open to commercial use in the form of 20 seater passenger planes[28].

To complete our task of making Solent City carbon neutral, we need to significantly reduce the carbon emissions. There are two major roads that you can go down when trying to reduce the carbon emissions of aircraft: electricity or biofuels. According to Boeing, electric hybrid short range aircraft won't be available until 2030[29], which puts them out of our 10-year

[27] http://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/

[28] http://www.dailyecho.co.uk/news/15529311.Plans_unveiled_to_offer_commercial_flights_from_airport_near_Fareham/

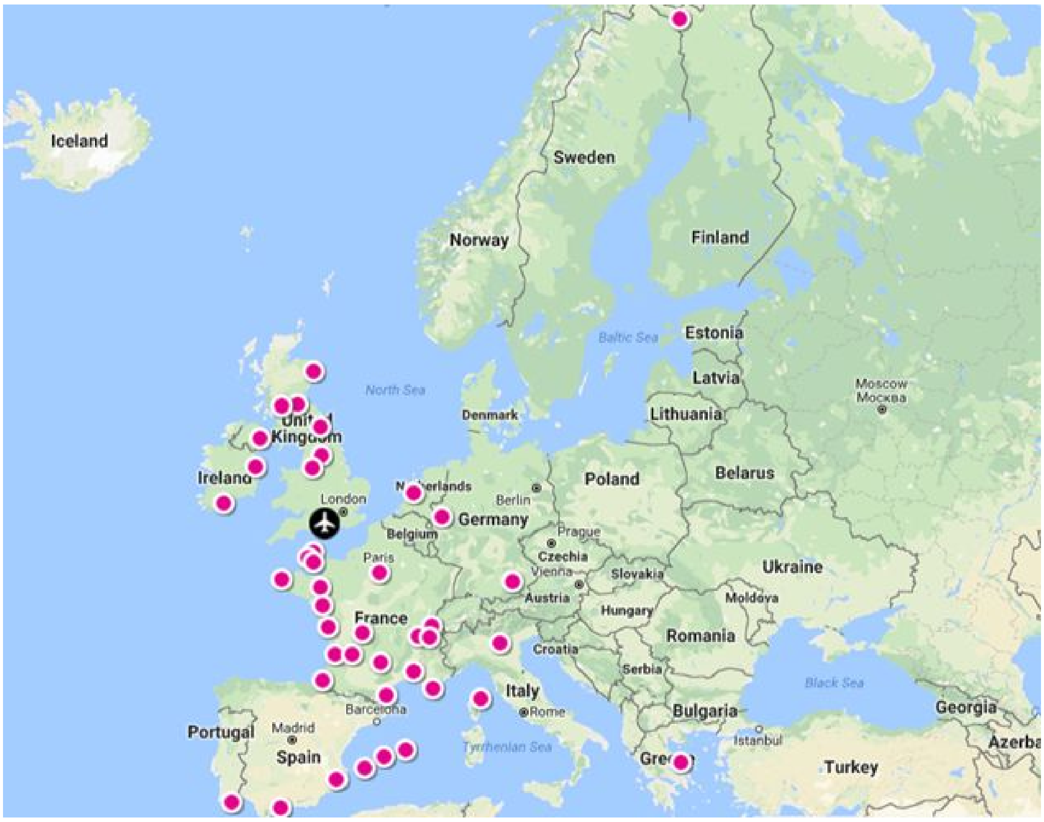
[29] http://www.boeing.com/resources/boeingdotcom/principles/environment/pdf/Backgrounder_Boeing_biofuel.pdf

time frame. This means that we will have to focus on using biofuels instead of electric hybrids.

The development of effective biofuels is a major area of interest for air travel companies, meaning that we can expect to see more effective forms of biofuel being produced during the next two years. The current best biofuel is hydrogen esters and fatty acids (HEFA) and is the best alternative to jet fuel. The White Paper on internationally compatible biofuel standards is an agreement between the Brazilian government, the EU, and the USA to increase use of biofuels to 40% by 2050[30]. Alongside this, the International Air Transport Association has set a 1.5% annual improvement in fuel efficiency until 2020 and carbon neutral growth to a 50% reduction in carbon emissions by 2050[31].

Air travel makes up for around 2% of global CO_2[32] emissions, which is why there is massive research into the use of biofuels for use as aircraft fuel. The most promising biofuels at the moment are Hydrogen Esters and Fatty Acids (HEFA). A biofuel mixed with regular aircraft fuel has been shown to reduce CO_2 emissions from aircraft by 50-70%[33]. However, as biofuel is biodegradable, it will slowly degrade whilst in the fuel tank. This is increased when exposed to light. This means that it is unsuitable for long distance air travel.

[30] https://www.astm.org/COMMIT/D02_InternationallyCompatibleBiofuelStandards(3).pdf
[31] http://www.iata.org/whatwedo/environment/Pages/index.aspx
[32] https://www.theguardian.com/environment/2010/apr/06/aviation-q-and-a
[33] https://www.flyingmag.com/nasa-confirms-biofuels-reduce-jet-emissions



Luckily, all the air travel from Southampton Airport goes to European destinations[34] (see picture above), meaning that large scale use of biofuel for aircraft in Southampton Airport is feasible as the effect of degradation won't have much of an impact.

We will also implement a plan where aircraft taking off maintain a maximum cruising altitude of 500m until they are outside of the city limits. This will greatly reduce the pollution levels of the city as taking off and climbing to cruising altitude uses up around 25%[35] of an aircraft's total fuel used during a flight due to the high forces required for acceleration.

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[34] https://www.southamptonairport.com/destinations/
[35] http://www.worldwatch.org/planes-utilize-most-fuel-during-takeoff

Emergency Services Air Transport

Other than commercial flights, the main use of aircraft is for the use of emergency services. This includes police helicopters and air ambulances.

The Hampshire and Isle of Wight Air Ambulance is the only air ambulance service in Solent City and they use the Eurocopter EC135. There are already uses of biofuels in helicopters, for example in the Royal Netherlands Air Force tested a Boeing Apache AH-64D using 50% biofuel[36]. Therefore, it would be easy for us to implement the usage of biofuels into the air ambulance. We have decided not to use an electric helicopter as the cost is

36 https://www.treehugger.com/renewable-energy/first-biofuel-powered-helicopter-flight-made-by-royal-netherlands-air-force.html

considerable, due to the technology being fairly new. An electric helicopter would not be suitable for an air ambulance as the recharge time is too great and it would not be able to handle two emergencies back to back.

The Southampton Coast Guard have two AgustaWestland AW189 helicopters[37] in service, which they recently acquired last year. As with the air ambulance, we have decided it would be best to stick with biofuel, again because of the faster refuelling times and because of the longer flight times.

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37 http://www.dailyecho.co.uk/news/15195915.New___20million_helicopters_for_coastguard/

The police helicopter used in Hampshire is an Airbus EC135, which is actually based in Bournemouth but assists the Hampshire police force. It is a manned aircraft that uses fossil fuel based aircraft fuels. It is used mostly for surveillance in situations such as car chases and finding suspects.

Instead of these helicopters, we would use small police drones (already in use in Devon, Cornwall, and Dorset[38]) for slower speed uses such as finding missing persons and chasing suspects. These drones are much easier and cheaper to use than police helicopters, and allow police to get a birds eye view of more situations, even for smaller operations such as crowd control, where the police helicopter wouldn't normally be used. We would still keep the police helicopter, but we would use it rarely and with biofuel.

Cost and implementation

Very few costly changes would be needed to made to the current set up in order for the plan to implemented. We have allowed a budget of £9 million to allow for the increase in use of biofuel infrastructure.

[38] http://www.bbc.co.uk/news/uk-england-devon-40595540

Conclusion

Total initial cost:

Initial set up	Costs
Energy	**£21.68 billion**
Bus routes	**£3.65 million**
BEV	**£122.4 million**
SolentLine	**£50.2 million**
Bikes	**£10.8 million**
Aviation	**£9 million**
Transport	**£196.05 million**
Total costs	**£21.876 billion or £21876000000**

The challenge of planning the construction of Solent City has come from the numerous factors that need to be considered. While sourcing our energy to power the large population, we made the decision to use nuclear energy. Currently in the UK nuclear fission energy is not on the forefront of innovation and has a negative image in the public. We hope that Solent City could prove that nuclear energy can be used as a strong base load in a city. We have also turned to the natural resources that are gifted to the Solent City airport within Hampshire. Since 1180[39], Portsmouth's wind has been used for sailing boats and it seems fitting for the area that its wind power will be able to used to keep the thriving city alive. Nowadays, the economy of the area is very different and relies much more heavily on tertiary industry which really puts a demand on the power usage too. The transport challenges were less significant, meaning our transport system should come out as a very slick system and significantly improve the efficiency of the economy of the area.

[39] http://www.portsmouth-port.co.uk/shipping/camber-dock

Team Millet - Blott Mathews 2018