Our Vision for a Renewable Solent City

by

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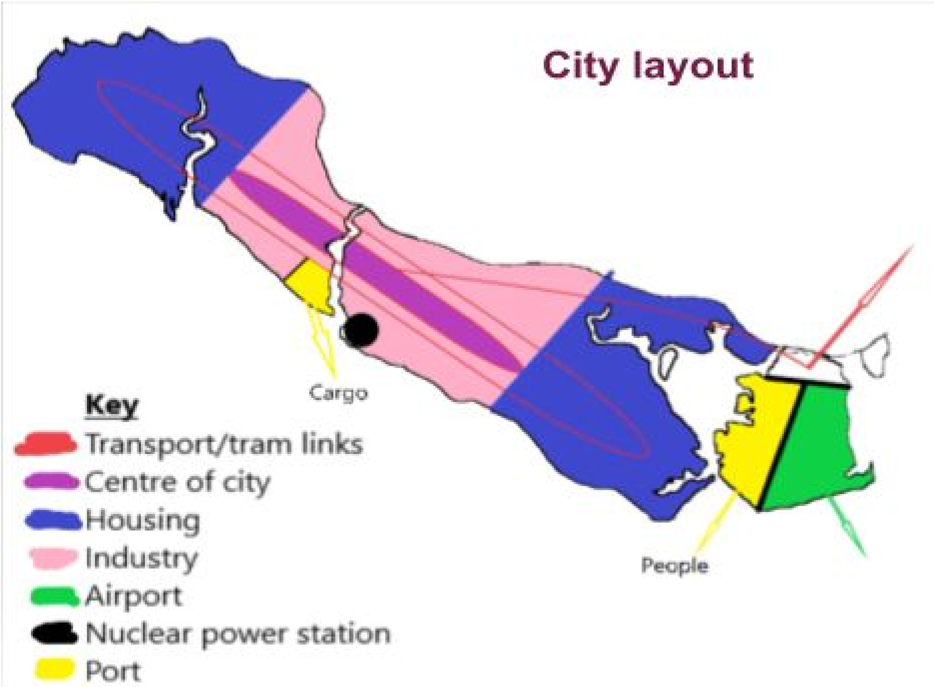
Overview



Our Solent city plans to only incorporate existing technology but in a way that we believe hasn't been done before. The main idea is that there would be efficient transport; meaning no one or no resource must travel any further than it has to. From this we found that if we laid our infrastructure out in concentric loops we could maximise the coverage for the least cost and with the least land used up.

At the centre of our city there will a nuclear power plant to supply the base load of the city's power needs. Although this is technically a renewable power supply, we believe it is the best, most reliable and carbon neutral solution. Closest to the power station will be outer production facilities such as the biogas generator, a power plant powered by sewage, as well as water cleaning plants etc. This is the first major area of our city and is the industrial district where most of the heavy production should take place as it is close to everything the sector requires to operate effectively, including transport such as the docks and trams.

The next key area within the city is the business and commercial district where most of the inhabitants will work and spend their leisure time. There will be supermarkets, shops and a large high street in this area, however most of the land will be designated to high rise offices.

Finally, the outer and largest area will be housing. Some of this housing will be integrated into the outer sections of the industrial areas. This housing will be high rise apartment buildings. The rest of the housing will be terraced. All of the housing in the city will be somewhat self sufficient, using a combination of renewable resources, including solar and wind power, as well having double glazing and cavity wall insulation in every building to improve heating efficiency. Also, in this area there will be the majority of the green space, schooling and other amenities (such as hospitals).

Meeting each major area and all other key points around the city (such as the airport) there will be an electric light rail system that will be capable of transporting all of the city’s population around at a reasonable price due to its efficient, synchronous design. There will be stations placed fairly regularly along the length of the tracks and an oyster card system will be applied so that people can move quickly on and off stations at a relatively cheap fixed rate for the length of their journey. A tram will only stop at a station if someone wants to get off or if someone is on the platform but the tram is not full, meaning that journey times can be made quicker and customer satisfaction is improved.

The tram system will operate using power from the grid, however if there is an issue, each tram is fitted with a back-up hydrogen fuel cell to allow the network to still function if electrical power is lost. The power cables running along the tramlines will also double as the backbone of the high voltage power distribution system. The electrical power will be transmitted at very high voltage and low current across thickened wires to minimise the energy lost due to the heating effects of the current . Then it will be stepped down for commercial or domestic use locally with transformers.

In conclusion, our aim with the Solent city project would be to create an efficient, carbon neutral city which provides maximum satisfaction and affordability for its residents. As well as that, it would lead the way in technological development for future ‘green’ cities.

Energy

Energy Requirement Analysis

(1)Data on energy consumption in the uk in 2015 with all values converted into kWh from ktoe (ktoe-kWh= x 11,630,000):

Final energy consumption in 2015= 1.5983109 x 10^{12} kWh

Transport= 6.374403 x 10^{11} kWh

- 40% of total energy consumption
- 74% road 23% air 1.9% rail 1.2% water
- Road transport= 4.7125923 x 10^{11} kWh
- Air transport= 1.4622399 x 10^{11} kWh
- Rail transport= 1.219987 x 10^{10} kWh
- Water transport= 7.75721 x 10^{9} kWh

Domestic= 4.6081549 x 10^{11} kWh

- 29% of total energy consumption

Industry= 2.7439822 x 10^{11} kWh

- 17% of total energy consumption

Services= 2.2565689 x 10^{11} kWh

- 14% of total energy consumption

Energy calculations for our city:

Population of uk= 65.13 million *(2)*

Total Uk energy/ total Uk population= energy per person= 24540.31783= 24,540 kWh

Total energy for the city= 4.908061 x 10^{10} kWh

Budgets (kWh)(+/-2%):

Domestic- 1.423377 x 10^{10}

Industrial- 8.343704 x 10^{9}

Services- 6.871285 x 10^{9}

Transport- 1.963224 x 10^{10}

Evaluation of Energy Sources

Nuclear fission releases approximately 83.14TJ/kg (23094000kWh/kg) *(3)*. Therefore to produce the total energy needed for the city, 2125 kg of uranium-235 would be required per year.

Solar power is a carbon free, renewables energy resource. A 4kW system of solar panels will provide around 3400 kWh per year *(4)*. This system cost around £6000 *(4)*, with a payback time of 15 years *(4)* and a system life span of 25 years *(4)*.

Wind power could be used to harness the wind across the British Channel and turn it into energy. The cost of a wind farm project is sizeable for the power output it would achieve. A 900 kW turbine costs around £1.4 million to construct and install *(5)*.This form is impractical and many people argue against wind energy as it may be viewed as disturbing the surrounding landscapes and environment.

Tidal power is a good idea due to the fact the city is in a coastal location, meaning any energy produced would have a short transmission distance, reducing loss. An underwater sea turbine typically costs around £3.5 million for 1 MW of power *(6)*, but costs are added due to the need for frequent maintenance.

Geothermal resources can be harnessed to heat water to provide a heating system for local houses Currently, one in Southampton has a 1800 metre deep aquifer *(7)* at a temperature of 76 ºC *(7)* which supplies a total of 70GWh of energy *(8)* in various forms per year. The project in Southampton cost £7 million to develop and saves 12,000 tonnes of carbon emissions per year ***(8)***.

Hydrogen combustion is an efficient way to heat homes as it releases large amounts of energy and it also produces zero carbon emissions. However hydrogen is a dangerous source of energy as it is explosive and hard to contain due to its low density, but as long as a system is properly thought out it can be made moderately safe. With efficient equipment, the electrolysis of water to produce hydrogen and oxygen requires the same amount of energy as is released by the combustion of hydrogen. However, by storing this electricity in a chemical form, no energy is lost through transmission, as would happen with electrical cabling.***(9)***

Energy Supply Strategy

A central nuclear power station, supplying 80% of the energy required for the city will be the main source of power. However, on the outskirts of the city, transmitting electrical energy is inefficient, so buildings will be fitted with solar panel systems to generate the required amount of power.

By situating the nuclear power plant in the centre of the city, maximum distribution efficiency is achieved as all points in the city lie upon its radius (which is the shortest length for power cables to run along). Another key aspect of the nuclear plant will be its adaptability. A future prospect for the generation of electricity in the future will be nuclear fusion. By constructing a large enough facility, capable of housing a fusion reactor when it becomes a viable source of energy, the plant could be easily modified to harness this power. This would theoretically be a great method for energy production as deuterium (one of the molecules required for fusion) is sourced from seawater. With our city being located by the sea, this would give great benefit to a fusion reactor as the costs of transporting the necessary resources would be lower. In addition, seawater can be used to cool the reactor.

For the whole of the city, there will be only one nuclear power plant as this improves the efficiency of the fission reactor; having two smaller reactors is less efficient than one larger reactor.

For the edge of the city, we have selected solar and wind power as major sources of energy production. Solar was chosen due to its lower cost and its potential to be integrated into buildings. Wind was chosen due to its potential to produce larger amounts on energy in comparison to solar.

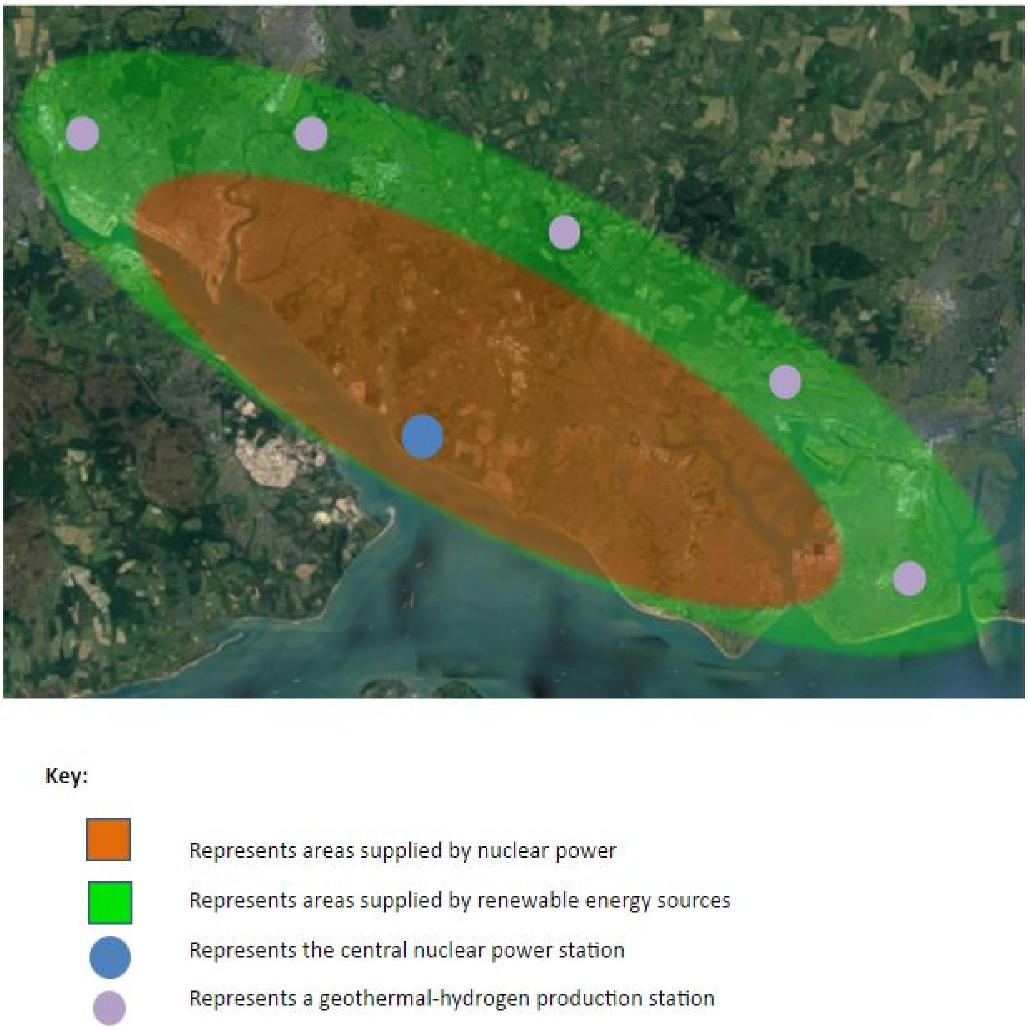
Having said this a large amount of wind power will come from wind farms located of the coast of the city and outside the city.

Also, some turbines can be integrated into the city by placing them in large sewage pipes.The gravitational potential and kinetic energy of the sewage flowing towards treatment works can be used to create a small, constant flow of electricity. This system is similar to hydroelectric power generation. Although the energy produced is not large in quantity, it would be enough to power simple devices. We could also place tidal barrages across areas of water by the city to produce some extra energy.

Not only do houses require a source of electricity, they also require a source of heat. In the city centre, this can come from electric powered heaters, however, in the outskirts, this can be provided by a combination of geothermal and hydrogen combustion.

Using the geothermal energy, hot water can be provided directly to homes or high temperature electrolysis can be completed, improving the efficiency of the process of creating hydrogen gas. The hydrogen produced can be piped to further away homes without losing any energy as it has been stored in the chemical bonds of the hydrogen molecules.

In people’s homes and businesses, hydrogen combustion can occur in specialised boilers and be used to heat buildings with lower cost than using conventional natural gas, which releases carbon emissions.



Energy distribution

A centralised energy supply system produces energy on a large scale, transmitting it across the grid through cables to multitude of users, often far away from the generation plant ***(10)***. These plants can often produce large amounts of energy ***(10)***, however they are less efficient than decentralised systems, which have less energy loss due to the lower transmission distance ***(11)***.

Many centralised plants often produce energy from fossil fuels due to the need for large amounts of energy. This means there tends to be a higher amount of carbon emissions compared to decentralised energy ***(11)***.

A benefit of decentralised energy is that is is on a smaller scale, therefore it can offer greater energy security in the sense that it will not affect large numbers of people ***(12)***. Because of the smaller scale it can also be useful as an emergency supply ***(13)***. For example if there was a natural disaster, such as a flooding, it is more likely that smaller more stable units will be less affected compared to the large power stations, as well as the infrastructure for transmission, simply because they are smaller.

Our main power system (nuclear) will be a centralised one. However the transmission distance is relatively low (having a maximum transmission distance of around 20km) due to the central position of it. Our plan also uses the concept of distributed energy with solar and wind turbines being on or close to buildings.

Energy Supply Technical Solutions

Nuclear

Across the globe there are over 400 nuclear power plants ***(14)***. Using data on each power station ***(15)*** it is possible to work out rough information about the power station we would need to create.

If we were to provide around 100 % of our energy from nuclear power then a nuclear plant similar to Gravelines in france (6th largest nuclear power station in the world ***(16)***). It has a net 5460MW ***(15)***, which would provide about 96.45% of the total. This power station takes up 1.5km^2 ***(16)*** with six 910MW PWR reactors ***(17)***. Based on the cost of The Palo Verde Nuclear Generating Station ***(18)***, this nuclear power station would cost around £13.7 billion.

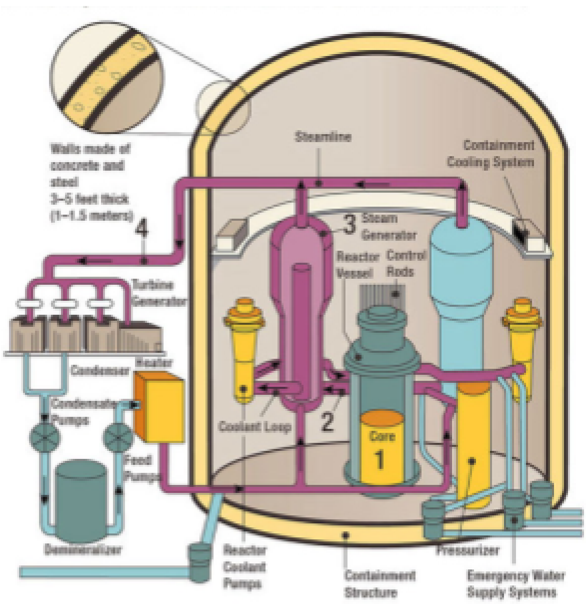
To begin with the aim with nuclear was to produce 70% of the cities total energy needs. This means that it must produce around 34.4 billion kWh per year.

For our nuclear plant to provide 70 % of the total, it would need to have a net capacity of around 3927MW. The Palo Verde Nuclear Generating Station in America has a similar net capacity to this of 3942 MW ***(15)***. This station cost around £9.9 billion ($5.9 billion in 1986 ***(18)(19)***) to build and contains 3 pressurised water reactors (PWR's) each with a capacity of just over 1,300MW ***(20)***.

However once we had looked at the energy output of renewables we decided to go with 80% of our energy being produced, 39.3 billion kWh a year, from nuclear. To provide 80% of the city's energy the nuclear plant should have a net capacity of around 4482MW. The Ōi Nuclear Power Plant in Japan provided a value close to this when it was active of 4494 MW ***(21)***. This power plant took up 1.88km^2 with 4 PWR's each with a capacity of just over 1,170 MW ***(21)***. Based on the cost of The Palo Verde Nuclear Generating Station ***(18)***, this nuclear power station would cost around £11.3 billion. A power plant of this size would produce 3.936744×10^{10}kWh, which would be 80.21% (80.20976104%).

Each one of these power stations uses PWR's to produce energy. They work by heating pressurised water to turn it to steam, which can then be used to turn a turbine to generate electricity.

The pressurised water is pumped in to act as coolant. This water is heated as it travels around the coolant loop. The heat from this loop vaporises water in a second loop inside the steam generator, creating stem, which is directed to turbines to generate electricity by the steam line. If any steam is unused it can be condensed and reused in the steam generator ***(22)*** .



Pressurised water reactor***(22)***

Solar

The aim for solar power production in the city is that each home will be partially self sufficient using solar power to do so. Based on this aim the plan is to coat the roofs/ sides of buildings with panels to produce energy.

To work out how much energy we can produce by placing solar panels on homes, we must first consider how much energy we can get from 1 solar panel, or in this case how much energy can be produced by $1m^2$ of solar panels. To calculate this you need to know the area of the panel, the conversion efficiency and the solar radiation for a specific area at a specific tilt angle ***(23)***. The area of the panel will be $1m^2$. Based on research the most common conversion efficiency of a solar panel is 15% ***(23-27)***. The solar radiation data was taken from the NASA atmospheric science data centre website and was based on the radiation at a specific longitude and latitude***(28)*** (Southampton: Long=-1.404 Lat=50.91***(29)*** Portsmouth: Long=-1.088 Lat=50.82***(30)***).

Southampton	Annual average ($kWh/m^2/day$)
Radiation- tilt 90°	2.47
Radiation- tilt 40.4°	3.64
Portsmouth	Annual average ($kWh/m^2/day$)
Radiation- tilt 90°	2.47
Radiation- tilt 40.2°	3.64
Average	Annual average ($kWh/m^2/day$)
Radiation- tilt 90°	2.47
Radiation- tilt 40.3°	3.64

Data found in table titled- Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface ($kWh/m^2/day$)
Southampton ***(31)*** , **Portsmouth** ***(32)***

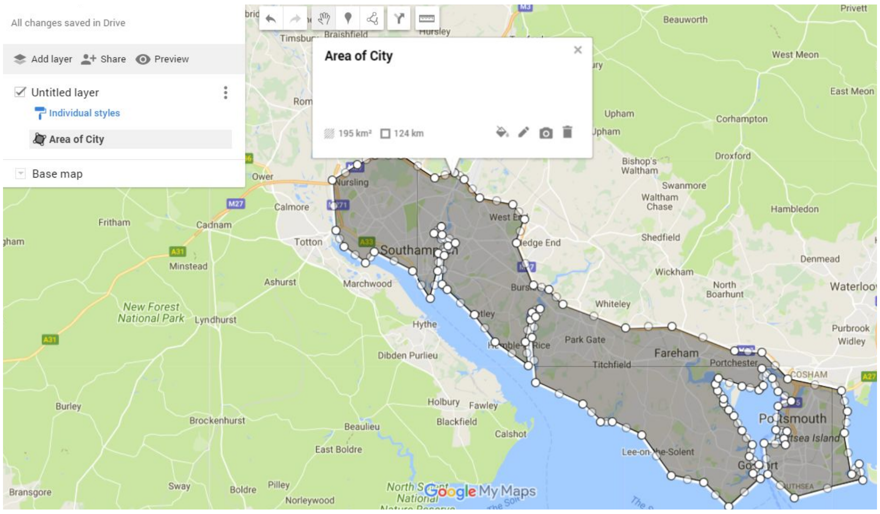
Using this data $1m^2$ of solar panels will produce 0.3705 kWh at a 90° tilt and 0.546 KWh at an optimum tilt of about 40° per day per m^2. Therefore producing 135.2325 kWh at a 90° tilt **(1 x 0.15 x 2.47= 0.3705 x 365= 135.2325)** and 199.29 kWh **(1 x 0.15 x 3.64=0.546 x 365= 199.29)** at an optimum tilt of about 40° per year per m^2.

To work out the amount of energy that can be produced from covering the roofs of these homes with solar panels, the number of homes must first be calculated. To do this we must use housing data from across the UK:

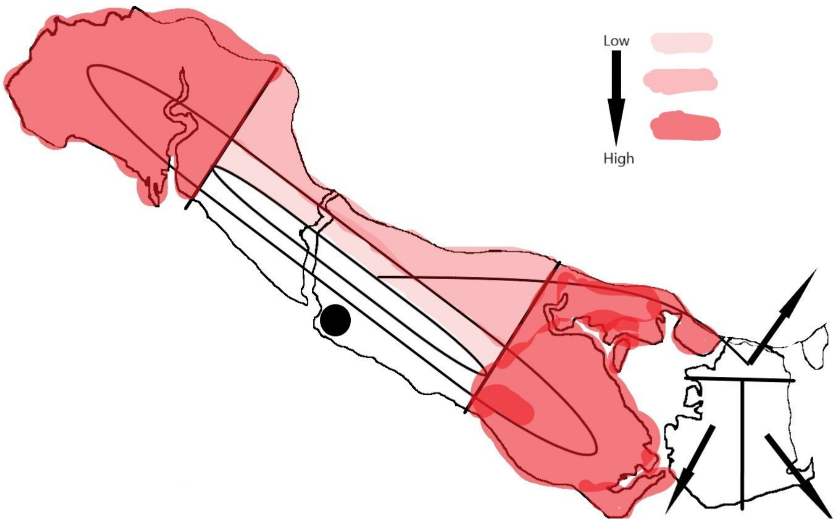
Number of households with...	Estimated number of households	Number of people
1 person	7,732,000	7,732,000
2 people	9,456,000	18,912,000
3 people	4,339,000	13,017,000
4 people	3,800,000	15,200,000
5 people	1,180,000	5,900,000
6+ people	535,000	3,476,000
Total number	27,042,000	64,237,000

(33)

With a population of 2 million and an overall area of 195km^2, the population density of solent city will be 10,257 people per square km^2, which is quite large.



However the plan for our city requires it to be divided into sections. As a result we get the population demographic similar to what is expressed below:



The 2 areas with the highest population (approximate overall area of 100km^2(Based on google maps function to calculate areas) will be where the majority of the population will reside. In these areas there will be terraced housing. The plan is to house two thirds of the population here. Using the housing data for the UK above we can estimate the number of homes:

Number of households with...	**Estimated number of households**	**Number of people**	**Estimated number of households per square km**	**Number of people per square km**
1 person	160,489	160,489	1,605	1,605
2 people	196,273	392,547	1,962	3,925
3 people	90,062	270,186	901	2,702
4 people	78,875	315,499	789	3,155
5 people	24,493	122,463	245	1,225
6+ people	11,105	72,149	111	721
Total number	561,297	1,333,333	5613	13,333

Giving each roof a tilt angle of about 40° and a roof area of $17m^2$ ***(34)*** each home will produce 3387.93 kWh per year. Therefore if there were 5613 homes per square km^2 then the amount of energy produced per year would be 1.901645109×10^7kWh. Overall the energy production for this total housing area would be 1.901645109×10^9kWh per year.

The remaining one third of the population will occupy the area shown as having the lower population. This area will also be where around half of the industries will reside. This area is around $30km^2$(Based on google maps function to calculate areas). Due to the fact that this area is mostly dedicated to industry realistically housing should take up less than one quarter of the area.
Using the housing data for the UK above we can estimate the number of homes:

Number of households with...	**Estimated number of households**	**Number of people**	**Estimated number of households per square km**	**Number of people per square km**
1 person	80,245	80,245	2,675	2,675
2 people	98,137	196,273	3,271	6,542
3 people	45,031	135,093	1,501	4,503
4 people	39,437	157,749	1,315	5,260
5 people	12,246	61,232	408	2,040
6+ people	5,552	36,075	185	1,203
Total number	280,648	666,667	9,355	22,223

To limit the amount of space taken up by housing in this area, these homes will be located in tower blocks. Working with 10 tower blocks per km^2 (giving a total of 300 across the whole area) and based on the knowledge that each home must have the minimum space according to housing space standards the total area needed for this building can be calculated.

Number of households with...	**Number of people**	**Estimated number of households**	**Floor area for 1 storey dwelling in m^2**	**Total area needed for each household type in m^2**
1 person	268	268	39	10,452
2 people	654	327	50	16,350
3 people	450	150	61	9,150
4 people	526	132	74	9,768
5 people	204	41	90	3,690
6+ people	121	18	116.5 (average)	2,097
Total number	2,223	936	//////////////////////////////	51,507

(35) **- floor area for 1 storey dwelling in m2**

If each block has 10 floors the area needed for homes per floor is $5,150.7m^2$. Allowing area for corridors and stairs we get a floor area of $6,000m^2$ or $0.006km^2$.

With this value in mind the energy production of 1 tower block can be considered. If the all of the sides (except north facing) of each block were coated in solar panels allowing around $37.5m^2$ per floor for windows (30 per floor per side, each 44 by 44 inches, area= approx $1.25m^2$ (common window size***(36)***)) and each floor has a height of 2.4 m ***(37)***, then the total area per floor for solar panels is 444m^2 **(2.4m x √6000= 185.9032006m^2 - 37.5m^2= 148.4032006= 148m^2 x 3= 444m^2).**

Across 8 floors (leaving the bottom 2 floors uncovered due to them being more likely to be shaded) the total solar panel area is 3552m^2. For a solar panel tilted at 90° the energy output of 1 tower block would be 4.8034584 x 10^5kWh **(3552 x 135.2325= 4.8034584 x 10^5).**

Also on each roof there will be a small solar farm,providing extra energy. Each roof has an area of 6000m^2, meaning that each side of the tower block is around 77.46m (√6000). Allowing for some area around the panels the length of solar panels would be 76m. If you have a row of 76m of solar panels with 1 m between each row (1m from the end of the solar panel) then there will be 38 rows of 76 1m^2 panels giving an energy output of 5.7554952 x 10^5 kWh **(199.29 x 76 x 38=5.7554952 x 10^5)** per tower block roof.

Therefore the total energy output for 300 tower blocks would be 3.16768608 x 10^8 kWh **(4.8034584 x 10^5 x 300 + 5.7554952 x 10^5 x300= 3.16768608 x 10^8)** per year.

Overall this plan leads to a total energy output of 2.218413717 x 10^9kWh **(3.16768608 x 10^8 + 1.901645109 x 10^9kWh= 2.218413717 x 10^9)**, which is 4.52% of the total energy requirements.

As well as coating housing, industrial buildings can provide area for solar panels within our city.

In total there were 1,794,592 industrial buildings across England and Wales in 2008 ***(38)***. In 2008 the population of england and wales was around 54.5 million ***(39)***. Therefore in our city there will be approximately 65,857 industrial buildings.

Estimating the roof area of each building to be 20m^2, tilted at optimum angle, each roof could produce 1992.9 kWh **(199.29 x 20=3985.8 kWh)** per year. We could also estimate a that a further 5m^2 of panels could be added to the buildings side. This would produce 676.1625kWh (135.2325 x 5=676.1625kWh) per year.
This means that in total 1 building will produce 4661.9625kWh per year, therefore giving a total energy output of 3.070088785 x 10^8 kWh across the entire 65,857 buildings. This amounts to 0.63% of the total requirements.

Overall solar power accounts for 5.15% of the total energy requirements.

Wind

In solent city part of the city's power comes from wind turbines. Before working out the overall energy output from wind power the energy output of a single wind turbine must be calculated.

The equation to calculate the power of a wind turbine is

Power (kW)=kCp½ρAV^3*(40)*, where:

K stands for a constant with the value 0.000133

Cp stands for the power coefficient (efficiency of the turbine) normally ranging from 0.25 to 0.45

ρ stands for air density of the value 1.225 kg/m^3 at 15°C *(41)*

A stands for rotor swept area

V stands for wind speed in mph:

	Southampton- wind speed in 2015 (mph)		Portsmouth- wind speed in 2015 (mph)		Total average	
	Average	Average maximum	Average	Average maximum	Average	Average maximum
Jan	5.1	23.0	17.2	23.0	**11.15**	**23**
Feb	4.5	18.6	15.0	19.7	**9.75**	**19.15**
Mar	5.1	19.6	14.3	17.9	**9.7**	**18.75**
Apr	4.5	17.8	11.2	15.0	**7.85**	**16.4**
May	5.3	21.5	13.2	17.7	**9.25**	**19.6**
Jun	4.8	18.7	11.6	15.4	**8.2**	**17.05**
Jul	4.8	20.2	12.3	17.0	**8.55**	**18.6**
Aug	4.0	17.0	11.0	15.7	**7.5**	**16.35**
Sep	3.9	15.9	13.0	16.3	**8.45**	**16.1**
Oct	4.0	15.9	13.6	17.4	**8.8**	**16.65**
Nov	5.6	22.9	19.2	25.1	**12.4**	**24**
Dec	7.4	28.2	22.4	27.5	**14.9**	**27.85**

Southampton-*(42)*
Portsmouth-*(43)*

Overall annual average= 9.708333333
Overall annual max average= 19.45833333

Using a turbine with a power coefficient of 0.25 and a diameter of 8m (based on an average from several turbine options*(44)*) we get an power output of 8205.51308kWh **(0.000133 x 0.25 x ½ x 1.225 x 16π x 9.708333333^3= 0.9367024064kW x 8760= 8205.51308 kWh).**

There is the option of using much larger industrial turbines that take up more space but produce comparatively more energy.

An average onshore industrial wind turbine has the capacity of between 2.5 and 3MW *(45)*, compared to an average offshore industrial wind turbine that has a capacity of 3.6MW *(45)*. Using this capacity the energy output for a year of one of these turbines can be calculated. The onshore wind turbine with a capacity of 2.5MW will have an energy output of 2.19 x 10^7 kWh **(2500 kW x 8760=2.19 x 10^7 kWh)**. The offshore wind turbine with a capacity of 3.6MW will have an energy output of 3.1536 x 10^7 kWh **(3600 kW x 8760=3.1536 x 10^7 kWh)**.

However when you take the efficiency of these turbines into account, these values change. The onshore wind turbine produces 24% of the theoretical maximum ***(45)***, giving a final energy output value of 5.256×10^6 kWh **($2.19 \times 10^7 \times 0.24 = 5.256 \times 10^6$ kWh)**. The offshore wind turbine produces 41% of the theoretical maximum ***(45)***, giving a final energy output value of 1.292976×10^7 kWh **($3.1536 \times 10^7 \times 0.41 = 1.292976 \times 10^7$ kWh)**.

Using this knowledge, the city's energy output from wind power can be calculated, however finding space for wind turbines in an already crowded city is difficult. Although an external wind farm is an option it would be better to produce at least some of the energy in the city to reduce loss from distribution, but due to a lack of space we had to think outside the box a bit.

When thinking about this we came across the idea for using wind power to power street lights ***(46-48)***. Scaling up on this concept we thought about simply extending the height of a street lamp to accommodate for a larger wind turbine, thus allowing energy to be produced not only to power the light itself but to power local buildings. Although this idea may be a little difficult to enact due the logistics of creating a taller street light pole, it would be no more difficult, if not most definitely easier, than creating 100m metre tall industrial wind turbines ***(49)***.

One of the good things about this idea is that because this area is a city it can be relied upon to be well light, meaning that there is a need for street lamps, making the idea of using them to produce energy a valid one.

In the uk there are 9,717,092 street lights ***(50)*** for a population of 65.13 million. This means that for our city, with a population of 2 million, we would need around 298,391 street lights **(9717092/(65130000/2000000)=298390.66482=298391).**

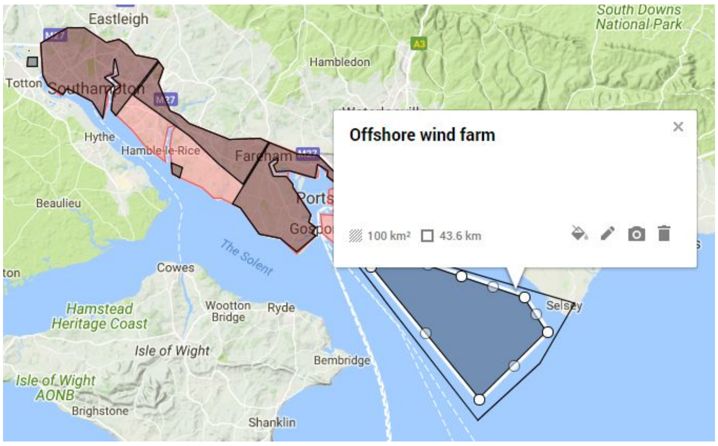
If we used a turbine with a power coefficient of 0.25 working at overall average wind speed with turbine of diameter 8m, each one producing 8205.51308kW.So for a total of 298,391 street lights, 2.448451253 $\times 10^9$ kWh per year would be produced.
This energy would power an L.E.D street light, which would increase the lights efficiency meaning more of the energy can be used to power the surroundings, ***(51)***. If each light used a 60W lamp (costing around £100-£110 ***(52,53)***) and was on for approximately 14 hours (5pm-7am), then the total energy consumption of 1 lamp would be 306.6kWh, meaning that each turbine could distribute around 7898.91308kWh **(8205.51308-306.6=7898.91308kWh).**

Another idea for utilizing space within the city efficiently is to build a turbine on each of the 300 tower blocks. Each onshore turbine produces 5.256×10^6 kWh of energy per year, therefore giving a total energy output of 1.5768×10^9kWh.

The overall aim with wind power is to produce a minimum of 10% of the total required energy, meaning that the energy output must be 4.908061×10^9 kWh ($4.908061 \times 10^{10} \times 0.1 = 4.908061 \times 10^9$ kWh) per year. The plan above produces 8.2% of the city's total energy requirements. To make the remaining 2.8% an offshore wind farm will be used. It would need to have at least 107 turbines.

The idea of having wind turbines on street lights needs further investigation, for example working out heights and supports for the added height and other details such as the weight that can be supported and the diameter of the turbine that would be safe for a city environment.

Therefore to account for the uncertainty, we will place as many wind turbines as possible into a suitable area.



After analysing the area available we have decided that a wind farm using up 100 km^2 would be best, as there is a clear shipping path left open, and plenty of space for the actual farm.

To work out the number of turbines that can fitted into this space we looked at the example of Rampion Wind Farm, in Shoreham, which has 116 turbines taking up a space of 72 km^2, 13 km from the coast ***(54)***.

Based on this we could fit around 160 wind turbines into the 100 km^2 area proposed, producing 2.0687616 x 10^{9}kWh.

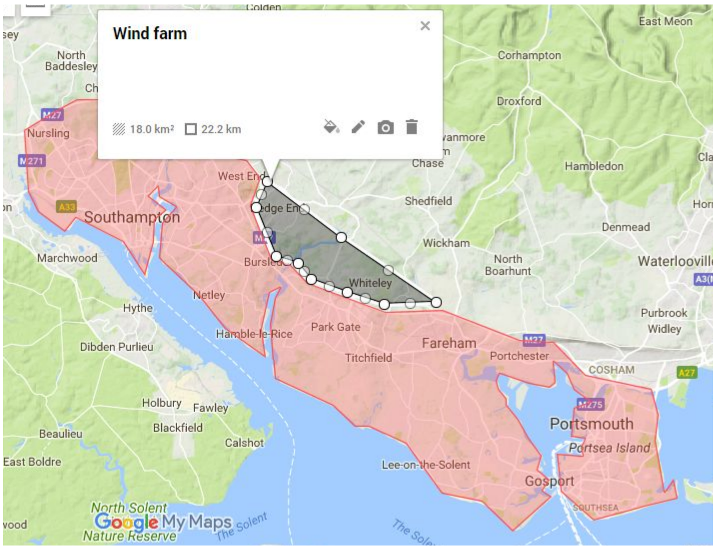
If the street light turbine idea is unforeseeable then the total energy from wind power will provide 7.4% of the city requirements. But if they do work then we could produce as much as 12% of the energy for the city using wind.

The amount of energy produced by wind could be increased further by adding more wind farms. This must be done to obtain our aim of 20% of our energy being generated by renewables.

Within the 20km limit there are 2 locations that an offshore wind farm could go:

The top section is an area that was meant to be for tidal (see tidal section below), however more energy could be produced by using the area for wind turbines. Using the information given above about the number of wind turbines on Rampion Wind Farm ***(54)***, the area towards the top of the map can have 16 offshore wind turbines (producing 2.0687616 x 10^{8}kWh), and the other area can have 40 offshore wind turbines (producing 5.171904 x 10^8kWh). This gives a total of 7.2406656 x 10^8kWh, which is 1.48% of the total energy requirements.

Another farm could be added above the city:



This could hold around 86 onshore wind turbines (using the example of Scout Moor wind farm***(55)***), and would therefore add 4.52016 x 10^8 kWh of energy to the city per year, amounting to 0.92% of the total energy needed.

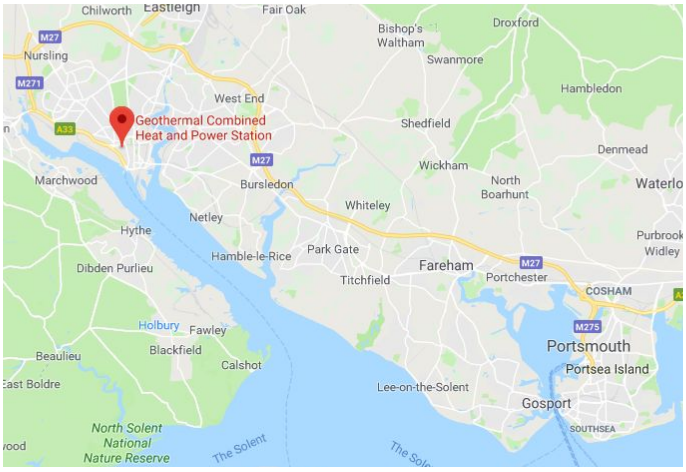
We could also increase it by following a similar idea to that above of adding turbines on top of the tower blocks. Much like this idea, wind turbines could be added on top of flat roofed industrial buildings.

Assuming that half of these buildings have flat roofs, the total number of added wind turbines (non-industrial, diameter 8m) would be 32929 (see solar section above, part about industry buildings). This would provide an extra 8205.51308kWh per building and an extra 2.701993402 x 10^8 kWh in total, 0.55% of the total energy requirements.

Therefore if all plans work wind power will provide a total of 15.37% of the total requirements.

Geothermal

Southampton's geothermal resource :



(56)

In Southampton there is a geothermal resource that has been accessed to provide hot water for local businesses. This geothermal well produces over 40,000MWh of heat ***(57)*** to heat water to provide to these businesses through 14 km of pipes ***(57)*** across a 2km radius ***(58)***. The well is 1800m deep ***(58)*** with water rising to 100 m from the surface ***(58)***. The water temperature is 76°C, 74°C at the surface ***(58)***. The hot salt water is pumped from the well to a heat station where it is treated and distributed. As well as 22,000MWh of electricity ***(57)*** are produced as well as 8,000MWh of water for cooling***(57)***.

The Plan

We will use this resource to provide hot water to surrounding homes.

In the UK we use 5.704515 x 10^{10} kWh(value converted from ktoe to kWh)***(59)*** to heat water in a domestic setting. This means that in our city, of population 2 million, 1.751731921 x 10^{9} kWh of energy would be required to heat water for homes.

If this resource produces 4 x 10^{7} kWh per year then it will provide enough water for 45,669 people.

With a total energy output of 7 x 10^{7} kWh per year, this energy source will provide 0.14% (0.1426225143%) of the total energy requirements.

Tidal

Tidal power makes sense as a power supply for our city as it is a coastal city. Due to the port being on the portsmouth island section, less thought needs to be put into consideration for shipping lanes coming from the southampton end of the city. This means that this section of water could be blocked off with a tidal barrage without shipping being too majorly affected.

To work out the potential energy that can be harnessed in a day, this equation can be used ***(60)***:

$E=1/2\ Apgh^2$

where:

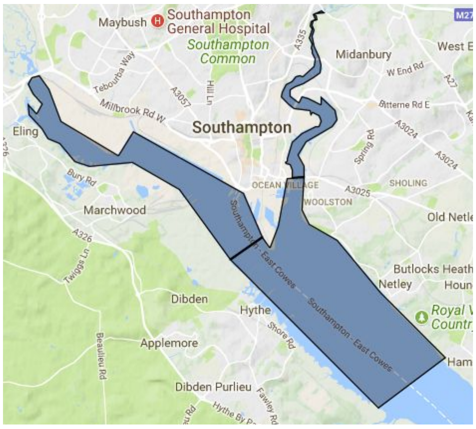
h is the difference in tide height

A is the area of the barrage basin,

ρ is water density (1025 kgm^{-3})

g is gravity (9.81 ms^{-2})

If we were to place a tidal barrage across the entrance to the southampton estuary we can produce energy to supply our city.



For this section, h is around 2.7979m as this is the value for the entrance to the estuary, therefore a value of 2.5m will be used instead and a is 1.72 x $10^7 m^2$(using google map function of measuring areas).

H	1st		15th		Average	
	High/m	Low/m	High/m	Low/m	High/m	Low/m
Mar	1.57	0.45	4.26	0.71	4.415	0.58
Apr	4.42	0.77	4.29	1.25	4.355	1.01
May	4.17	1.15	4.08	1.45	4.125	1.3
Jun	4.08	1.64	4.16	1.51	4.12	1.575
Jul	4.01	1.71	4.29	1.36	4.15	1.535
Aug	3.59	1.94	4.11	1.66	3.85	1.8
Sep	3.49	1.91	3.87	1.8	3.68	1.855
Oct	3.57	2.11	3.97	1.83	3.77	1.97
Nov	4.15	1.53	4.35	1.43	4.25	1.48
Dec	4.37	1.21	4.13	1.39	4.25	1.3
Jan	4.56	0.74	4	1.22	4.28	0.98

Feb	4.61	0.39	4.15	0.94	4.38	0.665

(61)

Average high tide at point= 4.1354m

Average low tide point= 1.3375m

This gives a total potential energy of 1.08093975 x 10^{12} J **(0.5 x 1.72x10^{7} x 1025 x 9.81 x 2.5^{2}= 5.404696875x 10^{11} x 2(2 high tides a day)= 1.080939375 x 10^{12}J)**. This means that 3.002609375 x 10^{5} kWh of energy is produced per day and therefore 1.09595242.1875 x 10^{8} kWh of energy is produced per year. If it is 30% ***(62)*** efficient then the total amount of energy produced is 3.287857265625 x 10^{7} kWh.

Another option is to place 2 barrages across the smaller areas of water further into the estuary.

For the blue section, h is 2.9504m and a is 1.3 x 10^{6}m^{2}(using google map function of measuring areas).

H for blue section	1st		15th		Average	
	High/m	Low/m	High/m	Low/m	High/m	Low/m
Mar	4.77	0.29	4.35	0.58	4.56	0.435
Apr	4.61	0.65	4.26	1.15	4.435	0.9
May	4.41	1.1	4.23	1.31	4.32	1.205
Jun	4.15	1.58	4.25	1.41	4.2	1.495
Jul	4.01	1.64	4.37	1.26	4.19	1.45
Aug	3.71	1.96	4.13	1.57	3.92	1.765
Sep	3.43	2.2	3.84	1.96	3.635	2.08
Oct	3.68	2.12	3.92	1.81	3.8	1.965
Nov	4.26	1.26	4.4	1.37	4.33	1.315
Dec	4.45	1.11	4.24	1.36	4.345	1.235
Jan	4.71	0.6	4.16	1.19	4.435	0.895
Feb	4.77	0.19	4.23	0.86	4.5	0.525

(63)

Average high tide at point= 4.2225m , Average low tide point= 1.2721m

This gives a total potential energy of $1.137884087 \times 10^{11}$J **(0.5 x 1.3×10^{6} x 1025 x 9.81 x 2.9504^{2}= $5.689420433 \times 10^{10}$ x 2(2 high tides a day)= $1.137884087 \times 10^{11}$J)**.
P=e/t=$1.137884087 \times 10^{11}$J/86400=1316.995471kW/ per day
1316.995471 x 24= $3.1607891306 \times 10^{4}$kWh
This means that $3.1607891306 \times 10^{4}$kWh of energy is produced per day and therefore $1.153688033 \times 10^{7}$kWh of energy is produced per year. If it is 30% ***(64)*** efficient then the total amount of energy produced is $3.461064099 \times 10^{6}$kWh.

For the red section, h is 2.9483m and a is $5.1 \times 10^{6}m^{2}$(using google map function of measuring areas).

H for red section	1st		15th		Average	
	High/m	Low/m	High/m	Low/m	High/m	Low/m
Mar	4.77	0.29	4.33	0.58	4.55	0.435
Apr	4.61	0.65	4.25	1.15	4.43	0.9
May	4.41	1.1	4.23	1.31	4.32	1.205
Jun	4.15	1.58	4.25	1.41	4.2	1.495
Jul	4.01	1.64	4.37	1.26	4.19	1.45
Aug	3.75	1.96	4.22	1.57	3.985	1.765
Sep	3.43	2.2	3.84	1.95	3.635	2.075
Oct	3.67	2.12	3.92	1.81	3.795	1.965
Nov	4.26	1.46	4.4	1.37	4.33	1.415
Dec	4.45	1.11	4.24	1.36	4.345	1.235
Jan	4.71	0.6	4.16	1.19	4.435	0.895
Feb	4.77	0.19	4.28	0.86	4.525	0.525

(65)
Average high tide at point= 4.2283m
Average low tide point= 1.28m

This gives a total potential energy of $4.457654389 \times 10^{11}$J **(0.5 x 5.1×10^{6} x 1025 x 9.81 x 2.9483^{2}= $2.228827195 \times 10^{11}$ x 2(2 high tides a day)= $4.457654389 \times 10^{11}$J)**. This means that $1.2382373303 \times 10^{5}$ kWh of energy is produced per day and therefore $4.519566256 \times 10^{7}$ kWh of energy is produced per year. If it is 30% ***(66)*** efficient then the total amount of energy produced is $1.355869877 \times 10^{7}$ kWh.

The first option provides $3.287857265625 \times 10^{7}$ kWh of energy, which provides 0.07% (0.0669889243%) of the total energy requirements.

The second option provides $1.701976287 \times 10^{7}$kWh($3.461064099 \times 10^{6} + 1.355869877 \times 10^{7}$= $1.701976287 \times 10^{7}$) of energy, which provides 0.03% (0.03467716247%) of the total energy requirements.

In the wind section (see above) it is stated that the area that is added to option 1, in comparison to option 2, is being used for wind power instead therefore the second option will be the plan for tidal.

Hydrogen

Hydrogen cells

How they work***(67)***:

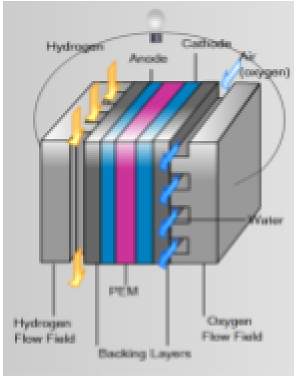
PEM fuel cells work by separating hydrogen at the anode using a catalyst into positive hydrogen ions and electrons.

As they move to the cathode the electrons are stopped by the Polymer Electrolyte Membrane (PEM) and forced to move through an external circuit to reach the cathode. This creates a current, which can power components.

When they reach the cathode they combine with the hydrogen ions and the oxygen molecules from the air to form water, which leaves the cell.

The hydrogen from this would be obtained by electrolysis of water. To do this between 38 to 49 kWh of energy is needed to produce 1kg of hydrogen ***(68)***.

PEM fuel cells can be used as back-up power supplies to keep the trams running in the event of an electrical fault supplying the tram network.



(69)

Hydrogen as a Fuel

As well as in fuel cells, hydrogen can be used to heat homes as described in the our energy supply strategy. The hydrogen would be piped into buildings underground, then it would be combusted in a boiler to release energy to heat the building at water. Hydrogen would release 120 MJ per kilogram ***(70)***, which, in comparison to natural gas (54 MJ per kilogram), is significantly more energy for the amount of fuel burned. In addition, the only product of hydrogen combustion is water, so this process is carbon neutral.

Total percentages of energy produced from each source

Total for city= **4.908061 x 10^{10} kWh**

80.21% nuclear- slightly more than 80%, but allows for any uncertainty in renewable energy production

Energy= 3.936744 x 10^{10} kWh

20% renewable:

Solar=5.15%

- On homes= 4.52%
- On industrial buildings= 0.63%

Wind=15.37%

- On tower blocks= 3.21%
- Offshore= 4.22% + 1.48%= 5.7%
- Onshore= 0.92%
- Street lights= 4.99%
- On industrial buildings= 0.55%

Geothermal= 0.14%

Tidal= 0.03%

=20.69% total

Back-up Energy Strategies

Businesses and Industry:

This sector of the city consumes 17% of the total energy and would be a major employer within the city. If power were to be lost for a few short days, this could have a large, negative impact on the city's overall economy. In general usage, emergency power generators would be the solution to a loss of electricity, however these generally burn diesel or petrol to produce the electricity, which would release carbon dioxide ***(71)***. If power was down for a period of two days, the industrial sector alone would require 45.7 million kWh of energy to continue its operations as usual. This is equivalent to around 3800 tonnes of diesel being combusted (releasing 12 tonnes of carbon dioxide). The obvious solution to this problem is to use stored hydrogen gas as an alternative fuel for these generators. However, hydrogen is far less dense, even as a liquid, than diesel or petrol, making it hard to store. Large, underground tanks could hold the gas – this is safer than storing it above ground as there is no oxygen for the hydrogen to react with and it also means that no space has to be taken up above ground, meaning there is more room for the industrial facilities. Hydrogen is an ideal fuel for these emergency generators as it releases 76.6 MJ/kg more energy than diesel, meaning less of it is required to produce power (only 1400 tonnes, which is nearly one third of the amount of diesel)***(72)***.

Hospitals:

In London, there are 20 hospitals serving a population of 8.788 million people. This suggests that our city would require a minimum of 4 large hospitals. An average hospital consumes 61 kWh ***(73)*** per square foot annually and the average hospital floor space area in the is about 74600 square feet ***(74)***, meaning that 4 hospitals would use 18.2 million kWh of electricity per year. For a power blackout of two days, this is 99740 kWh of energy that must be generated. A connected system of solar panels on the roof of the hospital operating at 54.6 kWh per square metre annually could generate 5.6% of this power, which would easily cover the energy requirements for patients on life support in the hospital. The rest of the energy could be generated using emergency generators as with the industrial sector, consuming only 3 tonnes of hydrogen.

Transport Systems:

Airport:

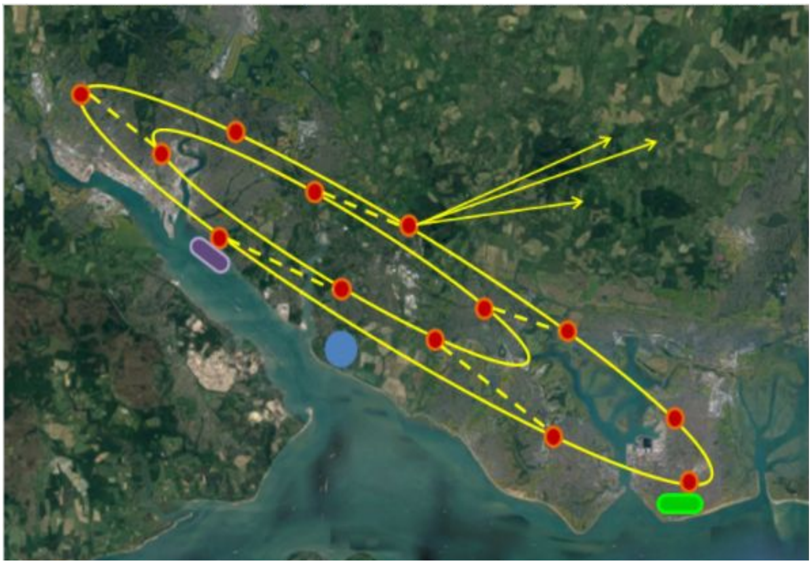
Without electrical power, flight operations would have to be halted as communications would be down and vital control computers would not function. This could endanger passenger's lives. In a typical airport, a large amount of space is unoccupied by anything other than grass. However, the grass serves an important function of preventing dust building up, which could affect aircraft engines. On the other hand, grass is only necessary immediately by the sides of a runway, and solar panels could be installed on all other available land for backup power.

Trams:

The trams in the city will normally be run of off electricity; however, to maintain an efficient transportation system during a power blackout, non-electrical trams must also be in operation. Hydrogen fuel cells convert the chemical energy in hydrogen to electrical energy through an electrochemical reaction with oxygen ***(75)***. They can produce a constant power supply, which is their major benefit over using large batteries as a backup power supply on trams. If each operational tram is installed with a fuel cell, they would all be able to continue running to a point where they are taken out of the network. If the electricity is out for a few days, the usual trams would be systematically removed from the network to be replaced with emergency trams with more powerful fuel cells that could then be run on a reduced timetable around the city.

Transport

Overall transport System Concept



Key:

Tramline

Tram station

Cruise terminal / Docks

Nuclear power plant

Tramline link between inner and outer loop

Airport

Out-of-city train links

The main transport system within the city is a tramline. Along this line, electric trams will run between stations, transporting people and goods around the city. The system is divided into two loops for maximum efficiency as all trams can run synchronously and if one loop is out of action, the other is unaffected as no trams pass between the two lines. Power is distributed to the tramline primarily from the nuclear power station (shown in blue). Strategically placed links between stations allow people to move between the two loops. The stations themselves are situated such that the average commuter in the city would not have to travel more than a kilometre to a station each morning, which would help limit the use of cars, and reduce carbon dioxide emissions. If cars are used, people will be encouraged to use electric cars. To allow for this there will be plenty of electric charging stations.

Currently in Southampton, the docks play a vital part in industry and are a major source of employment in the south. Having a station located immediately next to the docks is very important as a large number of people may be using the trams to get to work, or to arrive for a cruise. Goods brought of off large container ships could then also be transported on the tramline to make its way out of the city.

A station near the airport is very important as well, not only for the convenience of tourists, but also to supply quick routes to and from the airport to prevent it from becoming overwhelmed with a large influx of people. The airport would be situated on the south end of Portsea Island, away from the main city. This is done so that aeroplanes do not fly directly over the city, minimising any disturbance that it could cause to residents.

Reasoning Behind the Use of Trams

Energy Usage of Electric Trains

- 117 MJ per kilometre of energy for the whole vehicle
- 0.39 MJ per kilometre for each seat on the train ***(76)***
- Average speed of 100 km/h ***(77)***

Energy Usage of Single Deck Bus

- 14.2 MJ per kilometre of energy for each bus
- 0.29 MJ per kilometre for each seat on the bus ***(76)***
- Average speed of 43 km/h in built up areas ***(78)***

Energy Usage of Trams

- 47 MJ per kilometre of energy for the whole tram
- 0.18 MJ per kilometre for every seat on the vehicle ***(76)***
- Trams can operate up to speeds of 70 km/h, however it is more common to operate them at lower speeds (30 to 50 km/h) ***(79)***

As can clearly be seen from this data, a tram network can run using less energy than other common transportation methods. In addition, each individual tram can carry more people for the energy that it consumes (0.18 compared to the 0.39 for a train, meaning that a tram can carry at least two times more people than a train).

If an average 265 passenger tram were to travel 300 kilometres per day, within a year, that tram would require 5147 TJ (1.43 million kWh) of energy. Therefore 1 tram requires 0.0029 % of the total energy requirements and 0.0073% of the total transport requirements. Using 1.6% of the energy requirement for the transport sector, a tram network could have 220 fully operational vehicles running simultaneously all year round. If an average daily commute distance was 15 kilometres, the tram system would be capable of transporting a maximum of 1.17 million people per day.

Backup Power for Trams

As a backup power source hydrogen fuel cells would be used. If a 5000W PEM fuel cell ***(80)*** with an efficiency of 40% ***(80)*** was used then 1 cell could produce a maximum power of 2000W. This means that each cell can produce 7.2 x 10^6J (2000x3600= 7.2 x 10^6J) per hour.

The number of cells needed for 1 tram varies depending on speed of travel:

- 30km/h:
  For each hour a tram is used, the energy needed is 1.41 x 10^9J **(4.7 x 10^7 x 30= 1.41 x 10^9J)**. For each second a tram is used, 3.916666667 x 10^5J **(1.41 x 10^9J/3600=3.916666667 x 10^5J)** of energy is needed. Each cell can produce 2000J per second **(2000x1=2000J)**. Therefore the number of cells needed is 196 **(3.916666667x 10^5J/2000= 196 cells)**.
- 50km/h
  For each hour a tram is used, the energy needed is 2.35 x 10^9J **(4.7 x 10^7 x 50= 2.35 x 10^9J)**. For each second a tram is used, 6.527777778 x 10^5J **(2.35 x 10^9J/3600=6.527777778 x 10^5J)** of energy is needed. Each cell can produce 2000J per second **(2000x1=2000J)**. Therefore the number of cells needed is 327 **(6.527777778 x 10^5J/2000= 327 cells)**.

Therefore each tram will need 327 cells so that they can travel at speeds up to 50km/h. To have 1 tram with this number of cells would cost around £4.5 million (£13667.63 ***(80)*** x 327 =£4,469,315.01) per tram.If we were to use this number hydrogen cells in each tram to power provide enough power for each tram to run, it would cost around £990 million for 220 trams.

Reducing Carbon Emissions From Aircraft

Currently, aircraft produce 2% of global carbon dioxide emissions, which is expected to increase to 3% by 2050 ***(81)***. The best way to minimise the emissions of this sector is to use biofuels to power the airplanes. An alternative method would be to use electric planes; however, these are not widely used as designing batteries capable of storing enough energy for long haul flights is extremely difficult. Additionally, using biofuels means that planes do not require extensive modification before they can fly. Biofuels are produced by extracting oils from crop plants, and then by various processes (such as cracking, distillation and hydrogenation) the oil is refined to create a product suitable for jet engines. The land used to grow the crops from which the fuel is obtained can then be reused to grow more crops, which absorb carbon dioxide through photosynthesis. This makes biofuel production theoretically carbon neutral. One study conducted by a group from Yale found that using certain plants can reduce emissions by 85% ***(81)***.

Transportation By Water

Currently, ferries between the mainland and islands such as the Isle of Wight are powered using non-renewable fossil fuels. Replacing these with electric ferries would help to minimise the amount of carbon dioxide produced by the city. In Norway, a new design of electric ferry is now in operation. It is powered by a 1000 kWh battery supplying two 450 kW motors, which is could drive the ferry 204 kilometres per day ***(82)***. By using this ferry instead of a diesel powered one, 2430 tonnes less of carbon dioxide would be produced annually per boat. In addition, an electric ferry could transport 360 people and 120 vehicles each trip, which is equivalent to most ferries that are currently in use in the Solent. As well as transporting people and goods between the mainland and the Isle of Wight, the ferries could also be used to carry people from Portsea island (where the airport is situated) to other coastal areas of the city, which would reduce any strain on the tram network. It would also provide better links from the airport to the rest of the city, which would benefit the tourism industry.

Electrics cars

In our city people will be encouraged to use the tram system, however there will be roads in place for those who wish to use electric cars.

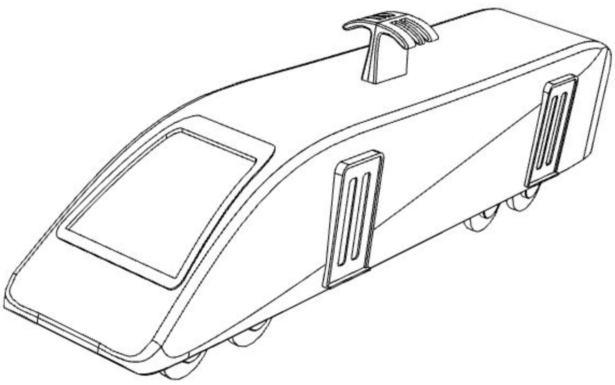
Electric cars are powered by a rechargeable battery ***(83)***. As our electricity will be produced from carbon neutral/zero carbon energy sources, these cars will have no carbon emissions, and will therefore be better for the environment than diesel or petrol cars.

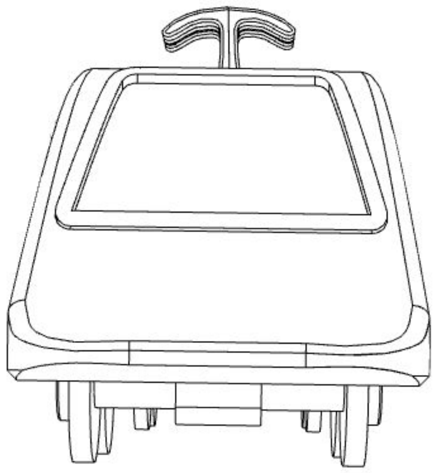
The right electric car can travel between 150 and 180 km ***(83)***, which is more than enough to travel around the edge of the city once, meaning that if cars were used for travel in the city they may only need charging 1-2 times a day.

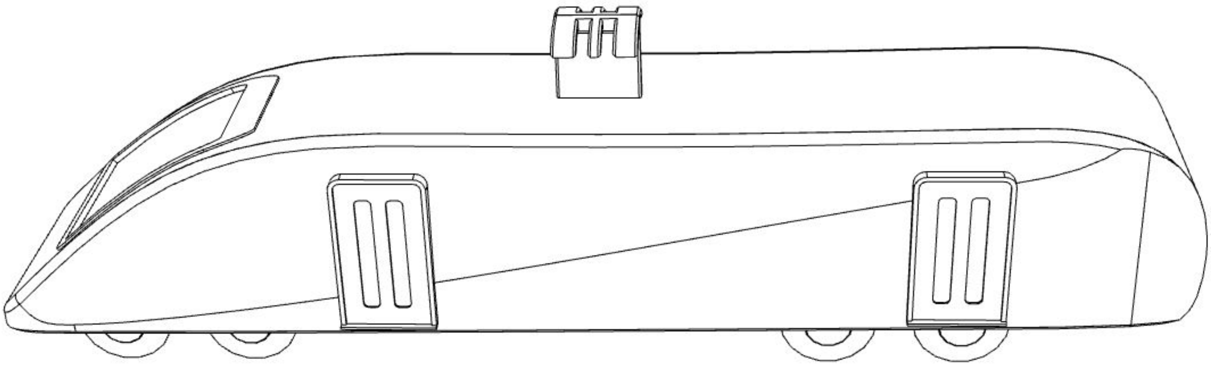
These cars could also have regenerative braking. This is a mechanism which allows a cars battery to be recharged ***(84)***. Using this technology some of the energy can be regained.

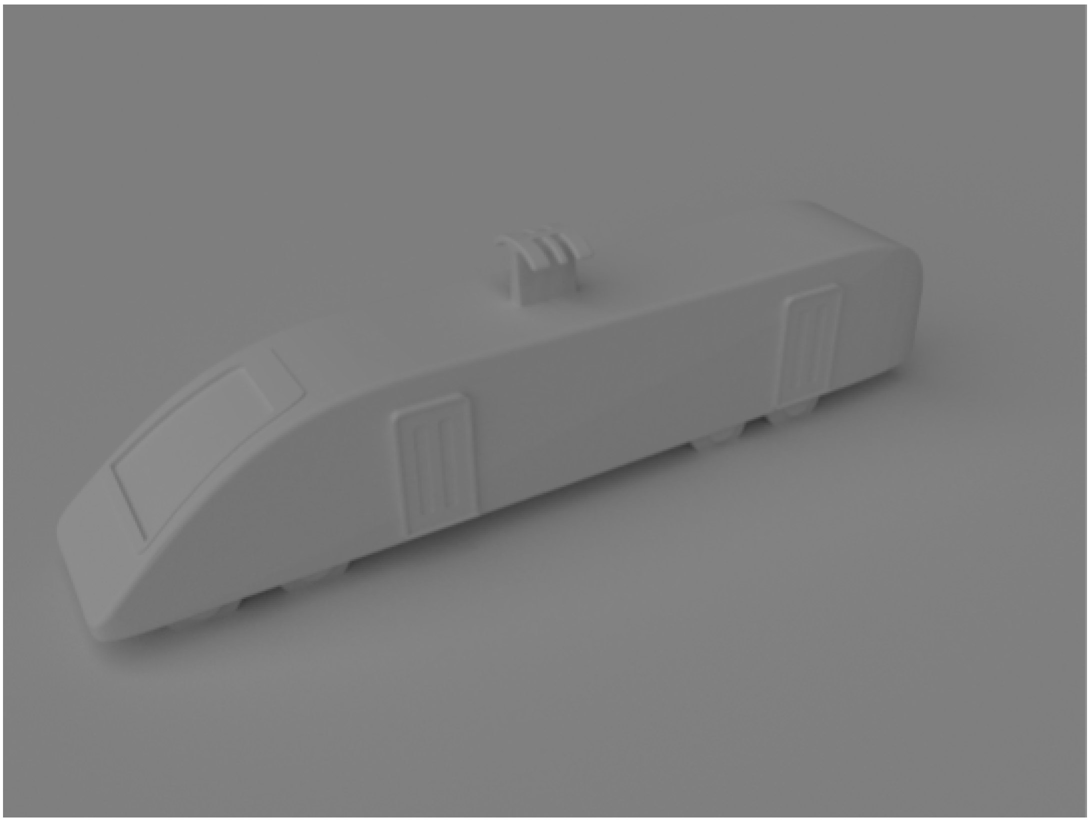
Vehicle designs and infrastructure

Potential tram design









With the tram design, each car is modular with only one specification of car being required for the front, end and middle sections of the tram. Using a modular design would reduce the manufacturing costs and make the trams more adaptable for use within the city. There would be designated standing and seated sections within each car.
The front and rear cars of the tram would house the drive motors, capable of reaching a total power output of 650kW. The electricity supplying the motors would be delivered from overhead cables, which is safer for pedestrians than by using electrified rails. Overhead cables are also quicker to fix if something were to go wrong than rails are, meaning that services would not be significantly impacted.
The gauge of the tracks would be 1,435 mm (a standard for most tram rails). Using standard measurements means that the installation time of the rails is reduced, reducing the overall cost of the network.
Each tram will be equipped with Polymer Electrolyte Membrane (PEM) hydrogen fuel cell capable of producing up to 1000 kW of power in total ***(85)*** and an electric hook up to over head cables. This allows the car to power itself when needs be, use power from the mains system, both or put electricity back into the city's power grid. The hydrogen fuel cells would be situated in the middle cars of the tram where there is more free space (the motors require a large amount of underfloor space in the front and rear cars). On board, there would be sufficient storage space for hydrogen to carry the tram to the nearest station in the event of a power failure. To keep the trams running in this event, specialized trams with increased storage capacity would be added to the network, with most of the electric trams being temporarily removed. Hydrogen storage cars could also be added to existing trams.
The trams themselves will be automated, controlled by a central computer which monitors the progress of trams around the network and adjusts the tram timetable accordingly. For safety reasons, a trained driver would have to be on the tram as well, however, their primary job would be to act as a conductor, checking tickets and helping people with their inquiries.

Roughy 120 km of track would be needed for the city's tram system, including rail for the two main rings, connections between them and a small amount extra used for depos and any inclines requiring more track. The cost of light rail track per km is £6.46 million ***(86)***. This means the total for this rail infrastructure alone would be £775.2 million.

Our tram design idea has an extra low clearance this allows for the station to be low to the street level making it easier for people to get on and off and although it will not be moving particularly fast it is roughly bullet shaped and one peice to reduce the energy lost to drag. Unlike meany tram systems ours has no tight corners,just three gently curved rings which means that our tram doesn't need to flex. It will only have a limited amount of seating as the majority of passenger will be only going a couple of stops in one go and this allows for more room for prams and wheelchairs. The rams surface is smooth and will be coated in anti stick anti graffiti paint to protect against vandalism and ensure it lasts, this coating is hydrophobic meaning any water that lands on it will bead off and collect dust as it goes this will reduce the need to clean there outside.on the inside all of the surfaces will be acrylic plastic that easy to wipe down.with steel handlebars

General, Costs & Implementation

Carbon Neutral Technologies and Implementation

Cement Production:

To make 1 kilogram of cement, around 0.5 kilograms of carbon dioxide are released into the atmosphere through the thermal decomposition of limestone in a cement kiln ***(87)***. This contributes to approximately 5% of global carbon dioxide emissions. However, recent research has led to the discovery of alternative methods of cement production which result in negative emissions (carbon dioxide is taken in by the process). By replacing the limestone in cement with a mineral called wollastonite, no carbon dioxide is released when the cement is fired in a kiln; however, it is absorbed from the air as the cement cures to become hard. Using this method to produce cement and concrete for buildings in the city could massively reduce the carbon emissions during construction.

Vehicle Exhaust:

Eliminating fuel-burning vehicles from our city entirely is impossible. However, in the UK, 25% of carbon dioxide emissions were caused directly by transport, so minimising the carbon contribution of this sector is key ***(88)***. One way to reduce carbon dioxide emissions from the transport sector is to encourage people to switch to electric cars. Seeing as all electricity in the city is generated without a large carbon footprint, this would mean that personal vehicles would no longer be adding to the carbon dioxide being produced. New technology in the field created by companies such as Tesla, means that electric cars are now far more efficient and within an average person's price range for a car. A good way to encourage people to switch to electric cars is to limit the sale of petrol and diesel, meaning either that residents of the city must pay more for fuel or that they can only purchase a certain amount at a time. We can also supply frequent charging stations so that having an electric car is actually possible.

Other methods of reducing carbon dioxide emissions are to provide high quality public transport services around the city, and to promote other modes on transport such as cycling. As well as being a source of exercise for people in the city, public bikes could easily be used to travel between different areas of the city.

Landfill:

As well as producing carbon dioxide, landfill sites also release large quantities of methane, a gas which is a worse agent for global warming than carbon dioxide. Methane is readily combustible, however it is very expensive to capture methane effectively and burn it as a fuel to generate power. The best way to reduce the impact of landfill sites is to implement strict recycling policies, where all waste is sorted separately and compostable waste is fully converted into carbon dioxide rather than methane. This compost can then be used in people's gardens in the city, which means that less carbon dioxide is released into the atmosphere as plants can photosynthesize and absorb it.

Industrial Building Modifications

When it comes to the buildings in the industrial district it is less about the looks and more about practicality and floor space that's why we have designed this following building that fills all of the requirements of a typical industrial company while being as energy efficient as possible.

The large roof space is a key asset which we plan to fill with photovoltaic cells in the east westerly direction. Remaining roof space can be used for urban greening to minimise carbon dioxide in the atmosphere.

The building can be assembled rapidly in a similar way to flat pack furniture, and parts can be easily replaced due to its modular design.The frame is made from regular steel girders that are of standard length and width which means they can be purchased at competitive prices. The actual walls, however, will be made from fiberglass and a recently developed cellulose-based insulation material that is low cost to manufacture and will adequately insulate the building, making it energy efficient.

This cellulose insulation material is made from 85% recycled paper and wood pulp products . Additionally, due to its treatment, it is fire retardant as well. The fiberglass for the walls can also be made from 50% recycled material and is extremely strong.

Cost and Implementation Schedule

Underground piping
Phase of development: 1
Description:
These pipes will transport the essential resources such as water and gas to the places that need it as well as taking away waste products such as sewage to a biogas power plant

Carbon impact
These pipes are going to be mostly made from concrete from recycled sand and pvc plastic to reduce the impact this may have
Cost
Approximately 70 million at about £300,000 per mile of piping and installation costs
It will take approximately 6 months

Roads
Phase of development: 1
Description:
These roads will allow the transport of the materials and people for construction and everyday life

Carbon impact
The roads will be made of recycled bitumen and will reach across the whole city, but will be pedestrianised later on
Cost
(89,90)Approx £1 million per mile per lane. We will need approximately 30 miles of double laned and 10 miles of single laned roads so about 70 million pounds
It will take approximately 5 months

Nuclear power station
Phase of development: 2
Description:
The main power supply from harnessing the energy of uranium fission

Carbon impact
Although the construction will have a large negative carbon footprint we believe it will be redeemed by the green energy it will produce
Cost
Approximately £11.3 billion based on previous calculations
It will take approximately 40-60 months

Geothermal hydrogen production facilities
Phase of development: 2
Description:

A green environmentally friendly power supply harnessing the heat of the rocks below

Carbon impact
(91)The production of these plants will release some carbon dioxide however this will be quickly redeemed
Cost
Like Southampton's geothermal power supply system this should cost around £7 million
It will take approximately 10 months

<u>Power (cables, pylons and transformers) And data transmission, fiber optics etc.</u>
Phase of development: 2
Description:
These cables supply the electrical power from the power station to where they're needed

Carbon impact
These power lines will mostly be run along underground so large quantities of carbon dioxide will be released in the installation phase, however the high voltage and thick cables should reduce the power lost through transmission
Cost
We will need approximately of 60 miles of underground, high voltage cabling at £2 million per mile(3). Including the cost of transformers, other cabling and pylons, the total cost comes to about £150 million
It will take approximately 7 months

<u>Tram line and low voltage power lines</u>
Phase of development: 3
Description:
The tram network will be one of the largest and an integral part of the city's infrastructure and we hope it would be used by all residents as the primary method of transportation

Carbon impact
This light rail system will more than repay its carbon debt in the reduced car traffic emissions around the city
Cost
It will cost around £800 million to fully implement the tram network
It will take approximately 20-25 months

<u>Airport and tourist facilities</u>
Phase of development: 3
Description:
These facilities help people arrive in the city from abroad and drive the development of the economy

Carbon impact
The airport will probably be the least carbon friendly part the city however by implementing biofuels to drive the vehicles and small planes the carbon footprint can be vastly reduced
Cost
It will cost around £3.5 billion to build a new inner-city airport, this is based on similar airport construction costs around the world ***(92,93)***
It will take approximately ***(94)*** 60 months however it will be partially operational by 20 months allowing smaller flights

Commercial offices and housing complexes
Phase of development: 3
Description:
These compact living and working spaces will be housed in tall, modern skyscrapers. They will have a large floor space for the proportion of the city area that they take up and will provide a great view for all who are in the building

Carbon impact
These buildings will be extremely energy efficient with the best insulation and temperature control systems.there will be solar panels for heating water and photovoltaic cells for electricity and with the closer proximity the heat wasted between the apartment will be minimised
Cost
About £200 million per complex however this is extremely cost effective when you think about how much each apartment actually costs
It will take approximately 25 -30 months

Heavy industry facilities
Phase of development: 3
Description:
Closest to the power production plants in the centre of the city, there will be a large industrial complex of warehouses that various companies can adjust to there construction needs as well as a shipping and dockyard area for transporting goods to and from the buildings

Carbon impact
These production facilities will undoubtedly require the process of combustion in many of the production processes but we hope to minimise that by situating the buildings close to the power station so they can use the most electrical power without excess being lost to transmission. The large flat roofs of these warehouses will be covered in photovoltaic cells to help make up for the carbon that has been lost
Cost
Each building costs around £330 thousand ***(95)***. The dockyards dredging and construction should cost £50 million pounds
It will take approximately 10 months

High street
Phase of development: 4
Description:
This is where a lot of residents and tourists will be spending their time and hopefully money, to relax and have a good time.The high street will consist of a pedestrianised road along the circumference of the middle ring with a terrace of shops on either

Carbon impact
These buildings will not waste any space. The majority of them will have the single ground floor for the shop and the first floor as a cheap housing. The buildings will use energy efficient bulbs and the electricity will be on a timer so when the shops close, no energy will be wasted
Cost
Around £15 million for the shops and further £2 million for the paving and other facilities
It will take approximately 10-12 months

Toilets, tourist information, markets

Phase of development: 4

Description:

These facilities are an important part of every city and it makes time in the city easier and more enjoyable

Carbon impact

These facilities will be built in the shopping spaces for the high street

Cost

£500,000

It will take approximately 1 month

Benches, litter bins, signs, maps, directions and street lighting

Phase of development: 4

Description:

This 'street furniture' will aid everyone during their time in the city. The signs and directions help people get to where they need to be without harm and benches help the elderly. There should be a litter and recycling bin within a one minute walk from

Carbon impact

The bins around the city will be brightly colored and regularly emptied to encourage people to use them and with every regular bin there will be a recycling bin to reduce the waste that goes to landfill

Cost

A bright colored steel litter bin is £195 and a concrete bench for two is £250,with bike parking facilities.

£30 per street sign and other signs are around £200

It will take approximately 1 month

Costs of building each energy source

Nuclear= to build a plant providing 80% of the total energy would cost around £11.3 billion (***(96)***-based on the value for this power station)

Solar= £3 billion

Assuming a price of £270 per m^2 ***(97)***

- On homes= 10,607,700m^2 of panels in total across the city, so a total cost of around £2.9 billion
- On industrial buildings= 355,200 m^2 of panels in total across the city, so a total cost of around £96

Wind= £11 billion

- Offshore= 216 costing around £5.2 million each ***(98,99)***, so a total cost of around £1.1 billion
- Onshore= 386 costing £3.3 million each ***(100)***, so a total cost of around £1.3 billion
- Smaller 8 diameter turbines= 331320 costing around £26 thousand each (***(101)***-7m diameter blade= Bergey Excel 10 (***(102)***-cost of turbine)), so a total cost of around £8.6 billion

Geothermal= the current scheme in southampton had a total cost of around £7 million ***(103)***

Tidal= around £140 million ***(104)***

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